Dr. Philos. thesis

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Long-term telecommunication forecasting

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Long-Term Telecommunications Forecasting

by

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To Kari Synnøve,
Liv and Håkon

Abstract

The key word for the thesis is long-term demand forecasting which have been applied on telecommunications and especially on broadband accesses and traffic.

The objective with the thesis has been to structure and present work on long-term broadband forecasting, to evaluate the forecasting results and to extract the learning. Each main chapter ends with a section called experiences and conclusions.

The thesis is organized in seven main parts.

The first part addresses application of the Delphi technique for long-term forecasting broadband accesses. Three Delphi surveys, which have been conducted during a long period, have been evaluated. All three Delphi surveys have used similar procedures in carrying out the survey, except that two of the Delphi surveys were postal surveys, while one was carried out on site. The applied procedure is evaluated based on an important reference article on Delphi surveys and also based on the long-term forecasting results. The Delphi surveys are not very often used. Hence, the description of the way to conduct the surveys and the experiences and also the evaluations of the results are given specific attention in the thesis.

The second part of the thesis has the title “Long-term broadband technology forecasting”. Results from three papers are presented and evaluated. The papers show the evolution of the forecasting modelling. The first forecasts for the broadband evolution in Western Europe were made before broadband was introduced in the residential market in Western Europe. The long-term forecasts were developed based on Logistic models. The modelling also includes substitution effects between broadband technologies. Experiences have shown that technological knowledge and techno-economic evaluations are crucial for making long-term broadband forecasts. Some attention is also put on available broadband accesses statistics and an approach to separate aggregated broadband statistics to access statistics for the business market and for the residential market.

“Long-term forecasting models for cost components and technologies” is the third part in the thesis. To be able to evaluate broadband technologies, techno-economic calculations of the “economic” value of the relevant broadband technologies are very important. The extended learning curve model invented by Borgar T Olsen and Kjell Stordahl is presented. The model is much more powerful than the simple exponential learning curve. The extended learning curve makes long-term forecasts of component costs and has the ability to be used directly on techno-economic calculations, as opposed to the traditional learning curve model, which does not predict the cost as a function of time. In addition the extended learning curve model has interpretable parameters. It is shown that the model may utilize a priori information in cases where too few observations are available.

The fourth part addresses long-term traffic forecasting. Three papers are enclosed. The chapter starts with a short overview of relevant forecasting models. Then attention is paid to forecasting and network planning. A comprehensive overview of the field is given together with numerous references in the enclosed paper “Forecasting – an important factor for network planning”. Long-term forecasts for the core network is analyzed and discussed. Also some figures for the total broadband traffic evolution in the Norwegian core network is presented. The last paper described in the chapter shows how long-term traffic forecasts on aggregated level can be used for traffic matrix forecasting by using the extended weighted least square method. The chapter ends by listing several important drivers for new and enhanced broadband traffic that are important in traffic forecasting models.

Long-term forecasts are of course encumbered with uncertainty. Four papers are attached in the fifth part. The papers show how risk analysis is used to evaluate the consequences of uncertainty. All papers analyses rollout of broadband technologies. The long-term forecasts are important inputs to the techno-economic analysis of broadband rollout. The risk analysis evaluates the effect of the uncertainties in the long-term forecasts through the "economic value" of the rollout. The economic value is often expressed by net present value (NPV), payback period or internal rate of return. The experiences show that especially the long-term broadband forecasts and the average revenue per user (ARPU) forecasts are the most critical variables, which have the most significant influence on the variation in the economic value of the broadband rollout.

Long-term adoption rate forecasting is the second last part. These forecasts are essential for broadband rollout strategies. One paper describes optimal rollout strategies in the high capacity broadband market. Long-term adoption rate forecasts have been differentiated based on the order the operators are entering the exchange area. The first operator, who enters, gets all demand which has been aggregated over years, while the operators who enter later only have to fight to get parts of the future yearly growth. The strategy shows how limited investment means should be applied taking into account the effectiveness of investing in large exchange areas and utilizing the "first mover's advantage".

The second paper in this part is called: "Broadband in the residual market: First mover's advantage". The paper is so far unpublished and included completely in the thesis. Long-term broadband adoption rate forecasts play an important role in the analysis. The residual market is defined as the part of the market, which is not covered by broadband infrastructure. The business case for rolling out DSL in small exchange areas is based on monopoly considerations. If the areas are small enough, the long-term adoption rate forecasts for the first mover are locally upgraded because no other competitor gets a good business case by entering the area as number two. Analysis is carried out to develop optimal broadband rollout in the residual areas for given values of a set of critical variables i.e., long-term adoption rate, long-term ARPU forecasts, DSL equipment costs, OPEX costs and others.

The thesis ends with a part called "Forecasting new broadband revenue". This is a very important and challenging aspect in the telecommunication world. The paper documents that the telecommunication spending per household both in Norway and selected European countries have increased significantly during the last years. The statistics of households purchasing behavior is analyzed. The hypotheses is that parts of the spending categories, which the households now are paying for, will in the future be partially substituted by services in the mobile and fixed network. Relevant spending categories are purchase of films and music, leasing of films and music, TV licenses, on demand ordering of films etc, on-line games, gambling, books, newspapers, magazines, e-learning. A framework for long-term broadband revenue forecasts is suggested.

Preface

Since 1992 I have been working on the techno-economic broadband projects partly financed by the European Commission and the last two years by the Norwegian Research Council. I have been privileged to be responsible for the market analysis and the forecasting in these projects.

Therefore, I have had the opportunity to follow the development of broadband technologies at an early stage, to participate in techno-economic analyses of broadband business cases and to follow the broadband market evolution in Western Europe closely.

I am particular indebted to Borgar Tørre Olsen, Nils Kristian Elnegaard and Leif Aarthun Ims for very constructive and fruitful cooperation during these years.

The thesis is based on work and papers I have produced during a long period. Often we do not have time to put "things" together, to evaluate completed work and to examine what is learned. When I finally decided to make a thesis, I found great pleasure in structuring the thesis, to "review" and select my own papers for the thesis and lastly to evaluate earlier work. Since I have been working a lot with long-term forecasting, I have had the opportunity to compare my long-term forecasts with the real evolution and even extract some learning from the process!

I have participated in these research activities in parallel with my ordinary job at Telenor Networks/Telenor Nordic, and the main part of the work has been done at home during late hours and weekends.

I would like to thank Carlo Hjelkrem, Lars Rand and Borgar Tørre Olsen for constructive comments to the thesis.

And last, but not least, I want to thank my family for their support, patience and willingness to do more than I could expect during these years. I hereby dedicate the thesis to my wife Kari Synnøve, and my children Liv and Håkon.

Kjell Stordahl

Oslo, 22th February 2006

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1 INTRODUCTION

1.1 Background

I have for some decades been working with telecommunications forecasting. The area has been very interesting and challenging. In the 70's and 80's few telecommunications services were available. In Europe there was no competition and the incumbents controlled the telecommunications market. At that time it was much more straightforward to make forecasts in the telecom market. The demand evolved more smoothly than we see today and more advanced econometric and mathematical/statistical models were used for long-term forecasts.

During the last 15 years the world of telecommunication has changed dramatically. The European mobile system GSM was introduced in 1993. The European networks were digitalised in the 90's. Internet gained speed after the release of the World Wide Web in 1990 and the first graphical browser, Mosaic in 1993. ISDN was introduced and after some years the broadband technologies ADSL and Hybride Fibre Coax (HFC). During the last years the broadband technologies Fibre To The Home (FTTH), Fibre To The Building (FTTB), ADSL2+, power line connections (PLC), SHDSL, Fixed Wireless Broadband Access (FWA) and Wireless Local Access Network (WLAN) have been introduced and coming up technologies are VDSL2, Dynamic Spectrum Management (DSM), Wireless Fidelity (WiFi) and Wireless Metropolitan Area Network (WiMAX). The mobile market evolves at the same time by the technologies GPRS, EDGE and UMTS and the enhancement High Speed Downlink Packet Access (HSDPA). The traditional POTS service has during a short period lost significant market share to Voice over IP (VoIP).

Three decades ago a telephone access had no additional functionality. Now, the broadband terminal is a PC, while the mobile terminal is a small computer often with a camera. We see a variety of new services every year. New complex relations between services are generated. Knowledge about substitutions and migration effects are important for understanding the dynamics of the services. Now, there are many new competitors and the incumbents have been forced to open up their markets through wholesale and Local Loop Unbundling. In Norway 170 operators have entered the broadband market.

To be able to make forecasts and especially long-term forecasts in this complex and very dynamic market, it is not enough to apply advanced classical forecasting models. A very important aspect is ability to obtain and to utilize technical information about new services and technologies, which may affect the established services. Also techno-economic calculations and evaluation of new and established technologies are important input to the forecasts. Hence, the process, especially for making long-term telecommunications forecasts, is more complex than before.

From 1992 until now I have participated in the international projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA, IST-2000-25172 TONIC and ECOSYS through the European programs RACE, ACTS, IST and EUREKA/CELTIC. The main objectives have been to develop a techno-economic tool and to apply the tool to analyse broadband and mobile technologies, the rollout strategies and defined business cases in this area. An important input to the analysis has been long-term forecasts for the Western European market.

1.2 Motivation

The Dr. Philos thesis is mainly based on papers on “Long-term telecommunications forecasting”. The thesis gives a short review and evaluation of each of the enclosed papers. To be able to make reasonable evaluation of long-term forecasting models and long-term forecasts a natural approach is to wait and see the real evolution. Therefore, parts of the evaluations are based on comparing the long-term forecasts with the real data. This is the main reason for including some older publications in the thesis.

The motivation for the thesis has been to view a selection of papers on long-term forecasting, review the results and examine what is learned.

The majority of the papers are concentrating on broadband and long-term broadband forecasting. The papers include both broadband access forecasts and traffic forecasts.

Techno-economic calculations and evaluation of technologies show their “economic” value, which is an important input to the long-term forecasts. A part of the techno-economic calculations is long-term forecasts and long-term forecasting models for technology and component cost evolution. Therefore, a paper of these subjects is included in the thesis.

There are of course significant uncertainties connected to long-term forecasts. To be able to evaluate the impact of the uncertainties, risk analysis has been applied to show how the uncertainties in critical variables affect the results. Some papers focused especially on uncertainties in the market and penetration forecasts are included in the thesis, because this type of analysis cannot be avoided when long-term forecasts are used.

Long-term adoption rate forecasts are crucial for rollout strategies. Adoption rate is the genuine demand and defined in chapter 7 of the thesis. The operator’s rollout strategy should be based on the long-term adoption rate forecasts, which is described in the enclosed papers.

Finally, also forecasting models of new broadband revenue are included. The paper shows the potentials for new broadband and mobile revenue and settles a framework for long-term mobile and broadband revenue forecasts.

Some of the papers are found in “Telecommunications Forecasting”, Telektronikk (100) no 4, 2004 where I have been the guest editor. The issue contains a comprehensive collection of papers in this field from several international experts.

1.3 Organisation of the thesis

The thesis covers the following main areas:

- Long-term demand forecasting and application of the Delphi technique
- Long-term broadband technology forecasting
- Long-term forecasting models for cost evolution of components and technologies
- Long-term traffic forecasting
- Forecast uncertainty and risk
- Long-term adoption rate forecasting
- Forecasting new broadband revenue

The thesis covers long-term forecasts of the broadband market and not other markets (mobile, satellite).

The following papers for the Dr. Philos thesis are enclosed:

Long-term demand forecasting and application of the Delphi technique

- Stordahl K, “Bruk av ekspertundersøkelser til prognoser for nye teletjenester i privatmarkedet” (Use of expert surveys to forecast the demand for new telecommunications services in the residential market) *Telektronikk no. 1, 1994.* [Stor94a]
- Stordahl K and E Murphy, “Forecasting long term demand for wide- and broadband services in the residential market”. *IEEE of Comminications no.2 1995*. [Stor95a]
- Stordahl K and L. Rand. “Long term forecasts for broadband demand”. *Telektronikk (95) no2/3, 1999*. [Stor99a]

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- Stordahl K, L. Rand. “Long term forecasts for broadband demand”. *Telektronik (95) no2/3,* 1999. [Stor99a] (Same paper as the previous one)
- Stordahl K, K O Kalhagen, “Broadband access forecasts for the European market”. *Telektronikk (98) no 2/3*, November 2002. [Stor02a], (Chapter 1-4,and 6[1]. The first part overlaps with [Stor99a])
- Stordahl K. “Long-term broadband technology forecasting”, *Telektronikk (100) no 4,* 2004. [Stor04a]

Long-term forecasting models for cost evolution of components and technologies

- Olsen B. T., K Stordahl, “Models for forecasting cost evolution of components and technologies” *Telektronikk (100) no4,* 2004. [Olsen04]

Long-term traffic forecasting

- Stordahl K, “Forecasting – an important factor for network planning”. *Telektronikk (99) no 3,* 2003 [Stor03a]
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- Stordahl K "Methods for traffic matrix forecasting". *In Proc 12th International Teletraffic Congress*. Torino, Italy, June 1-8, 1988. [Stor88]

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[1] Chapter 5 in [Stor02a] presents mobile forecasts, which is outside the scope of the thesis.

Forecast uncertainty and risk

- Stordahl K, L A Ims and B T Olsen “Risk assessment and techno-economic analysis of competition between PNO and Cable operators” *In Proc Networks 96*, Sydney, November 24 –29, 1996. [Stor96]

- Stordahl K, N. K. Elnegaard, L. A. Ims, B.T. Olsen. Overview of risks in multimedia broadband upgrades. I*n proc Globecom ’99*, Rio de Janeiro, Brazil, December 5-10, 1999. [Stor99b]

- Stordahl K, N K Elnegaard, B T Olsen, “Broadband access rollout strategies in a competitive environment”. *In Proc Optical Hybride Access Network/Full Service Access Network workshop*, Yokohama, Japan, April 4-6, 2001 [Stor01]

- Elnegaard N. K., K Stordahl “Analysing the impact of forecast uncertainties in broadband access rollouts by use of risk analysis”, *Telektronikk(100) no 4*, 2004 [Elne04]

Long-term adoption rate forecasting

- Stordahl K, N K Elnegaard, B T Olsen, M Lähteenoja “Competition in the Local Loop – How to Minimize the Market Risks” *In Proc. XV International Symposium on Services in the Local access - ISSLS 2004.* Edinburgh, Scotland, 21-24 March, 2004 [Stor04b]

- Stordahl K, N K Elnegaard, “Broadband in the residual market: First mover’s advantage” Unpublished so far, but sent to WTC/ISSLS 2006 [Stor06]

Forecasting new broadband revenue

- Stordahl K, B. Craignou, T Smura, J O Paret, I Welling, K R Renjish, T Monath “Potential new broadband revenue streams”, *The 2005 Networking and Electronic Commerce Research Conference*, Lake Garda, Italy, 6-9 October, 2005 [Stor05a]

2 LONG-TERM DEMAND FORECASTING AND APPLICATION OF THE DELPHI TECHNIQUE

2.1 The Delphi technique

When there are no possibilities for making quantitative forecasting models, qualitative forecasting methods may be applied. Relevant qualitative forecasting methods are judgemental methods, market surveys, expert opinions, the analogy method, the Scenario method and the Delphi method.

The Delphi technique is an advanced expert opinion method developed by Rand Corporation during the 1950's. The Delphi technique is a relevant forecasting method when quantitative statistical models cannot be used because of lack of available or appropriate data.

The Delphi technique is based on four main principles:

1) Selection of a number of experts who are responding anonymously without interactions
2) Application of structured questionnaires and controlled feedback from the facilitators
3) The questionnaire is sent several rounds until the expert's views iterate to a sort of common opinion
4) The final result is based on statistical aggregation of the expert's responses.

The following papers, where the Delphi technique is used for long-term forecasting, are a part of the thesis:

- Stordahl K, "Bruk av ekspertundersøkelser til prognoser for nye teletjenester i privatmarkedet" (Use of expert surveys to forecast the demand for new telecommunications services in the residential market) *Telektronikk no. 1, 1994.* [Stor94a]

- Stordahl K and E Murphy, "Forecasting long term demand for wide- and broadband services in the residential market". *IEEE of Comminications no.2 1995*. [Stor95a]

- Stordahl K and L. Rand. "Long term forecasts for broadband demand". *Telektronikk (95) no 2/3,* 1999. [Stor99a]

The first paper describes and evaluates the results from a Norwegian Delphi survey conducted in 1975-1976. The second and third paper describes the results from two Pan European Delphi surveys conducted in 1993-1994 and 1997. In all cases the Delphi surveys were used to make long-term forecasts for new broadband services in the residential market. All three Delphi surveys are included in the thesis because the approaches are very similar, which makes it easier to draw conclusions about the methodology.

To be able to evaluate the results and the long-term forecasts, especially for the two last surveys, the year 2005 may be a natural check point level for the validation.

The basis for the three papers was to make forecasts for new telecommunication services when no historical demand data were available for most of the services and demand data would not be available for several years.

The evaluation of each of the papers is performed in two steps. The first step is to evaluate how the Delphi technique is used. The reference article for this part is:

- Rowe G, and G. Wright “Expert opinions in forecasting: The role of the Delphi technique”. Principles of Forecasting. J Scott Armstrong, ISBN 0-7923-7930-6, Kluwer Academic Publishers, 2001 [Rowe01]

The article is summing up the knowledge on this field and gives recommendations for conducting Delphi surveys based on experience from a set of Delphi surveys and related research.

The second step is to analyse the Delphi results and compare the results with the actual historical evolution of the demand until 2005.

2.2 “Use of expert surveys to forecast the demand for new telecommunications services in the residential market” [Stor94a]

2.2.1 Background

The results from the Delphi survey was described in:

- Trælnes T, K Stordahl ”Behovsstudie for nye teletjenester i hjemmene“ TF rapport no 19, 1976 [Træ76]

The most important results and evaluation of the results 19 years later are also documented in [Stor94a].

The objective of the study was to estimate the long-term demand for new telecommunication services in the residential market. The results were used as input to Long-term planning activities in Televerket (Telenor).

It is important to underline that the study was conducted in a period where most of the services described were not known either in Televerket or outside Televerket. In 1975-76 no available national or international surveys were available for most of the services. Some information of the services described and defined in the Delphi survey was found in professional international, mainly American magazines. At that time Televerket’s main services were: telephony, telex, datel and telegram. Televerket did not conduct marketing, market analyses or market surveys because the organisation at that time had to concentrate their effort to reduce the huge waiting line for getting telephone access.

2.2.2 Selection of experts

[Rowe01] discusses the effect of having experts with a general background compared of appropriate knowledge in the domain examined. The conclusion was that the quality increases especially in the additional rounds because the experts were able to understand and adopt arguments and reasons, which was distributed together with the quantitative part of the feedback. [Rowe01] also recommend heterogeneous experts not to get too “uniform” answers from the participants.

In the Norwegian Delphi survey it was decided to include expert from a large part of the society, but a dominating part with relation to existing and future telecommunication services. Out of 64 experts 15,5% represented Televerket, 15,5% telecommunication industry and distribution, 8% newspapers and their organisations, 5% Norwegian broadcasting, 5% governmental departments, 5% publishing houses, 5% technical universities, 5% education and media research, 3% post organisation, 25% special experts and 9% separate institutions. The new telecommunication services defined in the survey covered not only the traditional telecommunication services, but services which were supposed to interact with newspapers, publishing houses, educational institutions, postal distribution, Norwegian broadcasting etc.

The survey was postal and not “on site”.

2.2.3 Number of experts

[Rowe01] discusses the number of experts in a Delphi survey and recommends 5- 20 persons. Arguments for the limitation are: “Larger groups make conflicts and produces to a greater extent irrelevant arguments, easier to create information overflow and not too high administrative costs”. However, the article also states “The answer to the question of what is the optimal size however is uncertain”. Number of experts available may limit the possibilities. More in depth feedback might suggest a smaller panel of experts. However, direct empirical research in this domain is limited.

In the Norwegian Delphi survey 123 experts were asked to participate. 54 experts participated in both Delphi round one and two. 64 experts participated either in round one or round two. The question is if the needed number of experts has been overestimated in the survey. Personally I think this is a very difficult question. First of all, it must be very difficult to recommend a general size of number of experts independent of the complexity of the Delphi survey. In the Norwegian survey a set of new services were examined and it was necessary to include experts on various fields in the society to cover specific aspects. Each of the experts had the possibility to deliver specific arguments and reasons for their answers and many did. These verbal answers were classified in groups and sent to every expert together with the structured quantitative aggregated answers. [Rowe01] states: *“More in depth feedback might suggest a smaller panel of experts”*. It is important to notice that one of the main principles of the Delphi technique is the anonymity of the experts. Hence, it is not easy to understand how the feedback could be more in dept than the process described in the Norwegian Delphi survey.

2.2.4 Individual arguments and reasons

[Rowe01] documents that the Delphi results improve when the feedback contains individual arguments and reasons for the responses. In the Norwegian survey the individual arguments for each telecommunication service were listed and classified, and sent back together with the quantitative part of the responses.

2.2.5 Number of rounds

Number of rounds is recommended to be 2-3 depending on the variation of the answers in the questionnaire [Rowe01]. In the Norwegian Delphi survey there were few outliers after the second round and the variation in the responses were assumed to be acceptable. In the analysis the median, not the statistical mean, were used to avoid bias because of some outliers. Therefore, it was decided to stop the Delphi survey after round two. However, each participant was invited to attend a half-day workshop with presentation and discussions of the Delphi results. 55% of the experts participated and gave additional value to the Delphi survey.

2.2.6 Structuring the questionnaire

[Rowe01] gives many advices regarding phrasing questions, being precise in the questions and definitions, avoiding irrelevant information, etc.

This point is of course the most fundamental for carrying out a successesful Delphi survey. First of all, the objectives and the main content for the survey have to be determined. Both research and extensive literature search were carried out to identify the future telecommunication services. A total of 20 new telecommunication services were defined. Before answering questions about a service, the following information was presented:

- Description of the service
- Presentation of how the service was used
- Presentation of technical conditions for the service
- Illustrate (Figure) of the service

In addition a standardized questionnaire for the services was developed. By using this procedure, the experts got the same questions for each service, which made responding easier.

The standardized questionnaire is shown in [Stor94a]. The questions in the Delphi survey covered:

- Desirability for the service
- Usage of the service (Mean time and frequency)
- Annual price for the service
- Demand for a set of prices
- Introduction time for the service
- Demand 5 and 10 years after introduction, respectively
- Deployment coverage respectively 5 and 10 years after introduction

2.2.7 Evaluation of the results

The services defined in 1976 Delphi survey were:

- Additional TV channels
- TV program with separate payment (Later called: Pay TV)
- TV programs from program library (Later called: Video on demand)
- Video recorder
- Text transmission on the TV screen (Later called: Text TV)
- Extraction of information from data banks (Later called: Prestel in UK and Teledata in Norway)
- Self service on the network (Later called: Tele shopping)

- Tele education with teacher (Later called: Tele learning)
- Tele education with computer (Later called: Tele learning)
- Tele newspaper on subscription (Later called: Electronic newspaper)
- Specialised Tele newspaper on demand
- Tele post (Later: Fax, Data communication, E-mail)
- Video phone
- Home office
- Data response and tele control
- New telephone services
- Long distance tele control
- Radio programs on demand (Radio programs and music on demand)
- Still picture phone

The evaluation of the results from the Delphi survey is done in [Stor94a] based on information until 1994 – 19 years after the Delphi survey was conducted. The evaluation of service by service is performed rather detailed and will not be repeated here - only the main conclusions.

All defined services have proved to be future proof. This was of course an important basis for the experts of the Delphi survey. The introduction year for most of the services was estimated to be 1990 with a 75% quartile ranging from 1995 to 2000 and a 25% quartile ranging from 1990 to 1985. For some services introduction year were estimated to be 1985. Even if the services video on demand, radio programs on demand and newspaper on demand has been significantly delayed, the introduction year forecasts from the Delphi survey is surprisingly good taken into account the telecommunication situation in 1976 when the forecasts were produced.

2.3 “Forecasting long term demand for wide- and broadband services in the residential market”[Stor95a]

2.3.1 Background

The Delphi survey was carried out in 1993-1994 as a part of the European Commission project TITAN in the RACE II programme. The TITAN project developed techno-economic methodologies and a tool to calculate economic value (NPV, payback period, Internal rate of return) and evaluate various technologies for narrowband and broadband networks. The Delphi survey was conducted to develop long-term forecasts for demand for new broadband applications and broadband access capacities. The demand forecasts, together with information of willingness to pay, were used as input to techno-economic calculations and evaluations of new technologies.

2.3.2 Selection of experts

Since TITAN was a Pan European project and the results should be valid for Western Europe, it was decided to conduct a Delphi survey, which reflected the Western European market. Therefore, the intention was to establish a panel with experts from the 10 participating countries in the project. The selection of experts was carried out based on the same criteria as in the Norwegian Delphi survey.

The survey was postal and not “on site”.

2.3.3 Number of experts

It was decided to select 10 experts from each of the countries, Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Norway, Portugal, and United Kingdom – a total of 100 experts. However, some non-response occurred and 58 experts participated in the first round and 50 in the second. The further South in Europe, the higher was the non-response.

Since the objective with the Delphi survey was to make long-term forecasts for Western Europe, it should be important to increase the number of expert participants compared to [Rowe01], since the economic situation, the telecommunication infrastructure and the willingness to pay varies between countries in Western Europe.

2.3.4 Individual arguments and reasons

[Rowe01] documents that the Delphi results improve when the feedback contains individual arguments and reasons for the responses. In the Pan European survey the individual arguments for each telecommunication service were listed and sent back together with the quantitative part of the responses.

2.3.5 Number of rounds

The difference between 75% quartile and the 25% quartile was reduced significantly from round one to round two for most all questions. In the analysis the median, not the statistical mean, were used to avoid bias because of some outliers and get more robust statistical results. In addition it turned out to be more difficult than anticipated to persuade the international experts to complete their questionnaire. Therefore it was decided to stop the Delphi process after two rounds.

2.3.6 Structuring the questionnaire

The questionnaire was structured as in the Norwegian Delphi survey. Before answering questions about an application, the following information was presented:

- Description of the application
- Presentation of how the application was used
- Presentation of technical assumption for the application
- Illustrate (Figure) of the application

In addition a standardized questionnaire for the applications was developed. By using this procedure, the experts got the same questions for each application, which made responding easier. The questions of the Delphi survey covered:

- Reasons for purchasing the application
- Comments

- User characteristics
- What kind of alternatives to the described applications exist
- Demand for a set of annual prices for Wideband (2 Mbit/s) and for Broadband (8Mbit/s) quality
- Forecasts for 1995, 2000, 2005, 2010 and the expected saturation for Wideband (2 Mbit/s) and for Broadband (8Mbit/s) quality
- Willingness to pay for Wideband (2 Mbit/s) and for Broadband (8Mbit/s) quality as a function of the households disposal income

The questions were asked for 128 kbit/s access, 2048 kbit/s access and 8 Mbit/s access and for 12 different broadband applications.

Finally, the experts were asked to indicate which three broadband applications they expected to have the greatest number of subscribers.

The total number of questions was 398 in the first round and reduced to 365, in the second since some of the qualitative questions were not resubmitted to experts.

2.3.7 Evaluation of the results

The selected and defined broadband applications were:

Tele interaction (Entertainment)

- Video on demand
- Multimedia telegame
- Videophony
- Telecommunity (Telemedicine home)

Tele shopping (Electronic market)

- Home ordering with electronic bill payment
- Advertising and marketing

Thematic Channels

- Interactive TV and specialized channels
- Electronic newspaper

Teleworking

- Home office (simple)
- Home office (advanced)
- Remote education (home)
- Remote education (studio)

The defined applications from 1994 are still very relevant and important. The main part of the applications was assumed to use a broadband access. Looking at the evolution from 1994 to 2005, a very important group of applications arise based on Internet, the first graphical Internet browser and the release of WWW client, Mosaic in 1993. The first years only simple low capacity browsing and information retrieval was possible, but during the last part of the period also high capacity information retrieval and downloading are possible.

Table 2 in [Stor95a] shows the ranking of the applications with video on demand, home office and video telephony on top. Table 3 and 4 show the willingness to pay for the services and the penetration forecasts which confirm the ranking. Video on demand is in the introduction phase in Western Europe. However, the broadband access makes possible downloading of film clips, movies, news, earlier distributed TV programs etc. Many employees utilise home offices today by use of broadband connection. Video telephony has not turned out to be very popular. Multimedia telegame, which was ranked as number 5 is extremely popular among the young broadband users [MMI03]. The demand curves for the services are still difficult to evaluate because business models for broadband content and payment is under development. So far most of the countries in Western Europe have a flat rate regime, but some countries have traffic tariffs above a given monthly Gbyte volume [Point04].

It is important to validate the Delphi questionnaire and the results based on the situation in 1993-1994. At that time the concept broadband was mainly unknown and also the main access technologies, which is used today. The concepts narrowband (- 128kbit/s), wideband (128 kbit/s – 2Mbit/s) and Broadband (2Mbit/s -) existed. Today wideband is eliminated and included in broadband. The future tariff regime for broadband was unknown. In the Delphi questionnaire it was assumed that the user should pay for the access and for the services. Now, because of flat rate in most of the European countries and no specific monthly tariff for the services, it is difficult to evaluate the forecasting table 4 in [Stor95a]. If a customer has a broadband access, then many of the listed applications will be available, independent of the usage or not.

The figure 2.1 in the thesis shows the experts view on the demand different accesses. The figure is shown in [Stor94b] and chapter 3 in [Ims98].

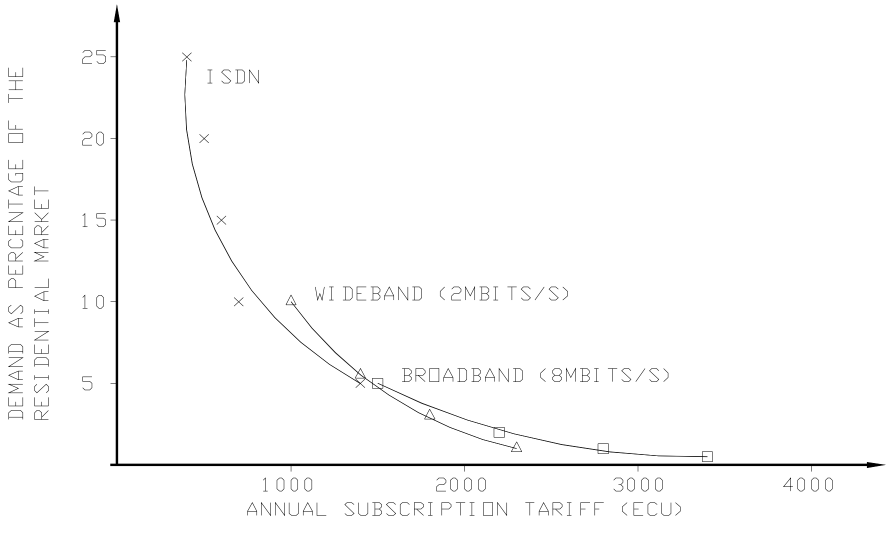


Figure 2.1 Estimated demand curves for ISDN, wide- and broadband accesses.

The willingness to pay for ISDN, wide- and broadband accesses is shown as a function of annual subscription tariff in ECU (Euro). When the survey was conducted, the broadband access was assumed to be very expensive compared with what is seen now. New technology, especially DSL and HFC and mass production of equipment and network components have reduced the access price significantly.

Figure 2.1 and table 1 in [Stor95a] show a set of very high annual subscription tariffs for 2Mbit/s (wideband) access, but the Delphi experts do a very good evaluation, telling that even for the lowest alternative, 1000 Euro, only 10% of the residential market is willing to order the access. At the end of 2004, the monthly tariff for 2Mbit/s access varied mainly between 40 and 60 Euro among the Western European countries [Point04]. The tariff corresponds to 500-700 Euro per year. At that time total broadband penetration including also lower access capacities than 2Mbit/s was about 20% (Section 3.4, Table 3.7 in the thesis).

Figure 2.1 and figure 3 in [Stor95a] show in the same way a set of very high annual subscription tariffs for 8Mbit/s (broadband access), but the Delphi experts do a very good evaluation in this case too, telling that even for the lowest alternative (1500 Euro per year) only 5% will order the connection. Until 2004 few operators in Europe offered 8Mbit/s or more and the capacity price was to some extent lower. One year later, 8-15 Mbit/s is going to be a more common access capacity because the cost of ADSL2+ line cards has been significantly reduced during 2005. The ADSL2+ line cards can be put into the same DSLAM as for ADSL cards. The lower production costs will also influence the end user prices and increase the demand for higher capacity.

Figure 2.2 shows the long-term access forecasts for ISDN, wideband (2 Mbit/s) and broadband (8 Mbit/s). The figure is shown in [Stor94b] and chapter 3 in [Ims98].

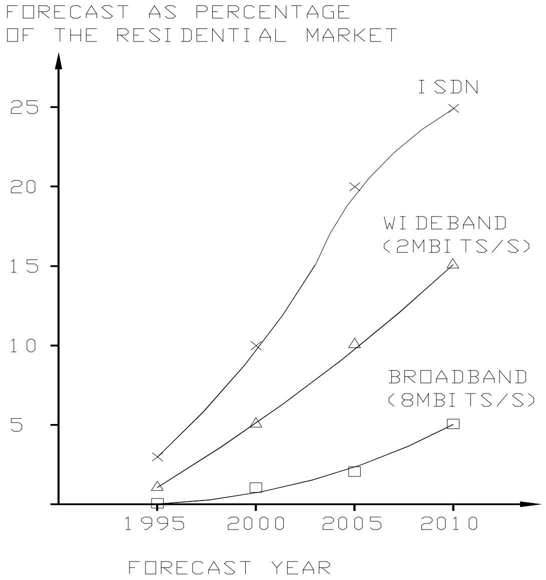


Figure 2.2 Long-term forecasts for ISDN, wide and broadband accesses as percentage of the residential market.

The long-term forecasts for ISDN was optimistic and substitution effects between ISDN and wide/broadband was not foreseen in the Delphi survey. Figure 5.1 in the thesis shows that ISDN reached 26% penetration in 2002 in Norway, 7 years after introduction. Norway and Germany had the highest ISDN penetration in the world and are not representative of the European ISDN evolution. The wide/broadband accesses for the residential market were introduced in Western Europe in 1999. The accesses offered were mainly below 2 Mbit/s. Since there were only two alternatives, it is reasonable to interpret the 2 Mbit/s class to include also lower capacities. Hence, the forecasts were too high for year 2000 and too low in 2005. (Precise West European statistics on access capacities is not available). So far, not much high capacity access volume has been offered in the Western European market. Therefore, the forecasts for 2005 seem fairly ok.

However, because of extensive rollout of ADSL2+ cards, the 2010 forecasts are probably too low.

Access capacity forecasts from this Delphi survey is also discussed in the following paper [Stor99a] together with access capacity forecasts from the 1997 Delphi survey.

Chapter 3, "Demand for new services" page 23-38, by K Stordahl, in the book "Introduction strategies and techno-economic evaluations" [Ims98] shows additional results from the Delphi survey.

2.4 "Long term forecasts for broadband demand". [Stor99a]

2.4.1 Background

In 1997 broadband accesses were not introduced in the European residential market. Leased lines were at that time the most relevant technology for high capacity connections in the business market. The Delphi survey was conducted during the workshop "Techno-economics of Multimedia networks" in 1997 arranged at University of Aveiro by the project OPTIMUM. The European Commission supported the project through the ACTS program. The objective for OPTIMUM was to develop a techno-economic tool and to evaluate various network architectures. The Delphi survey was carried out to develop long-term demand forecasts for new broadband services and broadband access capacities and for predicting the expected broadband tariff evolution.

Because the experience from the TITAN Delphi survey from 1993-94 was assumed to be reasonable good, it was decided to carry out a Delphi survey based on mainly the same approach. The only difference was the duration of the survey, which now was conducted as an "on-site" survey, which produced the final Delphi results in two days.

2.4.2 Planning and conducting the Delphi survey

The questionnaire was finalized before the workshop. A data program was developed for implementing the answers from the experts and for producing figures and tables with accumulated statistics from the experts. On the first day of the workshop, introduction of the Delphi survey was given in plenum. The presentation included objectives, how the survey would be conducted, and information of technical and financial prerequisites. The whole questionnaire was presented and there were comments and questions from the floor, which were answered by the facilitator (Kjell Stordahl). The questionnaires were distributed to the conference participants, who answered the questions during the Delphi- session. The next day a new Delphi-session was scheduled. The facilitator (Kjell Stordahl) presented accumulated statistics for all questions from the first round and clarified and answered questions from the floor. Then the conference participants filled out the questionnaire for the second round. The final results were produced and posted on a wall the third day.

2.4.3 Selection of experts/number of experts

The experts were participants of the workshop on "Techno-economics of Multimedia networks". There were 36 participants in the first round and 32 in the second. The experts were not selected, but attended as experts because of the workshop. They represented 16 different European countries. However, the experts attended the workshop, and could be considered as a homogeneous group in that sense. The workshop covered demand, economics and telecom technology related areas.

The Delphi criteria on anonymous experts were not satisfied and can be evaluated to be a weakness in the survey. The question is how much time the experts had to discuss the Delphi survey after a long conference day and how much the questions from the floor influenced the Delphi results.

2.4.4 Individual arguments and reasons

The questionnaire had some open questions for each service (comments, alternative suggestion to the service). However, there was limited time to present all individual verbal comments. Some individual arguments/reasons were presented to the experts after the first round, and the same experts also presented their views and raised some discussions.

2.4.5 Number of rounds

The number of rounds was decided beforehand to be two since the conclusions had to be reached during the workshop. The workshop program included two Delphi sessions. Therefore, the final Delphi results were not presented in plenum, but the tables and figures were posted on a wall, which was available for all the experts. Analysis showed that the interval between 75% and 25% quartile was significantly reduced from round one to round two. One example is shown in figure 4 [Stor99a].

2.4.6 Structuring the questionnaire

The questionnaire was structured similar to the TITAN Delphi survey. Instead of asking questions of specific applications, the questions were divided in groups of applications. Like in the two previous Delphi surveys, the application group questions started with general description of the application group, presentation of technical assumptions and an illustration (figure).

The main questions in the survey were:

- Application groups: Usage as a function of price
- Access capacity: Penetration as a function of price
- Access capacity: Penetration as a function of time (2000, 2005, 2010, 2015 and saturation)
- Access capacity: Demand as a function of disposable income

The defined access capacities were:

- ISDN
- 2-4 Mbit/s
- 25Mbit/s (downstream)/384 kbit/s (upstream)
- 25Mbit/s (downstream)/6 Mbit/s (upstream)

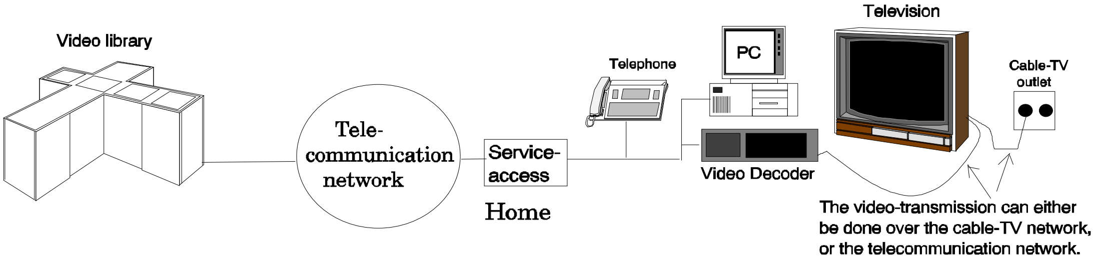
The experts were also asked to rank the most important leading application groups.

Figure 2.3 shows how the description of applications were structured in the questionnaire.

Example of application: Video on demand and Audio/Music on demand.

General description:
This is an application where a video-library is accessed, and programs may be ordered and transmitted to the home.
This application could substitute some part of the time spend on ordinary TV and part of money spent on renting videos in video shops.

Technical assumptions:
The user may either use an advanced telephone or a PC to communicate with the video-library. The transmission of the video may either be done via a Cable-TV network, or a telecommunication network. The access capacity will be in the range of 2- 4 Mbit/s.



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1 Given the following alternative prices per hour (1997 ECU). What do you believe will be the expected use of this group of applications (Tele-entertainment)?

<u>Note</u>: We assume that the tele-entertainment applications are supplementary to the traditional TV channels, but there may be some substitution effects.

Round 1 (medians)					
Prices per hour	**0,5 ECU**	**2 ECU**	**5 ECU**	**10 ECU**	**20 ECU**
Minutes per day	**70**	**40**	**12**	**5**	**1**

Having seen the above results, what would your answers be to the corresponding question today?

Round 2					
Prices per hour:	**0.5 ECU**	**2 ECU**	**5 ECU**	**10 ECU**	**20 ECU**
Minutes per day:					

Comments (if any):

Figure 2.3 Description of an application and related questions to the application (1997 Delphi survey)

2.4.7 Evaluation of the results

The broadband applications were classified in the following 7 main groups:

Tele-entertainment

- Multimedia telegame
- Virtual reality
- Video on demand
- Audio/music on demand

Information services

- Information retrieval
- Electronic magazines
- Information retrieval by intelligent agents
- Electronic newspapers

Teleshopping

- Teleshopping
- Advertising

Private communications services

- Videophone
- Teleconferencing

Teleworking

- Videophone
- Joint editing/publishing
- Teleconferencing
- Information retrieval
- Multimedia applications

Telelearning

- Video on demand
- Virtual reality

Telecommunity

- Telesurveillance
- Videophone
- Telediagnostics

The applications and application groups defined 8 years ago still covers the main broadband applications in 2005.

Table 3 in [Stor99a] compares the ranking of application in the 1994 and 1997 Delphi survey. The application groups Teleworking, Information services and Tele-entertainment were the highest ranked in 1997. Even in 2005 this ranking seems to be very good. The ranking is comparable with the 1994 ranking except that video telephony is substituted with information services.

The 1994 Delphi survey questionnaire handled each broadband application separately. The conditions in the 1997 Delphi survey presupposed that a broadband access was necessary to offer broadband applications and subscription fee had to be paid for the broadband access. In addition the customers had to pay for the traffic generated by the different broadband applications. Figure 2 and 3 in [Stor99a] shows the expected usage as a function of price per hour for the defined application groups. The willingness to pay was definitely highest for teleworking, especially when the employing company paid for all usage. Telelearning and tele-entertainment were ranked as 2 and 3. Since the households will not use all services the experts was asked to estimate the usage of a broadband access in minutes per day for 5 alternative prices. The conclusion was 45 minutes per day for 2 Euro per hour and 120 minutes per day for 0,5 Euro per hour. The estimates indicates a monthly traffic charge between 30 and 45 Euro per month, which had to be paid in addition to the access subscription fee.

As mentioned, it is difficult to evaluate the estimates of willingness to pay for the usage, because the main traffic regime in Western Europe today is the broadband flat rate regime. However, there are also exceptions. The incumbents Belgacom, Deutsche telecom, KPN, TDC and Telecom Italy have one or more broadband access products, where the traffic is charged per time unit or per traffic volume beyond a given monthly limit [Point04]. In Belgium practically all broadband operators avoid the flat rate regime. The white paper “Broadband Incentive Problem” by Broadband Working Group MIT Communication Future Program, [BWG05], states “*that the broadband traffic per user continuously increases and generates operational costs and investments without reflection in increased traffic charges and revenue for the operators. The operators may reach a situation where they want reduce the traffic instead of stimulating to increase and create value for the society. Bandwidth demanding innovation will not be stimulated because there exists no incentives. One possibility may be to introduce charge for broadband traffic”*. So far, it is difficult to draw conclusions about the future broadband tariff regime.

The Delphi experts were asked how much a household is willing to pay for broadband capacity with 128kbit as a reference level. They estimated, see figure 12 in [Stor99a], that a household was willing to pay 50% more for 2Mbit/s, 100% more for 50Mbit/s and 120% more for 500Mbit/s.

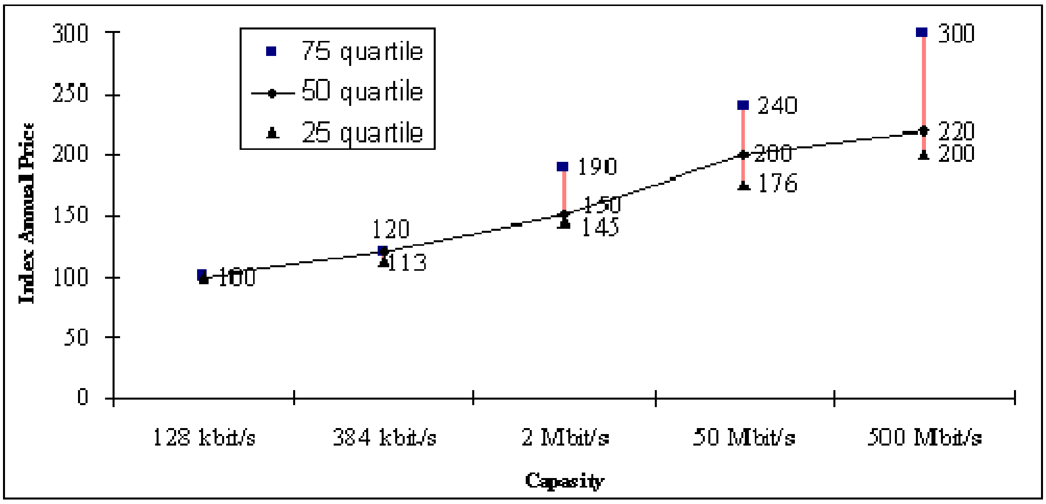

Figure 2.4 Willingness to pay for increased capacity relatively to 128 kbit/s

The results show that there is no linear willingness to pay as a function of increased bandwidth. The increased willingness to pay as a function of bandwidth is rather moderate. Figure 11 in [Stor99a] gives the same conclusions. The figure shows that even households with high disposable income are willing to pay marginally more for high bandwidth. This knowledge is important and gives directions for relevant prices for higher bandwidths. The broadband evolution so far supports these results. When higher access bandwidths are introduced in the market, the prices are not significantly higher than for lower bandwidth products. At the same time the prices on all established products are reduced as a function of time.

The long-term broadband residential access forecasts, from the 1994 and 1997 Delphi surveys are found in figure 5 [Stor99a]. The figure shows that the high capacities (8Mbit/s, 25Mbit/s) forecasts have been too optimistic in the period 2000 – 2005. However, if all capacities are accumulated the forecasts are reasonable good. In 2000 the broadband access penetration per household in Western Europe was 1%.

At the end of 2005 the broadband residential penetration is estimated to be about 28,5% (See chapter 3.4 in the thesis). The 1994 Delphi forecasts for 2005 were 11,3%, while the 1997 Delphi forecasts were 20,5%, which must be very acceptable taking into account that no demand data were available and broadband was not introduced when the forecasts were made. The 1994 Delphi survey’s 2005 broadband forecasts (11,3%) was very right for 2003 (11,4%), while the 1997 Delphi survey’s 2005 broadband forecasts (20,5%) was very right for 2004 (19,9%). See chapter 3.4 in the thesis.

2.5 Experiences and conclusions

The strength of the Delphi method is to give the best prediction based on available knowledge and perspectives about the future. The weakness of the approach is lack of scientific and statistical analysis of historical data and the possibility for including biased knowledge. However, the approach of answering questions in several rounds supplemented with individual arguments for the answers should reduce the bias in the results.

The results from the Delphi surveys has been better than what could be expected taking into account the information available at the time when the surveys were conducted. The evaluation of applications/services, the evaluations of expected demand, and the long-term forecasts have been of accepted quality.

A lot of preparations and also research were done in beforehand to be able to define the relevant applications/ services, to give necessary background information about the applications/services, to formulate separate questions and finally the questionnaire.

It is recommended to describe new applications/services by a description, by presentation of how the service is supposed to be used, by a short presentation of technical conditions for the application/service and an illustration (figure) of the application/service. The approach for presentation is shown in figure 3.3 and 3.4 in [Stor94a] and in figure 1 in [Stor99a].

The same design of the questionnaire was used in all three Delphi surveys. It is also recommended to use exactly the same type of questions for each service, so that misunderstandings may be avoided. Figure 3.2 in [Stor94a] and figure 1 in [Stor99a] show the question design. The question design is also timesaving and makes it possible to include more questions compared with more complex questionnaires.

The Delphi approach used is recommended for future Delphi surveys. The approach corresponds mainly with the guidelines described in [Rowe01].

The on-site Delphi survey, where the Delphi results were produced in two days, was effective. The small deviations from the basic Delphi principles do not seem to reduce the quality of the results.

3 LONG-TERM BROADBAND TECHNOLOGY FORECASTING

The next type of models applied for long term broadband forecasting are diffusion models. These models are quantitative forecasting models, which are based on a time series. One class of the diffusion models are the Logistic models. These models have been used in the following papers, which are a part of the thesis:

- Stordahl K, L. Rand. "Long term forecasts for broadband demand". *Telektronikk (95) no 2/3,* 1999. [Stor99a]
- Stordahl K, K O Kalhagen, "Broadband access forecasts for the European market". *Telektronikk (98) no 2/3,* November 2002. [Stor02a] (The first part overlaps with [Stor99a])
- Stordahl K. "Long-term broadband technology forecasting", *Telektronikk (100) no 4,* 2004. [Stor04a]

The papers describe long-term broadband access demand forecasting models for the fixed network.

The main part of the chapter deals with long-term residential broadband demand forecasts. The residential broadband market is the dominating part of the broadband market and constitutes for the moment about 80% of the total access market in Western Europe.

The data availability is commented and broadband statistics are analysed to separate the residential and business market.

Section 3.5 deals with long-term broadband penetration forecasts for the business market. This part of the thesis has not been published before.

3.1 "Long term forecasts for broadband demand" [Stor99a]

In [Stor99a] Logistic forecasting models uses the results from 1997 Delphi survey as input. The broadband forecasts have been revised and table 4 in [Stor99a] shows the information used to estimate the parameters in the Logistic model. The forecasts were developed in the TERA project [Stor98b] and the conclusions were published in [Stor99a]. In the document [Stor98b] it is showed that a three-parameter model (α is level parameter, β growth parameter and M saturation) gave bad fitting for 2000 and 2005 and also low multiple correlation coefficient. Hence, an additional growth parameter γ was introduced. The document shows that the multiple correlation coefficient of course increased significantly when an additional parameter was introduced, but the most important point was that the model got much better flexibility and gave much better fitting for 2000 and 2005. The estimation procedure is described in section 4.5 in [Stor99a]. Examination of the effect of γ on RMSE(root mean square error), showed that the value of γ did not change RMSE for high values. ($\gamma = 500$ and $\gamma = 20.000$ gave about the same fitting and the same RMSE). The conclusion was to apply a four parameter Logistic model instead of a three parameter Logistic model because the model had much better fitting flexibility.

The value of the saturation parameter is found directly based on the Delphi experts' answers, while the other parameters are found by minimising RMSE. The long-term forecasts for 2, 8 and 26 Mbit/s access are shown in figure 6 in [Stor99a].

Another simple three parameter Logistic model was defined to forecast the distribution between asymmetric and symmetric accesses for each capacity class. The three parameters were estimated based on the following three conditions:

- Estimate of the long-term saturation level (degree of symmetric accesses)
- Rough estimate of time (number of years) until half the saturation was reached
- The degree of symmetric accesses in EoY (end of year) 2000

The long-term asymmetric and symmetric accesses for 2, 8 and 26 Mbit/s from 2000 to 2010 is shown in figure 8. The accumulated forecasts follow the results from the 1997 Delphi survey except for year 2000, where the forecasts are set to 2,6%. The actual broadband penetration for year 2000 was 1%. The forecast for year 2005 is 20,5% and the actual broadband penetration for 2005 seems to be about 28,5% (See chapter 3.4 in the thesis) in the residential market. However, the forecasts for 8 Mbit/s and 26 Mbit/s access capacities have not evolved as fast as predicted. The capacities have been introduced in 2003/2004 but do not have very high market share. So far mainly the business market have got symmetric broadband accesses through SDSL or SHDSL. Therefore, the degree 6 –10% symmetric accesses in 2005 have been too optimistic. Another important point, which is missing in the modelling, is substitution effects between capacities.

3.2 "Broadband access forecasts for the European market" [Stor02a]

In [Stor02a] more advanced residential broadband demand forecasting models were developed for the Western European market. Available demand at that time was annual demand observations from 1999-2001. The main part of countries in Western Europe introduced ADSL in 1999 or 2000. The cable modem technology was introduced in the same period and the cable modem had a very high market share in 1999.

Substitution effects between the main broadband technologies were modelled by applying a set of Logistic models. The main technologies were:

- DSL
- Cable modem (HFC – Hybride Fibre Coax)
- Other broadband technologies

In addition DSL was split in ADSL and VDSL. At that time other broadband technologies were assumed to catch limited market shares during the first years.

The technology forecast modelling was performed in the following way:

The first step was to develop a forecasting model for the total residential broadband penetration. The next step was to make forecasting models for the market share evolution of each of the main broadband technologies. Finally the broadband technology penetration forecasts were found by multiplying the market share forecasts for the technology with the total broadband penetration forecasts. The forecasting models applied were four-parameter Logistic models.

In [Stor02] a four-parameter Logistic model was chosen to forecast the Western European residential broadband market. The number of parameters in the model exceeds the number of observations. A possible solution is to estimate the saturation level independently. The yearly demand observations for the period 1999-2001 was: 0,2%, 0,9% and 2,9%. However, the demand each year is not representative for all countries since broadband were introduced on different times in the period 1999 – 2001 in Western Europe.

The long-term saturation level was estimated to 90% of the households because of coverage limitations. Estimation of the additional parameters based on the demand observations the first years, gave forecasts which were evaluated to be too high. (The year 2005 forecast was about 30%). Therefore, the forecasts were reduced taking into account earlier forecasts (Delphi survey 20,5%). A "compromise" was to develop forecasts in between and EoY 2005 forecasts were fixed to about 25%. The forecasts are shown in figure 4.1 in [Stor02a].

Figure 9 in [Stor02a] shows the Cable modem (HFC) market share forecasts. The market share forecasts were found by making a forecasting model for DSL and other broadband technologies and subtract the forecast from 100%. OVUM [OVUM01], Forrester [Forr00] and Strategy Analytics [Stra01] had at that time very optimistic forecasts for the cable modem market in Western Europe. They predicted 24% - 44% market share at the end of 2005. The market share forecasts in Figure 9 are close to 20% at the end of 2005. The cable modem market share forecasts modelling is described in more detail in [Stor04a] page 24.

The broadband survey performed by Idate, [Idate05a], [Idate05b], showed 21,9% market share at the end of 2004. Figure 3.1 shows the long-term market share forecasts in [Stor02a].

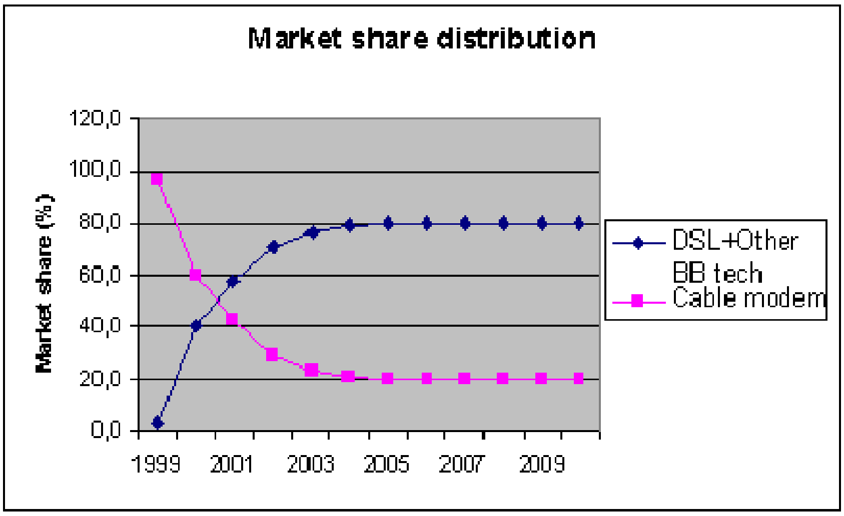

Figure 3.1 Long-term market share forecasts between cable modems (HFC) and DSL + Other broadband technologies [Stor02a]

Figure 10 in [Stor02a] shows the market share evolution of ADSL and VDSL. This is a very difficult forecast. No other VDSL forecasts were published at that time. The forecasts were based on extensive techno-economic analysis of the VDSL technology and VDSL rollouts ([Stor00], [Stor01], [Henr02]). Applications described in the Delphi surveys are applicable on VDSL. The analysis indicated significant VDSL potentials and a positive net present value for roll out of the new technology. Since there are capacity limitations on the twisted pair as a function of the length of the copper line, the market share saturation for VDSL was set to 40%. It was assumed that the "cherry picking strategy"(no additional infrastructure deployment), would be used the first years limiting the VDSL potential demand.

VDSL was introduced in Western Europe in 2004 (Belgium). IP-TV (TVoDSL) was introduced in 2005 in several European countries. In addition ADSL2+ with 10-15Mbit/s capacity is installed very extensively. From October 2005, Telenor installs only ADSL2+ line cards instead of ADSL line cards. Because the same DSLAM is used, the ADSL2+ line cards constitute the overall part of the new investments. Therefore, the long-term monthly tariff will evolve against to days ADSL tariff level. A similar evolution is seen for the HFC network. The capacity of the network has increased significantly through new versions of Docsis cable modem specifications: Docsis 1.0, 1.1, 2.0 and 3.0 [CaLab05]. The last version, Docsis 3.0, with minimum dowstream capacity of 160 Mbit/s and minimum upstream capacity 120 Mbit/s, will probably be approved in 2007. However, the hybrid fibre coax network may probably have bottlenecks in the upper part of the coax tree structure if the customers utilise too much capacity in the busy hour.

Anyhow, these facts indicate significant increase in the long-term demand for high capacity broadband.

The evolution of VDSL (figure 10) follows these lines, but should have been delayed 1-2 years.

Another important point arises from these considerations. When long-term technology forecasting models are developed, understanding of technology, the trends and the possibilities are vital. Techno-economic modelling of new technology will often be an important part of the forecasting.

Figure 11 in [Stor02a] shows the prediction of the market share of ADSL capacity classes. The forecasts show how ADSL capacity classes substitute each other. In many West European countries more capacity classes are available. The evolution so far has been based on more differentiation in the lower classes, but the evolution tends to remove the lower capacity classes. In Norway (Telenor) 384 kbit/s and 512 kbit/s are removed and 1024 kbit/s is the lowest capacity[2]. Exceptions are subscribers with very long copper length. 2, 4 and 6 Mbit/s have been introduced in the market. Hence, the trend described is reasonable even if the capacity classes are more differentiated. The mean values in figure 12 gives a better fundament for comparisons.

Figure 12 is a simple transition from figure 11. It is important to underline that this is mean access capacity, and have nothing to do with carried broadband traffic in the busy hour. Available statistics for Western Europe are not found. However, the ADSL capacity forecasts are evaluated in detail in the chapter 5.3 in the thesis based on Norwegian data. Figure 5.2 in the thesis shows the capacity evolution in the Norwegian market.

Figure 13 gives a complete picture of the market share evolution. The development of the market share forecasts for the class “Other technologies” are not commented in the [Stor02a]. When the forecasts where developed, demand data of other broadband technologies were not available. The forecasts were developed based on an assumption of smooth increase during the first years with a market share of 1,3% at the end of 2005. Later, available data shows that market share evolution for the class “Other technologies” has fluctuated between 1,2% and 1,8% in the period 2001-2004. The future expected evolution is commented in chapter 3.6.

The country group forecasts for the three groups (Finland, Norway), (France, Germany, UK) and (Greece, Portugal) are developed in the same way. The forecasts were based on broadband statistics from OVUM [OVUM01], Jupiter [Jupi01], and Strategy Analytics [Stra01], in the period 1999 –2001 and supplementary information gathered from each participating country in the Tonic project. It turned out that there were some deviations between the national data gathered in the project compared to data from the consultancy companies.

The broadband access penetration forecasts for (Finland, Norway) and for (France, Germany, UK) were rather similar. (Finland, Norway) had the highest growth the first years because of the

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[2] A low end ADSL 704 kbit/s product was reintroduced at the end of 2005

higher initial penetrations. The long-term saturation level was estimated to be lower in (Finland, Norway) because the countries were more sparsely populated. Therefore, the penetration forecasts for (France, Germany, UK) were estimated to be a little bit higher in the period 2007-2010. However, an important enhancement of the DSLAM technology was invented: The mini DSLAM. The technology made it profitable to roll out DSL in more sparsely populated areas. The saturation level would have been higher and also the forecasts if this fact had been known when the forecasts for (Finland, Norway) were developed.

The broadband access penetration forecasts for (Greece, Portugal) are much lower because of delayed introduction in Greece, low initial demand the first years and lower willingness to pay for broadband.

There are great variations between market share forecasts in the three country groups. The reason is different positions for the DSL operators and cable modem operators regarding initial roll out and especially the cable modem coverage.

3.3 Data availability

During the period 1999 – 2001, broadband data from consultancy companies were available and used as the basic statistics for the analysis. There were some deviations in the statistics from the companies, so mean values were used as the basic statistics. For the country group forecasts [Stor02a], information from the participating countries was collected and adjustments were done in the statistics. For the last years, data from Point topic [Point05] is used. This statistics seems to have very good quality. The main problem is that the statistics show the accumulated number of broadband accesses in the residential and the business market. The statistics is shown for DSL and for cable modem. However, the statistics do not contain other broadband technologies. The statistics include the broadband penetration per 100 households in all countries with broadband infrastructure.

The European Commission funded a project to establish broadband statistics for Western Europe. Idate made four surveys in the period 2003-2004 each half-year to establish the statistics [Idate05a].

[Idate05b] is a detailed broadband statistics that is not published, but has been available for the Ecosys project and also for this thesis. The Idate statistics from EoY 2003 together with Point topics statistics were used for the broadband forecasting in [Stor04a]. The Idate statistics for EoY 2004 and the Point topic broadband statistics have been used in chapter 3.4 and 3.5 in the thesis.

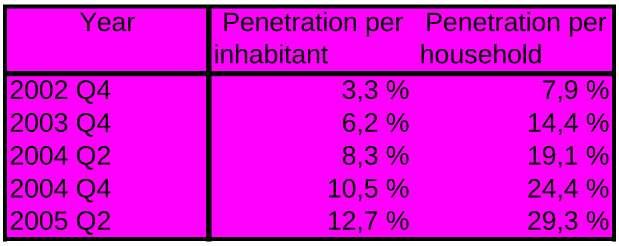
3.4 Broadband access statistics

During 2000 – 2002/2003 the traditional broadband statistics was reported as pure residential penetration related to number of households. Penetration is a very relevant measure since the total residential demand can be calculated by multiplying the total number of households in a country with the penetration.

The business access statistics is more difficult to handle. The reason is that the business population and the broadband potential are not so easily defined. One possibility is to define the business population as the number of business locations in a country. The definition of business locations is identical with the Norwegian Statistical Bureau of Census definition of a business unit. However, some refinements have to be done because many business units are not active companies and do not need a broadband access. On the other hand, some business units order more than one broadband accesses. Therefore, the broadband potential for the business market is difficult to estimate and then also the penetration forecasts.

The solution has been to present statistics of the broadband market as the sum of the residential and the business market to avoid some statistical problems. As mentioned in chapter 3.3 the statistics have limitations. Point topic makes this type of statistics [Point05]. The broadband statistics are presented as the number of broadband accesses per 100 inhabitants. The statistics covers most of the countries in the world that has deployed broadband. By accumulating the accesses for all countries in Western Europe, the following table is constructed:

Table 3.1 Broadband penetrations (DSL and cable modem) in Western Europe for sum residential and business market [Point05]

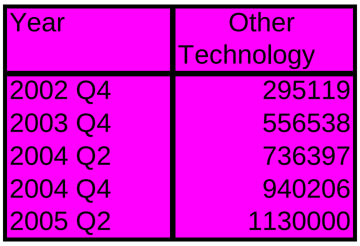


Year	Penetration per inhabitant	Penetration per household
2002 Q4	3,3 %	7,9 %
2003 Q4	6,2 %	14,4 %
2004 Q2	8,3 %	19,1 %
2004 Q4	10,5 %	24,4 %
2005 Q2	12,7 %	29,3 %

Western Europe covers the EU15 countries and Iceland, Norway and Switzerland.

In [OECD05] the status of other broadband technologies in Western Europe is described. The access demand and a backward projection are presented in table 3.2.

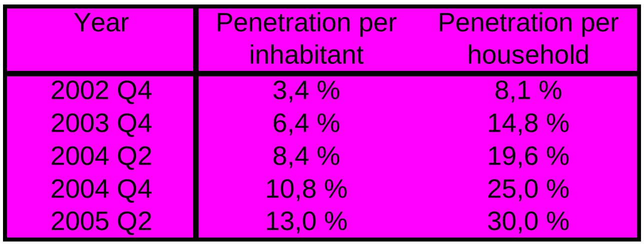
Table 3.2 Evolution of demand for other broadband services than DSL and cable modem in Western Europe [OECD05]



Year	Other Technology
2002 Q4	295119
2003 Q4	556538
2004 Q2	736397
2004 Q4	940206
2005 Q2	1130000

Table 3.3 includes other broadband technologies and shows the sum of table 3.1 and 3.2.

Table 3.3 Broadband penetrations in Western Europe for sum residential and business market [Point05] and [OECD05]



Year	Penetration per inhabitant	Penetration per household
2002 Q4	3,4 %	8,1 %
2003 Q4	6,4 %	14,8 %
2004 Q2	8,4 %	19,6 %
2004 Q4	10,8 %	25,0 %
2005 Q2	13,0 %	30,0 %

In order to establish statistics for the residential and the business market, additional information is necessary. The Idate statistics [Idate05b] are used. The Idate statistics do not cover Switzerland. Therefore, adjustments for Switzerland have been made to get a complete statistics for Western Europe.

The adjusted Idate statistics have been used to separate the residential and the business market, which is showed in table 3.4 and 3.5

Table 3.4 Broadband penetrations per inhabitant for the residential and business market in Western Europe [Idate05b]

Year	Penetration per inhabitant		
	Residential	Business	Total
2003 Q4	4,8 %	1,4 %	6,2 %
2004 Q2	6,0 %	1,6 %	7,5 %
2004 Q4	8,2 %	1,9 %	10,2 %

Table 3.5 Broadband penetrations per household for the residential and business market in Western Europe [Idate05b]

Year	Penetration per household		
	Residential	Business	Total
2003 Q4	11,3 %	3,3 %	14,6 %
2004 Q2	14,2 %	3,7 %	17,9 %
2004 Q4	19,6 %	4,6 %	24,2 %

Table 3.3 and 3.5 show that there are minor differences in Point topic's and Idate's total estimate for the broadband market in Western Europe. The total penetration per household for 2004 Q4 is 24,2% for Idate and 25,0% for Point topic. The difference is larger for 2004 Q2 (1,7%), while the difference is 0,2% for 2003 Q4.

The Point topic total number of broadband accesses (included other technology) for 2004 Q4 was 40.267.220.

The Idate statistics (including Switzerland) of total number of broadband accesses for 2004 Q4 was 39.925.582.

The difference between the two volumes is less than 1%.

The deviations between the total penetrations per household: 25,0% and 24,2% is 0,8%. However, the relative difference (0,8% / 25%) is 3,2% which is much more than 1%. The reason is the use of different population sizes and household sizes when the penetrations were calculated.

In the following, the mean value of the adjusted Point topics and Idate statistics are used as a reference level.

Estimation of the 2005 Q2 statistics for residential and business penetration, prediction of the market share is made in table 3.6.

Table 3.6 Proportion between the size of the business market and the residential market as a function of time

Year	Market share		
	Residential	Business	Total
2003 Q4	77,5 %	22,5 %	100,0 %
2004 Q2	79,2 %	20,8 %	100,0 %
2004 Q4	80,9 %	19,1 %	100,0 %
2005 Q2	82,6 %	17,4 %	100,0 %

The last line in the table is a prediction, while the other values are found from table 3.5. The table shows that the residential market grows faster than the business market. The reason is that the broadband business accesses increased relatively faster than the residential accesses during the first years.

Finally, table 3.7 shows the demand broadband access statistics based on mean value of the broadband demand from Idate and Point topic statistics.

Table 3.7 Broadband penetrations per household for the residential and business market in Western Europe. [Point05] and [Idate05b]

Year	Penetration per household		
	Residential	Business	Total
2003 Q4	11,4 %	3,3 %	14,7 %
2004 Q2	14,8 %	3,9 %	18,7 %
2004 Q4	19,9 %	4,7 %	24,6 %
2005 Q2	24,4 %	5,1 %	29,5 %

The residential broadband penetration per household in Western Europe is shown in the left hand side of table 3.7. The penetration reached 24,4% in Western Europe second quarter 2005. No information is available of the penetration EoY 2005. Table 3.7 shows that the half year difference between 2004 Q4 and 2004 Q2 was 5,1%, while the difference between 2005 Q2 and 2004 Q4 was 4,5%. The broadband penetration per household at the end of 2005 is estimated to be about 28,5%.

3.5 Long-term broadband forecast modelling of the business market

As mentioned, broadband penetration forecasts are very convenient to use. These types of forecasts have an upper limit (saturation), which some time can be estimated independently.

The objective with this section is to identify differences between the growth in the broadband residential and business market and to show how broadband penetration forecasts of the business market can be modelled.

The broadband access demand for the business market is found from table 3.7:

Table 3.8 Evolution of the business market access volume in Western Europe

Year	Access Volume
2003 Q2	4524660
2003 Q4	5407806
2004 Q2	6159391
2004 Q4	6960718

A Logistic model has been applied for the business market broadband penetration forecasts. The model, or the data, does not separate IP-VPN and Internet accesses.

This approach uses assumptions from broadband forecast modelling of the Norwegian market.

The following considerations are important for estimating the market potential:

- The number of business units
- Many business units have been constructed of pure tax reasons
- 62% percentage of business units in Norway have no employees [SSB06]
- Small business units like fishermen and farmers and others do not order business DSL, but instead private (residential) DSL

On the other hand, additional broadband accesses must be included for larger business units. In modelling the demand for the Norwegian market, it is assumed that potential number of broadband accesses per business unit is the number of employees divided by 20. In other words, 20 employees should as a mean consideration have the possibility to use one broadband access in parallel. The assumptions have been based on busy hour concentration and packet switching concentrations discussed in [Stor02b] and in section 5.3 in this thesis. The number 20 is continuously evaluated because the evolution of higher subscription access capacity and usage of more demand capacity applications.

A factor to be used for downscaling number business units to potential broadband access for the business market is 0,48. The factor takes into account reduction in number of business units that will order broadband and adjustments for larger business units, which in the long run will order more than one broadband access. The downscaling factor also includes a long-term saturation of 85% of the potential broadband business accesses.

The factor 0,48 has been used for Western Europe assuming that the business structure is the same as in Norway.

The number of business units is found in the [Idate05b]. The number for Western Europe including Switzerland is 28.503.000.

This yields a broadband access potential for the business market of 13.681.000. The penetrations are estimated to be:

Table 3.9 Estimated broadband access penetration for the Western European business market

Year	Penetration
2003 Q2	33,1 %
2003 Q4	39,5 %
2004 Q2	45,0 %
2004 Q4	50,9 %

A four parameter Logistic model is used to make long-tem forecasts.

The business penetration forecasts are shown in figure 3.2. Also the residential penetration forecasts developed in [Stor04a], see next section of the thesis, are shown in figure 3.2.

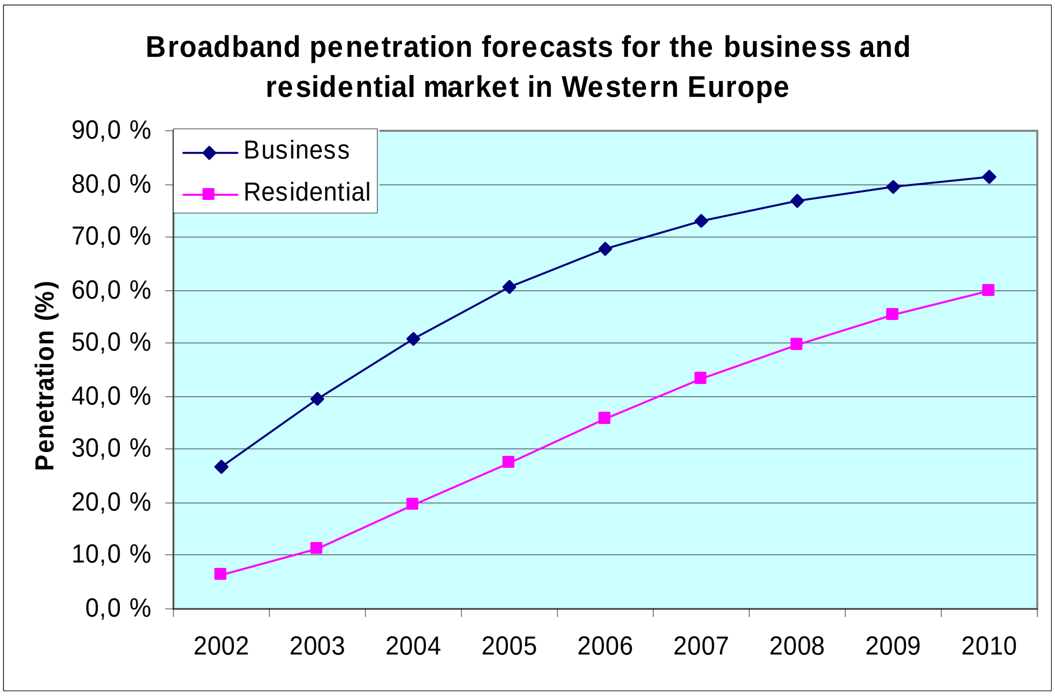


Figure 3.2 Broadband penetration forecasts for the business and residential market in Western Europe

The broadband forecast modelling shows that some assumptions of estimating the potential are necessary to make penetration forecasts for the business market.

An alternative method is to make forecasts based on the access demand in table 3.8. Then the forecasts will not be dependent on a set of assumption for estimating the broadband potential. However, it is very difficult to make long-term forecasts on these statistics alone. The best should be to utilise additional information like number of business units etc.

The method suggested could be developed further taking into account specific aspects for different countries.

One important message is the very different penetration evolution in the business and residential market.

Over time, table 3.6 shows that the relative proportion of broadband business accesses to residential accesses changes in favour of residential accesses. Figure 3.2 confirms the evolution and shows that the broadband business market has a higher penetration and is closer to saturation than the residential market.

Therefore, it is recommended to separate the most common available broadband statistics, which shows the broadband evolution as the total number of business market accesses and the residential accesses per 100 inhabitants. Development of separate forecasts for the business and residential market makes it possible to forecast the access evolution in various areas with different mix of residential and business customers.

3.6 “Long-term broadband technology forecasting” [Stor04a]

The paper gives an overview of different broadband technologies and underlines the necessity to understand the strength and weaknesses of each technology. Section 6 in the paper introduces “Techno-economic assessments” because the methodology is important for the evaluation of the various broadband technologies.

The position of the dominating broadband technologies is influenced by the supply side because the mass production of network components generates low component costs, reduced investments and reduced tariffs. The roll out and coverage of the various technologies are also of great importance. The residual market which cannot be covered by the dominating technologies, also gives possibilities for alternative technologies. Two - tree years ago the residual market was a rather significant part of the total market. At that time, the residual market in Norway was estimated to 25%. However, when mini DSLAMs were introduced, the residual market was reduced significantly. Such technology innovations increase the market possibilities and the forecasts. Relevant technologies for the residual market are DSL, WiFi, WiMAX and possibly DTT, UMTS/HSDPA and satellite for very sparsely populated areas.

The broadband forecasting methodology follows the same approach as described in [Stor02a]. The four main broadband technologies are:

- ADSL
- ADSL2+/VDSL
- Cable modem (HFC)
- Other technologies.

The DSL- and cable modem coverage is analysed. Coverage forecasts which are important premises, are developed and long-term penetration forecasting models and the forecasts are described.

The broadband penetration forecasts for end of year (EoY) 2005 were estimated to be 26,6%. The forecasts are shown in figure 8.4 in [Stor04a]. Because of a very strong growth the last year, penetration in the Western European market will increase from 19,9% EoY 2004 to about 28,5% EoY 2005.

The broadband survey data from Idate, [Idate05a], [Idate05b], shows a significant reduction of the cable modem market share during the last year ending up with 21,9% in the end of 2004. The reason is relatively higher DSL growth compared with cable modem growth. Therefore, the long-term saturation level for cable modem will be lower than originally estimated.

The broadband survey from Idate, [Idate05a, Idate05b], confirms the very significant ADSL growth and the dominating market share of 76,4% EoY 2004. Now, ADSL2+/VDSL have been introduced commercially in the Western European market. Some operators like Belgacom have introduced VDSL and many operators are installing ADSL2+ cards in the DSLAMs. Therefore, ADSL2+/VDSL will capture a significant market share during the next years. Figure 8.9 in [Stor04a] shows the ADSL2+/VDSL market share forecasts and gives argumentation for the forecasts. The Logistic model is used for the ADSL2+/VDSL market share forecasts. The next DSL generation with 50 to 100 Mbit/s access capacity is DSM [Ciof04]. This technology is so far not included in the forecasts modelling.

In [OECD05] an overview of broadband subscribers by technology per 100 inhabitants is shown per June 2005. The statistics cover both the business and the residential market.

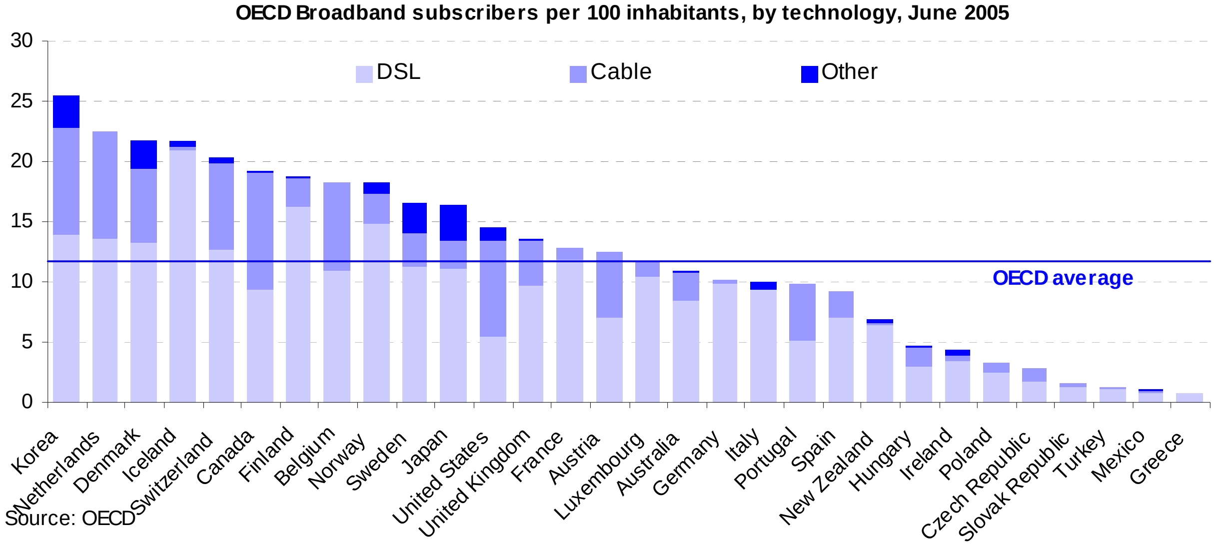


Figure 3.3 Broadband penetration per 100 inhabitants (Business + Residential) by technology, Q2 2005, for the OECD market (OECD June 2005)

The statistics shows that the South Korea, Netherlands, Belgium, Switzerland, Canada and the five Nordic countries have the highest broadband penetration followed by Japan and United States. The broadband statistics also show that Japan, South Korea, Sweden, Denmark and United States have a much higher market share of new technology than other countries. Norway is no 6 on this list. The statistics also show that all countries with a relatively high market share of other technologies were among the 12 OECD countries with the highest broadband penetration. The [ECC05] supports the statistics regarding other technologies.

Figure 8.7 in [Stor04a] shows the market share evolution of “Other technologies” than DSL and cable modem. Relevant technologies for the residential market are: FTTB, FTTH, FWA (WiFi, WiMax, CDMA 450) and possibly PLC (Power Line Communication). The figure shows the market share evolution 2000 –2003: 0,4%, 1,2%, 1,8%, 1,6%.

For 2004 the market share is estimated to be 1,7%, ([Idate05b], [OECD05]). During the last three years the market share has not increased in the Western European market. Of course the volume of accesses of other technologies has increased, but only in the same proportion as the total broadband access volume.

Figure 3.4 shows the market share evolution of the main broadband technologies in the Norwegian market.

The figure shows that wireless solutions were established very quickly in the Norwegian market, but did not succeed in capturing higher market share. The reason is that the wireless solutions are expensive and the technology looses market share when the DSL technology is established in the same areas. However, there is still about 10% of the Norwegian market, which is not covered by broadband, and the technology has potential in these areas. Fibre solutions are now growing significantly. Status for Q3 2005 is 4,7% market share consisting of 3,5% fibre and 1,2% wireless solutions. Operators in the market are offering excellent triple play solutions. In addition fibre are deployed in new “green fields” for dwelling and the modern cottages market and in areas with much failures in the access networks. In Denmark and Sweden fibre is deployed to large buildings with inside Ethernet connections. Other possibilities, which may be used later, is to utilize old (and new) tube structure in the cities to draw fibre to the buildings.

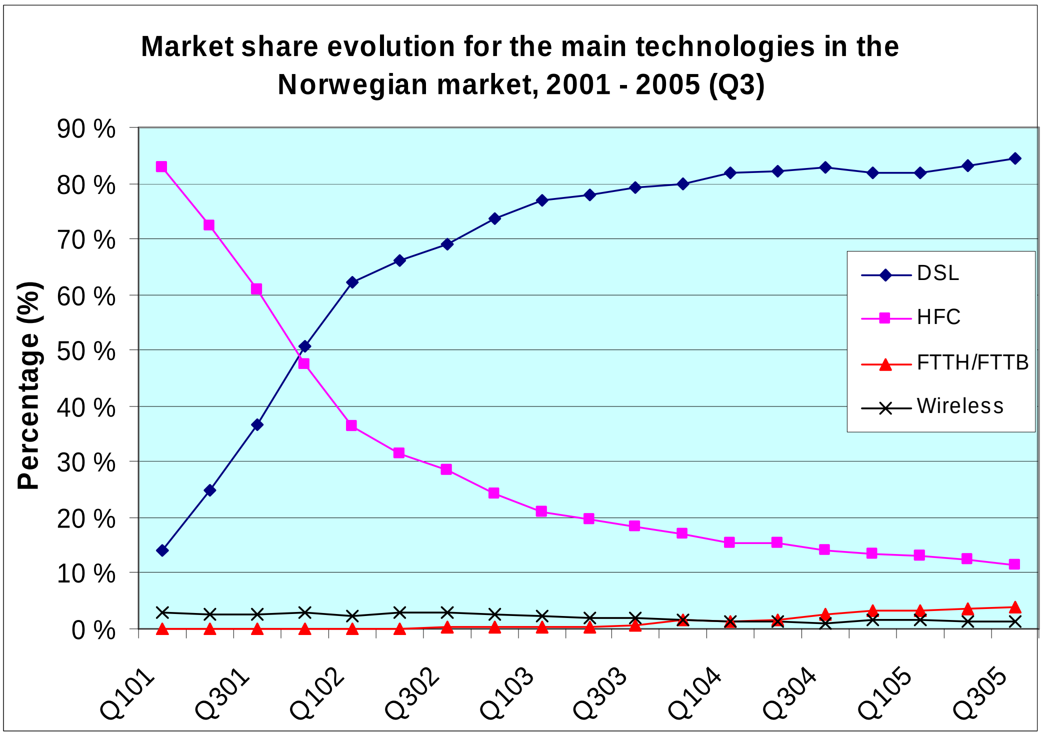


Figure 3.4 Market share evolution between broadband technologies in the Norwegian market Q101-Q305 (Internal statistics, Telenor Nordic, Market analysis, Kjell Stordahl November 2005)

The OECD statistics showed that the countries with high broadband penetration to a larger degree have utilized FTTH/FTTB solutions. This is taken into account when forecasts for the class “Other technologies” are performed. Figure 8.10 shows the broadband market share forecasts for Western Europe. The dominating technology among ”Other technologies” is FTTH/FTTB. In addition the radio solutions WiFi and WiMAX will cover parts of the residual market where the dominating technologies seems to be too expensive.

The time series on market share of other technologies for the Western European residential market is rather stable, fluctuating between 1,8% and 1,6% in the period EoY 2002-2004. So far it is difficult to use for example a diffusion model because we have only five annual observations and the last three are very stable. If the models are used and estimated parameters based on the annual time series, the forecasts will be too conservative. The fibre solutions will be the ultimate broadband solution. But techno-economic analysis has shown that FTTH and FTTB are very expensive solutions especially because digging and ducting costs are very high. Based on the fact that 50% of the 12 OECD countries with the highest penetration have a significantly higher market share of “Other broadband technologies”, it is expected that the other countries will go in the same direction. The Norwegian data, figure 3.4, support this view. In [Stor04a] the market share forecasts was set to 7.5% in years 2010 and parameters in a Logistic model were estimated based on this assumption.

The West European market share forecasts are shown in figure 8.10 and the technology penetration forecasts are shown in figure 8.11 in [Stor04a].

3.7 Techno-economic analysis

Techno-economic analysis is described in section 6 in [Stor04a].

From 1992 to 2005 the European programs RACE, ACTS, IST and CELTIC through the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA, IST-2000-25172 TONIC and ECOSYS have developed a methodology and a tool for calculation of the overall financial budget of any access architecture. The techno-economic analyses are used to evaluate technical projects and portfolios.

The tool handles the discount system costs, operations, maintenance costs, life cycle costs, net present value (NPV) and internal rate of return (IRR). The tool combines low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters for performing evaluations of various network architectures.

The analyses were applied on different broadband technologies to examine prospects of the different technologies. The analyses and evaluations performed are important input to the broadband technology forecasts.

The techno-economic analyses have been used rather extensively in the mentioned European projects to analyse broadband and mobile business cases, technology roll out, studies of actors like operators, broadband strategies etc.

Figure 3.5 illustrates how the techno-economic assessments are performed.

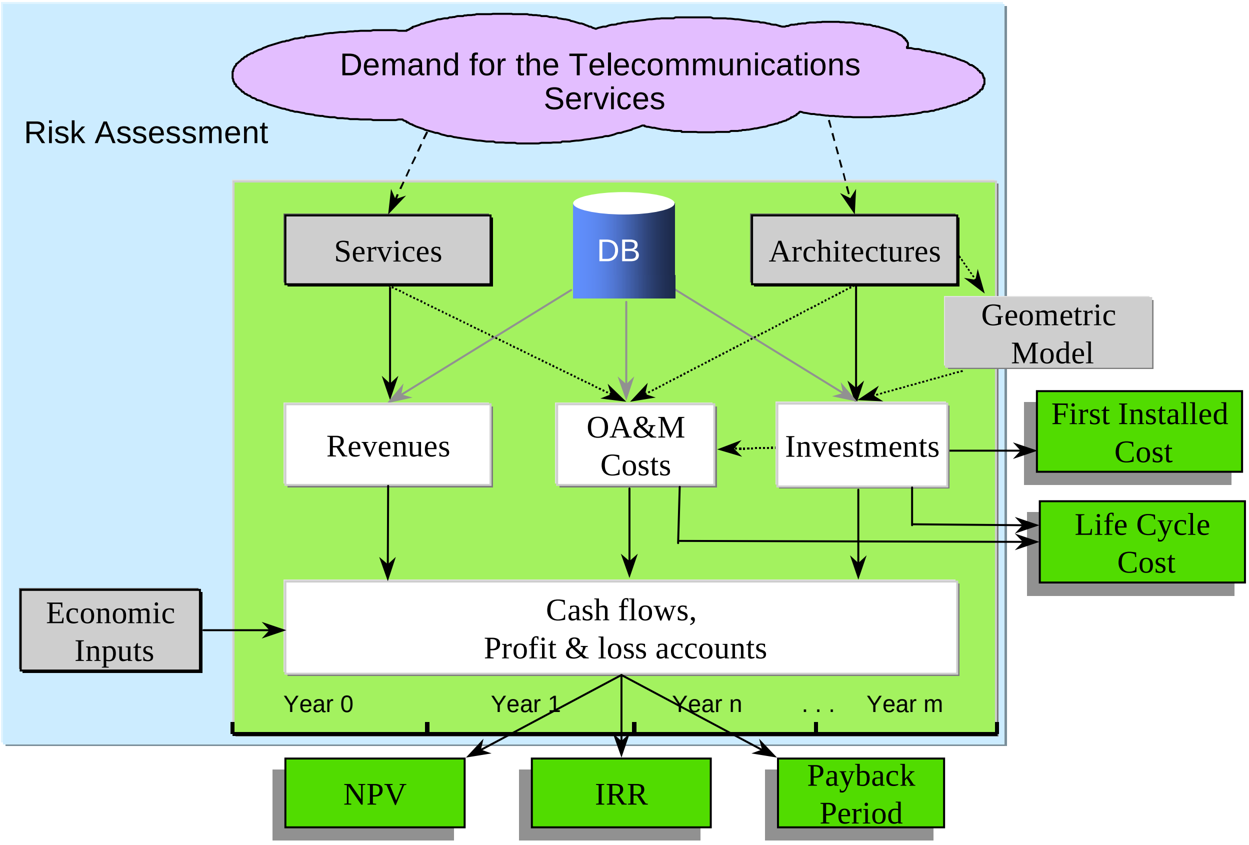


Figure 3.5 Techno-economic tool for calculation NPV, IRR and payback period for telecommunications projects

Figure 3.5 shows that broadband demand forecasts are fundamental inputs to the analysis.

In [Ims98] more detailed descriptions of techno-economic modelling and the tool are found.

Chapter 20 in [Ims98] gives a very good overview of the findings from techno-economic analysis. Different broadband technologies have been analysed. The possibilities for each technology is described based on capacity offered, investments per homes passed, broadband connected demand etc. Similar results are described in [Olsen96], [Ims96], [Ims97b] and [Myhr99].

The techno-economic analysis shows the ability of the different broadband technologies in urban, suburban and rural areas combined with investment and revenue possibilities.

These results are important for broadband technology forecasting.

3.8 Broadband forecasts comparisons

Figure 10.2, section 10 in [Stor04a] makes comparisons between long-terms forecasts from:

- Tera (1998) [Stor99a]
- Tonic (May 2001) [Stor02a]
- Jupiter (February 2003) [Jupi03]
- Forrester (June 2003) [Forr03]
- Jupiter (April 2004) [Jupi04]
- Ovum (May 2004) [OVUM04]
- Ecosys (August 2004) [Stor04a]

The forecasts are plotted from 2000 until 2008, which is the last year because some of the consultancy forecasts stops at the end of 2008. The forecasts are shown in figure 3.6 in this thesis, which is the same as figure 10.2, section 10 in [Stor04a].

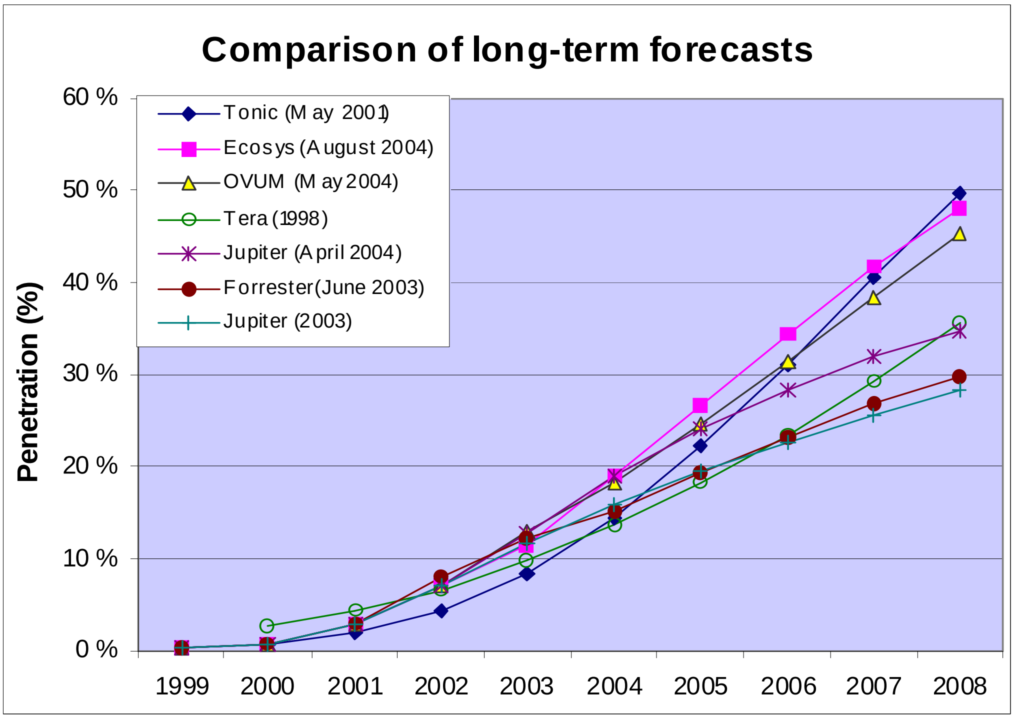


Figure 3.6 Comparisons of long-term broadband penetartion forecasts for the residential market

The forecasts are grouped in:

High Long-term forecasts:

- Tonic (2001)
- Ecosys (2004)
- OVUM (2004)

Low Long-term forecast:

- Tera (1998)
- Jupiter (2004)
- Forrester (2003)
- Jupiter (2003)

Looking on the Tera (1998) forecasts [Stor99a], we see a much steeper growth rate in 2008 compared to other forecasts in this group. Figure 6 in [Stor99a] shows that the Tera broadband penetration forecast in 2010 is estimated to be 44% for the Western European market. This will be considerably higher than the expected predictions for the other forecasts in that group. Hence, the Tera (1998) forecasts should be upgraded to the “High Long-term forecasts” group.

The crucial question is what the expected future evolution of broadband penetration in Western Europe is. The penetration is expected to be about 28,5% at the end of 2005. The annual growth seems to be about 8,5% percentages - a formidable annual increase.

In figure 10.2 the Ecosys (2004) forecast is the highest one in 2005 and estimated to be 26,6% EoY 2005. These facts support the conclusion that the “High” Long-term forecasts clearly seem to give the best forecasts. Based on knowledge from 2005, even the “High Long-term forecasts” group should be renamed to “Medium” Long-term forecasts. The Ecosys forecasts have a turning point in 2007, which indicates reduced growth in the Western European market.

3.9 Experiences and conclusions

The papers on long-term technology forecasting for the residential Western European broadband market documents fairly good results. There are of course deviations when the forecasts are compared with the real access demand. The EoY 2005 forecasts for the residential broadband demand were 20% [Stor99a], 24,9% [Stor02a] and 26,6% [Stor04a]. The penetration end of year 2005 is expected to be about 28,5%. It should be noted that no historical broadband observations were available when the first forecasts were developed.

The broadband forecasts made in 1998 [Stor99a] modelled each broadband capacity class independently without taking into account substitution effects. The approach has obviously been wrong. The capacity classes modelled was 2 Mbit/s, 8 Mbit/s and 26 Mbit/s. During the years 1999 –2005 we have seen much more differentiation in lower capacities and also substitution effects between each capacity class.

In [Stor02a] and [Stor04a] the substitution effects have been build into the models by using a set of Logistic models.

The experience from work with long-term forecasting models shows that it has been extremely important to catch up new information about recent developments in broadband technologies. Some examples are:

- The development of mini DSLAM, which made it possible to roll out mini DSLAM in sparsely populated areas
- The very low production price of ADSL2+ subscriber line cards, which in the long run will decrease the price and increase the demand on high capacity broadband accesses
- Enhancement of ADSL to Rate adaptive ADSL, which gives a larger coverage (will be implemented in Telenor's network in 2006).
- Introduction of DSM – Dynamic Spectrum Management, which will increase the DSL capacity considerably [Ciof04]
- Information about approved new standards, for example for WiMax and other services
- etc

Techno-economic analysis is also an important key for long-term forecasting. The analyses have been applied on the various broadband technologies. The papers [Olsen96], [Ims96], [Ims97b] and [Myhr99] documents strength and weakness of various broadband technologies. The analyses show that FTTH solutions are very expensive and the marked share evolution for FTTH will move slowly upwards. The main reason is large digging and ducting costs. The cost for a fibre connection to a home (FTTH) is expensive compared with fibre connection to buildings where many households shares the digging and ducting costs. The analyses have shown that DSL and cable modem (HFC) definitely are the cheapest broadband solutions. The techno-economic analyses have also examined many other broadband technologies. The results of the analysis are important input to the forecasting process.

International broadband access statistics is often published as the number of accesses per 100 inhabitants, but does not distinguish between the residential and business market. The statistics is easy to produce in that way, but the statistics create problems for forecasters since they have to transform the statistics to separate residential and business broadband access statistics in order to make better forecasts. Statistics of percentage of households with broadband access (residential broadband penetration) is much easier to use than total number of broadband accesses in the residential and business market together. Furthermore, the residential broadband penetration is interpretable, easy to use and helps the forecaster to make better forecast modelling.

A simple model for broadband penetration forecasts in the business market of Western Europe is developed. The model is based on estimating the potential broadband business market. It is important to notice that a registered business unit is not necessary a potential for a broadband access. In Norway 62% of the registered business units do not have employees. There are significant uncertainties in the estimation of the potential broadband access market.

It is showed that the relative proportion between residential and business broadband accesses continuously is changing, which shows that the penetration of the residential and business market evolves differently.

A main problem for making long-term forecasting models for the Western European market is lack of detailed information from each West European country. The forecasting models are only based on aggregated data, because it has not been possible to make separate forecasting models for each country in Western Europe. If each country had been treated separately by using detailed country specific information, the aggregated forecasts for Western Europe would have been better.

4 LONG-TERM FORECASTING MODELS FOR COST EVOLUTION OF COMPONENTS AND TECHNOLOGIES

Learning curves are used in the industry to predict reduction in production time and costs as a function of produced volume. Borgar T Olsen and Kjell Stordahl invented in 1993 and published in 1994 a new forecasting model for cost predictions [Olsen94]. The forecasting model is an extension of the learning curve model of Wight and Crawford ([Wrig36] and [Craw44]).

The extended learning curve model is more flexible, predict the cost evolution as a function of time and has interpretative parameters. The model has the ability to make long-term forecasts for component costs even when number of observations is limited.

The following paper is enclosed as a part of the thesis:

- Olsen B. T., K Stordahl, "Models for forecasting cost evolution of components and technologies" *Telektronikk (100) no4*, 2004. [Olsen04]

4.1 "Models for forecasting cost evolution of components and technologies" [Olsen04]

Wright and Crawfords' traditional learning curve models could not be used directly in techno-economic calculations because the cost function was a function of number of produced units and not a function of time. The learning curve model is a simple exponential function starting with given cost at t=0. The cost is reduced with the function $n^{-\alpha}$ where α is a parameter and n the production volume.

The first step was to derive a forecasting model of the production volume n(t). The production volume evolution, n(t), is assumed to follow a Logistic model with 3 or 4 parameters. The paper describes the substitution by the Logistic model into the learning curve model in more detail. Hence, the extended learning curve model can be used to forecast component costs as a function of time.

The second step was to transform the parameters of the model to be interpretative (Annex 1-3 in [Olsen04]). The transformations resulted in the following interpretative parameters:

- Production cost in the reference year (starting year)
- The relative accumulated production volume in the reference year
- The time span between 10% to 90% accumulated volume ("Mini life cycle" = main part of the life cycle to the component)
- The learning coefficient (How much the cost is reduced when the production volume is doubled)

The reference year is defined as the year when the component is implemented in a given project. However, the component may have been produced on worldwide basis some times earlier.

The traditional objective from a statistical point of view is to estimate the parameters. When the number of observations is limited or when there are no observations at all, statistical methods may not be used to estimate the parameters. However, when the parameters are interpretative, additional knowledge may be included for the estimation.

To give some examples:

- The component price in the reference year should be known because of negotiations with the industry who produces the components
- We should have an opinion about where the component is in the life cycle, when the component is bought
- Life cycle of new components is decreasing, because new technologies substitute the old technologies increasingly rapid than for ten years ago. Therefore, it should be possible to give a rough estimate of the “Mini life cycle” of a component.
- Based on experience regarding type of component, we should have opinion about how much the cost is reduced when the production volume is doubled. (Components based on new technology have higher reductions than more traditional components)

Table 7.1 in [Olsen04] shows how much different types of component costs are reduced when the production volume is doubled.

Table 7.2 shows how different components are classified in different volume classes. This is used for the extended learning curve forecasts.

Figure 5.1 and especially 5.2 in [Olsen04] shows that the product life cycle decreases with time. In the projects TITAN, OPTIMUM, TERA, TONIC and ECOSYS, techno-economic calculations have been performed to evaluate different broadband technologies and rollouts.

In the techno-economic projects mentioned, a large database of network components has been established and maintained. The database contains more a large set of network components, which are classified according to the different volume classes.

Section 8 in [Olsen04] describes how the parameters in the extended learning curve model are estimated. Since the parameters are interpretative, the parameters may also be assessed. In the two cases presented, the estimated parameter values seemed to be reasonable.

4.2 Experiences and conclusions

The originally learning curve models by Wright and Crawford do not have the ability to predict the price as a function of time. The extended learning curve model developed by Olsen and Stordahl, has included a Logistic model enabling the model to forecast the component costs as a function of time.

The extended learning curve model is an important part of the tool for techono-economic calculations and analysis. Since the technology and the component often are new, very limited information is available of the cost evolution.

Very often the examined business cases includes rather new technologies or a set of rather new network components. Then, there are not enough statistics to estimate the model parameters.

The extended learning curve model includes both observations and a priori knowledge through interpretative parameters into the forecast modelling. Therefore, this type of model has much larger applicability than traditional models, which is more dependent on pure statistical estimation procedures.

5 LONG-TERM TRAFFIC FORECASTING

Long-term traffic forecasting is important for network planning. Short- and medium-term forecasting is important for local extensions in the network, while long-term forecasts gives valuable information for larger investments in the networks and for decisions regarding services and new network platforms.

Three papers are enclosed as a part of the thesis:

- Stordahl K, "Forecasting – an important factor for network planning". *Telektronikk (99) no 3,* 2003 [Stor03a]

- Stordahl K, K O Kalhagen, B T Olsen, J Lydersen, B Olufsen, N K Elnegaard, "Traffic forecast models for the transport network". *In Proc Networks2002*, Münic, Germany, June 23-27, 2002. [Stor02b]

- Stordahl K "Methods for traffic matrix forecasting". *In Proc 12th International Teletraffic Congress*. Torino, Italy, June 1-8, 1988. [Stor88]

5.1 Forecasting models

[Stor03] lists relevant classes of forecasting methods for network planning. The following forecasting methods were recommended for access forecasting: Diffusion models, regression models, econometric models, ARIMA models, Kalman filter models and smoothing models. The same classes of models with exception of diffusion models were recommended also for traffic forecasting. The reason that diffusion models were excluded is that the models have a saturation level, which cannot be identified for the traffic.

The ARIMA models, Kalman filter models and Holt-Winters' smoothing models are convenient for modelling seasonal behaviour. The Kalman filter models and the smoothing models may be used for "automatic" forecasting without specific interference for estimating the model parameters. It is recommended to use "back casting" to improve the quality of the smoothing models forecasting ability. Now, program packages exist for automatic estimation of autoregressive and moving average parameters and identification of the number of differences in the ARIMA models. Therefore, these types of models may be used automatically. Automatic forecasting methods were used to forecast the traffic elements in the Extended weighted least squares method [Stor88], while manual procedures for developing the forecasting models were used for the aggregated traffic.

Diffusion models, regression models and econometric models are candidates for long-term forecasting. The reason is that regression models and econometric models have the ability to include important explanatory variables. When a forecasting model with explanatory variables is assessed based on historical fitting, it is important to note that for example a very high multiple correlation coefficient does not necessary mean that the model is good. The model fitting is based on exact values of the explanatory variables. However, the model forecasts are based on forecasts of the explanatory variables, which of course will not be true values, but forecasts with uncertainties. Therefore, explanatory variables with large uncertainties in the forecasts should not be included in the forecasting model even if the fitting has turned out to be very good. Forecast of some explanatory variables regarding the Norwegian economy from the Bank of Norway or the Norwegian Bureau of Census may be relevant as explanatory variables and it may be other. However, it is important to understand the dynamics of the forecasting process.

Diffusion models perform an interesting class of models for access forecasting. The models are based on annual data, which may be a weakness. On the other hand, in its simplest form, the models have only one explanatory variable and the variable is the time (number of years). There is no uncertainty to forecast this explanatory variable. The models consist of a set of growth parameters and a parameter for the saturation level. Usually, the saturation may be estimated directly and not by the historical observations. Several alternatives may exist for estimation. Results from market surveys may be one alternative. The percentage of the population – for example based on long-term coverage assumptions for a broadband access may be another.

As shown in this thesis, the Logistic models have been used to develop long-term forecasts. It has also been commented that the choice of model among the diffusion models had not been very important because the number of observations have been limited and some time not enough even to estimate the parameters in the model. However, when number of observations is sufficient a two steps iteration procedure is used to estimate the parameters in the logistic model. The iteration procedure is explained in section 4.5 in [Stor99a]. Regression analysis is applied for the estimation. It is important to underline that the multiple correlation coefficient cannot be used as a criteria for fitting quality. The fitting is based on accumulated data, which means that the observations itself have a very high self-explaining effect and the observations are not at all independent, which is a criteria for using the multiple correlation coefficient.

The selection and application of the logistic models for long-term forecasting has not been based on the multiple correlation coefficient, but more on experience regarding the forecasting results, which is commented earlier in this thesis.

The statistical modelling and estimation is usually not enough for the long-term forecasting process. As commented several times in the thesis, it has been important to make techno-economic evaluations of various broadband technologies to evaluate the future possible market share for the technology. Also specific break through in production technology is important. Therefore, additional information has to be included in the modelling.

5.2 " Forecasting – an important factor for network planning" [Stor03a]

The paper gives an overview of forecasts and forecasting methodology for network planning. Many network planning issues need long-term forecasting. [Stor03a] lists a set of network planning processes. The following are linked to long-term forecasting:

- Choice of technology and network components
- Design of network structure
- Implementation of new network functionality
- Introduction of new services
- Replacement strategies for old technology/old components
- Long-term strategy planning

Investment analyses are usually based on Net Present Value and Payback period is applied. The horizon of this type of analysis will usually be 4-5 years or more. Crucial input to the investment analysis is long-term forecasts.

The paper also gives an overview of different forecasts, which support the planning process. The following long-term forecasts are relevant:

- Forecasts for service demand
- Subscription/access forecasts
- Traffic volume forecasts for services and applications
- Market segmentation forecasts
- Forecasts based on competition/market share
- National/regional/local level forecasts
- Forecasts allocated to various network
- Forecasts allocated to transport/access network

[Stor03] shows several examples of strategic evaluations and decisions regarding new technologies and new networks where long-term forecasts play an important role. Some major introductions in the Norwegian network during the last 20 years are listed.

Substitution effects are important for long-term forecasting. New technology substitutes old technology for the long run. This of course affects the forecasts. The paper mentions narrowband Internet, which continuously is substituted by broadband regarding accesses and traffic.

The following figure (newly developed and not a part of [Stor03a]) shows the penetration growth of some technologies in the Norwegian network:

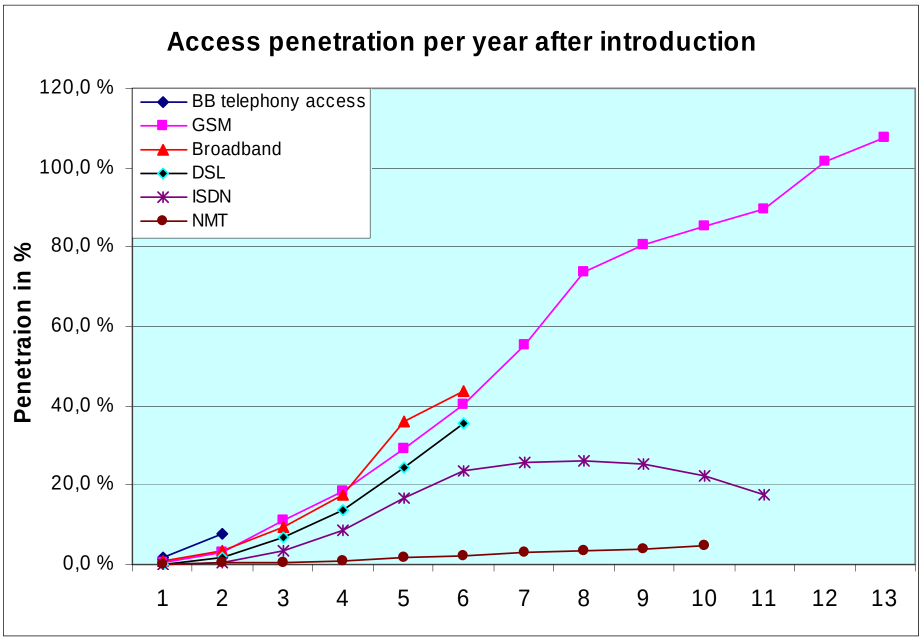


Figure 5.1 Access penetrations for different technologies in the Norwegian market as a function of number of years after introduction (Kjell Stordahl, November 2005).

The penetration for NMT and GSM is based on the Norwegian population, while penetration of the other services are based on the number of households in Norway

The figure shows what is stated in [Stor03a]: That broadband is substituting narrowband Internet, which affects the evolution of ISDN. The figure also shows the strong growth of Broadband telephony accesses.

[Stor03a] describes subscriber/access, capacity and traffic forecasting which is commented earlier in this thesis.

The last part of the paper discusses uncertainties and risks related to the forecasts. This aspect will be treated in the next chapter of the thesis.

5.3 “ Traffic forecast models for the transport network”[Stor02b]

In 2002 the broadband technology was well established and the broadband traffic had started to be a noticeable part of the total traffic. The paper analyses the broadband traffic, propose a structure of the expected traffic based on different traffic segments and suggest some general long-term traffic forecasting models.

Separate models are suggested for the residential and business market. The traffic forecasting models estimates the traffic load in the busy hour. The traffic load in the busy hour will vary in different places in the network depending on the respective shares of mix between residential and business customers. The generated busy hour is in addition dependent of traffic behaviour of the two customer classes since they don’t have busy hour at the same time. This procedure has to be followed for network planning. However, to get information about the general traffic growth, the traffic indicator formulas in the paper may be used.

Input to the traffic indicator defined in equation (1), are residential broadband access forecasts described in [Stor02a] and the revised forecasts [Stor04a] evaluated in Chapter 3 in the thesis.

Input to the traffic indicator defined in equation (2), is business broadband access forecasts. Description of broadband business forecasts is found in section 3.5 in the thesis. Input to the traffic indicator defined in equation (3), is mobile access forecasts shown in figure 5 and described in [Stor02a] and adjusted forecasts described in [Stor04a] and [Stor05b].

The total traffic volume in busy hours may be found by adding traffic from the three indicators mentioned and also the traffic from other operators who are leasing parts of the network.

The broadband traffic load is a function of the traditional busy hour concentration, but also the packet switching concentration factor. The last factor depends very much of the applications applied and how they are used. In addition the available access speed or capacity is important.

The traffic forecasts for the incumbent are based on a set of traffic indicators. The formula is rather complex because representative traffic measurements were not available for pure broadband traffic. The traffic forecast indicator segments the incumbents broadband traffic based on the following variables:

- Broadband penetration forecasts
- Number of households/business units
- Busy hour concentration factor
- Packet switching concentration factor
- Access capacity utilisation factor
- Mean downstream access capacity

The variables are described in more detail in [Stor02b].

The two first variables give forecasts of the number of customers, which were available. Since the traffic behaviour of the users was not known, assumptions were made. *An important message in [Stor02b] is the exponential evolution of the future broadband traffic*.

Now, also the forecasts presented will be evaluated.

Figure 1 and 2 in [Stor02b] show the long-term forecasts for the residential broadband market, which are a part of the traffic forecast model. The broadband access forecasts have been examined in chapter 3 in the thesis. Figure 3 shows the forecasts for increased bandwidth in the Western European market.

Since West European statistic is not available, complete statistics of Telenor's residential retail market is used to assess the statistics. This market is about half of the total Norwegian ADSL market. Statistics from 2001 to 31. August 2005, gives the following figure:

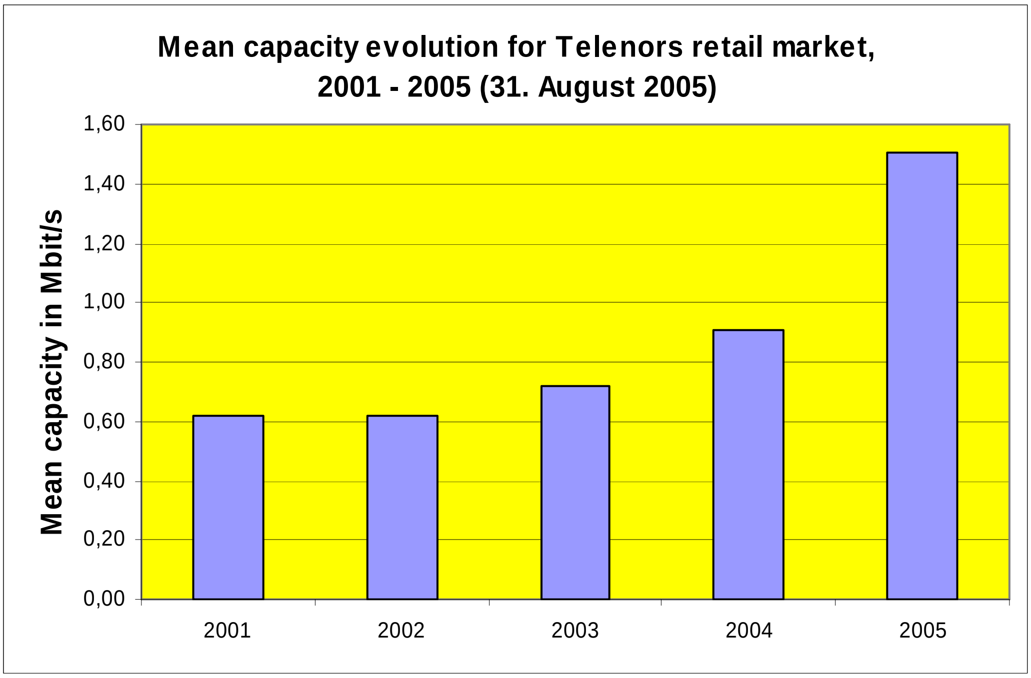


Figure 5.2 Evolution of mean ADSL capacity in Mbit/s for Telenors' retail market, 2001-August 2005 (Kjell Stordahl, September 2005).

The mean ADSL capacity is the weighted sum of capacities, where the weight for each ADSL capacity is number of ADSL customers with that capacity divided with total number of ADSL customers.

In the period 2002-2003 Telenor introduced ADSL capacity classes with 1Gbyte and 10Gbyte limitations respectively and then payment for the monthly usage beyond these limits. A large proportion of the high usage group churned at that time to other broadband operators. Then, Telenor went back to flat rate for all users. In 2005 Telenor introduced 2Mbit/s and 4Mbit/s access capacities and transferred at the same time all users on 704 kbit/s to 1024 kbit/s without changing the monthly tariff.

The 2005 mean value (1,50Mbit/s) is from August 2005 and may be higher at the end of the year. The slow increase the first years, is caused by high capacity users who churned to other operators. Usually, other operators lead an offering of higher capacity. There are reasons to believe that the incumbent mean capacities are lower than the country mean. Therefore, the capacity evolution on ADSL, 2001–2005, figure 3 in [Stor02b] seems not to deviate much from national Norwegian data. However, the mean Western European evolution may to some extent be lower, but information about the situation has not been found.

Figure 4 in [Stor2b] shows the predicted evolution of concentration of ADSL traffic per user as a function of busy hour concentration and packet switching concentration based on given assumptions. For estimating the broadband traffic per user, also forecasts of the access capacity utilisation factor and mean downstream capacity is needed. Figure 5.1 shows the mean ADSL capacity evolution 2001 – 2005. The user's behaviour regarding up- and downstream usage and the ability to utilise the whole capacity is not known. To be able to assess the forecasts from [Stor02b] the access utilisation factor is set to 70% for the whole period. Then the traffic forecasts per user can be calculated for each alternative (Figure 4 in [Stor02b]). The results are shown in figure 5.3.

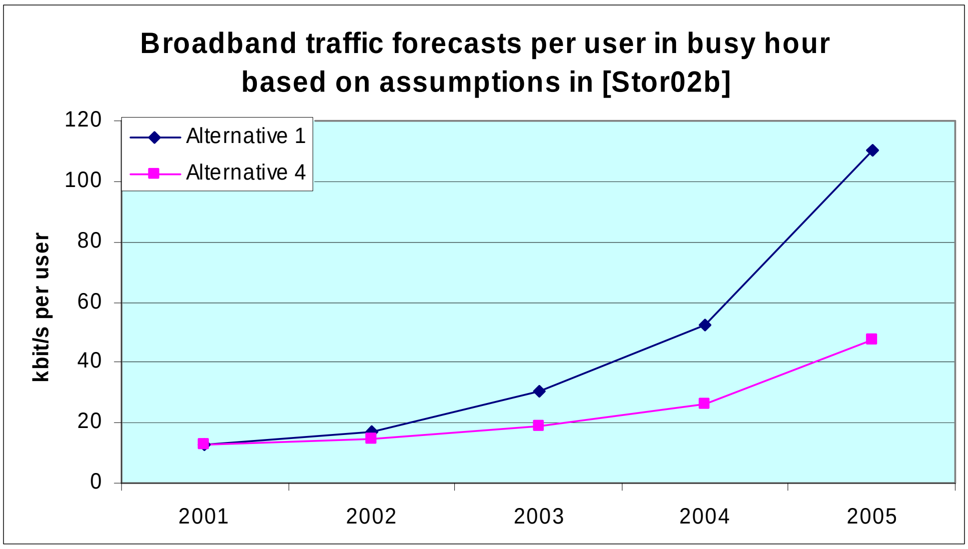


Figure 5.3 Broadband traffic forecasts per user in busy hour based on assumptions in [Stor02b]

Figure 5.3 shows an exponential increase in the traffic per user. This accounts for both the aggressive alternative (alt. 1) and the modest alternative (alt. 4). The yearly increase in the period 2003 – 2005 were: 74%, 73% and 111% for alternative 1 and 30%, 40% and 81% for alternative 4.

The long-term forecasts were developed in 2001 and the forecast period was 2001 –2010. The starting point in 2001 was assumed to be about 13 kbit/s per user in busy hour based on the situation in Norway.

Norwegian measurements showed that the traffic per user started at 20 kbit/s in 2002 and decreased to 12 kbit/s in 2003. The heavy broadband users caused the decrease in the traffic. They churned to other operators, when Telenor started charging the total traffic volume per month exceeding a given limit.

However, from the first quarter of 2004 there has been a very significant increase in the traffic per user in busy hour. Figure 5.4 shows the evolution of traffic per user in the Norwegian core network (T-nett). The broadband traffic evolution in the busy hour shown in the figure is the sum of residential traffic and the business traffic. The traffic per user is found by dividing the total measured traffic by the number of users.

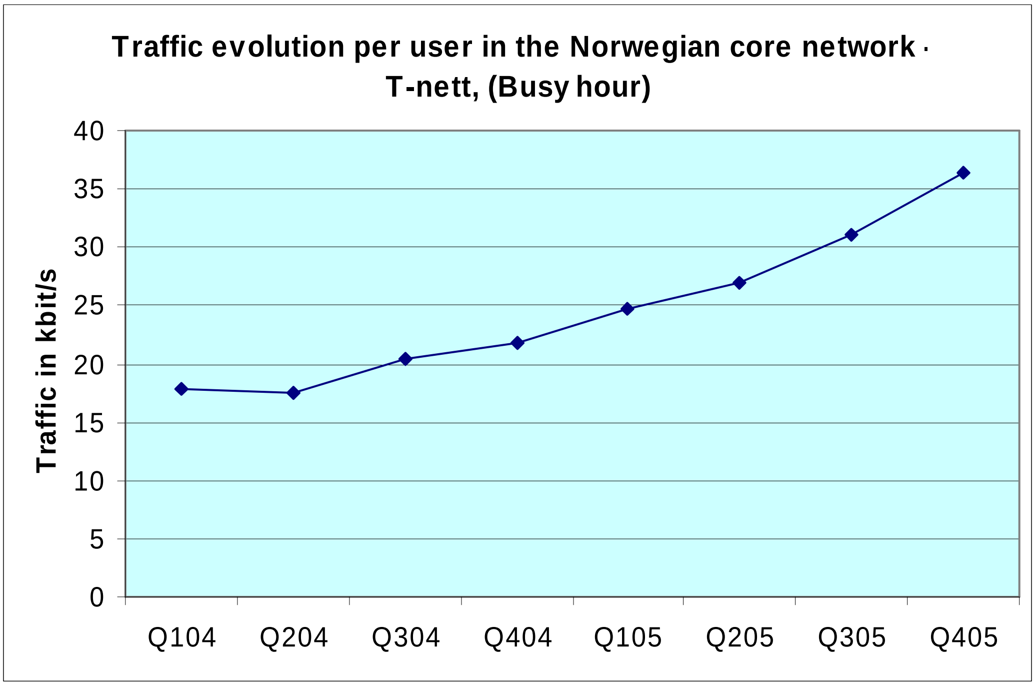


Figure 5.4 Traffic evolution per user into the Norwegian core network (T-nett) in busy hour (January 2006)

Figure 5.3 shows that the reference point in figure 4 [Stor02b] is 13 kbit/s per user. At the end of 2005 the four alternatives indicates an interval between 47 and 110 kbit/s per user.

Figure 5.4 shows 36,4 kbit/s per user in the busy hour in the Norwegian core network. The traffic increase per user has been 39% in 2004 and 67% in 2005.

Measurements at DSLAM level in the Norwegian network show significantly higher traffic per user in the busy hour compared to aggregated traffic is at the core network level. The reason is the law of large numbers. When the busy hour is defined based on aggregated traffic, busy hour from many DSLAMs are not taken into account. Therefore, the aggregated busy hour traffic on a lower level in the network will always be higher than the aggregated busy hour traffic on a higher network level.

The conclusion is that the assumptions done in 2001, seems not all to be out of scale. The forecasts 2006 - 2010 will be commented at the end of the chapter.

Figure 5.5 shows the traffic evolution in the Norwegian core network.

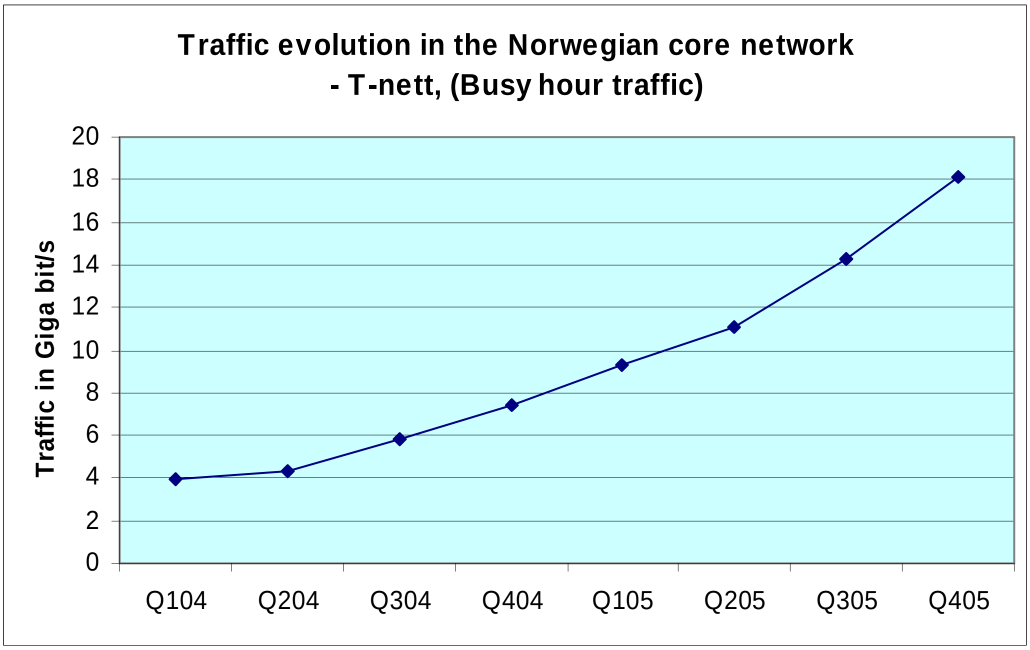


Figure 5.5 Total traffic evolution in Gigabit/s in the Norwegian core network (T-nett) in busy hour. (January 2006)

The traffic is a function of number of users and traffic per user. The figure shows the traffic evolution from Q1 2004 to Q4 2005. The traffic increased 138% the first year and 145% the last year. Both figure 5.4 and 5.5 shows an exponential growth, in fact with increased growth in the period Q2 – Q4 2005!

5.4 "Methods for traffic matrix forecasting" [Stor88]

[Stor02b] describes long-term forecasts for the total traffic volume in the core network. In the same way long-term forecasts can be developed for outgoing and incoming traffic at each node at the edge of the core network. The traffic inside the core network is a logical mesh network. Traffic matrix measurement and forecasts are important for planning and dimensioning all the routes in the core network.

The network consists of n nodes having a related nxn traffic matrix showing the incoming and outgoing traffic between the nodes. Kruithof [Krui37] invented the first traffic matrix forecasting method by adjusting the traffic elements in the matrix by incoming and outgoing traffic (row sums and column sums) forecasts from each node.

In [Stor85] and [Stor88] new models were developed to further improve the traffic matrix forecasts. The idea was to utilize more information. The improved method, called the *"Weighted least squares method"*, was based on making forecasts for the traffic elements and for row and column sums, and corrects the deviations (make consistence in the traffic matrix) by minimizing a weighted sum of squares. The weights represent the estimated uncertainty of the various forecasts. A computer program was developed by Norwegian Computer Center to handle relatively large traffic matrices.

In [Stor88] also the forecasts for the total traffic generated by the matrix was included in the model, which was called *"Extended weighted least squares method"*. The paper describes the Extended weighted least squares method, evaluates the method and discusses the effects of the weights used in relation to the forecast uncertainty.

Large traffic matrixes contain a lot of traffic elements and it is of course very time consuming to make advanced forecasts for each element. The established procedure was to use simple forecasting models for the traffic elements and more advanced forecasting models for the outgoing and incoming traffic and for the total traffic. Here, long-term forecasting models are relevant as well as medium-term forecasting models.

5.5 Experiences and conclusions

The improved traffic matrix forecasting methods were recommended and included in the CCITT recommendations [CCITT86], [CCITT88].

The methods were adapted by the Central Traffic Planning office in Televerket (Telenor) and used in the beginning of 1990's on Telenor's long distance network (core network). (Contact person: Arne Østlie, Telenor). Model input was quarterly time series for all traffic elements, incoming traffic, outgoing traffic and the total traffic. After some years the structure and the number of long distance exchanges were changed and it turned out to be difficult to reconstruct the time series in the new traffic matrix structure. Hence, the methodology was not used any longer. The future development has shown an evolution to a more flexible network where it would have been difficult to maintain a constant structure of the statistics.

The paper [Stor02b] gives a framework for traffic forecasts of the core network. Because of lack of measurements, assumptions had to be used for specific factors in order to make long-term traffic forecasting.

Measurements from the Norwegian core network have been used to evaluate the forecasts made in 2001. The broadband traffic evolution in the busy hour in Norway follows the modest alternative described in [Stor02b]. Because of many uncertainties and no available measurements when the forecasts were made, the quality of the forecasting assumptions have not at all being out of scale.

Now, it is of course not necessary to use the traffic indicator-forecasting model any longer. First of all the time series it-self should be used to make short-term forecasting. A natural approach is to use forecasting models for the number of users and multiply the forecasts with forecast of the traffic per user in the busy hour.

Long-term forecasts for the traffic in the core network are still very complicated subjects. When such a model is built, it is important to include many different aspects. Some of them are commented here.

One question is how ADSL2+ and IP-TV or TVoDSL and VDSL will influence the future capacity evolution. Several operators in Europe have introduced TVoDSL in 2004, and this is only the start of the evolution. This evolution will definitely create substantially higher capacity traffic in the network.

As commented the ADSL2+ access price will be significantly reduced because of low production price on the ADSL2+ cards, which will push the capacity evolution significantly upwards because of increased demand.

Another important factor is the TV transmission technology. In a long period both MPEG 2 and MPEG 4 signals will be used for the transmission. The signals have to be transmitted in parallel to every household who orders TV programs over DSL because it takes time to remove one standard from the whole TV market. In addition HDTV signals will also be transmitted. In an initial period three parallel TV signals instead of one for each TV program, will probably be transmitted. On the other hand, multicast will be used not to send the same TV program in parallel down to different subscribers in the same area.

An interesting evolution is also identified in the HFC (cable modem) network. The Docsis 1.1 standard is going to be changed into Docsis 2.0 and Docsis 3.0 [CaLab05]. This means that the end user capacity will increase from max 26Mbit/s down- and max 4Mbit/s upstream to minimum 160 Mbit/s downstream with a fairly high upstream. The cable modem specification, Docsis 3.0, is supposed to be approved in 2007.

It is important to underline that not all traffic will be part of the transport network. The TVoDSL distribution will probably be downloaded to the transport network, which will be used for the TVoDSL distribution. However, Video on demand services will be offered on specific decentralized servers for distribution in the local areas.

The described evolution supports the forecasts 2005 – 2010 which is showed in figure 4 [Stor02b], even if the development the first years not have been very aggressive. To make a more complete traffic forecast model for 2005 -2010, it is recommended to make the same type of capacity model for High capacity broadband (ADSL2+, VDSL2, DSM and HFC) as was shown for ADSL. A set of applications including TV applications, have to be part of the model.

[Stor03b] pointed out that forecasts and long-term forecasts are crucial for network planning. The paper gives an overview of the areas where the forecast modelling is important. The paper gave a short review of different forecasting models, which are relevant for network planning. One problem is that few forecasting models give confidence intervals of the forecast uncertainty. However, this aspect is addressed in the next chapter of the thesis.

6 FORECAST UNCERTAINTY AND RISK

Forecasts are needed in many telecommunication areas. However, forecasts and especially long-term forecasts are uncertain. Important decisions are many times based on forecasts. When Telenor makes important investment decisions, sensitivity analysis is performed for selected critical variables. Usually, the forecasts will be one of the critical variables.

Net present value (NPV) is a natural measure for the economic value of investment projects or a portfolio of investments. A good approach for evaluating the NPV is to perform either sensitivity of risk analysis to see how robust the NPV is when the value of the critical variables changes.

Risk analysis is more advanced than sensitivity analysis. Risk analysis defines a priori probability densities for each critical variable and makes simulations of the economical measures like NPV, internal rate of return and payback period based on simulations of the probability densities representing the selected critical variables. One such critical variable is the long-term demand forecasts.

Kjell Stordahl developed the first framework for risk analysis in the RACE 2087/TITAN project in the period 1994-1996 [Stor95b]. The framework was also documented in chapter 9, page 99-110, in the book “Introduction strategies and techno-economic evaluations” [Ims98]. Since then, risk analysis has been applied extensively in the techno-economic projects TITAN, OPTIMUM, TERA, TONIC and ECOSYS. The risk methodology has up to 2005 been enhanced. These projects have developed a techno-economic tool for calculations. However, it was decided not do specific programming for risk analysis inside the tool, but instead use the risk simulation tool Crystal Ball [Crys06]

The following papers on risk analysis, where long-term forecasts are a critical variable, are enclosed as part of the thesis:

- Stordahl K, L A Ims and B T Olsen “Risk assessment and techno-economic analysis of competition between PNO and Cable operators” *In Proc Networks 96*, Sydney, November 24 –29, 1996. [Stor96]

- Stordahl K, N. K. Elnegaard, L. A. Ims, B.T. Olsen. Overview of risks in multimedia broadband upgrades. I*n proc Globecom ’99*, Rio de Janeiro, Brazil, December 5-10, 1999.[Stor99b]

- Stordahl K, N K Elnegaard, B T Olsen, “Broadband access rollout strategies in a competitive environment”. *In Proc Optical Hybride Access Network/Full Service Access Network workshop*, Yokohama, Japan, April 4-6, 2001. [Stor01]

- Elnegaard N. K., K Stordahl “Analysing the impact of forecast uncertainties in broadband access rollouts by use of risk analysis”, *Telektronikk(100) no 4*, 2004 [Elne04]

6.1 “Risk assessment and techno-economic analysis of competition between PNO and Cable operators”[Stor96]

The analysis in [Stor96] was carried out several years before the first broadband networks were deployed in Europe. A similar paper was published in 1997 [Ims97a]. [Stor96] addresses different challenges faced by incumbents and cable operators adapting their present networks to broadband competition. Extensive risk analysis was performed based on long-term forecasts for a basket of services and for market shares between the incumbent and the cable operators. Four different upgrade alternative were examined, two for the incumbents and two for the cable operators:

- Incumbent: Fibre to the node (FTTN) with enhanced copper
- Incumbent: Fibre to the building (FTTB) architecture based on ATM-PON
- Cable operator: Fibre to the node (FTTN) architecture based on HFC and cable modem
- Cable operator: Fibre to the building (FTTB) architecture based on HFC and cable modem

The following variables, considered as the most critical one for the risk analysis, were selected:

- Market shares between PNO (Incumbent) and cable operators
- Penetration forecasts for POTS, ISDN, 2Mbit/s ASB(Asymmetric Switched Broadband), 2Mbit/s SSB(Symmetric Switched Broadband), CATV
- Tariffs

Section 3 in [Stor96] shows the long-term market forecasts for POTS, ISDN, CATV, 2Mbit/s ASB and 2Mbit/s SSB accesses. Parts of the access forecasts (Figure 1) and tariff forecasts (Figure 2) are based on the TITAN Delphi survey from 1994 [Stor95a]. The broadband access forecasts have been commented, but not the ISDN forecasts. Figure 1 shows a very significant growth of ISDN (about 40% in 2005) and an inverse reduction of POTS. However, this situation did not occur. The main reason was growth of broadband, which substituted the expected ISDN growth. Norway and Germany had the highest ISDN penetration in the world. Figure 5.1, chapter 5, in the thesis shows that the maximum ISDN penetration in Norway was about 25%.

The annual tariff forecasts in the paper from 1996 are reasonably good. One exception is 2Mbit/s symmetric accesses, which have mainly not been available in the residential market in Western Europe [Point04]. The 2Mbit/s (SSB) tariff predictions for the Norwegian business market seem reasonable for 2003 and 2004, but the competition is now pressing the tariffs downwards. The 2Mbit/s symmetric tariffs for the residential and SOHO seem to be too high in 2004-2005 and also for the further forecasts.

Figure 7 in [Stor96] shows the evolution (forecast) of estimated standard deviation of the long-term forecasts for each of the services in the period 1997 – 2006. The Normal distribution is used as the probability density for each of the critical variables. For each year the standard deviations of the forecasts are plotted in figure 7. The standard deviations were estimated based on the variation in answers among the experts for the various forecasting questions in the Delphi survey.

Since the Normal distribution is uniquely defined when the expectation (here the forecasts) and standard deviation are given, then all probability densities are defined for the long-term forecasts which are used as input to the simulations in the risk analysis. Figure 8 in [Stor96] shows that a truncated Normal distribution is used in the simulations to avoid negative forecasts.

Section 7.1 – 7.4 show the risk analysis of the four described rollouts, while section 7.5 – 7.6 evaluate the effects of the critical variables and effects on the upgrade alternatives.

The risk analysis results for the four different architectures were described and primary figures and tables show the frequency distribution of net present value, the ranking of the critical variables according to their influence on variation of NPV/IFC(Installed first cost) and a frequency distribution of the payback period. The factor NPV/IFC represents roughly the profit relatively to the investments.

Table 3 and 4 show the ranking of the critical variables according to their influence on the variation of respectively NPV/IFC and NPV respectively.

Figure 9 and 10 in [Stor96] describe the frequency distribution of the NPV for the incumbent FTTN based on about 1000 simulations. Figure 9 (Figure 6.1 in the thesis) shows that no simulations of NPV are less than 200.000 ECU (Euro) and there is a probability of 10% of a NPV less than 402.000 ECU (Euro).

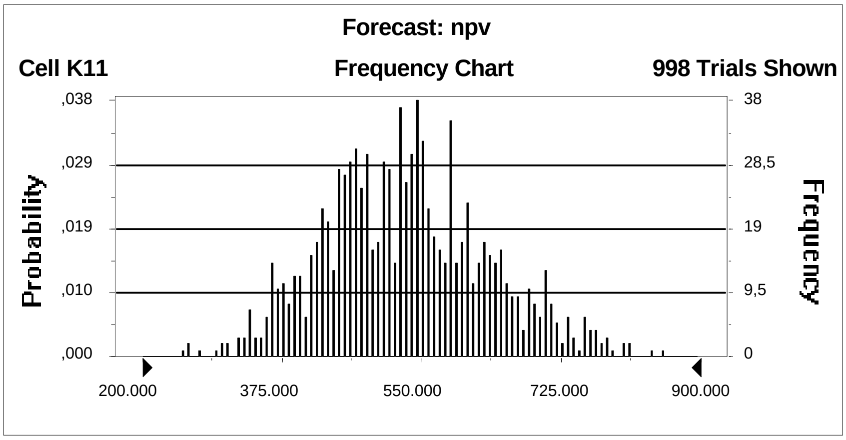


Figure 6.1 Frequency distribution of NPV based on 998 simulations

Figure 11 (Figure 6.2 in the thesis) and 12 show the cumulative frequency distribution of the payback period. The cumulative frequency distribution describes the probability for having a payback period less than a given value and vice versa the probability of having a payback period greater than a given value.

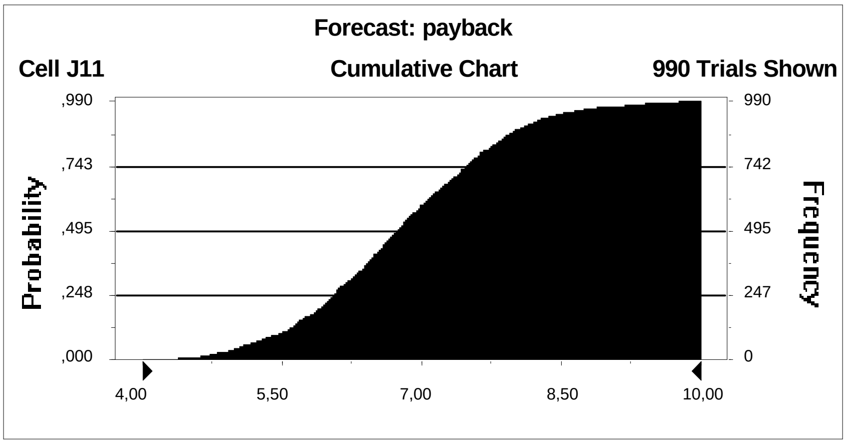


Figure 6.2 Cumulative frequency distribution payback period based on 990 simulations

The risk assessments and additional analysis show that the FTTN alternative for the incumbent is the best economic alternative with the lowest risk. The FTTB alternative for the CATV operator was the least economic alternative and also with the highest risk.

The NPV, payback period, etc are always calculated for making decisions of rollout of new technologies. [Stor96] shows that risk analysis gives important supplementary information for these types of strategic decisions.

6.2 "Overview of risks in multimedia broadband upgrades". [Stor99b]

The first part gives an overview of risks connected to roll out of a broadband network structure. Specific attention is put on market risks, competition risks, regulatory risks, technology risks, operation risks, investment risks and economic risks.

The second part of the paper describes the methodology for quantifying the risks. A new methodology had been developed to define probability densities for the critical variables. Instead of using truncated Normal distributions and Beta distributions were introduced. The risk simulations were performed by the Latin Hyper Cube approach. Latin Hyper Cube simulations use segmented probability distributions to be sure that the whole probability distribution is represented in the simulations.

The long-term cost forecasts were performed by application of the extended learning curve model.

The long-term broadband access forecasts, figure 4, were based on the results from the latest Delphi survey [Stor99b]. The long-term forecasts describe the evolution of demand for 2Mbit/s, 8Mbit/s and 26 Mbit/s accesses. The long-term forecasts are commented in chapter 3.

The long-term tariff forecasts were based on information from the latest Delphi survey [Stor99b].

The broadband case study examined is a very competitive SOHO and residential area, consisting of large apartment blocks. The incumbent offers ADSL and VDSL based on:

- Introduction of DSL in year 2000 (Fibre to the Lex (Local exchange))
- Introduction of VDSL and Fibre to the node in year 2005 and then stepwise deployment of fibre nodes (FTTN128 and FTTN512)
- The incumbent starts with 100% market share in the area, but is loosing market share continuously until Fibre to the node is deployed.

The uncertainties based on the following critical variables, are studied:

- Long-term market share evolution
- Long-term access penetration, 2Mbit/s asymmetric/symmetric, 8Mbit/s and 26Mbit/s
- Long-term tariff forecasts

Specific probability densities were defined for the different variables. In addition three different uncertainty values were allocated to the market share uncertainty:

- 10% relative standard deviation
- 20% relative standard deviation
- 30% relative standard deviation

The relative standard deviation was defined as the percentage of the expected value (market share).

Figure 5 in [Stor99b] shows the expected life cycle costs (Total discounted sum of investment and operations and maintenance costs). The life cycle costs are shown for the three different uncertainties of the market share evolution. The other dimension of the figure gives the risk evaluation based on 10% and 5% fractiles of the simulated life cycle distribution.

Figure 6 (Figure 6.3 in the thesis) is an analogue figure for the net present value. The figure shows that the probability of a negative NPV is quite low when the relative standard deviation of the market share is 10 –20%.

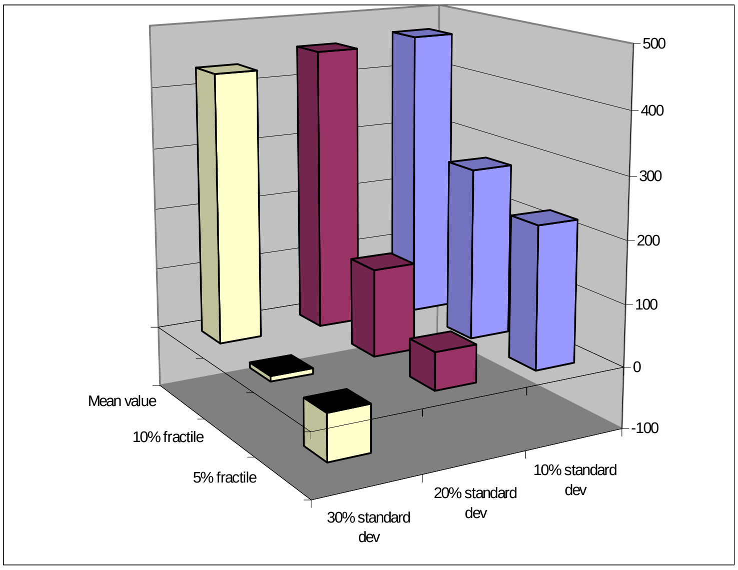


Figure 6.3 Net present value distribution(mean, 10%, 5% fractile) based on different degree of market share uncertainties

However, when the relative standard deviation is 30%, we clearly see a risk for negative net present value. The 10% fractile indicates NPV of about 0, while the 5% fractile indicates a negative NPV.

[Stor99b] describes how risk analysis add valuable information to the traditional economic calculations of a broadband case study.

6.3 “Broadband access rollout strategies in a competitive environment”[Stor01]

The paper examines different access rollout scenarios in dense urban areas where the incumbent and a cable operator fight to take additional broadband market share. The analysis focuses on different evolutionary paths starting with the twisted copper pair network. The strategy for the incumbent is to roll out ADSL and VDSL at the right time.

The rollout case study analyses the broadband demand in a highly competitive dense urban area where a cable operator and the incumbent plans to upgrade the network to offer broadband. The incumbent plan to offer the following DSL capacities: 0,5Mbit/s, 1Mbit/s, 2Mbit/s, 6Mbit/s and 24Mbit/s, while the cable operator plans to offer services on HFC.

Information about long-term forecasts from the latest Delphi survey and the adjusted TERA forecasts [Stor99] is known. However, the forecasts used in this business case are not based on mean forecasts for whole Western Europe, but for a specific highly competitive area, which significantly deviates from West European mean values. Therefore, also the long-term forecasts shown in figure 1 are significantly higher than West European mean forecasts. The long-term tariff evolution is shown in figure 2.

Because the area is highly competitive, rather aggressive rollout scenarios are examined. In total 7 different rollout scenarios of ADSL/VDSL for the incumbent and HFC rollout for the cable operator are described. Figure 4-10 show the introduction time and describe the market share evolution for the competitors.

Figure 11 shows the incumbents installed first cost and net present value for each of the 7 scenarios. The scenarios showed that the incumbent looses market share and low net present value on broadband rollout if the rollout is significantly delayed compared with the cable operators HFC rollout.

Risk modelling was used to evaluate the results taking into account uncertainties in the critical variables. The “uncertainty” variables were grouped in the following main categories:

- Price evolution of DSL equipment
- Long-term penetration forecasts, all services
- Erosion of monthly access fee

The long-term access penetration forecasts were based on a four parameters Logistic model. The tariff erosion was modelled by a simple exponential distribution.

Figure 12 shows the probability for negative NPV. The figure shows that scenario 4 and 3 and may be 7 are acceptable for the incumbent. Figure 13 shows ranking of the three groups of critical variables according to the influence of the NPV’s variation for the 7 scenarios. The figure shows that uncertainty in the tariff evolution explains 55%-70% of the variation in NPV. The uncertainty in the demand forecasts explains 15%-35%, while uncertainty in the cost evolution of DSL contributes with 7%-17%.

The conclusions about the rating of the groups of critical variables are not surprising. In 2001 much experience have been learned about the component cost prices. The broadband demand was at an early stage and the relative uncertainty was assumed to be high. Also the uncertainty in the tariff evolution was assumed to be high. However, the uncertainty in the tariff evolution influences the NPV more than the long-term demand forecasts. This is because the forecasts influence both the revenue and the investment part of NPV, while the tariffs only influence the revenue part.

In chapter 6.4 in the thesis the effects of demand and tariffs are analysed more closely. The conclusion is reduced overall uncertainty of NPV because of negative correlation between demand and tariffs.

6.4 “Analysing the impact of forecast uncertainties in broadband access rollouts by use of risk analysis”[Elne04]

Before reading the comments, it is recommended to go to the next chapter and read [Stor04b] or comments to [Stor04b] because the risk analysis presented, is based on the case study described and analysed in [Stor04b].

This paper gives an updated overview of the various uncertainties and risks based on the overview given in [Stor99]. Substantial risks are connected to predicted evolution of the broadband market regarding market share predictions, demand for enhanced and new services and demand for accesses. The uncertainties are usually expressed by measures like standard deviations and confidence limits. Traditional statistical methods may in some situations be used to estimate forecast uncertainties. There are two different uncertainty elements in a statistical forecasting model. One uncertainty element is caused by the parameter estimation itself. The other is caused by the forecasting period. If the only explanatory variable is the time, then no additional uncertainty in prediction of the time itself is added. However, if other explanatory variables are included in the forecasting model, forecast uncertainty for each of the variables also influences the forecasting uncertainty. As mentioned in [Elne04], modelling and estimating the uncertainty in this situation is complicated.

Section 2 in [Elne04] describes two probability distributions of NPV, representing two projects. It is showed that the project with highest expected NPV value and largest variance in the distribution is the best investment alternative. The conclusion is to examine the combination of the expected value and the variation when the evaluations of investment projects are performed.

Section 4 gives an overview of the risk methodology. The use a priori information for estimating the probability distributions for the critical variables is crucial. The paper proposes to use either the Beta distribution or the Log Normal distribution. The procedure is developed by Nils Kristian Elnegaard and described in Appendix A. The risk analysis is performed as illustrated in figure 2 in [Elne04] by making a number of simulations of the (critical) variables and make calculations of the NPV/Internal rate of return/Pay back period for each run. After a number of simulations a distribution like the one in figure 2 will be built. The simulation package Crystall Ball [Crys06] is used for the simulations. The simulations may be carried out as pure simulations or by using Latin Hyper Cube simulations.

The risk analysis was applied to 6 scenarios with different timing and ambition levels for ADSL2+/VDSL rollout. The long-term adoption rate forecasts for ADSL2+/VDSL rollout are shown in [Stor04b]. Adoption rate forecasts also called take rate forecasts are adjusted penetration forecasts taking into account the coverage. The forecasts are commented more in detail in [Stor04b] and the next chapter.

Figure 3 in [Elne04] shows the NVP for the different scenarios. Table 1 gives an overview of critical variables:

- ARPU
- Line card price
- Sales costs
- Provisioning costs
- Equipment price reduction rate
- ADSL/VDSL adoption rate forecast, reference year 2011
- Customer installation costs
- Content costs
- Smart card costs
- Customer operations and maintenance

including the following values:

- Minimum value
- 5% percentile
- Default value (used for traditional NPV calculation)
- 95% percentile
- Maximum value

The parameters of the Beta distribution are estimated based on the values in table 1.

Three approaches for risk analysis were carried out:

- Risk analysis based on the 10 critical variables in table 1
- Risk analysis based on Adoption rate forecasts and ARPU
- Risk analysis based on Adoption rate forecast.

The 5% percentile, the 95% percentile and the standard deviation of the NPV for all scenarios and the three approaches are shown in table 2. It is shown that the adoption rate forecasts contribute heavily to the uncertainty in NPV, while the adoption rate forecasts and the ARPU contributes much more and close to the total contribution of all 10 critical variables.

So far all variables have been simulated independently. There is significant negative correlation between adoption rate forecasts and the ARPU. (If ARPU decreases, the adoption rate forecasts increases, and vice versa).

Now, two alternatives can be used to improve risk results. One alternative is to construct a demand curve, which give the relation between the adoption rate and the ARPU and add noise components to generation of the drawn values. Another alternative is to correlate the two variables when their values are drawn in the simulations. The last alternative was used in [Elne04] and the correlations used were: -0,25, -0,50 and –0,75.

Figure 5 (figure 6.4 in the thesis) shows the 5% percentiles of the NVP for the 6 scenarios, when all 10 critical variables are simulated with no correlation, -0,25, -0,50 and –0,75 between adoption rate forecasts and ARPU.

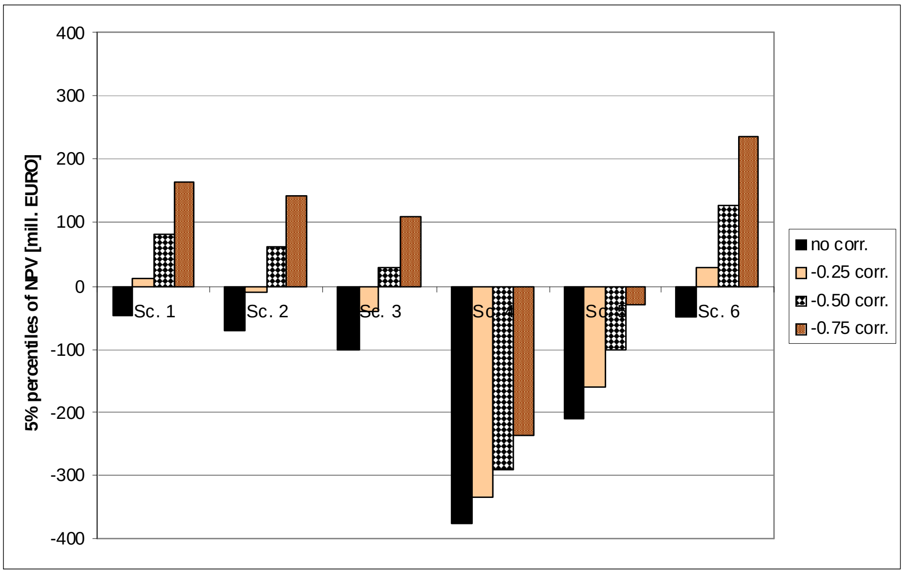


Figure 6.4 5% percentiles for various degrees of correlation between ARPU and Adoption Rate forecasts. Ten variables simulated

The figure shows very clearly that the 5% percentile of NPV (risk level) reduces significantly for all scenarios as a function of negative correlation between ARPU and adoption rate forecasts. The same calculations are carried out for adoption rate forecasts and ARPU. Figure 6 shows the same type of results. Still the size of the 5% percentile is not much lower compared to the situation with 10 critical variables. Hence, the adoption rate forecasts and the ARPU are still the dominating factors for generation of NPV uncertainty.

6.5 Experiences and conclusions

Risk analysis is an analytical approach used for examining the effects of uncertainties in critical variables. [Stor96] shows different outputs from the risk analysis and describes how the risk probabilities should be interpreted.

The papers in this chapter show how risk analysis is used to evaluate the following broadband business cases:

- FTTN with enhanced copper
- FTTB architecture based on ATM-PON
- FTTN architecture based on HFC and cable modem
- FTTB architecture based on HFC and cable modem
- DSL with enhanced copper
- VDSL with FTTN
- Competition between DSL and HFC operators
- Competition between DSL operators

In all broadband business cases the long-term market evolution and in particular the long-term forecasts are critical variables analysed by the risk analysis.

The risk analysis for the business cases shows that the market evolution induces greater uncertainties than the cost evolution. Even when the main part of the component costs are grouped together, the cost forecasts from this group of components does not contribute as much to the uncertainties as tariff/ARPU forecasts or broadband penetration forecasts.

[Elne04] shows that ARPU and broadband adoption rate forecasts are the dominating critical variables in the ADSL2+/VDSL roll out business case. The paper also documents that the total uncertainties are reduced significantly when negative correlation are modelled between ARPU forecasts and adoption rate forecasts.

7 LONG-TERM ADOPTION RATE FORECASTING

Usually the broadband demand in a given country is characterised by the broadband penetration. To be able to identify the potential broadband demand, defined as broadband adoption rate, we need to know the broadband penetration and the coverage. Suppose that the rollout at time t gives the broadband coverage, C_t, and that the broadband penetration at that time is P_t. The broadband adoption rate (or take rate), A_t, is the ratio between demand and coverage in an area.

$$A_t = P_t / C_t$$

The same relation is valid not only for the total broadband penetration, but also for the penetration of different broadband technologies and for disaggregated areas.

Suppose that the broadband coverage in a country is 80% and the broadband penetration 25%. When broadband is deployed and offered in a new area, the real broadband demand (adoption rate) in this area is 31%, not 25%.

Long-term adoption rate forecasts are important for evaluation of broadband rollout strategies. This chapter shows how the long-term adoption rate forecasts are used to make rollout strategies for high capacity broadband ADSL2+/VDSL2 and for broadband rollout in the residual market.

The following papers, where long-term adoption rate forecasts play an important part of the rollout strategy, are enclosed as a part of the thesis:

- Stordahl K, N K Elnegaard, B T Olsen, M Lähteenoja "Competition in the local loop – How to minimize the market risks" *In Proc. XV International Symposium on Services in the Local access - ISSLS 2004.* Edinburgh, Scotland, 21-24 March, 2004

- Stordahl K, N K Elnegaard, "Broadband in the residual market: First mover's advantage" Unpublished, but sent to WTC/ISSLS 2006.

7.1 "Competition in the local loop – How to minimize the market risks" [Stor04b]

Section 2 in [Stor04b] describes the long-term broadband penetration forecasts. Section 3 and 4 describes the ADSL2+/VDSL rollout strategy by starting with the largest exchanges because the coverage is high and the investment per customer is less than in other areas.

The differentiated adoption rate forecasts shown in Figure 5.1 in [Stor04b], are the key to the rollout strategies. The adoption rate forecasts is shown:

- when an operator enters the area and is alone
- when two operators enters the area at the same time
- when one operator enters the area one year delayed
- when one operator enters the area two years delayed
- etc

The model for the differentiated adoption rate forecasts assumes that the first operator takes the initial market, while a second operator entering next year takes 20% of the growth. The second operator takes 35% of the market growth the second year, and 50% the next years. Figure 7.1 shows the adoption rate forecasts for ADSL2+/VDSL based on these assumptions.

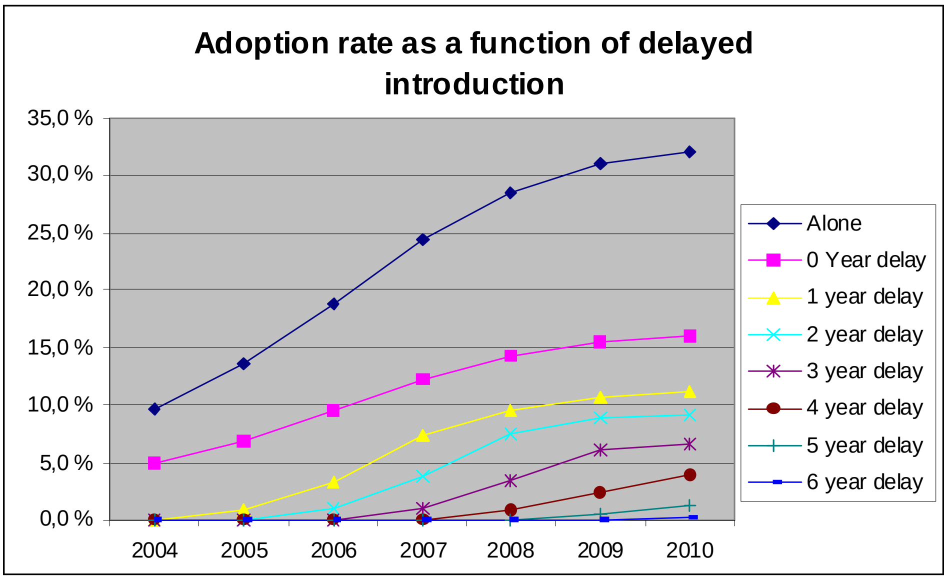


Figure 7.1 ADSL2+/VDSL adoption rate forecasts as a function of delayed introduction

The business case is based on rollout of ADSL2+/VDSL in a large country. The high capacity broadband market is divided in five market segments according to the sizes of the exchanges. It is assumed some differentiation in the adoption rate in the different market segments: The larger exchange areas, the higher demand.

The business case is based on competition between two main operators rolling out ADSL2+/VDSL with limited resources each year. Table 7.1 – 7.6 show the rollout each year as a percentage of the whole market. The main point is of course to start the rollout in large exchange areas. When the most attractive areas are occupied, the operator continues with the second best and at a given point, the operator enter the most attractive exchange areas as the second operator instead of entering small exchange areas. The long-term adoption rate forecasts are an extremely important factor for choosing the most optimal rollout strategy.

The results from scenarios 1-6 give some guidelines for the rollout strategies. Figure 9.1 and 9.2 show that two years delayed rollout for the incumbent gives very poor results, while an aggressive rollout of the incumbent gives high NPV.

It is interesting to see that the largest operator in Europe seems to follow the strategy based on adoption rate forecasts presented in this paper. Deutsche Telecom announced 14. November 2005 that they have decided to spend *3 Billion Euro* to roll out a VDSL FTTN in Germany [OVUM05].

7.2 “Broadband in the residual market: First mover’s advantage” [Stor06] Full paper.

7.2.1 Abstract

Long-term broadband penetration forecasts for Western Europe are presented. The broadband penetration forecasts take into account the historical evolution. The broadband penetration forecasts show the predicted mean demand in Western Europe. However, the penetration forecasts do not reflect the genuine broadband demand in specific areas. The broadband penetration forecasts are adjusted according to the broadband coverage. The adjusted forecasts are defined as adoption rate forecasts. These forecasts are used as input to the techno-economic calculations.

The techno-economic calculations examine broadband roll out in the different access area types. Furthermore, copper loop length distribution, distributions of number of potential subscribers and the adoption rate in the area are analysed.

The paper documents the profitability of broadband rollouts in sparsely populated areas and estimates the limits for having monopoly areas as a function of given characteristics.

The identified monopoly areas will of course contribute to higher broadband coverage because the profitability in these small areas will be better than earlier expected because of none competition.

The paper ends with recommended broadband roll out strategies for the residual market.

7.2.2 Introduction

In 2004 the Norwegian Government gave the following statement regarding broadband:

The government looks at deployment of the broadband network as establishment of a national infrastructure, which during the coming years will be as important for evolution of the modern Norway as the telephone network, power line network, railway network, roads, water and sewage network earlier have been for the Norwegian Society.

In 2005 the newly elected Norwegian government announced that they wanted to roll out broadband toentire country within the end of 2007. *The Norwegian Ministry of Government Administration and Reform* has calculated the cost to cover the last 5% of the Norwegian rural areas to about 120 million Euro.

The Norwegian government has so far utilised the free market dynamics and handed over the broadband deployment to the operators. To speed up rollout of the very last part of the infrastructure, which so far is not commercially profitable, the government has decided to support with the financing.

This paper does not analyse Norwegian business cases. The paper analyses the residual markets in Western Europe.

During the last five years West European countries have rolled out broadband extensively. DSL technology is the dominating technology followed by HFC. Most of the countries in Western Europe still have a residual market, which so far is not covered by broadband. The size of the residual market in Western Europe varies mainly between 5 – 10% of the total market size. For countries outside Western Europe the residual market is on average much higher. Exceptions are: South Korea, Taiwan, USA, Canada and some others.

The strategy for the broadband rollout has been to cover the most densly populated areas as the first step. DSLAMs have been installed in large exchange areas, and cable networks with many subscribers have been upgraded to HFC. Also wireless systems have been used for the coverage. By entering the most densly populated areas, the operators secured high market shares and also low investments per customer. High net present value and relatively short pay back period have generated the broadband rollouts so far.

At present, only more sparsely populated areas have no broadband coverage in Western Europe. This paper shows that important factors like increased broadband demand, lower production price of broadband equipment and relatively higher market shares for operators who are entering smaller areas give reasonable good business cases also in these areas.

The paper pays specific attention to DSL technology and rollout strategies in the residual broadband market. DSL is the dominating technology in rural areas. The residual market consists of parts of the access network with too long copper lines and areas with too few potential subscribers, where broadband so far has not been rolled out. The analysis presented in this paper shows how DSL can be deployed in smaller areas to increase the broadband coverage.

7.2.3 Residual broadband market

The residual broadband market is defined as the part of the market, which is not covered by broadband accesses. 100% minus the broadband percentage coverage is a measure for the residual broadband market. The broadband coverage is a function of rollout of different broadband technologies like DSL, HFC (cable modem), FWA, FTTB/FTTH etc. The definition of broadband is not quite clear. A definition often used expresses broadband as downstream capacity greater than ISDN (2x128kbit/s+16kbit/s = 144kbit/s). Other alternatives used, are 384kbit/s or 512kbit/s. The costs to cover the broadband residual market increase as a function of the defined minimum access capacity.

7.2.4 Market evolution and penetration forecasts

To evaluate broadband rollout strategies, broadband modelling and long-term broadband access forecasts have been developed. The broadband forecast modelling is based on work in the techno-economic project ECOSYS ([Stor04a], [Stor04b]).

7.2.4.1 Relevant broadband technologies for the residual market

Newly updated forecasts for the Western European broadband market based on the methodology showed in [Stor04a], have been developed. Figure 7.2 shows the market share forecasts of the most dominating technologies. The forecast modelling is based on Logistic models with four parameters.

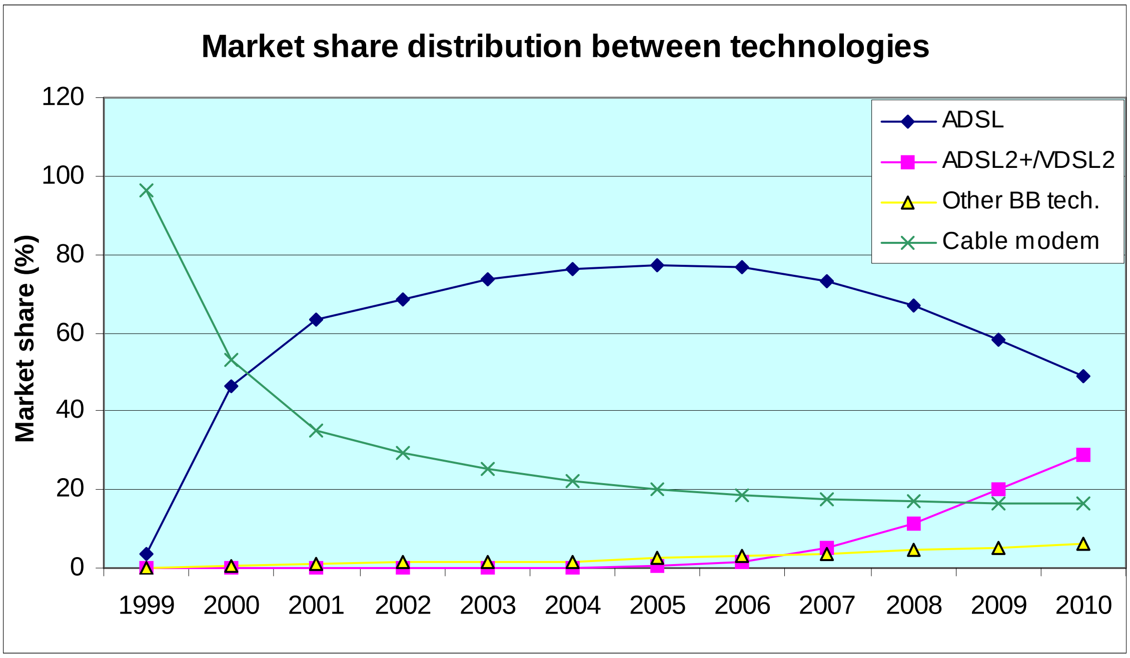


Figure 7.2 Market share forecasts between ADSL, ADSL2+/VDSL, Cable modem and other technologies for the West European residential market

The figure shows that DSL and cable modem are the dominating broadband technologies in Western Europe. Other technologies have relatively small market shares in the period 1999 – 2006. The most important technologies in this group are FWA and FTTB/FTTH. The fibre solutions are rather expensive to establish and are not candidates for the residual market for most of the countries in Western Europe. The HFC network is an enhancement of the traditional TV distribution network, which has been rolled out in urban and suburban areas. The HFC network will not be deployed in rural areas because of very high investment costs. Hence, HFC (cable modem) is not a candidate for the broadband residual market.

DSL is an important alternative for the broadband residual market. However, the technology has limitations. First of all, the copper loop length limits the coverage possibilities. Secondly, it will not be profitable to cover too small areas with DSLAM installations because of too high investments per customer.

Other possibilities are especially WiFi, WiMAX and satellite. For some countries also the Digital Terrestrial Television network (DTT) could be a candidate. The network has limited capacity for individual communication and the network will probably be deployed too late.

7.2.4.2 Broadband penetration forecasts for the residential market

Newly updated forecasts for the Western European broadband market based on the methodology presented in [Stor04a], have been developed. Figure 7.3 shows the penetration forecasts.

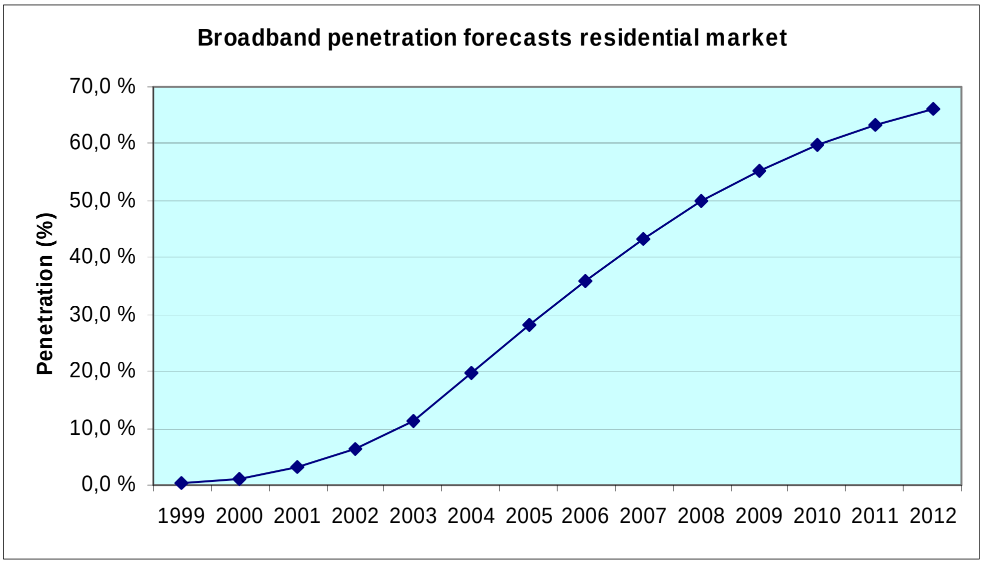


Figure 7.3 Broadband penetration forecasts for the residential market, Western Europe

The figure shows the broadband penetration forecasts per household for the residential Western European market. The mean value for the all countries in Western Europe is shown in the figure. There are of course great differences between the Western European countries. The Netherlands, Switzerland, Belgium and the five Nordic countries have a significantly higher penetration than the mean value for 2005, while especially Greece and Ireland have a very low broadband penetration [OECD05].

7.2.4.3 Broadband forecasts for the business market

The broadband forecasting model for Western Europe has not been easily developed because of lack of data. The most important statistics used is the Western European broadband survey conducted by Idate and supported by the European Commission [Idate05b], Point topics [Point05], and broadband statistics from OECD [OECD05].

A central element of the access forecasts is the long-term saturation level. The number of business units for Western Europe reported in [Idate05b] is a basis for the saturation level. A business unit is placed at an independent location and a company consists of one or more business units. 62% of business units in Norway are units without employees and many of these units have been constructed to avoid taxes etc. [SSB06]. It is assumed that only a limited number of the business units without employees are ordering broadband access. On the other hand, larger business units have a potential to order more than one broadband accesses. The number of accesses needed depends of number of employees and the traffic concentration, which is a function of the busy hour concentration factor and the packet switching concentration factor. It is assumed that not all employees are using the broadband access. The traffic concentration factor is assumed to be 1:20. The traffic concentration factor will of course depend on the evolution of higher capacity connections and the evolution of usage of high capacity applications.

The number of business units in Europe is found in [Idate05b]. Based on the traffic concentration factor and reduction of business units, which are expected not to order broadband access, the broadband access potential for the business market in Western Europe is estimated. Figure 7.4 shows the penetrations forecasts.

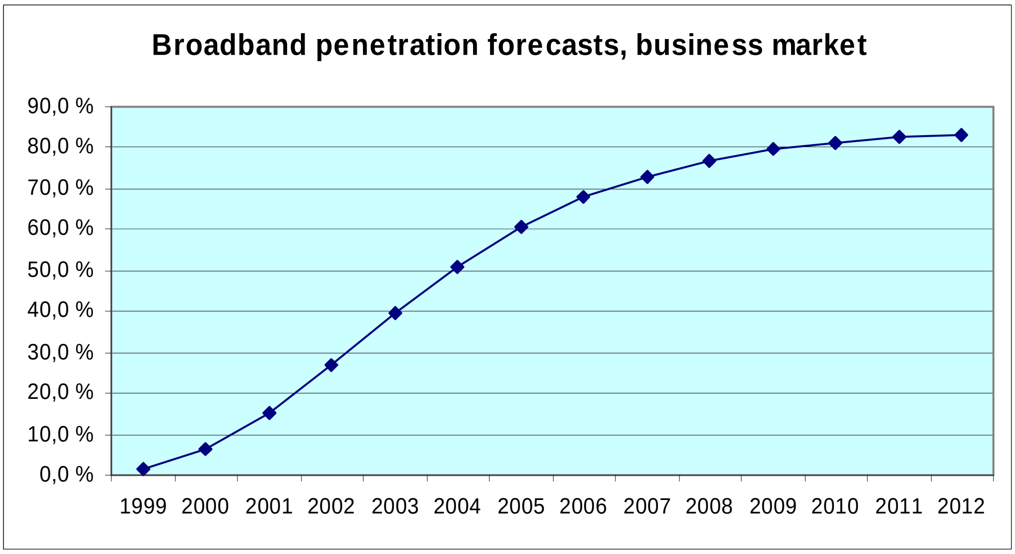


Figure 7.4 Broadband penetration forecasts for business market, Western Europe

Statistics from [Idate05b] indicates that the volume of accesses in the business market in EoY 2004 was about 19% of the total volume of broadband accesses (Table 3.6 in the thesis). Because the broadband evolution in the business market is closer to saturation than the residential market, the market share ratio increases in favour of the residential market.

The adoption rate forecast used in the analysis takes into account the different evolutions of the two markets.

7.2.5 Broadband coverage

The average broadband coverage in Western Europe was 91% at the end of 2004. Most countries had a broadband coverage of 90% or more, but some countries like Greece, Ireland and Norway had a significantly lower broadband deployment. Also in 2005 the broadband accesses have been deployed rather extensively. In Norway the broadband DSL coverage increased from 82,0% to 88,4% at the end of 2005.

Figure 7.5 shows coverage of the Western European countries for DSL and Cable modems as of December 2004.

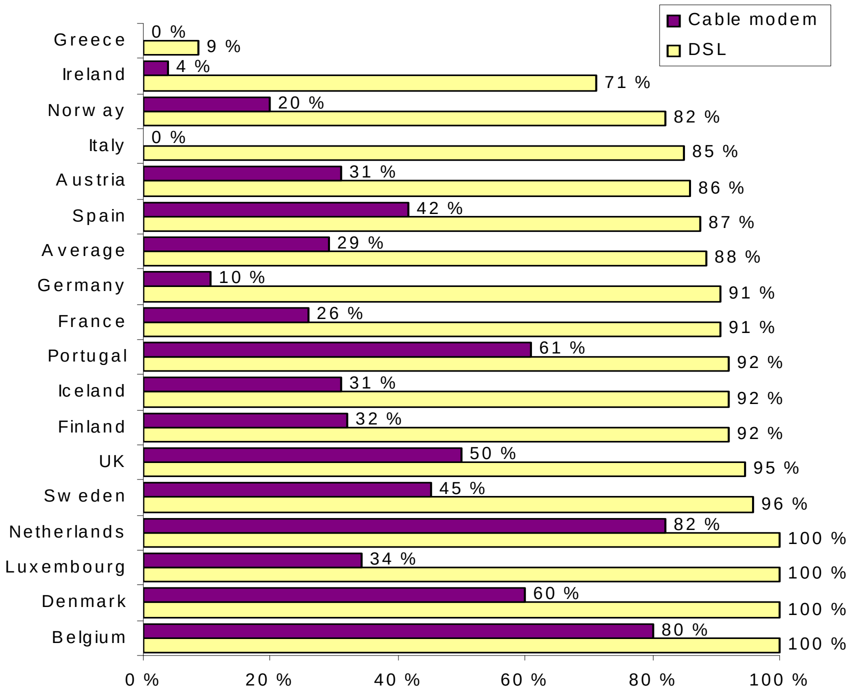


Figure 7.5 Broadband deployments in Western Europe December 2004 [Idate05a]

The rollout plans and the rollout possibilities for different broadband technologies are important factors for the future broadband coverage and for the broadband penetration forecasts.

7.2.6 Adoption rate forecasts

The broadband rollout has a crucial impact on the broadband *penetration*. To evaluate the penetration in Western Europe, the broadband *coverage* in the country must be identified. Assuming the rollout at time t gives the broadband coverage, C_t, and that the penetration at that time is P_t. Then the *Adoption rate*, A_t, is expressed by $A_t = P_t / C_t$. The adoption rate is the genuine demand in an area with 100% supply or coverage.

Hence, the penetration depends on the coverage and the broadband adoption rate, reflecting the genuine demand as a function of the broadband application availability, the broadband tariffs, the service quality, etc.

The penetration forecasts are shown in figure 7.3 and 7.4. The coverage is shown in [Idate05a]. Based on the business and residential market potentials, the penetration forecasts and the coverage, the adoption rate forecasts are calculated.

The adoption rate forecasts express the sum of business and residential accesses per potential subscriber. Potential subscribers in the area are defined as the sum of the households and relevant business units including possible additional business accesses (Business units with more than 20 employees will have more than one potential broadband access).

In the analysis different adoption rate forecasts are used to evaluate the broadband rollout options. Adoption rate forecasts with modest evolution are represented by countries in central Europe while adoption rate forecasts with more aggressive evolution are represented by the Nordic countries. The adoption rate forecasts are reduced because assumption of lower broadband demands in rural than in urban areas. Since information about lower demand in sparsely populated areas is not available, the reduction factor is set to 10% for the central European rollout case and 5% for the Nordic rollout case.

Many business case calculations are based on immediate rollout the first month of the year. The rollout presented here, assumes that the rollout is in the middle of the first year. This is also representative for an operator with a portfolio of rollout projects.

Experiences have shown that it takes time from the DSLAM is installed and the DSL is offered, to the customers have ordered DSL (to the adoption rate demand is reached). The model assumes that the demand gradually increases in a 4 months period until adoption rate is reached.

The adoption rate forecasts for rural areas are shown in figure 7.6 for Central European and the Nordic countries. The adoption rate forecasts are not corrected for entering the area in the middle of the year and the delay in the adoption.

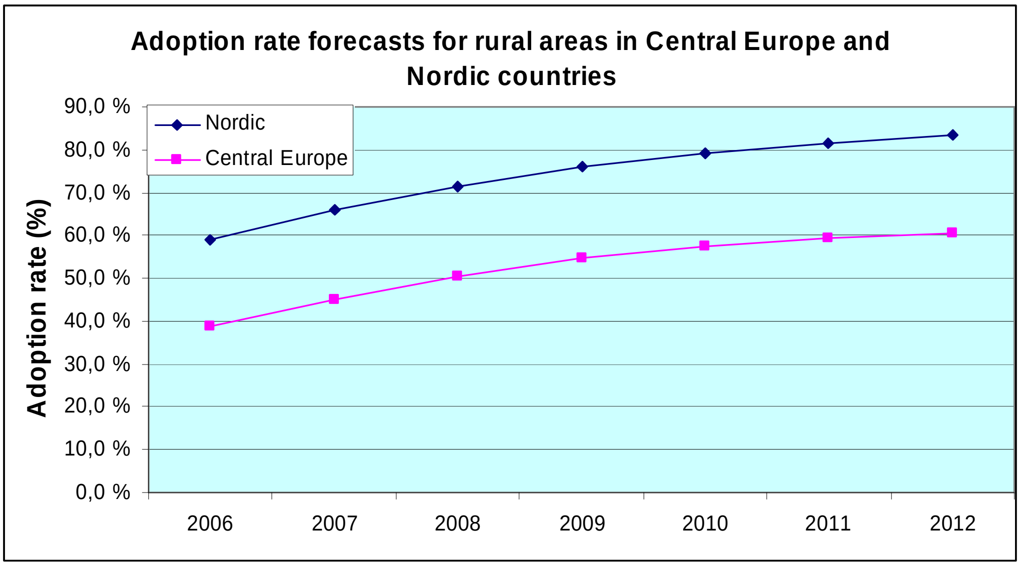


Figure 7.6 Adoption rate forecasts, mixed residential business for rural areas in central Europe and Nordic countries

7.2.7 Business case model

The model describes important characteristics of the access areas. Futhermore, copper loop length distribution, distributions of number of potential subscribers and distributions of market share between residential and business accesses are combined. The techno-economic calculations examine broadband rollout in the different access areas.

The most important factors are copper loop lengths and the number of subscribers in the area.

Areas analysed are assumed to have ADSL coverage of 95% and ADSL2+ coverage of 70%.

The areas analysed are rural with 5% potential business accesses and 95% potential residential accesses. *Potential subscribers* are defined as available subscribers in the long-term.

The reference level for monthly ARPU is set to 40 Euro per month with a 5% reduction the first year. The argumentation for the stable ARPU level is minimal competition and the possibility to offer higher capacities and ADSL2+. The business market contributes marginally to higher

ARPU because of the relatively small proportion of business accesses. The reference level for the connection fee is 30 Euro.

The CAPEX cost elements as follows:

- ADSL2+ line cards
- Mini DSLAM
- DSLAM interface
- DSLAM installation and power
- DSLAM internal cabling
- Backhole costs to DSLAM

The cost predictions are found by using the learning curves [Olsen04].

The OPEX costs is segmented in the following main segments

- IP cost per subscriber
- Network operations cost per subscriber
- Support and billing costs per subscriber
- Sales and marketing costs per subscriber

The discount rate is 10% and the riskfree rate of return is 5%. The investment horizon is 2006 – 2015. The study period could, alternatively have been shorter i.e. 2006 – 2011 with a terminal value. Because of a monopoly situation for the operator with minimal risks, a fairly long study period is acceptable.

7.2.8 Techno-economic calculations

A techno-economic tool is used to calculate the economical value of broadband rollouts. The tool and the techno-economic methodology have been developed by the European programs RACE, ACTS, IST and EUREKA/CELTIC through the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA, IST-2000-25172 TONIC and ECOSYS. The techno-economic methodology and the tool calculate the overall financial budget of any access architecture. The tool handles the discount system costs, operations, maintenance costs, life cycle costs, net present value (NPV) and internal rate of return (IRR). The tool is well suited to combine low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters for performing evaluation of various network architectures. More detailed descriptions of techno-economic modelling and the tool are found in [Ims98].

To evaluate broadband rollout strategies for the residual market, techno-economic analysis uses the generic access area models, broadband adoption rate forecasts and predictions of other important factors like tariffs, component costs, operation and management costs etc

7.2.9 Roll out analysis

The DSL rollout analysis handles two main cases:

- A central European case
- A Nordic case

Central European case

Net present value (NPV) for DSL broadband rollout has been calculated as a function of the number potential subscribers in the area. The calculations have been performed to examine the sensitivity of NPV, when the adoption rate forecasts are changing. Three different alternatives for the adoption rate forecasts are used:

- Pessimistic adoption rate forecasts
- Default adoption rate forecasts
- Optimistic adoption rate forecasts

The default adoption rate forecasts are shown in figure 7.6. The pessimistic adoption rate forecasts ends 10% lower than the default adoption rate forecasts in 2015, while the optimistic adoption rate forecasts end 10% higher in 2015.

The default adoption rate forecasts are close to, but not identical to the Western European mean.

Figure 7.7 shows the results. The results presuppose a monopoly area.

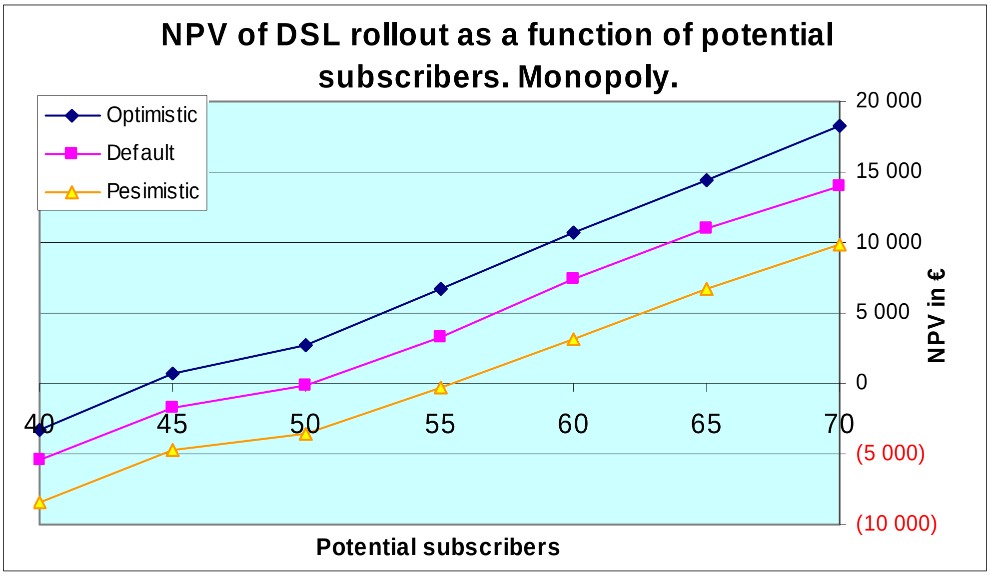


Figure 7.7 NPV of DSL rollout as a function of potential subscribers and different adoption rates. Monopoly. Central European case.

The figure shows that the NPV is positive for the default adoption rate case where there are 50 or more potential subscribers in the area. With a pessimistic adoption rate the critical number of potential subscribers in the area is 55.

Suppose a second operator enters the same areas as operator no 1, but is one year delayed. Then the new operator will loose the initial demand and is only able to fight to get parts of the yearly growth. It is assumed that operator no. 2 takes 20% of the growth the first year and 50% the next years.

Figure 7.8 shows the NPV for operator no 1 in the case when a new operator enters the area one year delayed.

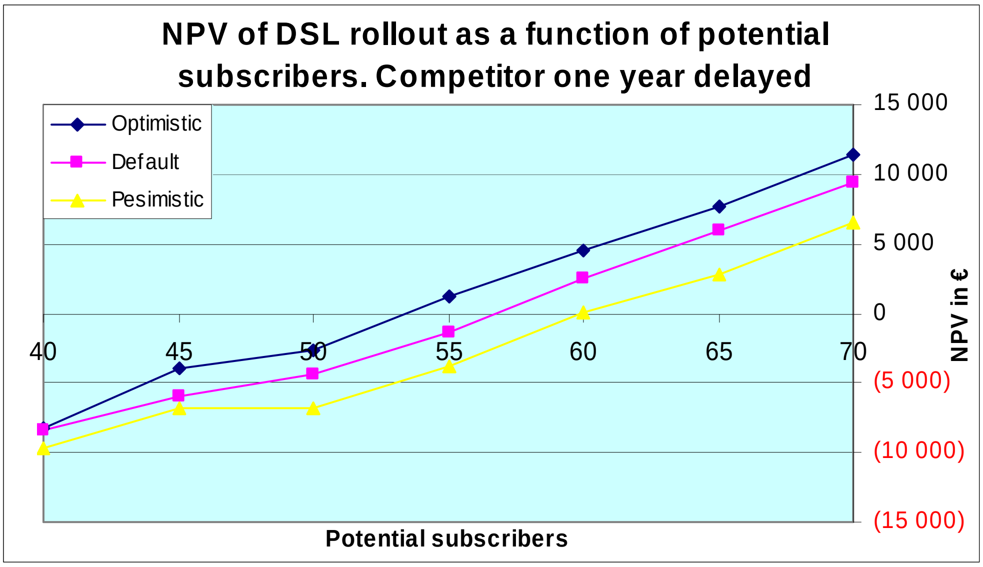


Figure 7.8 NPV of DSL rollout as a function of potential subscribers and different adoption rates. Competitor one year delayed. Central European case.

Because of the new competitor, the critical size for the DSL rollout has changed from 50 to 58. The relevant question is what type of analysis the new operator has done, since the operator will never get a positive business case simply because the operator was too late and had no possibility to utilise the first mover's advantage!

However, the conclusion is that the operator no. 1 has a fairly good business case, independent of entrance of a competitor. The explanation is that the first mover's advantage is utilised before new operators are entering the area.

Figure 7.9 shows how the NPV for DSL rollout in an area with 40 potential subscribers is changing when the value of the main critical variables deviates from their default value.

The vertical line in the figure shows the default values of the critical variables. The NPV is about – 5.000€. A positive NPV require that the monthly ARPU level has to increase from 40€ to 45€. Another option is to find dense areas concentrations where the distance between the exchange and mini DSLAM is not too long, such that the backhaul costs are less than 20.000€.

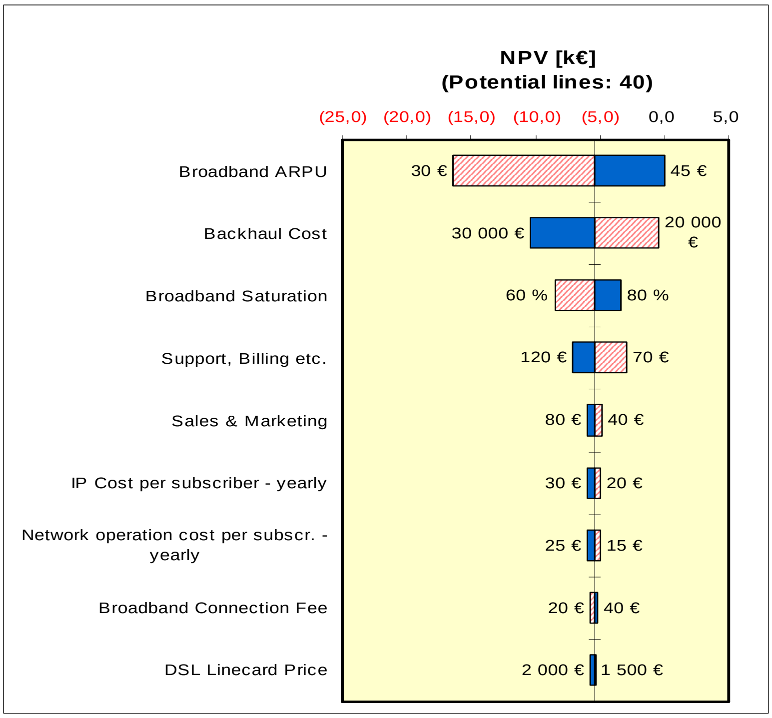


Figure 7.9 Sensitivity analysis. NPV of broadband rollout in an area with 40 potential subscribers. Monopoly area. Central European case.

Figure 7.9 indicates clearly that the ARPU, backhaul costs, broadband adoption and to some extent support/billing are the variables which have the strongest influence on the ARPU.

Figur 7.10 shows the same analysis for an area with 60 potential subscribers.

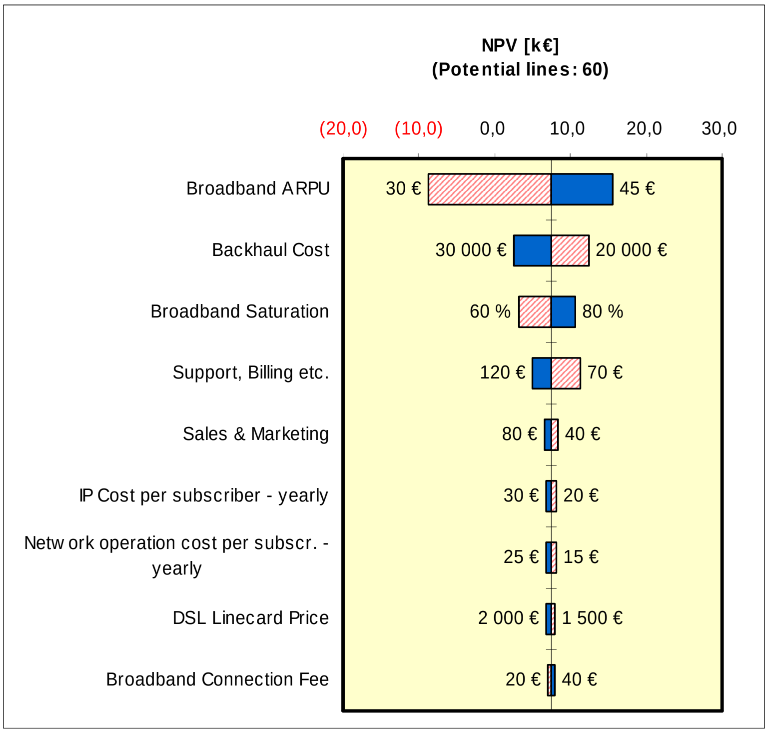


Figure 7.10 Sensitivity analysis. NPV of broadband rollout in an area with 60 potential subscribers. Monopoly area. Central European case.

When the DSL rollout area has 60 potential accesses, the NPV is about 8.000€. Only a very low ARPU may squeeze the NPV below 0. No other variables are significant in this respect.

Nordic case

In some Western European countries the broadband penetration is much higher than the mean West European penetration. Higher penetration will of course improve the rollout business case. The adoption rate forecasts for mixed business residential rural areas are shown in Figure 7.6. The adoption rate forecasts for central Europe starts with 35% EoY 2005, while the Nordic adoption rate forecasts starts with 54% EoY 2005.

The Nordic case is analysed with and without competition. The analysis performed is based on the incumbent point of view. In case of competition, it is assumed that operator no 2 enters one year later than the first one and takes 20% of the growth the first year and 50% of the growth the next years.

Figure 7.11 shows the NPV as a function of the number of potential subscribers in the area.

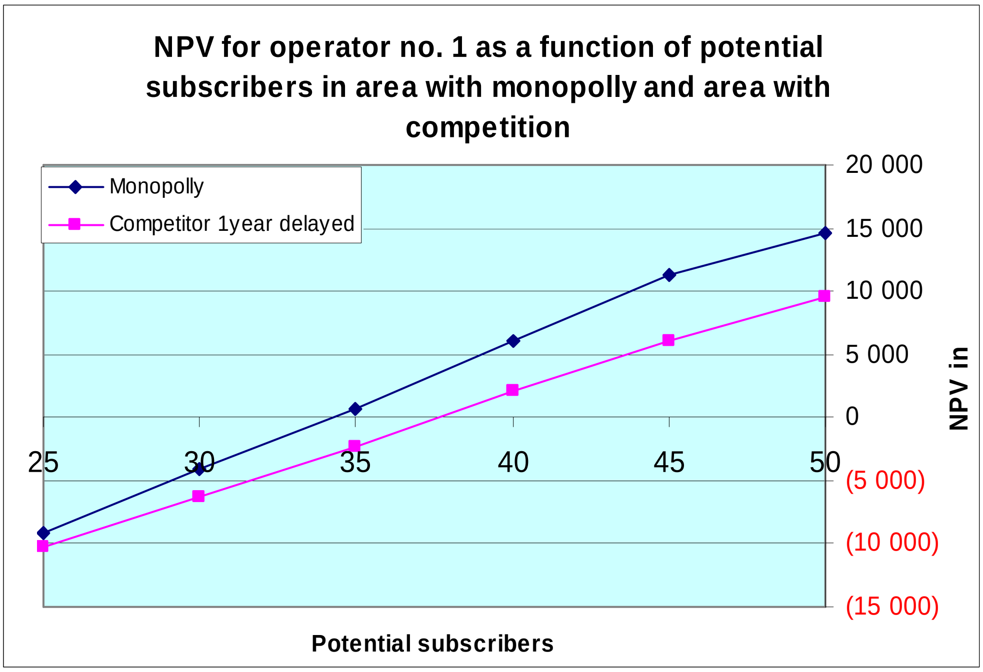


Figure 7.11 NPV as a function of potential subscribers in the area with and without competition. Nordic case.

When the area is a monopoly area, the number of potential subscribers must be 34 or more to reach a positive NPV. If another competitor enters the area one year delayed, the critical size of the areas is 38 potential subscribers. The adoption rate for the Nordic case, see figure 7.6, shows that the adoption rate is increasing slowly from 2007. The yearly growth is not very large in absolute terms. Hence, the loss for operator no 1 by sharing 50% of the yearly growth with operator no. 2 is not a very great loss, compared to the initial gain catching 60% of the potential subscribers during the first year.

The analysis of the Nordic broadband rollout case shows clearly the first mover's advantage. In situations where the adoption rate is very high, it is crucial to roll out broadband before other competitors are entering the areas.

Figure 7.12 shows the results of a sensitivity analysis of the Nordic case with area size of 40 potential subscribers.

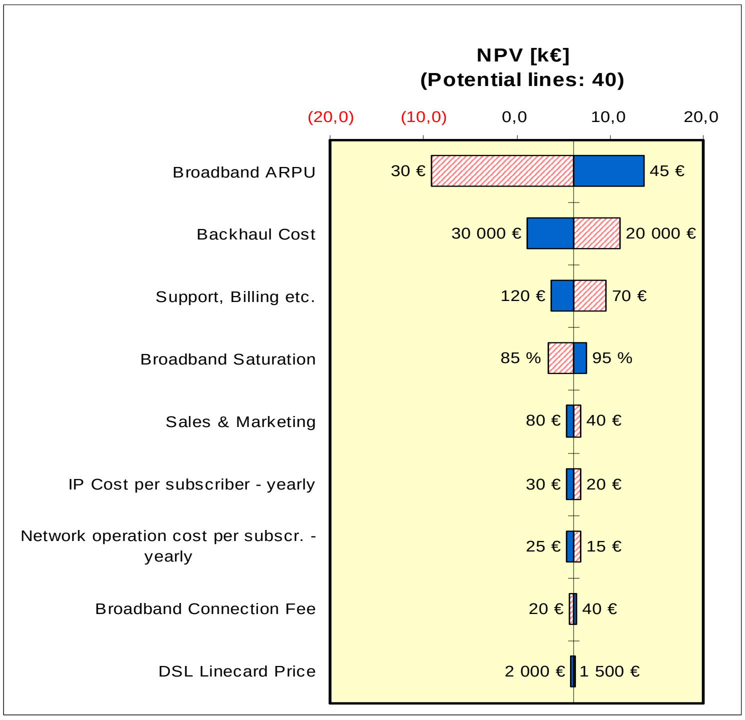


Figure 7.12 Sensitivity analysis. NPV of broadband rollout in an area with 40 potential subscribers. Monopoly area. Nordic case.

The figure shows that only large changes in the ARPU will reject rollout when there are 40 or more potential subscribers in the area.

Figure 7.13 shows the sensitivities in NPV for operator no. 1 when a new operator enters the area one year delayed.

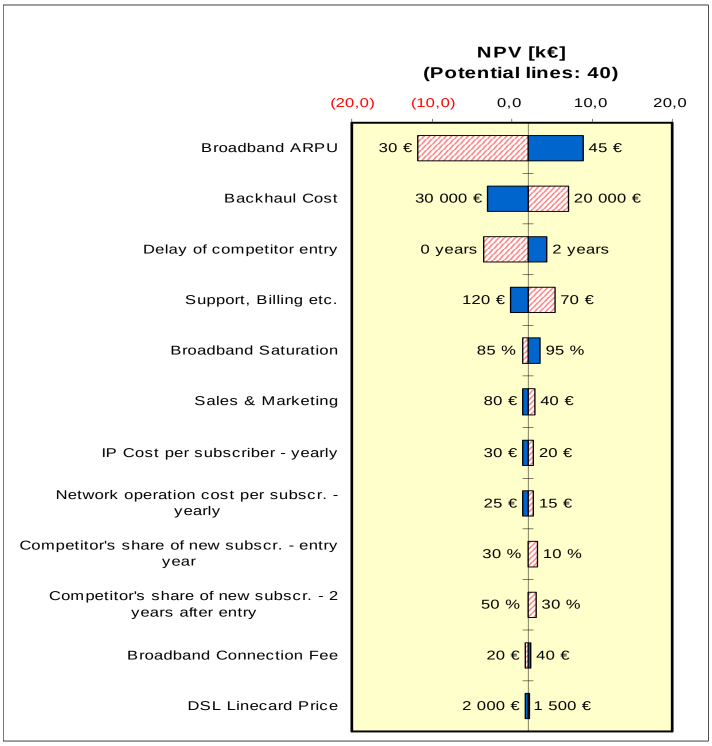


Figure 7.13 Sensitivity analysis. NPV of broadband rollout in an area with 40 potential subscribers. Competition area. Nordic case.

When there is competition in the area, rollout in areas with 40 potential subscribers give a positive net present value. However, changes in the critical variables may change the NPV value to be negative.

7.2.10 Rollout strategies and conclusions

The analysis shows that the most critical variables in the rollout analysis are:

- The size of the area
- ARPU
- Backhaul costs
- Adoption rate forecasts

For the central European monopoly case, the operator reaches positive NPV when number of the potential subscribers in the area is about 50. In case a new operator enters the area one year delayed, the critical value for operator no. 1 is an area size of 58 potential accesses.

The Nordic case has much higher adoption rate than the central European case. The operator who rolls out broadband, needs only to have 34 potential subscribers to get a positive NPV. In case of competition (competitor one year delayed) the critical number of potential subscribers is 38. The very small difference between the critical values with and without competition is caused by the high adoption rate when the rollout starts.

The ARPU is the most uncertain variable; hence it has the strongest influence on NPV. But the ARPU is also the key variable. Since the area is a monopoly, the operator may claim higher ARPU in these sparsely populated areas, arguing that the costs are higher for the broadband rollout. Another option is supplementary financing from the government (The Norwegian case) or from the municipalities. If so, rollout of DSL may occur in even smaller areas.

Only some figures have been presented to show the critical area size for DSL rollouts. There are many combinations of the values of the critical variables, which have not been presented. However, there will only be minor changes in the results if the variables do not deviate from the intervals shown in the figures.

The analysis of the Nordic broadband rollout case shows very clearly the first movers advantage. In situations where the adoption rate is very high and the areas are large, it is crucial to roll out broadband before other competitors enters the area. If not the whole area may be lost.

7.3 Experiences and conclusions

The adoption rate forecasts distinguish between the operator who enter a local area as the first one and operators who enters later. The first operator catches all initial demand, which has been aggregated through many years, while the other operators have to fight to win parts of the growth in the following years.

[Stor04b] shows how adoption rate forecasts are used to roll out ADSL2+/VDSL and presents ADSL2+/VDSL rollout strategy based on a set of analyzed scenarios. The optimal rollout strategy is to start the roll out in large exchange areas, followed by proactive rollouts compared with the other competitors.

[Stor06] documents the profitability of broadband rollouts in sparsely populated areas based on long-term adoption rate forecasts and limits for having monopoly areas as a function of given characteristics.

The two papers show that long-term adoption rate forecasts are crucial for the evelopment of optimal broadband roll out strategies.

8 FORECASTING NEW BROADBAND REVENUE

The telecommunication spending has increased very significantly during the last decade, both in Norway and in Western Europe. The market is willing and has the purchasing power to pay for enhanced and new telecommunications services. Network based broadband and mobile content are in the initial phase. Significant additional revenue may be generated in this area during the coming years.

The following paper is enclosed as part of the thesis:

- Stordahl K, B. Craignou, T Smura, J O Paret, I Welling, K R Renjish, T Monath "Potential new broadband revenue streams", *The 2005 Networking and Electronic Commerce Research Conference*, Lake Garda, Italy, 6-9 October, 2005 [Stor05a]

8.1 "Potential new broadband revenue streams"[Stor05a]

[Stor05a] focuses on the household spending as a basis of new potential telecommunications revenue. The paper shows that the telecommunication spending per household adjusted for inflation has increased significantly during the last years. See Figure 8.1.

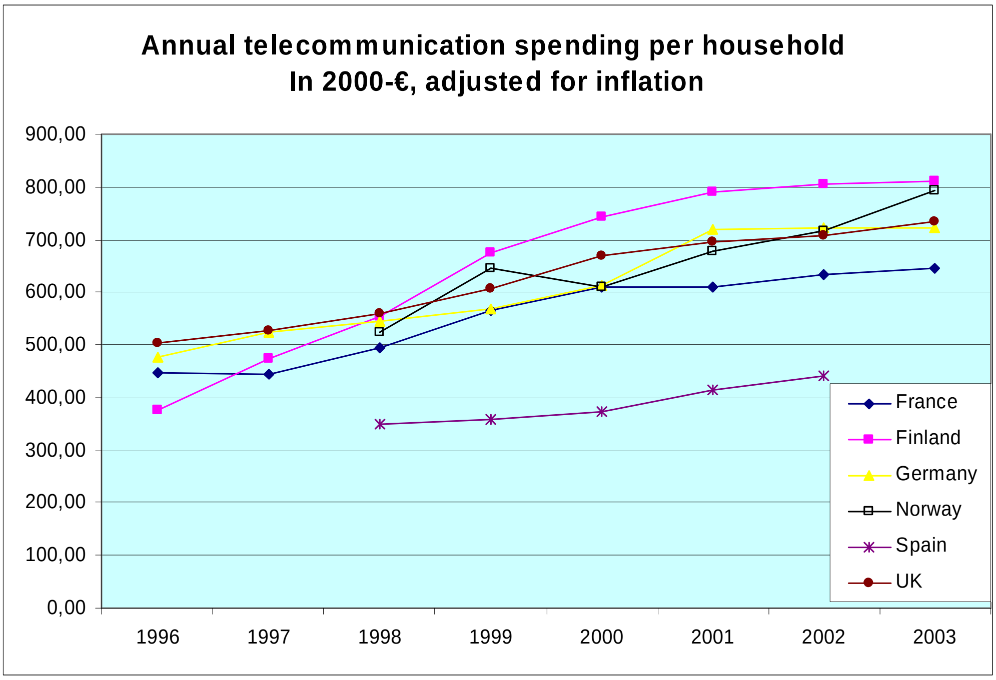


Figure 8.1 Evolution in telecommunication spending, in 2000-€ adjusted for inflation, for selected European countries

Parts of the spending categories may in the long run be substituted by new broadband and mobile services and applications. Relevant spending categories for new revenue streams are: TV, cinema, theatre, concerts, music, books, newspapers, newsletters, journals, gambling, education and learning and gaming. Figure 8.2 shows the evolution in annual spending in Norway. The data is taken from the Norwegian Bureau of Census [SSB05].

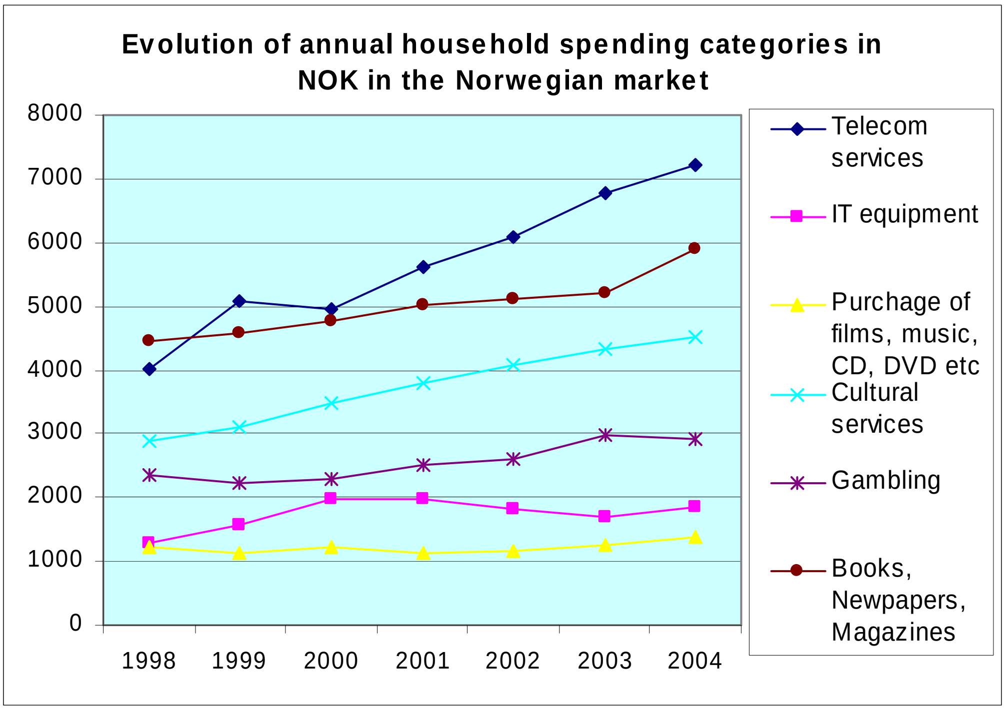


Figure 8.2 Evolution of annual household spending categories in NOK adjusted for inflation, in the Norwegian market 1998 - 2004.

The household spending on almost all the selected categories in the Norwegian market have increased in the period 1998 – 2004. One exception is the relatively constant spending on purchase of films, music, CD, DVD etc. Probably this may be explained by cheap or free downloading of films and music from the network.

The evolution of spending on the selected categories in France, Finland, Germany, Norway, Spain and UK in the period 1998 – 2003 is shown in [Stor05a]. The results indicate that the household spending mainly evolves in the same way in all the selected countries. Since parts of the spending categories are potentials for telecommunications, introduction of new and enhanced services for both mobile and the fixed network may continue to rise the telecommunication spending.

Furthermore, the paper shows how new content services may be classified.

A framework for long-term revenue forecasts based on the substitutions is described. Important elements in the long-term revenue forecasts are:

- The proportion of each spending category which on long-term may be substituted
- The proportion of each spending category which is allocated to broadband/mobile
- The inclusion of a Logistic models, forecasting the substitutions, as a function of time
- The inclusion of a long-term broadband access forecasting model
- The inclusion of a long-term mobile technology forecasting model

Finally, the long-term forecasts for additional broadband and mobile revenue have to be shared between the different players (content creators, content brokers, service providers, operators, etc).

8.2 Experiences and conclusions

The number of households and the spending per household has increased significantly over time and also the spending per household in Western Europe have increased significantly during the period 1998-2003. This is explained by increased purchasing power for households and significantly additional potential for telecommunications.

The analyses show that the telecommunication spending per household has increased with about 33% during the period 1998-2002 for the selected country sample. The results indicate that introduction of new and enhanced services for both mobile and the fixed network may continue to rise the telecommunication spending.

An important area for new telecommunication services is the content services. The analysis show that households are spending significant amount of money on leasing and buying videos and music, pay-TV and TV licenses, on cinema, theatre, concerts, gambling, books, journals, newsletters, newspapers, education and learning, and on-line gaming. The challenge for the operators is to capture parts of these spending, through establishment of new and enhanced telecommunications services and applications.

A general framework for the new revenue streams is established. Long-term broadband and mobile access forecasts are an important part of the framework.

The papers identify large potentials for new telecommunications revenue streams. Even, if a general framework is described, there are many unsolved problems and challenges. The paper should be considered as the very first start of forecasting models in this area.

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ACRONYMS

ACTS	Advanced Communications Technologies and Services
Adoption rate	Proportion between demand and supply.
ADSL	Asymmetric Digital Subscriber Line
ADSL2+	Enhanced Asymmetric Digital Subscriber Line
ARIMA	Autoregressive Integrated Moving Average model
ARMA	Autoregressive Moving Average model
ARPU	Average Revenue Per User
ATM	Asynchronous Transfer Mode
ASTN	Automatic Switched Transport Network
AR	Autoregressive model
BJ	Box Jenkins methods
Busy hour	Travel time
Cable modem	HFC – Hybride Fibre Coax
CAPEX	Capital expenditure
CaTV	Cable Television
CDMA	Code Division Multiple Access
CELTIC	Cooperation for a European sustained Leadership In Telecommunications
DVB-H	Digital Video Broadcasting – Handheld
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM	Dynamic Spectrum Management
DTH	Direct To the Home satellite system
DTT	Digital Terrestrial Television network
DWDM	Dense Wavelength Division Multiplexing
DXX	Digital Cross Connect
EDGE	Enhanced Data for GSM Evolution
EoY	End of year
Extended learning curve	Forecasting model for product and component costs.

model	
ETSI	**European Telecommunication Standards Institute**
FTTB	**Fibre To The Building**
FTTC	**Fibre To The Curb**
FTTH	**Fibre To The Home**
FWA	**Fixed Wireless broadband Access**
GPRS	**General Packet Radio Service**
GSM	**Global System for Mobile communications**
HDSL	**High Bit Rate Digital Subscriber Line**
HDTV	**High Definition Television**
HFC	**Hybrid Fibre Coax**
HSCSD	**High Speed Circuit Switched Data**
HSDPA	**High-Speed Downlink Packet Access**
ICT	**Information and Communication Technology**
IFC	**Installed First Cost**
IP VPN	**IP Virtual Private Network**
IRR	**Internal Rate of Return**
ISDN	**Integrated Service Digital Network**
IST	**Information Society Technologies**
IT	**Information Technology**
ITU	**International Telecommunication Union**
LAN	**Local Area Network**
Learning curve model	**Prediction model for product costs**
Learning curve coefficient	**Parameter in the Learning curve model**
LL	**Leased Lines**
LLU	**Local Loop Unbundling**
LMDS	**Local Multipoint Distribution System**
Monte Carlo simulation	**A procedure for simulating real-world events.**
MP3	**MPEG-1/2 Audio Layer-3**
MPE	**Mean Percentage Error**
MPLS	**Multi Protocol Label Switching**

MVNO	**Mobile Virtual Network Operator**
NMT	**Nordic Mobile Telephone**
NPV	**Net present value**
NxISDN	**Multiple ISDN lines**
OA	**Operator access**
OA&M	**Operation, Administration and Maintenance**
OECD	**Organisation for Economic Co-operation and Development**
OLS	**Ordinary Least Squares**
OPEX	**Operations Expenditure**
OSI	**Open System Interconnection**
OTN	**Optical Transport Network**
P2P	**Peer To Peer**
PON	**Passive Optical Network**
POTS	**Plain Old Telephone Service**
PLC	**Power Line Connection**
PSTN	**Public Service Telephone Network**
QoS	**Quality of Service**
RACE	**Research in Advanced Communications in Europe.**
READSL	**Reach Extended Asymmetric Digital Subscriber Line**
RMSE	**Root Mean Squared Error**
RSS	**Remote Subscriber Stage**
RSU	**Remote Subscriber Unit**
SDH	**Synchronous Digital Hierarchy**
SDSL	**Symmetric Digital Subscriber Line.**
SHDSL	**Single pair High speed Digital Subscriber Line**
SIM	**Subscriber Identity Module**
SLA	**Service Level Agreement**
SMAKS	**SMalbånds AKSess (Norwegian) Narrow band access**
SME	**Small and Medium Enterprises**
SMP	**Significant Market Power**
SMS	**Short Message Service**

Take rate	**Proportion between demand and supply.**
TVoDSL	**TV over DSL**
UMTS	**Universal Mobile Telecommunication System**
VDSL	**Very high speed digital subscriber line**
VOD	**Video On Demand**
VoIP	**Voice over IP**
WAN	**Wide Area Network**
WAP	**Wireless Application Protocol**
WLAN	**Wireless Local Area Network**
Wi-Fi	**Wireless Fidelity**
WiMax/WMAN	**Wireless Metropolitan Area Network**
WWW	**World Wide Web**
xDSL	**(Any) Digital Subscriber Line**

Bruk av ekspertundersøkelser til prognoser for nye teletjenester i privatmarkedet

AV KJELL STORDAHL

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1 Bakgrunn

Det å kunne lage prognoser for en ny teletjeneste er i seg selv problematisk. Det vil være lettere å lage prognoser for en teletjeneste som har vært på markedet en periode. Da vil utformingen og funksjonaliteten til tjenesten være kjent. Kostnadene til investering for utbygging av tjenesten og for drift av tjenesten vil være kjente. Samtidig vil også takstene for tjenesten være gitt, og ut fra dette vil kundene over perioden ha generert abonnements- og trafikketterspørsel.

Når tjenesten er ny og ennå ikke introdusert i markedet, vil ingen av de ovennevnte data være tilgjengelige. Dette gjør at prognostisering for etterspørsel etter tjenesten blir spesielt vanskelig og også usikker.

Tradisjonelle kvantitative prognosemetoder kan derfor ikke benyttes. Isteden må en benytte andre angrepsmåter. Aktuelle kvalitative angrepsmåter/ prognosemetoder er:

- Markedsundersøkelser
- Potensialvurderinger
- Ekspertbedømmelser
- Analogimetoden
- Scenariometoden
- Delphimetoden.

Metodene omtales nærmere i følgende kapittel.

Hvorfor er det viktig å utarbeide prognoser for tjenester som vi ennå ikke har på markedet? I en del tilfeller er det ikke tatt noen beslutning på innføring av tjenesten. Da vil ekspertvurderinger og markedsundersøkelser være et viktig underlag for å kunne anslå det potensielle behovet for tjenesten. Denne type vurderinger er helt nødvendig som en del av et beslutningsgrunnlaget for innføring av en tjeneste.

Ser vi spesielt på privatmarkedet og tjenester som krever stor kapasitet i nettet, vil en prognose for slike tjenester allerede i dag influere på hvorledes abonnentnettet skal bygges. Mange har i lengre tid arbeidet med tekniske løsninger for FTTH (Fiber To The Home), FTTB (Fiber To The Building) og FTTC (Fiber To The Curb). Den fremtidige etterspørsel etter høykapasitets tjenester både til bedriftskunder og privatkunder vil være avgjørende for de nettløsninger som etter hvert skal velges for å tilfredsstille etterspørselen. Gravekostnadene er en vesentlig del av de totale kostnadene i abonnentnettet. Det er derfor svært viktig så tidlig som mulig å ha kjennskap til en sannsynlig utvikling i etterspørselen etter høykapasitetstjenester. Sammen med utnyttelse av ny teknikk – det vil si bruk av optiske nettkomponenter – vil etterspørsel gi grunnlag for nye strukturplaner som nå lages i hvert sentralområde.

I denne artikkelen ses det på resultatene fra en eldre Delphiundersøkelse som ble gjennomført av Televerket midt i 70-årene. Det foretas en vurdering av hvor gode prognosene var og av hvilke erfaringer som en fikk både fra gjennomføringen og fra resultatene fra undersøkelsen. Deretter omtales en ny Delphiundersøkelse som nå gjennomføres av Televerket på det samme markedet – privatmarkedet. I tillegg gis det en oversikt over ulike kvalitative metoder som kan brukes til å lage prognoser.

2 Ulike kvalitative metoder for å utarbeide prognoser

2.1 Markedsundersøkelser

Markedsundersøkelser kan også brukes som underlag for prognoser. Et eksempel på bruk av markedsundersøkelser for å lage prognoser er å spørre aktuelle abonnenter på den nye tjenesten om hva de er villig til å betale for tjenesten. Det kan også stilles et sett med prisspørsmål slik at en kan få estimert en etterspørselskurve som funksjon av prisen. Ut fra forutsetninger om kostnads- og prisutviklingen kan det så ut fra etterspørselskurven lages en prognose for tjenesten.

Markedsundersøkelser kan også brukes til å kartlegge substitutter for en tjeneste. Eksempelvis vil møtevirksomheten i norske bedrifter være et volum som kan være et substitutt for bildetelefon og konferansefjernsyn.

2.2 Potensialvurderinger

Et potensial er det samme som metningsnivået for en tjeneste. Det betyr at det eksempelvis kan være det maksimale antall abonnenter som vil etterspørre en tjeneste.

Anslag for et potensial kan gjøres på ulike måter. Som nevnt i 2.1 kan et potensial finnes ved bruk av markedsundersøkelser. Ved å kartlegge møtevirksomhet i bedrifter finnes et potensial for telemøter fremfor 'face to face' møter.

Anslag for potensialer kan også finnes ved å gå inn i offisiell statistikk. Totalt antall norske husstander vil kunne være et potensial for en gitt teletjeneste – eller det kan være summen av antall leiligheter, bolighus og hytter.

En fremgangsmåte for å lage prognoser ut fra et anslag for potensialet er å benytte metningsmodeller der potensialet eller metningsnivået er en av de fundamentale parametrene i modellen.

2.3 Ekspertbedømmelser

Når det ikke eksisterer data, utviklingstrender eller annen kvantitativ informasjon som underlag for prognosene, vil ekspertbedømmelser være en aktuell metode.

En metode som er velkjent er brainstorming. Det vil si at det innkalles en gruppe eksperter som sitter sammen og inspireres og influeres av hverandre. Resultatene her kommer frem gjennom en forholdsvis ustrukturert prosess.

En annen fremgangsmåte er at en prognoseansvarlig plukker ut et sett med eksperter og at han på en systematisk måte fremlegger problemstillingen gjerne med et sett med gjennomarbeidede spørreskjemaer. Ekspertenes svar vil da være prognosegrunnlaget.

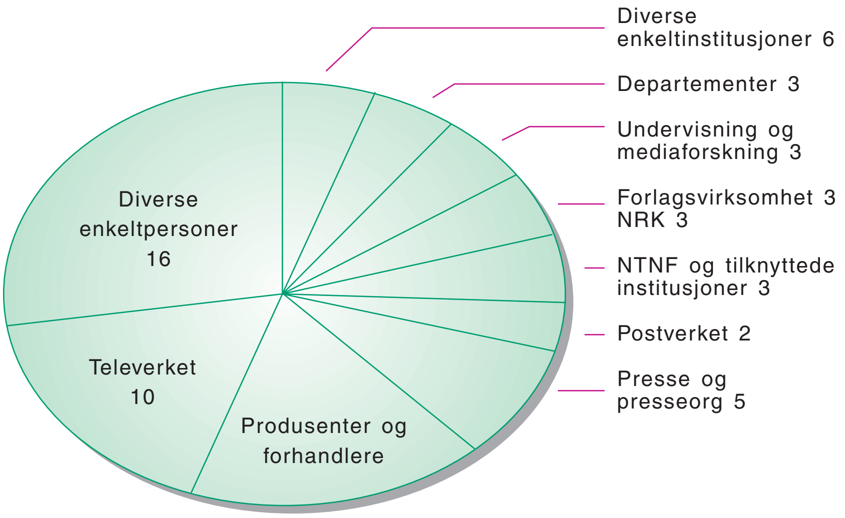
2.4 Analogimetoden

Analogimetoden går ut på å anta at utviklingen for ulike produkter er sammenliknbar eller at utviklingen av like produkter i ulike områder, eksempelvis ulike land, kan være lik, men i forskjellige tidsintervaller.

Dersom det skal lages prognoser for utviklingen av en ny teletjeneste, kan det være naturlig å se på hvorledes utviklingen har vært i et land der denne tjenesten allerede har blitt introdusert. Ved å se på utviklingen av ISDN i Frankrike der tjenesten en periode har vært kommersielt tilgjengelig og anta at utviklingen i Norge vil ha analogt forløp etter kommersiell introdusjon, er det mulig å lage prognoser for ISDN også for Norge. En må imidlertid være varsom med slike avledninger fordi forholdene i de to land som sammenliknes kan være vidt forskjellig – både demografisk, økonomisk og med hensyn til utforming og funksjonalitet av tjenesten.

2.5 Scenariometoden

Metoden går ut på å lage enkeltprognoser, men med en fremstilling av flere variable



Figur 3.1 Deltakernes sammensetning i Delphiundersøkelsen

som gjensidig varierer og som kan påvirke hverandre. Det er en konstruktiv metode som kan benyttes til å avdekke og vurdere nærmere årsakssammenhenger og påvirkninger.

Metoden går ut på å ta utgangspunkt i et spesielt år – eksempelvis 10 år frem i tid. Det skal så lages en forventet beskrivelse av situasjonen dette året. Hvis vi tar utgangspunkt i Televerket, vil det være naturlig å se på Televerkets konkurransesituasjon dette året. Her åpnes det selvsagt for ulike situasjonsbilder, og dette er en av fordelene med scenariometoden. Det er mulig å foreta ulike beskrivelser avhengig av de forutsetninger som legges til grunn. Deretter går metoden ut på å gi en beskrivelse av utviklingen av de tilhørende variable 10 år fremover i tid. Beskrivelsen av denne utviklingen for å komme frem til det gitte fremtidsbilde blir da scenariometodens prognoser.

2.6 Delphimetoden

Delphimetoden er en raffinering av ekspertundersøkelse. Navnet Delphi kommer fra oldtidens Hellas der oraklet ble oppsøkt og hvor det gav prognoser som var mer eller mindre vel funderte.

I Delphimetoden velges det ut et sett med eksperter. En del av ekspertene skal være spesialister innenfor det aktuelle fagområdet, men mange eksperter kan også være spesialister innen andre områder.

Delphimetoden går ut på å gjøre et grundig forarbeid før undersøkelsen foretas. Deretter utformes det et spørreskjema til bruk i undersøkelsen. Aktuelle spørsmål i en Delphiundersøkelse er forventet introduksjonstidspunkt for en ny tjeneste, forventet utvikling av tjenesten og gjerne etterspørsel etter tjenesten som funksjon av pris.

Det sendes så ut spørreskjema til et sett med eksperter. Svarene returneres, hvoretter de behandles på statistisk form slik at enhver vil se hvorledes han har svart i forhold til de øvrige. Disse resultatene sendes så sammen med spørreskjemaet tilbake til hver enkelt ekspert som igjen skal svare på de samme spørsmålene. I tillegg skal det også sendes ut spesielle opplysninger som enkelte av deltakerne har angitt som begrunnelse for sine vurderinger. På denne måten skal ekspertene etter hvert nærme seg en felles oppfatning. Vanligvis vil det være tilstrekkelig å bruke to til tre runder i en Delphiundersøkelse.

I det videre vil det bli sett mer detaljert på Delphiundersøkelser som Televerket har gjennomført.

3 Erfaringer fra tidligere Delphiundersøkelse

3.1 Målsetting og bakgrunn for undersøkelsen

Fra august 1975 til september 1976 gjennomførte Televerkets Forskningsinstitutt i samarbeid med Industrikonsulent A/S en større Delphiundersøkelse. Resultatene er dokumentert i TF-rapport 19/76 "Behovsstudie for nye teletjenester i hjemmene" [1].

Målsettingen med undersøkelsen var å finne grove anslag for den langsiktige etterspørsel etter nye teletjenester for privatmarkedet. Resultatene skulle være et underlag for langtidsplanleggingsarbeidet i Televerket. Med den lange levetiden som nettkomponentene har og ut fra både teknologisk utvikling, økonomisk utvikling og samfunnsutviklingen var det viktig for Televerket å kunne kjenne til markedsutviklingen for nye teletjenester. Langsiktige planer for utbygging av Televerkets infrastruktur var avhengig av denne type prognoser.

I sluttrapporten fra undersøkelsen heter det "Ambisjonsnivået ved de tallmessige og kvalitativt angitte uttrykk for tjenestebehov, har i lys av usikkerheten i problemstillingen ikke vært særlig høy. En har vært inneforstått med at de resultater som fremkom, neppe ville være direkte egnet for drastiske beslutninger om idriftsetting. Undersøkelsen må heller sees på som et første skritt i markedsanalysene og som en læreprosess om hvilke teleanvendelser som kan muliggjøres i fremtiden".

En må også være klar over at undersøkelsen ble gjennomført på en tid da de fleste tjenestene som ble beskrevet i undersøkelsen ikke var kjent eller definert i Televerket. Mange av tjenestene i undersøkelsen ble beskrevet ut fra litteratursøk og ut fra utenlandske – spesielt amerikanske – fagtidsskrifter. På den tiden var det heller ikke noen kjente markedsundersøkelser tilgjengelig internasjonalt for disse nye tjenestene.

Delphiundersøkelsen ble gjennomført blant et sett eksperter – et sett subjektivt utvalgte personer – for å vurdere en rekke nye teletjenester som først var forventet innført i det norske telenettet frem mot århundreskiftet.

I Norge hadde vi på den tiden praktisk talt ingen som arbeidet med markedsanalyser. Vi hadde bare de klassiske tjenestene telefon, teleks, datel og telegram og vi hadde svært lange ventelister på telefonabonnement. Det var ikke noe behov for verken markedsføring eller markedsanalyser for å få økt salget og dermed økt inntektene av tjenestene.

3.2 Gjennomføring av undersøkelsen

Planleggingen av gjennomføringen av Delphiundersøkelsen tok tre måneder. En svært viktig aktivitet i denne perioden var arbeid med definisjon av de aktuelle tjenester og med utforming av selve spørreskjemaet. Det er også på dette punktet Delphiundersøkelsen skiller seg fra en del andre kvalitative undersøkelser. Selve underlaget skal være godt gjennomarbeidet og det som det spørres om, skal være godt definert og strukturert. Dette gjør det enklere for ekspertene å svare på spørsmålene selv om det er kompliserte problemstillinger.

Spørsmål i Delphiundersøkelsen

Eksempler på anvendelser:

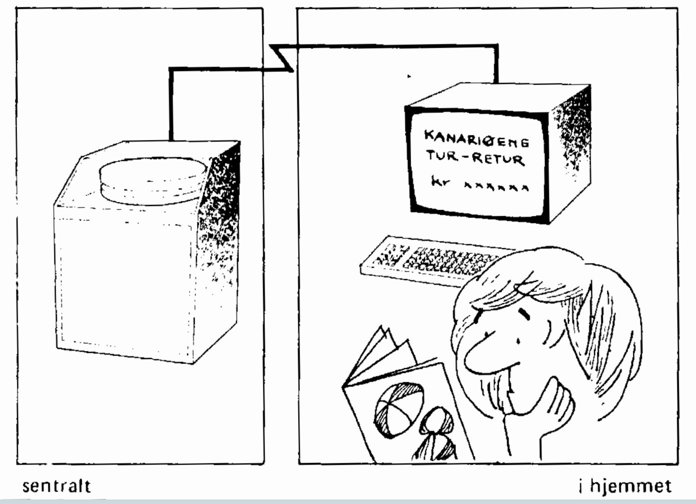
Tekniske forutsetninger:

	Spørsmål	Svar		Kommentar
Ønskelighet	1 Hvordan ser De på ønskeligheten av en slik tjeneste ut fra en samfunnsmessig helhetsvurdering?	Sterkt uønsket Indifferent (likegyldig) Sterkt ønsket ☐ ☐ ☐ ☐ ☐ ☐ ☐ -3 -2 -1 0 1 2 3		
	Ved besvarelse av spørsmål 2, 3, 4 og 5 må man forsøke å tenke seg at disponibel inntekt målt i 1976-kroner er 50 % høyere enn i dag. Videre må spørsmålene ses i sammenheng med hverandre.			
Bruksvolum	2 Hvor mange ganger pr uke tror De en norsk husstand som har anskaffet nødvendig utstyr for tjenesten, vil benytte den?	☐	ganger pr uke	
	3 Hvor mange minutter pr gang tror De tjenesten gjennomsnittlig vil bli anvendt av dem som har anskaffet nødvendig utstyr?	☐	minutter pr gang	
	4 Hvor meget vil de som har anskaffet nødvendig utstyr for tjenesten, akseptere som månedlig utgift for det bruksvolum De har angitt ovenfor (målt i 1976-kroner og anskaffelsesutgiftene holdt utenfor)?	☐	kroner pr måned	
	5 Hvor stor prosentdel av norske husholdninger vil ønske å anskaffe og bruke utstyr for denne tjenesten dersom de må betale det beløp som De har angitt under spørsmål 4?	☐	% av husholdningen	
	Ved besvarelse av spørsmål 6, 7 og 8 må man forsøke å trekke både markedssiden og tilbudssiden inn i vurderingen. De må derfor basere svarene på egne forutsetninger om kostnader, teknologi, priser, markedsforhold, utbyggingstakt, politiske beslutninger, etc.			
Introduksj.	6 Når omtrent tror De tjenesten vil bli introdusert for norske husstander?	Årstall:	☐	
Utbygging	7 Hvor stor andel av de norske husstandene tror De vil være tilbudt tjenesten henholdsvis 5 år og 15 år etter introduksjonen?	Prosentvis andel etter 5 år ☐	Prosentvis andel etter 15 år ☐	
Markedsdekning	8 Hvor stor andel av de husstandene som er tilbudt tjenesten, vil ha anskaffet den henholdsvis 5 år og 15 år etter introduksjonen?	Prosentvis andel etter 5 år ☐	Prosentvis andel etter 15 år ☐	

Figur 3.2 Spørreskjema i Delphiundersøkelsen

Innhenting av informasjon fra databank

Tilgang til tekstinformasjon og stillestående bilde på TV-skjerm. Informasjonen kan være relativt spesialisert, og derfor dekke individuelle og lokale informasjonsbehov. Databanken oppdateres fortløpende, og er tilgjengelig til vilkårlige tidspunkter. "Teleavis på bestilling" er tatt med som egen tjeneste, nr 11.



Eksempler på anvendelser:

- Som tjeneste 5 "Teletekstoverføring på TV-skjerm", men med større datamengder og større individuelle valgmuligheter
- Informasjonsinnhenting, eksempelvis forbrukeropplysninger, juridisk informasjon, etc
- Oversikt over alternative reiseruter
- Varekataloger/vareoversikt
- Oversikt over bibliotektilbud
- Kontoforespørsel

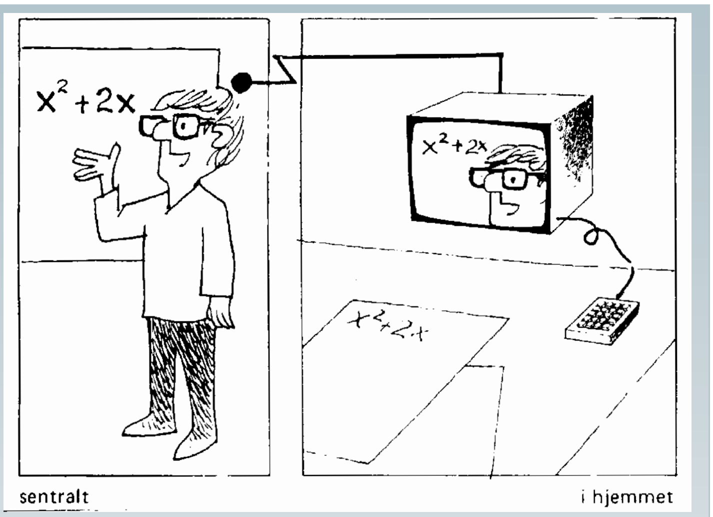
Tekniske forutsetninger:

Bestilling av informasjon skjer ved hjelp av et tastatur og en returkanal (eksempelvis telefonlinje) til databank. Informasjonen kan mottas på TV-skjerm.

Figur 3.3 Innhenting av informasjon fra databank

Teleundervisning med lærer

Tilgang til undervisningsprogram med levende bilde. Undervisningen foregår lokalt til fastsatte tidspunkter, og er basert på forelesninger hvor de hjemmeværende elevene kan gi enkle svar på spørsmål, etc. Elevene kan velge fritt mellom et begrenset antall programmer.



Eksempler på anvendelser:

Kurstilbud innen ulike emner som ikke krever fysisk oppmøte på et undervisningssted.

Tekniske forutsetninger:

TV-apparat og egen undervisningskanal. Samspill mellom lærer og elev ved hjelp av et tastatur og returkanal (eksempelvis telefonlinje).

Figur 3.4 Teleundervisning mot lærer

Deretter ble det arbeidet med å velge ut personer som skulle delta i Delphiundersøkelsen. Totalt ble det sendt ut forespørsel til 123 personer. Det ble lagt vekt på at deltakerne skulle være bredt representert for å kunne dekke flest mulig berøringspunkter mellom samfunn og nye teletjenester i hjemmene. Det skulle altså ikke være noen representativ markedsundersøkelse, men en undersøkelse med deltakelse av en rekke spesialister. Det deltok 54 personer i begge rundene, mens 64 personer deltok enten i første eller andre runde. Sammensetning av deltakerne er vist i figur 3.1

En Delphiundersøkelse gjennomføres vanligvis over to eller tre runder. I denne undersøkelsen ble det vurdert at to runder var tilstrekkelig. Til gjengjeld ble deltakerne invitert til et avsluttende møte hvor sluttresultatene fra runde to ble presentert og hvor det var mulig å komme med utfyllende kommentarer.

3.3 Definerte tjenester

De tjenestene som ble definert i Delphiundersøkelsen, var:

- Flere TV-kanaler – større programtilbud
- TV-program mot særskilt betaling
- TV-program fra programbibliotek
- Videospiller og -opptaker
- Teletekstoverføring på TV-skjerm
- Innhenting av informasjon fra databank
- Selvbetjening over telenettet
- Teleundervisning mot lærer
- Teleundervisning mot datamaskin
- Teleavis på abonnement
- Teleavis på bestilling
- Telepost
- Bildetelefon
- Tele-hjemmearbeid
- Datarespons og telekontroll
- Nye telefontjenester
- Telealarm
- Fjernkontroll
- Radioprogram på bestilling
- Stillbilde telefon.

Det registreres at det her er tjenester som krever både smal- og bredbåndskapasitet.

I Delphiundersøkelsen ble det for hver tjeneste spurt om:

- Ønskelighet for tjenesten
- Hvor ofte og lenge tjenesten ville bli brukt (bruksfrekvens)
- Pris for bruk av tjenesten
- Etterspørsel gitt pris
- Introduksjonstidspunkt for tjenesten
- Etterspørsel hhv 5 og 10 år etter introduksjon
- Utbyggingsgrad hhv 5 og 10 år etter introduksjon.

Figur 3.2 viser hvorledes spørreskjemaet var utformet.

Det var et spørreskjema for hver tjeneste. På spørreskjemaet ble det også gitt en illustrasjon av tjenesten. I tillegg ble det gitt eksempler på hvorledes tjenesten kunne anvendes, og endelig ble det gitt en teknisk beskrivelse av tjenesten.

Figur 3.3 og 3.4 viser hvorledes tjenestene “Innhenting av informasjon fra databank” og “Teleundervisning mot lærer” er illustrert.

3.4 Ønskeligheten av tjenestene

Figur 3.5 angir hvorledes en i 1976 på en skala fra -3 til +3 vurderte samfunnsmessig ønskelighet av de ulike tjenester. Det ses at vanlig TV og telefon, som var tatt med som kontrollspørsmål, lå høyest. Deretter kommer nye telefontjenester, telealarm og teleundervisning mot lærer og først deretter flere TV-kanaler. Alle tjenestene, unntatt teleavis som lå på rundt 0, får en positiv vurdering.

Det ble parallelt i prosjektet foretatt en markedsundersøkelse blant vanlige husstander. På spørsmål om ønskelighet for et utvalg av tjenestene, var den vanlige bruker noe mer tilbakeholden enn ekspertene.

Hvorledes ønskeligheten for disse tjenestene er i dag, er ikke så lett å svare på, men det er grunn til å tro at den ut fra forholdet mellom tjenestene ikke er så forskjellig.

3.5 Bruk av tjenestene

På grunnlag av spørsmål om forventet bruksfrekvens og brukslengde var det mulig å beregne gjennomsnittlig tidsforbruk på enkelte tjenester. Det forutsettes ikke her at en abonnent abonnerer på samtlige tjenester. Resultatet av beregningen er vist i figur 3.6.

Tidsforbruket som er angitt er relatert til en husstand. I 1976 var det gjennomsnittlig 2.9 personer i en husstand. Dette tallet er nå betraktelig lavere – noe som ut fra en 1993 betraktning vil redusere på det angitte tidsforbruk.

3.6 Introduksjonstidspunkt for tjenestene

Et av de mest interessante spørsmålene i undersøkelsen var introduksjonstidspunkt for de ulike tjenester. Resultatene fra undersøkelsen er angitt i figur 3.7.

I figuren er det oppgitt median og kvartiler. Dette er en vanlig fremstillingsform i Delphiundersøkelser. Årsaken til at det vanligvis brukes median og kvartiler fremfor gjennomsnittsverdi og standardavvik er at spesielt grove misforståelser og feilvurderinger kan føre til kvantifiserte svar som kan påvirke en gjennomsnittsverdi betraktelig. En median som er det samme som midtobservasjonen, er robust i forhold til slike outliere. Det samme er kvartilene som er det samme som 25 prosent- og 75 prosentpersentilen. Det ses av figuren at det er disse kvartilene som brukes. Det betyr at 50 % av alle svarene ligger mellom 25 % og 75 % persentilen som i en Delphiundersøkelse kan betraktes som et konfidensintervall.

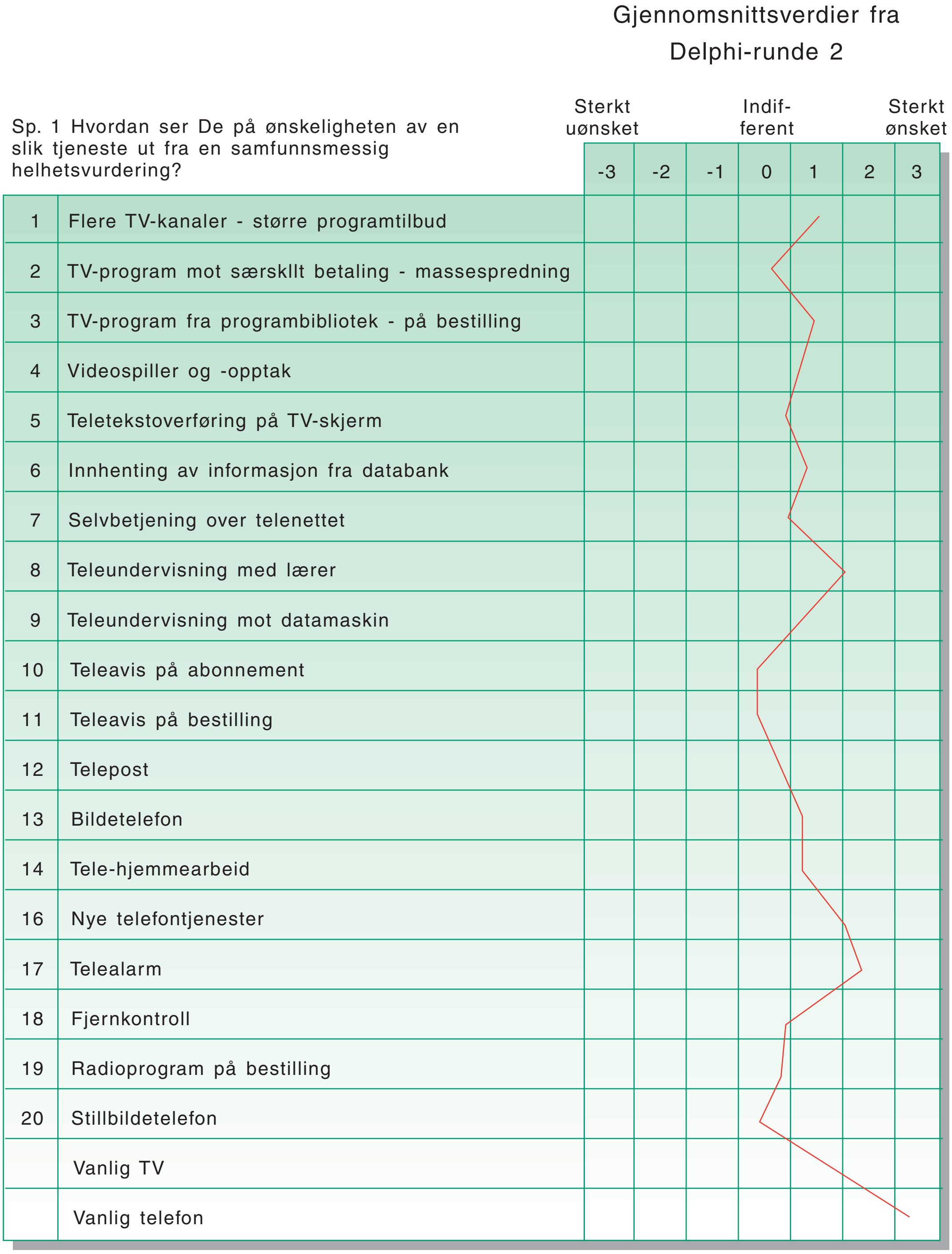
Flere TV-kanaler – større programtilbud
Det har vært en kontinuerlig utvikling på dette feltet. Kabelfjernsynsnettene har med sine store antenner tatt inn et stadig større programtilbud. Prisen på parabolantenner for den enkelte bruker har gått ned, noe som førte til en stadig større etterspørsel i 80-årene. På slutten av 80-årene ble også de første kringkastingssatellittene skutt opp, hvilket betinger enda mindre diameter på parabolantennene.

TV-program mot særskilt betaling
Innført i 1985. Kryptering og adgangskontroll blir nå i stigende grad benyttet.

TV-program fra programbibliotek
Er ennå ikke realisert.

Teletekstoverføring på TV-skjerm
Denne tjenesten ble kalt tekst-TV og kom omtrent midt på 80-tallet.

Innhenting av informasjon fra databank
Denne tjenesten ble kalt teledata. Etter en lengre prøveperiode ble den kommersiell et stykke ut på 80-tallet.



Figur 3.5 Ønskelighet for teletjenestene

Selvbetjening over telenettet
Tjenesten ble definert ved at en ut fra stillbildeinformasjon skal kunne foreta bestillinger. Vi har siden starten på 80-tallet hatt elektronisk betalingsformidling. Dette har imidlertid ikke vært fra betalingsterminaler i hjemmet. Slike transaksjoner kan nå gjøres ved postdata. Her er det ikke inkludert levende bilde. I Delphiundersøkelsen antas introduksjonstidspunkt mellom 1990 og 2000. En mer avansert tjeneste basert på sekvenser av levende bilde er nå under utredning. Den krever imidlertid et mer avansert nett enn det vi har i dag.

Teleundervisning mot lærer
Tjenesten har vært i utprøving i lang tid og må kunne sies å være introdusert.

Teleundervisning mot datamaskin
Denne tjenesten krever kun PC og datatilknytning og har i lengre tid vært realiserbar på datanettene. Datex ble innført i 1980 og datapak i 1985. Prisen vil i 1994 gå kraftig ned ved introduksjon av ISDN.

Teleavis på abonnement
Forløpig ikke realisert.

Teleavis på bestilling (spesialisert stoff fra flere aviser etter eget ønske)
Foreløpig ikke realisert.

Telepost
Har i prinsippet hatt tjenesten i mange år. Nå begynner tjenesten å bli attraktiv for hjemmene fordi faksmaskinene har sunket i pris og fordi ISDN gir mulighet for flere tilknytninger på samme nummer.

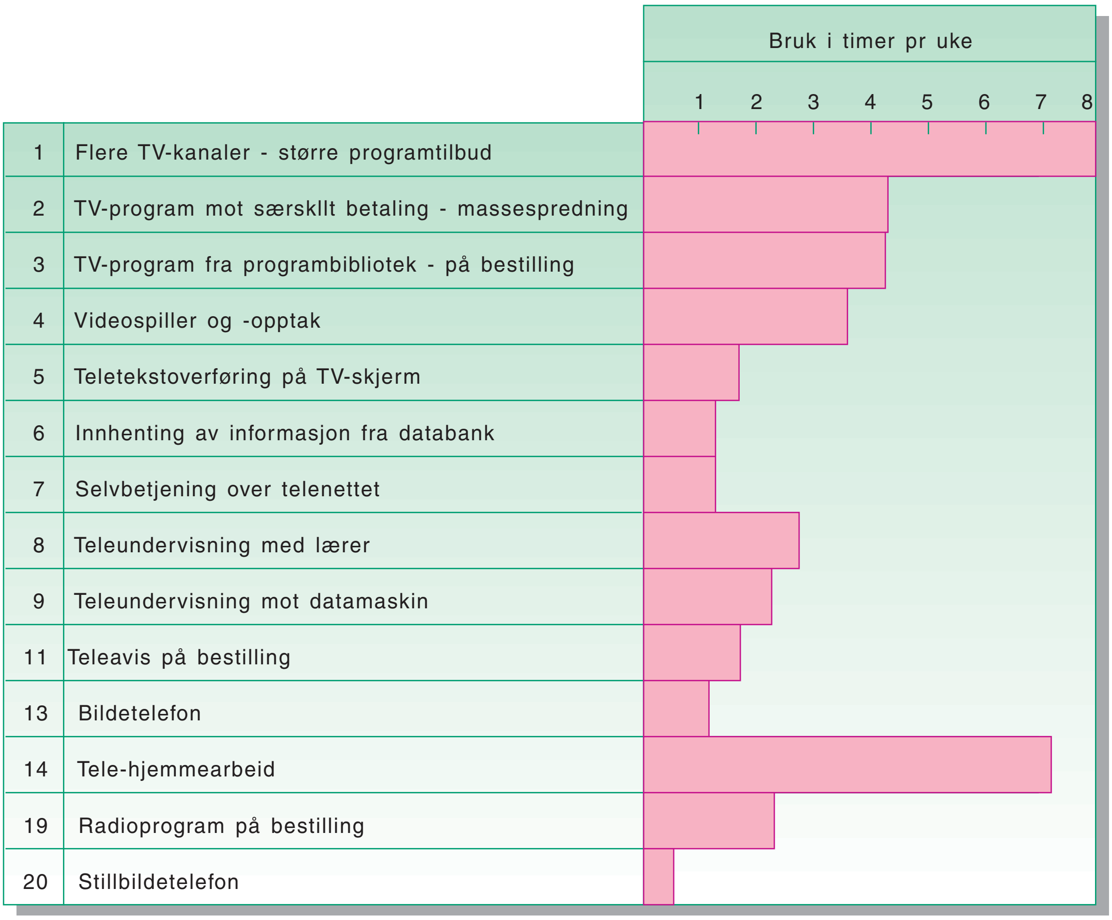
Bildetelefon
Kommersielt tilgjengelig i 1994 ved innføring av ISDN.

Telehjemmearbeid (Fjernarbeid)
Har vært tilgjengelig etter innføring av datanettene på første halvdel av 80-tallet.

Telealarm
Tilgjengelig fra 1980.

Fjernkontroll
Tjenesten har ikke noe med telenettets funksjonalitet å gjøre. Ble forholdsvis tidlig mulig ved bruk av telenettet.

Radioprogram på bestilling
Ennå ikke realisert.



Figur 3.6 Tidsforbruk for ulike tjenester

Stillbildetelefon
Dette navnet brukes ikke. Men funksjonen er fullt realiserbar eksempelvis i ISDN, som har vært i prøvedrift i flere år og som kommersielt innføres i 1994.

Resultatene fra Delphiundersøkelsen når det gjelder introduksjonsår, må sies å være overraskende bra, når det tas hensyn til at denne undersøkelsen ble utført i 1976 med det utgangspunktet en hadde på den tiden.

3.7 Utbyggingsgrad og etterspørsel

Vanligvis vil vi ha en prøveperiode i tilknytning til innføring av en ny tjeneste. Deretter settes den i kommersiell drift. Et godt eksempel på dette er ISDN som er et nett som muliggjør nye tjenester. Det har nå i lengre tid vært i prøvedrift. Et utsagn om når en tjeneste introduseres kan derfor tolkes på flere måter.

På figur 3.8 til 3.15 er det vist hvorledes ekspertene for et utvalg av tjenestene i Delphiundersøkelsen vurderte utviklingen av etterspørselen (markedsdekning) og utbyggingsgraden etter introduksjon av respektive tjenester.

Flere TV-kanaler – større programtilbud ble i Delphiundersøkelsen definert som mulighet til å få tilgang til utenlandske sendinger samt et eventuelt norsk TV2. Det med å ta inn utenlandske sendinger dekkes nå opp av kabelfjernsynsnettene samt med de som har egne parabolantenner. For øvrig vil vi nå om kort tid ha praktisk talt full dekning for et norsk TV2. Figur 3.8 gir en god beskrivelse av denne utviklingen.

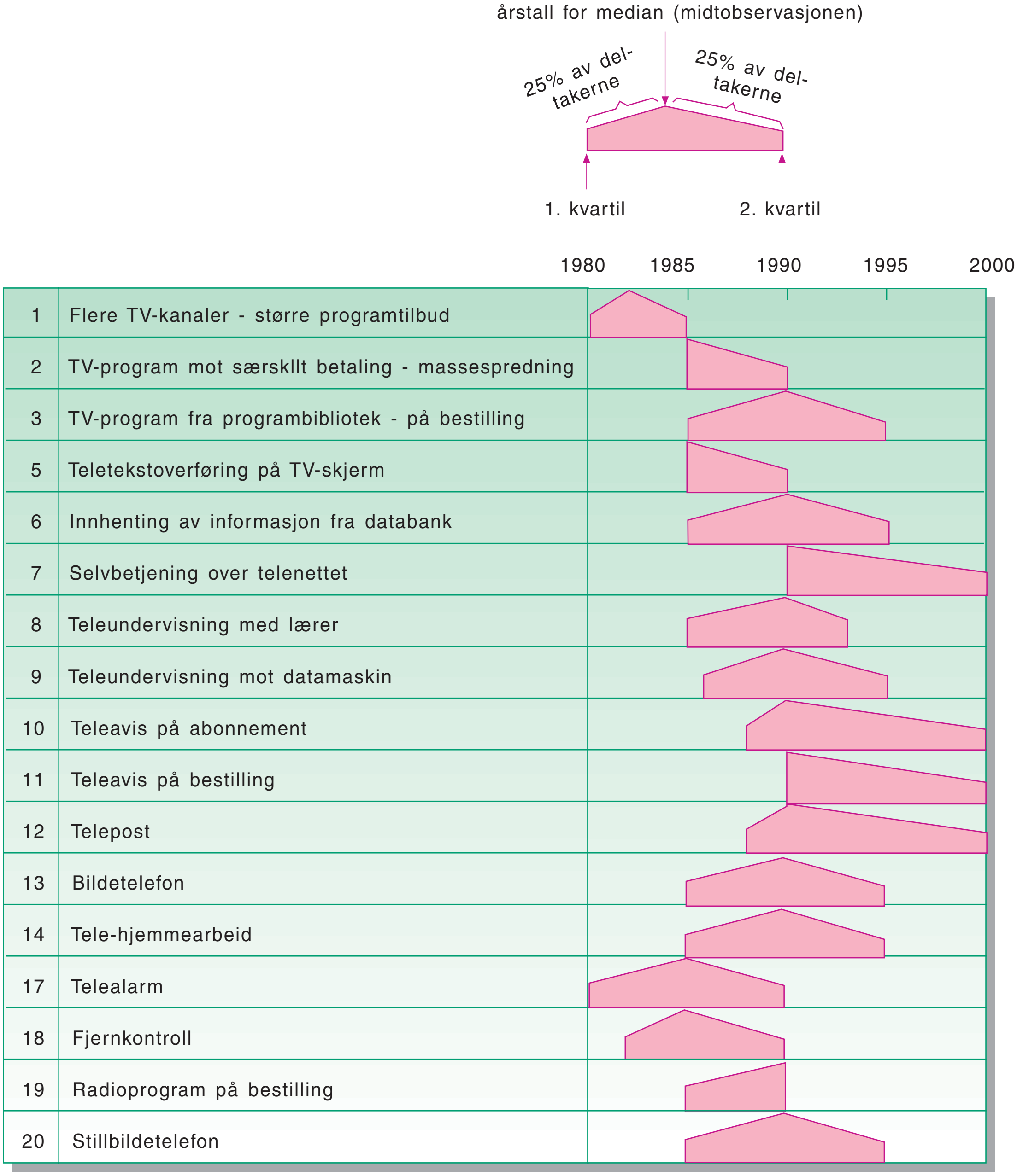
Så langt har vi ikke noe tilbud på TV-program fra programbibliotek eller video on demand, som tjenesten også kalles. Det finnes imidlertid tekniske løsninger ved bruk av IN-noden som muliggjør tjenesten. I USA er tjenesten på forsøksstadiet. Anslagene i figur 3.9 er derfor noe optimistiske.

Innhenting av informasjon fra databank kom relativt tidlig til Norge. Ideen ble hentet fra Prestel-tjenesten i England. Tjenesten fikk navnet Teledata og forsøk ble startet tidlig på 80-tallet. Tjenesten var basert på en kombinasjon av bruk av telefon og fjernsynsskjerm. Denne tjenesten tok imidlertid aldri skikkelig av. Vi har imidlertid i dag teletorgtjenester som gir ekspertinformasjon muntlig og vi har datatorget som blant annet tilbyr næringslivsinformasjon, offentlig registre, elektronisk telefonkatalog, databaser, etc.

Televerket drev de siste år på 80-tallet forsøksvirksomhet med teleundervisning med lærer. Utprøving av tjenesten fortsetter også i samarbeid med andre institusjoner. Det ses også på undervisningsformer i desentrale “studioer”. Ved kommersiell introduksjon av ISDN i 1994 vil tekniske muligheter for å få lyd-, data- og bildeforbindelse til en lærer være mulig. Dette krever en ISDN grunntilknytning samt et opplegg med lærer. Figur 3.11 gir en god beskrivelse av utviklingen. Vi vil imidlertid raskere komme opp i 100 % utbyggingsgrad.

Alle er kjent med den svært raske utviklingen i etterspørsel etter og bruk av faks i næringslivet. Det vil etter hvert skje en parallell utvikling i privatmarkedet som så vidt har startet opp. Muligheten til å bruke faksmaskin hjemme kom tidligere enn det som er angitt på figur 3.12, men start av en signifikant etterspørsel har det ikke vært tidligere. Nettet har imidlertid generelt vært utbygd slik at vi i lengre tid har hatt 100 % utbyggingsgrad.

Som nevnt blir ISDN etter en pilotfase på noen år kommersielt tilgjengelig i 1994. På forholdsvis kort tid vil infrastrukturen bli bygget ut slik at alle som ønsker ISDN skal kunne få abonnement. Det betyr at også bildetelefon blir tilgjengelig. Figur 3.13 treffer rimelig godt på denne utviklingen. Utbyggingsgraden vil raskt gå opp i 100 %, men det er grunn til å tro at etterspørselen de første årene før masseproduksjon av bildetelefon vil være noe lavere.



Figur 3.7 Introduksjonsår – median og kvartiler for tjenestene

Det kan være vanskelig med noen entydig definisjon av hvilke tekniske og kommunikasjonsmessige krav som stilles for at arbeid i hjemmet skal kunne defineres som fjernarbeid. Ulike arbeidsfunksjoner vil eksempelvis kreve ulike typer tjenester. Derfor er det også vanskelig å vurdere kurvene i figur 3.14. I Delphiundersøkelsen ble telehjemmearbeid (fjernarbeid) definert som arbeidsplass med mulighet for overføring av tekst, lyd og stillestående bilde. Ved introduksjon av ISDN i 1994 vil vi få mer avanserte muligheter til en forholdsvis akseptabel pris.

Nye telefontjenester ble i Delphiundersøkelsen definert som en pakke med tjenester som blant annet inneholdt kortnummervalg, ventekopling, medflytting og viderekopling i tillegg til et knappsatsapparat. Figur 3.15 gir en god beskrivelse av utviklingen. Tjenestene kom med den første 10C sentralen som ble installert i 1976. Etter en forsiktig startfase har det vært en jevn utvikling av disse tjenester ved innføring av 10C sentraler og digitale sentraler og ved bruk av CHATS utstyr.

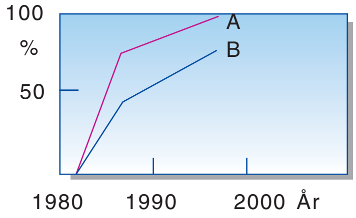
3.8 Evaluering av resultatene fra Delphiundersøkelsen

Alt i alt må det sies at de prognosene som ble laget, har vært gode og kanskje bemerkelsesverdig gode når det tas hensyn til på hvilket tidspunkt prognosene ble laget og de forutsetninger og den bakgrunnsinformasjon som en hadde på den tiden. Det var tross alt i en periode hvor Televerket kun hadde tjenestene telefon, teleks, datel og telegram og samtidig ingen markedsaktiviteter. Storparten av tjenestene ble definert og beskrevet i prosjektet, da denne type informasjon ikke var kjent i Norge.

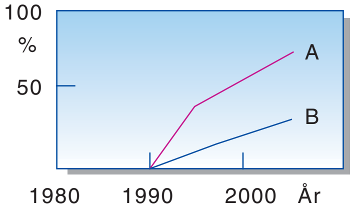
4 Delphiundersøkelse i TITAN-prosjektet

4.1 TITAN-prosjektet

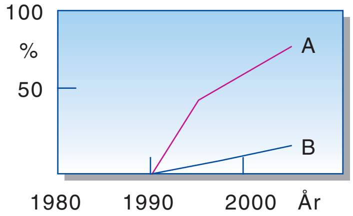
TITAN-prosjektet er et RACE-prosjekt [3]. Målsettingen med prosjektet er å utviklet et verktøy for å beregne utbyggingskostnader i abonnentnettet basert på innføring og bruk av ny teknologi i form av optiske nettkomponenter. Som underlag er det nødvendig å gå igjennom og vurdere ulike nettarkitekturer – både nåværende basert på eldre teknologi som et referansegrunnlag og ny arkitektur ved bruk av optiske nettkomponenter.



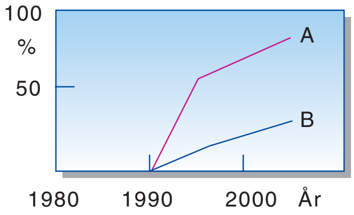
Figur 3.8 Flere TV-kanaler – større progamtilbud
A: Utbyggingsgrad,
B: Etterspørsel



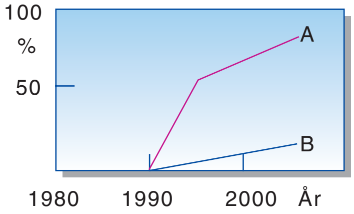
Figur 3.9 TV-program fra programbibliotek
A: Utbyggingsgrad,
B: Etterspørsel



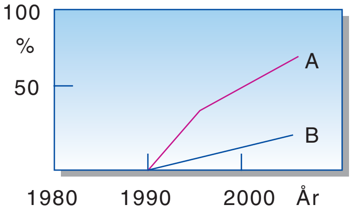
Figur 3.10 Innhenting av informasjon fra databank
A: Utbyggingsgrad,
B: Etterspørsel



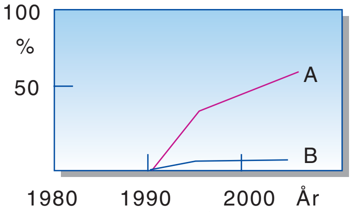
Figur 3.11 Teleundervisning mot lærer
A: Utbyggingsgrad,
B: Etterspørsel



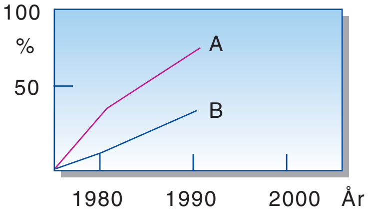
Figur 3.12 Telepost
A: Utbyggingsgrad,
B: Etterspørsel



Figur 3.13 Bildetelefon
A: Utbyggingsgrad,
B: Etterspørsel



Figur 3.14 Telehjemmearbeid (Fjernarbeid)
A: Utbyggingsgrad,
B: Etterspørsel



Figur 3.15 Nye telefontjenester
A: Utbyggingsgrad,
B: Etterspørsel

I prosjektet bygges det også opp en database med priser og prisutvikling for aktuelle nettkomponenter. Ut fra denne databasen lages det også prognoser for fremtidige priser på nettkomponentene [2].

For å kunne vurdere ulike arkitekturer og utbyggingsstrategi og utbyggingsvolum er det helt nødvendig å ha kjennskap til de tjenester og applikasjoner som vil bli etterspurt og til hvor stor etterspørselen vil være. Med andre ord, det må lages prognoser for etterspørsel etter de ulike tjenestene. I TITAN-prosjektet har en kun mandat for å lage prognoser for privatmarkedet. Dette er for hver enkelt tjeneste gjort ved bruk av potensialbetraktninger og metningsmodeller, og det er gjort ved bruk av en Delphiundersøkelse. Det er den siste undersøkelsen som vil bli omtalt her.

4.2 Delphiundersøkelse

Delphiundersøkelsen gjennomføres nå ved at det er sendt ut 100 spørreskjemaer til 10 eksperter i hver av de 10 deltakende landene i TITAN-prosjektet. I denne artikkelen trekkes ikke de nye resultatene frem, men det ses isteden på den angrepsmåten som er benyttet, samtidig som det er naturlig å sammelikne de to Delphiundersøkelsene fra henholdsvis 1976 og 1993.

Spørreskjemaet i Delphiundersøkelsen består av:

- Generell informasjon om undersøkelsen
- Tekniske forutsetninger og opplysninger
- Økonomiske forutsetninger og opplysninger
- Oversikt over de ulike tjenestene
- Selve spørreskjemaene – ett skjema for hver tjeneste.

De tjenestene som på sikt er aktuelle for privatmarkedet og som er definert i prosjektet, er følgende:

- Teleinteraksjon, underholdning
  - Video on demand
  - Multimedia telespill
  - Bildetelefon
  - Telemedisin
- Telekjøp, elektronisk marked
  - Vare- og billettbestilling
  - Avertering og marketing
- Temakanaler og informasjon
  - Interaktivt TV og spesialiserte kanaler
  - Elektronisk avis
- Fjernarbeid og fjernundervisning
  - Fjernarbeid – enkelt kontor
  - Fjernarbeid – avansert kontor
  - Fjernundervisning i hjemmet
  - Fjernundervisning i studio

Et meget avgjørende punkt med hensyn til kostnader er den kapasiteten som tjenestene vil kreve. Det er delt opp i følgende aktuelle hastighetsklasser:

- 64 kbit/s
- 2 Mbit/s (Vidbånd)
- 8 Mbit/s (Bredbånd).

Det forventes at også høykvalitetsfjernsyn på sikt ved bruk av optimal koding skal kunne overføres på 8 Mbit/s.

I TITAN-prosjektet ble det foretatt beregninger for de investeringer som må gjøres ut fra etablering av tilpasset nettarkitektur og ut fra antakelse om en gitt fyllingsgrad, om avskrivningstid på investeringskostnader, om driftsutgifter og om et gitt overskudd. Deretter ble det formulert spørsmål om betalingsvillighet basert på prisintervaller der det også tas hensyn til prognostisert prisnedgang på sikt.

I figur 4.1 er det som eksempel vist hvorledes en tjeneste beskrives i Delphiundersøkelsen. Det er her tatt utgangspunkt i video on demand. Først er det gitt en generell beskrivelse av tjenesten. Deretter informeres det om de tekniske forutsetningene på en forholdsvis ukomplisert måte. Her skilles det mellom vidbånd og bredbånd. Stort sett kan de ulike tjenestene overføres på begge hastighetsklasser. Det vil hovedsakelig være kvaliteten som endres.

Deretter gis det en illustrasjon av tjenesten og til slutt noen eksempler på bruk av tjenesten.

Deretter kommer det en rekke spørsmål om hver tjeneste. Disse spørsmål er for enkelthets skyld nesten identiske for hver tjeneste. Spørsmålene er som følger:

- Angivelse av grunner for bruk av tjenesten
- Karakteristikk av typiske brukere av tjenesten
- Angivelse av forventet etterspørsel som funksjon av prisalternativer
- Angivelse av forventet etterspørsel som funksjon av tiden
- Anslag for hvor stor andel av disponibel inntekt en husholdning er villig til å betale for tjenesten som funksjon av husholdningens disponible inntekt
- Angivelse for alternativer til bruk av tjenesten.

Det er også skilt på vidbånds- og bredbåndskvalitet på tjenestene.

For øvrig er det gitt mulighet for å kunne gi spesielle kommentarer og argumentasjon i tilknytning til de enkelte spørsmål. I figur 4.2 er det gitt et eksempel på et utsnitt av spørsmålene for video on demand tjenesten.

Til slutt i spørreskjemaet er det også laget “samlespørsmål” som kartlegger etterspørsel for den enkelte hastighetsklasse: 64 kbit/s, 2 Mbit/s og 8 Mbit/s.

4.3 Bruk av resultatene i TITAN-prosjektet

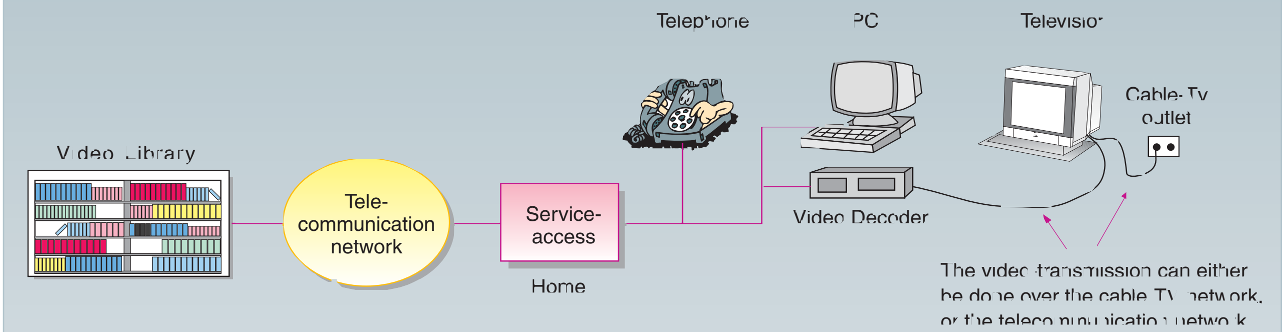
I Delphiundersøkelsen kartlegges etterspørselen etter de ulike tjenestene som en funksjon av pris. Samtidig finnes det også en direkte prognose for tjenestene for årene 1995, 2000, 2005 og 2010. Et metningsnivå for tjenestene angis også. I denne sammenheng er prognosespørsmålet det mest kompliserte å svare på. Det blir derfor lagt mest vekt på hva ekspertene mener de enkelte abonnenter er villig til å betale for tjenesten

I figur 4.3 og figur 4.4 er det gitt et eksempel på hvorledes resultater fra undersøkelsen kan brukes. Dette er foreløpige resultater fra først runde i Delphiundersøkelsen, og de er kun basert på 10 norske eksperter og kan i denne sammenheng ikke betraktes som signifikante resultater. De er imidlertid tatt med for å illustrere metodikken med bruk av denne type resultater. Tjenesten som er valgt ut her er video on demand.

Når det gjelder priser og kostnader, er det viktig å være klar over at trafikk-kostnader og trafikkvolum ikke er tatt med i dette prosjektet. Dette passer bra med hvorledes kostnadene allokeres i det norske telenettet. Alle kostnader som relateres til trafikkmaskinen – det vil si

Video on demand

Dette er en tjeneste der et video-bibliotek kan nås ved en hjelp av en teletjeneste, og programmer kan bestilles og overføres til hjemmet.



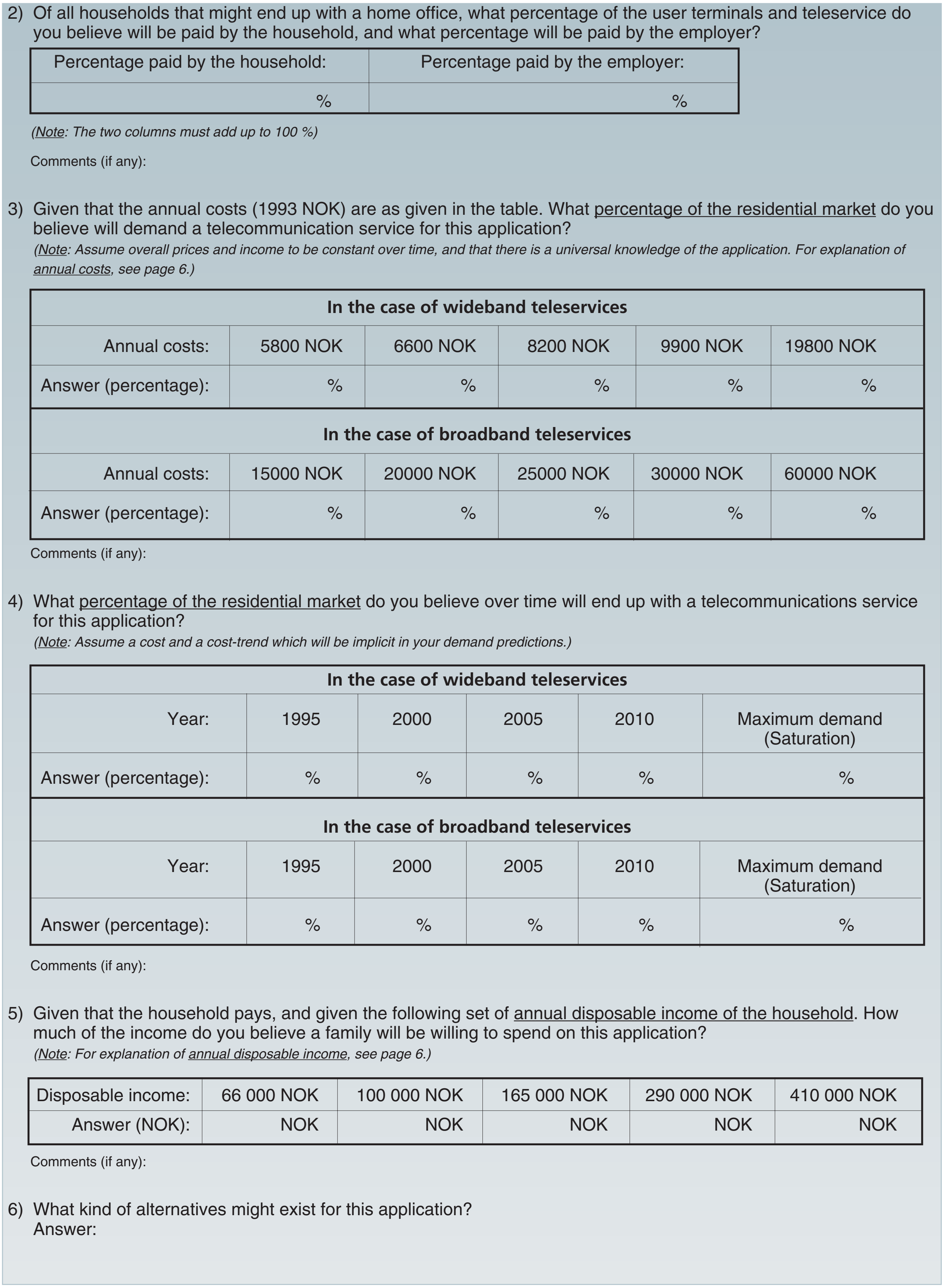
Eksempler på anvendelser:

Bestilling og mottak av spillefilmer, TV-programmer, musikk-videoer, osv.

Tekniske forutsetninger:

Brukeren kan enten benytte en avansert telefon eller en PC for å kommunisere med video-biblioteket via en teletjeneste. PC- eller telefon-tastaturet brukes for å velge videoer fra biblioteket. Overføringen av videoen kan skje enten via kabel-TV-nettet eller telekommunikasjonsnettet. Det antas at husholdningen må abonnere på enten en vidbånds- eller bredbånds-teletjeneste for å kunne bruke denne anvendelsen. Bredbåndstjenesten vil gi raskere overføring og bedre bildekvalitet, men både brukerutstyret og teletjenesten vil bli dyrere.

Figur 4.1 Beskrivelse av video on demand



2) Of all households that might end up with a home office, what percentage of the user terminals and teleservice do you believe will be paid by the household, and what percentage will be paid by the employer?

Percentage paid by the household:	Percentage paid by the employer:
%	%

(Note: The two columns must add up to 100 %)

Comments (if any):

3) Given that the annual costs (1993 NOK) are as given in the table. What percentage of the residential market do you believe will demand a telecommunication service for this application?
(Note: Assume overall prices and income to be constant over time, and that there is a universal knowledge of the application. For explanation of annual costs, see page 6.)

In the case of wideband teleservices					
Annual costs:	5800 NOK	6600 NOK	8200 NOK	9900 NOK	19800 NOK
Answer (percentage):	%	%	%	%	%
In the case of broadband teleservices					
Annual costs:	15000 NOK	20000 NOK	25000 NOK	30000 NOK	60000 NOK
Answer (percentage):	%	%	%	%	%

Comments (if any):

4) What percentage of the residential market do you believe over time will end up with a telecommunications service for this application?
(Note: Assume a cost and a cost-trend which will be implicit in your demand predictions.)

In the case of wideband teleservices					
Year:	1995	2000	2005	2010	Maximum demand (Saturation)
Answer (percentage):	%	%	%	%	%
In the case of broadband teleservices					
Year:	1995	2000	2005	2010	Maximum demand (Saturation)
Answer (percentage):	%	%	%	%	%

Comments (if any):

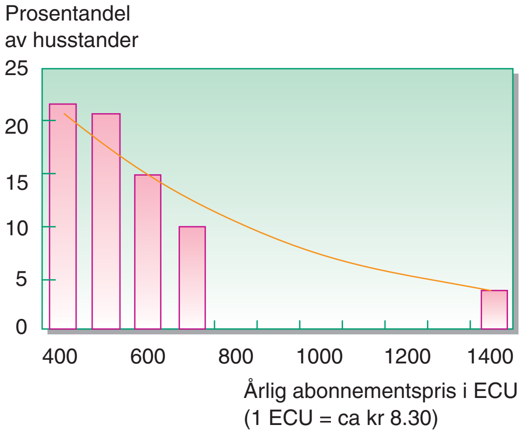
5) Given that the household pays, and given the following set of annual disposable income of the household. How much of the income do you believe a family will be willing to spend on this application?
(Note: For explanation of annual disposable income, see page 6.)

Disposable income:	66 000 NOK	100 000 NOK	165 000 NOK	290 000 NOK	410 000 NOK
Answer (NOK):	NOK	NOK	NOK	NOK	NOK

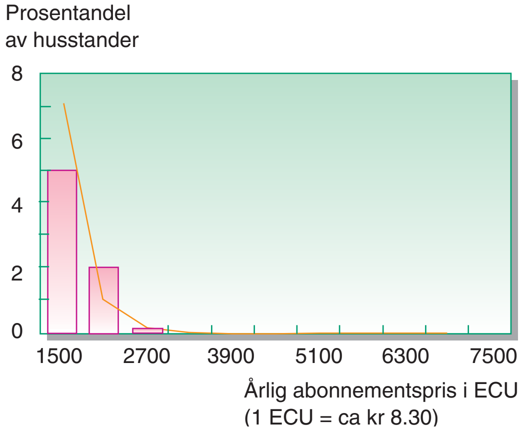
Comments (if any):

6) What kind of alternatives might exist for this application?
Answer:

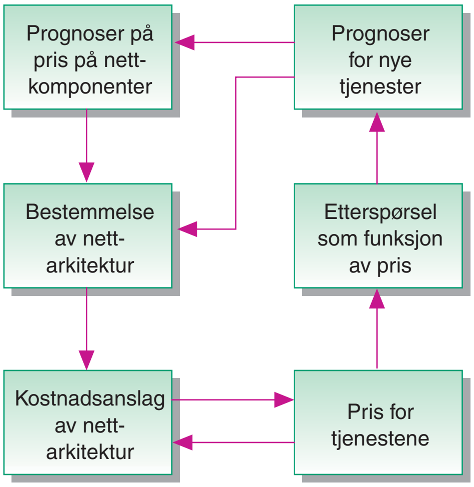
Figur 4.2 Spørsmål knyttet til video on demand tjenesten



Figur 4.3 Eksempel på estimert etterspørselskurve for video on demand med vidbåndstilknytning (2 Mbit/s)



Figur 4.4 Eksempel på estimert etterspørselskurve for video on demand med bredbåndstilknytning (8 Mbit/s)



Figur 4.5 Prosess for beregning av prognoser, kostnader og priser for ny infrastruktur i abonnentnettet

den delen av telenettet som ligger over abonnentmodulen i endesentralen – skal refunderes med trafikkinntekter. De øvrige kostnader – altså i abonnentnettet skal refunderes med abonnementsinntekter. Dermed holder det i TITAN-prosjektet å begrense seg til abonnementsetterspørsel, abonnementskostnader og abonnementspriser.

Som tidligere nevnt er det i TITAN-prosjektet bygd opp en database for pris på nettkomponenter. Ut fra denne databasen lages det også prognoser for prisnedgang på de ulike nettkomponenter. Ser vi på utbyggingsområder bestående av private abonnenter, vil det ut fra en gitt pris for en tjeneste kunne anslås en gitt etterspørsel.

Videre arbeid er ut fra etterspørsel etter ulike tjenester å bestemme en hensiktsmessig nettarkitektur. Dermed kan investeringskostnader og øvrige kostnader beregnes ved bruk av det utviklede beregningsverktøy. Spørsmålet er så om de kostnader som er beregnet harmonerer med de priser som opprinnelig er antatt for tjenestene. Dersom det er betydelig uoverensstemmelse her, må en gå inn et annet sted på etterspørselskurven og gjenta hele prosessen. Samme prosess benyttes også ved ulike tidsintervaller etter hvert som prisprognosene avtar. På den måten lages det også prognoser for etterspørselen etter tjenestene.

Det lages altså ikke direkte prognoser, men det lages indirekte prognoser for de ulike tjenester basert på etterspørselskurven fra Delphiundersøkelsen og prisprognoser sammen med kalkulasjon om kostnader ved oppbygging og drift av nettet. Figur 4.5 gir en oppsummering av dette. Det samme opplegget kan også brukes i blandede områder med forretningsabonnenter og private abonnenter og i områder med bare forretningsabonnenter, men det betinger informasjon om etterspørsel i bedriftsmarkedet på samme form som for privatmarkedet.

5 Sammenlikning av de to Delphiundersøkelser

Formen på de to undersøkelsene er svært like. Spørreskjemaene er laget nesten på identisk måte. Dette skyldes ikke minst den positive erfaring en hadde med den første Delphiundersøkelsen.

Ellers kan det konstateres at tjenestespekteret i to undersøkelser er overraskende likt. Ses det bort fra telegame og telecommunity (telemedisin) så er tjenestene fra 1993-undersøkelsen også definert i Delphiundersøkelsen fra 1976.

Konklusjonen er at i situasjoner der en ikke har historiske data om etterspørsel etter nye teletjenester, vil en Delphiundersøkelse være en av de aktuelle kvalitative prognosemetoder.

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Forecasting Long-Term Demand for Services in the Residential Market

The TITAN tool makes possible the examination of alternative implementation strategies for advanced services in the access network, relying on component cost trends and forecasts of demand for services to evaluate the overall economic viability of new networks for advanced service delivery.

Kjell Stordahl and Eddie Murphy

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This article describes the two particular aspects of work undertaken by the TITAN project – the development of an innovative approach to forecasting component cost trends over time, and the results of a Delphi survey of European telecoms experts that has been used to provide residential service demand forecasts for input to the TITAN tool.

This article shows how a learning curve model giving the cost of a component as a function of production volume can be transferred to a model predicting the costs as a function of time, by the introduction of a logistic model.

The Delphi survey results, presented in the second part of this paper, include demand forecasts for wideband and broadband bearer services in the residential market, as a function both of service price and of disposable income. The leading applications are forecast, and forecasts of application demand are presented.

The first section describes a method of developing forecasts for new services, which takes account of predicted costs. The method, developed as part of the TITAN project,[1] is based on earlier work by Wright and Crawford [5, 6], extended to introduce a logistic model to forecast the cost of network components as a function of time. The work described in the first section was carried out entirely by Telenor. The second section describes the survey carried out among European experts to determine their perceptions of the likely demand for advanced services in the residential market.

A Method of Developing Forecasts for New Services

The TITAN Tool for Cost and Revenue Calculation

For traditional telecoms services, there are fundamental and well understood relationships among network costs (service capital and installation, operations and maintenance, and network investment), service tariffs, and demand. These relationships can also be affected by factors such as competition, market strength, return on investment requirements, and market strategies. A substantial body of information on traditional services has been built up, which can be drawn upon for forecasting purposes. Such information includes the development of demand over time, demand by market segment, demand by demographic area, price elasticities, tariffs, market connectivity, investment costs, and operations and maintenance costs.

In contrast, only limited information is available concerning wideband and broadband services. In order to make reasonable techno-economic forecasts for these services, it is necessary to make assumptions about network architectures and predict the costs associated with service delivery. The structure of a network depends on the nature of the services offered and their requirements including: bandwidth, symmetry of communication, and expected levels of demand.

The TITAN tool implements a methodology for the techno-economic analysis of access networks for residential customers. Inputs to the tool include geographical characteristics such as subscriber density, operations and maintenance costs, investment costs, and demand (which is used to calculate network revenues and to dimension the network).

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[1] *The objectives of the TITAN project are to develop and use a tool for the techno-economic valuation and comparison of access network technologies and architectures. To date, the project has focused on developing a user-friendly and robust tool that integrates engineering inputs with cost and demand forecast data [1-4]. In the remainder of the project the emphasis will be on using the tool to generate comparative studies and introduction scenarios for narrowband, wideband, and broadband networks based on varioust architectures and technologies. The TITAN project, being undertaken by 12 consortium partners, is funded by the European Commission as part of the RACE II program. The project began in June 1992; although originally scheduled for completion in May 1994, it has now been extended until the end of 1995.*

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Investment costs depend on the demand forecasts for new services and on assumptions about architectures and strategies for the introduction of new access network technologies. The TITAN tool incorporates a database of costs for components, civil works, operations and maintenance. Learning curve models (see the following section on learning curves) are used to estimate cost trends for these elements.

The TITAN tool calculates discounted cashflows, and can be used to compare the economic viability of different network architectures and introduction strategies.

Forecasts of Cost Development

Learning Curves: Cost Versus Volume — Learning curve models were developed by Wright [5] and Crawford [6]; an historical review of the methodology is given in [7]. The models are used to estimate the reduction in production cost per unit when there is an increase in production volume. A number of factors influence the industrial production process, particularly: the introduction of new methods, the introduction of new technology, redesign of the equipment, standardization of the production process, automation, improvement of management, and organizational changes.

The Wright classic learning curve model is given by:

$$P = P_0 n^{\beta} \tag{1}$$

where

P = cost per unit produced

P_0 = cost of producing the first unit

n = total number of units produced

β = parameter in the model (normally negative)

Equation 1 shows that unit costs decrease as an inverse function of the number of units produced. The size of the parameter β varies according to the type of equipment, and is estimated by using ordinary least squares (OLS) regression. Generally, the learning curve rate K is used. The learning curve rate gives the reduction in unit cost when the production volume is doubled. The relation between K and β is given by:

$$\beta = \frac{\ln K}{\ln 2} \tag{2}$$

A weakness with Wright's model is that the learning curve passes through the first observed point — the production cost of the first unit produced. An alternative approach is to introduce a new parameter α into the model. The extended model is given by:

$$P = \alpha n^{\beta} \tag{3}$$

Here α and β are estimated by OLS regression. The extended model is more flexible than Wright's model and will better fit the observed data.

Model for Forecasting Component Production Costs as a Function of Time — We have described a model for predicting component production costs as a function of production volume. The requirement of the TITAN tool, however, is to predict production costs as a function of time.

One possibility is to forecast production costs directly by using a time series that is represented by the production cost for the last period (usually one year). Different types of forecasting models can be used, depending on the data available, including: simple or multiple regression models, smoothing models like Holt or Holt-Winters models, ARIMA models, transfer models, Kalman filter models, and growth curve models.

However, these models can only be used where sufficient historical data is available. TITAN has therefore developed an alternative method which is based on a combination of the extended learning curve model and a growth curve model, and can be used when only a few observations are available. The combination of these models is used to determine the cost trends contained in the TITAN database.

Suppose we have made a forecast of the number of units produced by time T, which is denoted $n(T)$, where $T = 1, 2, \ldots, s$. By putting the forecast into the extended Wright's model Eq. 3 we get:

$$P_T = \alpha n(T)^{\beta} \tag{4}$$

When new network components are introduced on the market, only limited information is available about the expected production volume. The approach chosen by TITAN was to find a growth curve model to fit the growth in production. The logistic model is a justifiable choice in this situation, and is given by:

$$n(T) = \frac{M}{(1 + e^{a+bT})^{g}} \tag{5}$$

where

T = time

$n(T)$ = forecast number of units produced by time T

M, a, b, and g are parameters in the model.

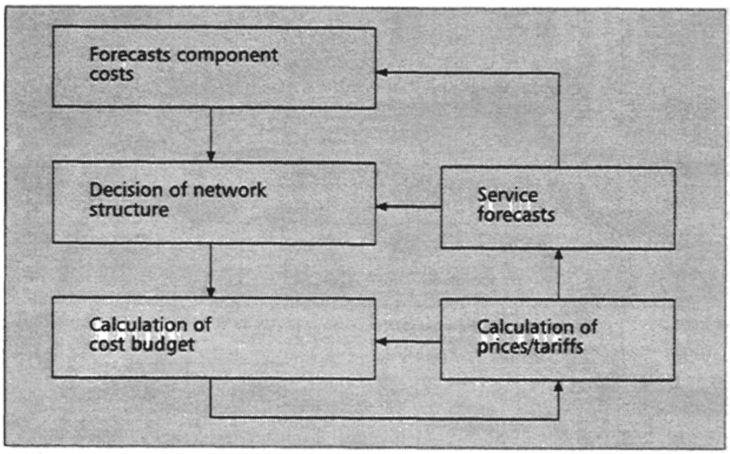
The parameter M represents the saturation level, while the parameters b and g represent the growth. If there is a time series of the production volume, then the parameters can be estimated either by using a non-linear estimation procedure or by using a two-step iteration procedure (see chapter 4 in [8]). However, when the number of observations is limited, it is necessary to reduce the number of parameters and so we set $g = 1$. Preliminary estimates of the saturation level M are then made. The saturation level for different network components will be a function of the number of customers. The introduction time is determined by a combination of parameter a and the time T. If no observations are available, both a and b must be estimated from past experience.

The forecast of network component cost at time T, P_T, is found by putting Eq. 5 into Eq. 4 to give:

$$P_T = \alpha \left(\frac{M}{(1 + e^{a+bT})^{g}} \right)^{\beta} \tag{6}$$

When the number of observations is limited, α can be substituted by P_0, the cost of producing the first unit. Initial estimates of β can be found using Eq. 2 and the learning curve rate K for similar network components.

The TITAN tool calculates discounted cashflows, and can be used to compare the economic viability of different network architectures and introduction strategies.



■ **Figure 1.** *Calculation of forecasts, costs, and prices.*

Annual price	25% fractile	50% fractile (median)	75% fractile
ECU 1000	5	10	12
ECU 1400	3	5	10
ECU 1800	2	3	5
ECU 2300	0	1	3
ECU 4600	0	0	1

■ **Table 1.** *Percentage of the residential market having a wideband subscription for a range of annual prices.*

When the network components have been in production for some time, both the parameter in the growth curve model (Eq. 5) and the parameters in the extended Wright's learning curve model can be estimated by ordinary least squares regression or other statistical procedures. Hence Equation 6 can be used to forecast the component costs at time T, without the need for preliminary estimates.

Relationship between Demand, Production Costs and Architecture — Figure 1 shows a simplified structure of the methodology used by the TITAN project, involving the following steps:
- Development of forecasts for each service — each forecast is related to a given network area.
- Development of forecasts for the costs of various network components.
- Design of a network architecture, on the basis of the applications required.
- Calculation of a cost budget for building the network, based on the TITAN tool — in addition to the investment costs, costs for operations and maintenance are taken into account.
- Calculation of appropriate tariffs for using various applications.

The calculated tariffs are incorporated in the forecasting process and all the steps in the calculations are repeated. Using this method, a number of different introduction strategies can be evaluated, based on calculated costs and the cost budget. This methodology can also be used to examine the consequences of introducing new services on a variety of network structures with varying levels of demand.

The Delphi Survey

A Delphi survey is a method by which the opinions of experts are canvassed, in order to achieve consensus on a particular issue. The methodology involves asking a set of questions, analyzing the results, and resubmitting the questions to the experts, together with a summary of first-round results. The experts then resubmit their opinions, which may have changed following consideration of results from the previous round. This procedure can be repeated a number of times, and usually leads to a reduction in the variance of the answers received.

Between the middle of 1993 and the middle of 1994 the TITAN project carried out a comprehensive two-round Delphi survey among experts in ten European countries.

The Nature of the Questionnaire

The applications covered by the questionnaire were video on demand, multimedia telegames, videotelephony, telecommunity (telemedicine), teleshopping, advertising and marketing, interactive TV, electronic newspapers, home office (simple and advanced), and remote education (home and studio).

For each application detailed questions were asked concerning likely demand (in terms of penetration of households) for services which deliver that application. The questions covered the expected level of demand:
- Over a range of different prices.
- At different times in the future (1995, 2000, 2005, and 2010).
- For various levels of household disposable income.

In addition, qualitative information was sought regarding typical users of each application.

Questions of a similar nature were asked concerning three bearer services: basic-rate ISDN (up to 144 kb/s), wideband (up to 2 Mb/s), and broadband (up to 8 Mb/s).

Respondents were also asked to indicate the number of applications a customer would subscribe to over each bearer service, and which three applications are likely to be the most popular. In all, 398 questions were asked in the first round of the survey. This was reduced to 365 for the second round as some of the qualitative questions were not resubmitted to the experts.

Execution of the Survey

The Delphi survey was carried out by TITAN partners across Europe. It was decided to ask ten experts in each of ten countries to complete the questionnaire. The countries chosen were Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Norway, Portugal, and the United Kingdom. Where possible, five of the ten experts approached in each country were from the dominant telecommunications operator (TO). The other five were chosen from companies within the IT industry, universities, and other companies and institutions concerned with consumer demand.

It proved more difficult than anticipated to persuade the experts to complete the questionnaire. By early December 1993, 58 questionnaires had been returned, and in order to keep to the agreed schedule it was decided to begin analysis of the replies.

Second-round questionnaires were sent out to the same experts in February 1994, incorporating details of the results obtained from the first round. By the end of May 1994, 50 second-round questionnaires had been returned, and it was decided to proceed with the analysis of the second-round results.

Results from the Survey

General — The survey was designed only to examine subscription demand, not traffic demand. The reason for this is that a network operator usually allocates all access network costs for operations, maintenance and investment to subscription tariffs. The results shown in this section are taken from the second round of the survey.

Wideband Services — The term wideband is used by the TITAN project to refer to bit rates from 64kb/s up to and including 2Mb/s. This type of access provides medium quality for some services, acceptable picture quality on video services, and a good response time for the transfer of still images and large volumes of text information.

Experts in the Delphi survey were asked what percentage of the residential market they believed would ask for a wideband connection, assuming a given set of annual prices. The results are presented in Table 1 as distribution fractiles for a range of different prices.

The figures based on the median or the 50 percent fractile represent the most likely demand. These median values can be used to construct a demand/price curve which is an extremely useful input when developing subscription forecasts.

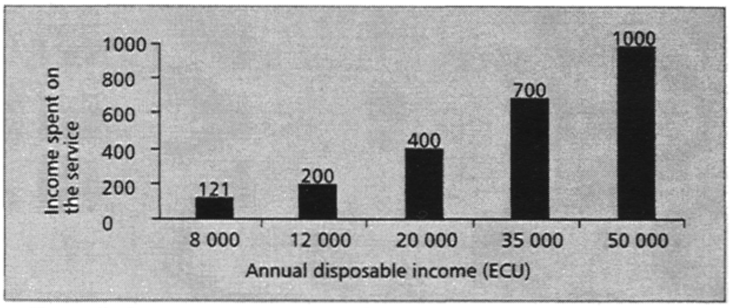
The interval between the 25 and 75 percent fractiles is often used in Delphi surveys as an indication of confidence limits. 50 percent of the experts' answers fell within the fractiles in the table. We can regard data between the 25 percent and 75 percent fractiles as within the bounds of probability for the service.

Table 1 illustrates the variance in the results from the second round of the survey. In the first round of the survey the differences between the 75 percent fractile and 25 percent fractile for the different annual costs were: 25, 18, 14.5, 9, and 4 percent, respectively. After the second round the corresponding differences (from Table 1) were: 7, 7, 3, 3, and 1 percent.[2] Thus, the second round resulted in a significant convergence in the experts' opinions.

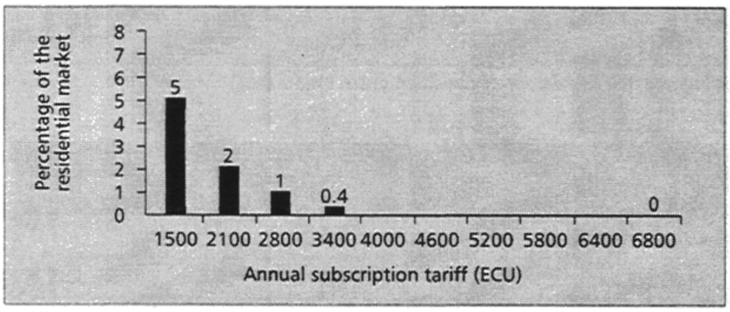
Another question in the survey was what proportion of its disposable income a household will be willing to spend on a 2 Mb/s connection. The results are shown in Fig. 2, as median values for different levels of disposable income.

The survey results show that for a given disposable (household) income, the experts believe that families in southern Europe will be willing to spend more on various services, including wideband and broadband access, than households in other parts of Europe. One reason for this may be the relative purchasing power in different countries for the same nominal income.

Broadband Services — For the purposes of the Delphi survey, broadband was defined to be an 8 Mb/s connection. This type of access offers good quality for multimedia services, very good picture quality on video services, and very good response time for the transfer of still images and large volumes of text.



■ **Figure 2.** *Income spent on wideband connections as a function of annual disposable income*



■ **Figure 3.** *Residential market penetration of broadband connections as a function of subscription tariff.*

Video on demand	41
Home office, simple	34
Videotelephony	27
Remote education, home	11
Multimedia telegames	10
Home office, advanced	6
Home ordering system	6
Interactive TV/specialized channels	6
Electronic newspapers	4
Advertising and marketing	1
Telecommunity/telemedicine	-
Remote education, studio	-

■ **Table 2.** *Ranking of services on wideband connections.*

Experts in the Delphi survey were asked what percentage of the residential market they believed would demand a broadband connection for a given set of annual prices. Figure 3 shows the results.

A comparison of the results shown in Table 1 and Fig. 3 illustrates that, for similar prices, demand is not expected to vary greatly between a wideband and a broadband connection. This indicates that, in the opinion of the experts consulted, households are unlikely to perceive a benefit in having a broadband connection rather than a wideband connection.

Leading Applications/Services — It is probable that most households that decide to subscribe

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[2] *The standard deviations of the answers from the experts in the two rounds were reduced in the same way by a factor of between 3 and 7. Similar trends were observed for the other questions in the survey.*

Service	Annual tariff			
	ECU 400	ECU 600	ECU 700	ECU 900
Video on demand	20	10	5	4
Videotelephony	18	10	7	5
Home office, simple	11	8	7	6
Multimedia teleshopping	12	8	5	2
Home office, advanced	–	7	6	4
Electronic newspaper	–	6	4	2
Interactive TV/special channels	10	5	4	2
Telecommunity	–	5	4	2
Multimedia telegames	10	5	3	1
Remote education, home	–	5	3	1
Remote education, studio	3	2	1	0.5

■ **Table 3.** *Demand for various services on wideband connections (as a percentage of the residential market), based on medians from the Delphi survey.*

	2000	2005	2010	Saturation
Videotelephoney	10	20	25	41
Video on demand	10	20	25	30
Multimedia teleshopping	5	10	20	28
Home office, simple	5	10	16	25
Multimedia telegames	5	10	16	25
Interactive TV/specialized channels	5	10	15	20
Electronic newspapers	5	8	12	20
Home office, advanced	5	8	10	19
Telecommunity/telemedicine	3	5	8	10
Remote education, home	2	5	8	10
Remote education, studio	1	3	5	8

■ **Table 4.** *The forecast demand and saturation for each wideband service as a percentage of the residential market.*

to advanced services will take more than one service. This will spread the cost of the wideband or broadband connection across a number of services, making each individual service more economic.

Experts consulted in the Delphi survey were asked about the average number of services they anticipate will be taken up by each household with a wideband or broadband connection. They forecast an average of 3.2 services for each household with a wideband connection, and 3.8 services for each household with a broadband connection. The experts indicated that the average number of service subscriptions will increase in line with the capacity of the connection.

The survey results also indicate that countries in southern Europe are likely to subscribe to fewer services per household than other European countries.

Experts in the survey were also asked to indicate which three applications they expect will have the greatest number of subscribers. Table 2 ranks services according to the number of times they were each selected by the experts.

For each service, the experts were asked to estimate the demand for a range of annual prices. A demand curve was constructed for each service based on medians from the survey. Table 3 shows the demand for each service delivered over 2 Mb/s connections, for a given range of prices.

Table 3 also indicates that the experts forecast high demand for video on demand, videotelephony, and home office, which corresponds with the ranking of the services in Table 2. One item worthy of note in Table 3 is that the home office service is expected to be less price-sensitive than other services. This is probably due to the fact that this service is seen as being paid for by employers who normally use a completely different set of criteria when deciding whether or not to purchase.

***Forecasts of Demand for the Services* —** The experts were asked to predict penetration for the years 2000, 2005, and 2010 and to give an estimate of the level of saturation demand for the services. Table 4 presents the median values of the predictions for those years, together with the saturation levels.

Service	Sex	Age	Educational level of users	Purpose
Video on demand	Male	All	All	Entertainment
Telegames	Male	Young	All	Entertainment
Videotelephony	Both	All	High and medium	Communication
Telecommunity	Both	Old	All	Communication
Advertising and marketing	Female	All	High and medium	Information
Interactive TV/specialized channels	Male	All	All	Entertainment and education
Electronic newspapers	Male	All	High	Information for personal and business use
Home office	Both	All	High and medium	For work
Remote education	Both	All	High and medium	For study and entertainment

■ **Table 5.** *Characteristics of typical users.*

Qualitative Information — In addition to the quantitative results described above, we asked the experts for qualitative information about future services, including the characteristics of typical customers for each service. Table 5 summarizes the information gathered from this part of the survey.

Conclusions

This article describes aspects of the TITAN tool which enable the examination of alternative implementation strategies for advanced services in the access network. The tool makes use of component cost trends in an innovative way, and relies on forecasts of demand for services in order to evaluate the overall economic viability of new networks for advanced service delivery.

The learning curve model giving the cost of a component as a function of production volume can be transferred to a model predicting the costs as a function of time, by the introduction of a logistic model.

Where an acceptable level of quality is provided by wideband bearer services, the Delphi survey indicates that customers will be unwilling to pay more for broadband bearer services. A low forecasts was made for broadband connections in the year 2010 (5 percent of the residential market).

TITAN's Delphi survey suggests that the services with the most potential are video on demand, videotelephony and the simple home office. Widespread take-up of video on demand is expected to occur. Demand for the simple home office is expected to be less dependent on price than other residential services, as employers use different criteria from private individuals when deciding whether to purchase a service. Experts consulted for the TITAN project believe that each household with a wideband or a broadband connection will have between three and four service subscriptions.

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Biographies

KJELL STORDAHL received his M.S. in statistics at Oslo University in 1972. He has been at the Research Department in Telenor for 15 years, with seven years as a manager for the teletraffic field. He is now as a manager for Planning Department in Network Division Oslo, where he is responsible for planning, development, and the investments in the telecommunication infra-structure in Oslo region. He also gives lectures on Forecasting at Oslo University. From 1973 to 1975 he participated in the CEPT project "Needs Research Programme" for making forecasts for new services. He has been associated raporteur and special raporteur 1981-1988 in CCITT SGII for the Question "Forecasting International Traffic" and he was responsible for the description of forecasting methods in CCITT GAS 10. He has also worked for ITU's headquarters as a specialist on forecasting.

EDDIE MURPHY studied computer science and mathematics at University College Cork in Ireland. He is currently employed as a consultant with Analysys, Europe's largest consultancy specializing purely in telecommunications, and works on projects to advise clients on issues of telecoms strategy. He spent more than a year as Analysys's representative on the TITAN project. Earlier in his career, he worked on software development for the System X telephone exchange, was a researcher in manufacturing engineering (with a particular emphasis on the communication between elements of the manufacturing process), and served as a Research Administrator with the European Commission, supervising research projects in the application of telecoms and IT to road transport.

TITAN's Delphi survey suggests that the services with the most potential are video on demand, videotelephony, and the simple home office.

Long term forecasts for broadband demand

KJELL STORDAHL AND LARS RAND

1 Introduction

What are the market drivers for future broadband demand? This paper shows that the long term demand for broadband services depends on a set of different market drivers. Some of the market drivers like application evolution, development of new technology and network architectures, terminal equipment technology, mass production of network components and tariff evolution are presented.

The long term demand for broadband services is estimated based on an international Delphi survey. The experts participating in the Delphi survey used information about market drivers as a basis for their evaluation of the evolution of a future broadband market. A comparison is done between the expectations the experts had about the market developments in 1994 and 1997. The results from the Delphi survey are used to model analytical forecasting functions for broadband demand. The aggregated forecasts for specific broadband capacities are split into asymmetric and symmetric broadband forecasts.

1.1 Technology development and new network architectures

In the transport network deployment strategies for substitution of PDH transmission equipment with SDH transmission equipment are now being carried out. In parallel the fibre capacity is expanded by the introduction of wavelength division multiplexing (WDM). Over the last years the development of new technology has dramatically reduced costs by significant expansion of the system capacity. During a 20 year period the transmission cost per capacity unit has been reduced from 10,000 to 1. However, the technical problem of high capacity switching is not yet solved. One possibility is to use ATM, another possibility is to use IP, and a third one is to implement ATM over the IP platform.

In the access network a wide range of fibre architectures are relevant, of which deployment depends on factors such as the subscriber area:

- Hybrid fibre coax (HFC);
- Fibre to the cabinet (FTTCab);
- Fibre to the node (FTTN);
- Fibre to the curb (FTTC);
- Fibre to the building (FTTB);
- Fibre to the home (FTTH).

In addition new multiplexing techniques, access protocols for point-to-multipoint configurations and modulation techniques are developed. Also the digital subscriber line (DSL) technologies, like ADSL (asymmetric digital subscriber line), HDSL (high bit rate subscriber line), VDSL (very high speed digital subscriber line) and SDSL (symmetric digital subscriber line) are of great importance for utilising twisted pairs [1, 2]. The technologies may substitute each other or may be deployed as supplements in different parts of the network.

Introduction of passive optical network components as TPON and ATM PON and the use of ATM- and SDH technology will increase the transmission capacity and reduce the costs. Wireless broadband access is a technology currently under development. The access radio technology is expected to evolve from carrying narrowband services to transport of services up to 2 Mbit/s capacity through local multipoint distribution service (LMDS) and multipoint multichannel distribution (MMDS) [3–5]. Another relevant architecture in the future is the universal mobile telephone system, UMTS.

Other alternatives are satellite communication combined with a wireline return channel. The cable operators will upgrade their networks with return channels offering both POTS/ISDN, Internet and broadband services together with CATV. The most relevant architecture is a combination of passive optical network and a coax droop called hybrid fibre coax system, HFC. The access technologies mentioned may substitute each other or may be deployed as supplements in different parts of the network.

1.2 Terminal equipment technology

The terminal equipment is evolving rapidly into several future options including specific electronic interfaces/terminals which may be used together with a TV, like a network computer. Another possibility is the use of a PC. There are several drivers connected to the terminals. During the last 20 years, from the 8080 to the Pentium processor, the number of transistors per chip has doubled every 18 months (Moore's law), while the speed in million instructions per second (MIPS) has increased proportionally [6]. In 1983 the cost per Mbyte was USD 300, while in 1995 the cost was reduced to 15 cents. Future exponential development of the storage capacity will enable software decompression of MPEG-2 video streams and direct computer storage.

1.3 Market drivers

The new technologies, the mass production of network components and low transmission costs are continuously creating new applications. At the same time an extraordinary expansion of the Internet has occurred. It seems that it is not a killer application for the broadband market, but that Internet is a 'killer network'. From 1998 wideband services were offered on the Internet, and broadband services are also expected to emerge soon. At the same time some CATV companies are installing cable modems and are offering broadband services on their networks. Some of the main drivers for the development of the broadband market are: new technology, new applications, increased computing power and storage, mass production, price reductions, the Internet revolution and the competition [7].

2 Prediction of network component cost trends

Within the European programs RACE and ACTS the projects RACE 2087/TITAN, AC 226/OPTIMUM and AC 364/TERA have developed a methodology and tool for calculation of the overall financial budget of any access architecture. The tool handles the discount cost system, operations, maintenance, life cycle costs and the cash balance. This enables a comparison of various optical or hybrid architectures through a global system assessment. The tool has the ability to combine low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters for performing evaluation of various network architectures [1, 8–11].

The TITAN project developed a methodology based on an expansion of the Wright and Crawford's learning curve models to predict future cost of the network components [12–14]. In the OPTIMUM project, Wright and Crawford's learning curve models for cost predictions were examined. The models for cost predictions were extended not only to estimate the costs as a function of number of produced units, but also as a function of time. The cost prediction of each network component is described by expansion of the learning curve given as a function of the parameters:

$f(0)$	the predicted costs at time 0;
$n(0)$	the relative proportion of produced components at time 0;
Δt	the time interval between 10 % and 90 % penetration;
K	the learning curve coefficient (relative decrease in the cost by the double production).

The extended learning curve function is:

$$\begin{aligned} f(t) &= f(f(0), n(0), \Delta t, K, t) \\ &= f(0)[n(0)^{-1} (1 + \exp[\ln(1/n(0) \\ &\quad - 1) - 2t \ln 9/\Delta t])^{-1}]^{\log_2 K} \end{aligned}$$

The parameters in the learning curve: $f(0)$, $n(0)$, Δt and K are given in the OPTIMUM cost database, which contains more than 200 different network components. The components are grouped in volume classes. The values used for the various volume classes are shown in Table 1. In the same way the K parameter is estimated based on type of component. The K value indicates how much the component price is reduced by a doubling of the production.

In the cost database all components are listed with a given $n(0)$, Δt and K value in addition to the estimated cost $f(0)$ at time 0. Then the extended learning curve is uniquely defined and the prediction of the costs is determined.

Table 2 shows that new components based on electronics or advanced optics experience a significant price reduction. When the production is doubled, the price is reduced by 20 % and 30 % respectively. An additional doubling of the production will reduce the cost by 36 % and 51 % respectively.

3 The Delphi survey

A Delphi survey is a method by which the opinions of experts are canvassed, in order to achieve consensus on a particular issue. The methodology involves asking a set of questions, analysing the results and resubmitting the questions to the experts, together with a summary of the first round results. The experts then resubmit their opinions, which may have changed following a consideration of results from the previous round. The procedure can be repeated a number of times and usually leads to a reduction in the variance of the answers received. Medians are used as a measure in the Delphi survey because they are more robust estimators than the mean value and standard deviations, and also less affected by extreme answers.

In 1994 the TITAN project carried out an international postal Delphi survey on broadband service demands among experts in ten European countries [14–15]. An additional comprehensive two-round, on-site Delphi survey was carried out during the OPTIMUM workshop "Techno-economics of Multimedia Networks" in Aveiro, Portugal in October 1997. The following countries were represented in the survey: Belgium, The Czech Republic, Denmark, Finland, France, Switzerland, Germany, Greece, Holland, Hungary, Ireland, Italy, Norway, Portugal, Spain and Sweden. The number of participants were 36 in the first round and 32 in the second round.

3.1 Broadband applications

The Internet development and the new technology continuously create new applications. To be able to evaluate the different broadband applications, they are divided into groups. The questions in the survey do not address single applications, but the main group of applications. The main groups of applications in the study are:

1 Tele-entertainment
(Symmetric and asymmetric)

- Multimedia telegame
- Virtual reality
- Video on demand
- Audio/music on demand;

2 Information services (Asymmetric)

- Information retrieval
- Electronic magazines
- Information retrieval by intelligent agents
- Electronic newspaper;

3 Teleshopping (Asymmetric)

- Teleshopping
- Advertising;

4 Private communications services
(Symmetric)

- Videophone
- Teleconferencing

5 Teleworking
(Symmetric and asymmetric)

- Videophone
- Joint editing/publishing
- Teleconferencing
- Teleparticipation
- Information retrieval
- Multimedia applications;

6 Telelearning
(Symmetric and asymmetric)

- Video on demand
- Videophone
- Virtual reality;

Table 1 Variation in n(0) and t for each volume class

Volume class	$n(0)$	Δt
1	0.5	5
2	0.1	5
3	0.01	5
4	0.5	10
5	0.1	10
6	0.01	10
7	0.001	50

Table 2 The K values for component groups

Component group	K value
Civil work	1
Copper	1
Installation	1
Sites and enterprises	0.95
Fibre	0.9
Electronics	0.8
Advanced optical components	0.7

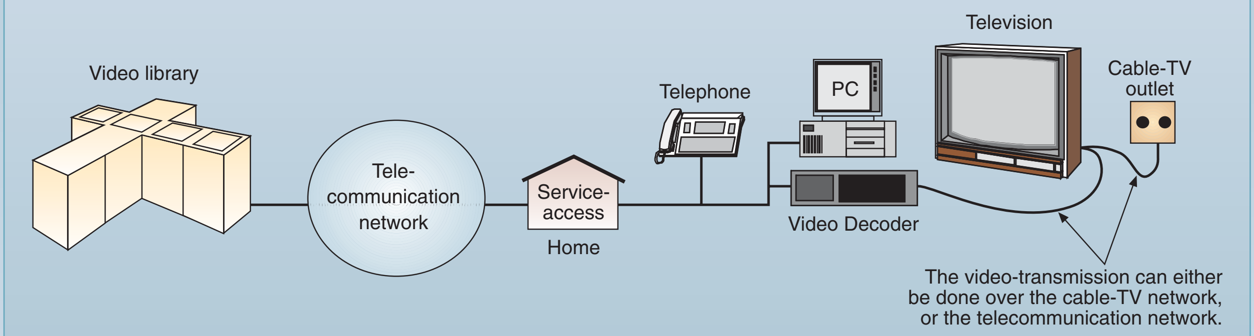
Example of application: Video on demand and Audio/Music on demand

General description:

This is an application where a video library is accessed, and programs may be ordered and transmitted to the home. This application could substitute some part of the time spent on ordinary TV and part of the money spent on hiring videos in video shops.

Technical assumptions:

The user may use either an advanced telephone or a PC to communicate with the video library. The transmission of the video may be done either via a Cable-TV network or a telecommunication network. The access capacity will be in the range of 2– 4 Mbit/s.



Given the following alternative prices per hour (1997 ECU), what do you believe will be the expected use of this group of applications (Tele-entertainment)?

Note: We assume that the tele-entertainment applications are supplementary to the traditional TV channels, but there may be some substitution effects.

Round 1					
Prices per hour:	0.5 ECU	2 ECU	5 ECU	10 ECU	20 ECU
Minutes per day:	70	40	12	5	1

Having seen the above results, what would your answers be to the corresponding question today?

Round 2					
Prices per hour:	0.5 ECU	2 ECU	5 ECU	10 ECU	20 ECU
Minutes per day:					

4 *Comments (if any):*

Figure 1 An example from the Delphi survey questionnaire

7 Telecommunity (Symmetric and asymmetric)

- Telesurveillance
- Videophone
- Telediagnostics.

3.2 Access capacity

The technology and network components are rather expensive today, but mass production may exponentially reduce production costs and consequently the prices. The following access capacities were examined in the Delphi survey:

- *2 – 4 Mbit/s asymmetric access including a 384 kbit/s symmetric upstream capacity;*
- *25 Mbit/s asymmetric access including a 384 kbit/s symmetric upstream capacity;*

- *25 Mbit/s asymmetric access including a 6 Mbit/s symmetric upstream capacity.*

Several factors contribute to an application's requirements in terms of bandwidth over the network. In most cases, high capacity is needed for large volumes of information.

First of all, the type of medium (speech, text, graphics, video, or several media simultaneously – multimedia), may indicate the possibility for large volumes of information. The types of applications demanding high bandwidth transmission are fast transfer of video, high quality images/graphics, large data files, or a simultaneous combination of these in multimedia applications.

High quality videophone, telecommunity and telemedicine are applications benefiting from a high symmetric upstream capacity. For example, interactive video applications transferring moving pictures like videotelephony or videoconferences, require a minimum image frequency depending on the speed of change in the pictures transferred. This increases the bit rate requirement, and so does the image resolution and colour richness.

3.3 The Delphi questionnaire

The questionnaire starts with a short description of the application, followed by some questions relating to it. The main questions in the survey are:

- Usage as a function of charge;
- Penetration as a function of charge;
- Penetration as a function of time (forecast);
- Demand as a function of disposable household income.

An illustration of the design of the questions in the questionnaire which includes a description and an illustrative figure is given in Figure 1.

As shown in Figure 1, in the second round of the survey the participants were presented the medians from the same questions in the first round of the survey. The participants took this into consideration when answering the second round questions.

In order to use the presented applications, an access in the range of 128 kbit/s – 25 Mbit/s is needed. The users will have to pay more for enhanced performance and quality generated by higher bandwidth. All the equipment and network components will gradually become less expensive, depending on factors like new technology, sales volume, competition, etc. Broadband communications costs can be divided into four elements:

- Costs for necessary terminal equipment;
- Subscription charges;
- Traffic charges;
- Charges for delivered information (eg. charge for hiring/ordering a video).

In the Delphi survey we were interested in how much the customers are willing to pay for the traffic and the subscription (connection) charges. It was assumed that the customers already possess the necessary terminal equipment like TV, PC, etc. Supplementary expenditure for specific adapters and 'interface' hardware for the applications which have to be installed, was assumed to be covered by a subscription (connection) charge. The costs of the delivered information were not taken into account.

Some information may be financed by advertisements. The teleshopping application may be financed by the sellers and not by the customers. The costs of other information like electronic newspapers may be substituted by a reduction of costs for buying hard copies (traditional

Table 3 Leading Group of Applications, percentage score

Choices 1994 survey *)	Answers 1994 *)	Choices 1997 survey	Answers 1997
Video on demand	28 %	Teleworking	28 %
Home office	27 %	Information services	25 %
Videotelephony	18 %	Tele-entertainment	24 %
Remote education	8 %	Teleshopping	7 %
Multimedia telegames	7 %	Private communications services	6 %
Home ordering system	4 %	Telecommunity	4 %
Interactive TV/specialized channels	4 %	Telelearning	3 %
Electronic newspapers	3 %	Others (Telebanking)	1 %
Advertising and marketing	1 %		
Telecommunity	0 %		

**) Source [15]*

newspapers). Nevertheless, it is reasonable to believe that the customers have to pay for some type of information.

4.1 Household budget and usage

A household has an annual disposable income, which is the income after tax or the part of the income which is available for purchasing goods and services, for savings etc. Part of the service budget is related to

- budget for entertainment;
- budget for telecommunications;
- budget for newspapers, magazines, dictionaries, specific books and videos, etc.

The household has both a time budget and a financial budget, dependent on the number of persons in the household. The budgets limit the use of applications. It is reasonable to expect some substitution effects between the household's use of time today and possible use of broadband accesses. In the questionnaire we have asked how much additional time a household would spend on the new broadband applications as a function of additional payment.

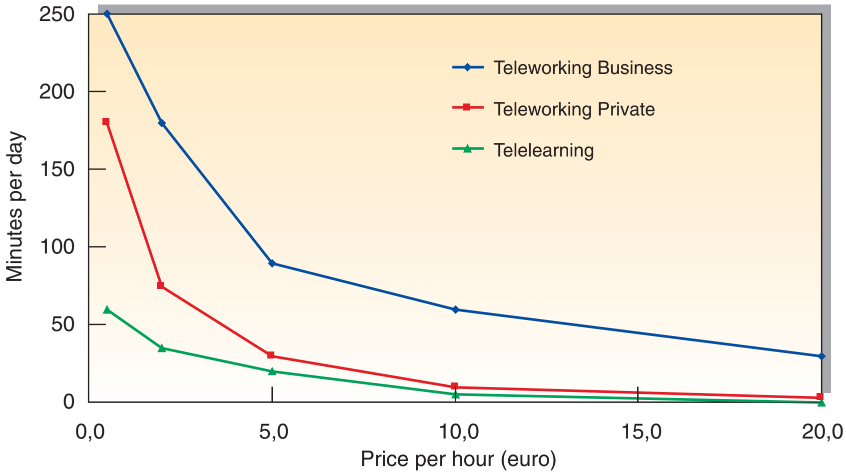


Figure 2 Demand curves for broadband access for teleworking and telelearning

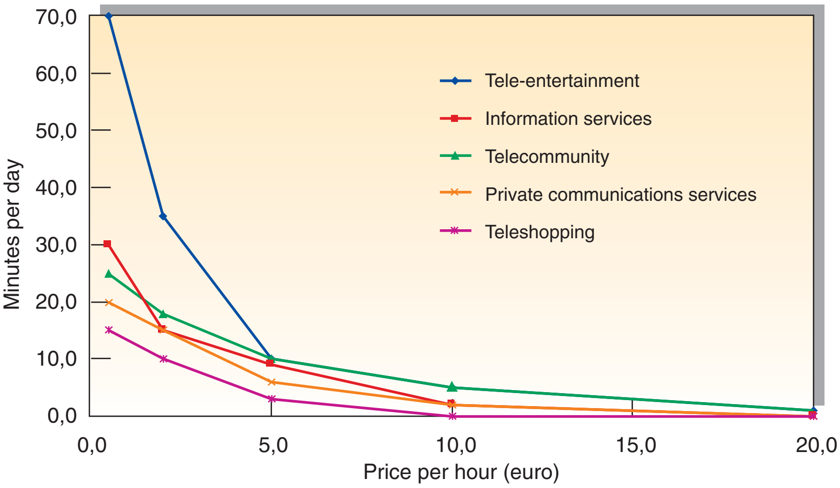


Figure 3 Demand curves for other private broadband applications groups

4.2 Ranking groups of applications

The respondents were asked to point out the three most important services for the future. This makes up 33 % the highest possible score for an application group. Table 3 shows the ranking of the group of applications in 1994 and in 1997. Teleworking, information services and tele-entertainment stand out as the anticipated most popular services for broadband. A comparison with a similar Delphi survey in 1994 [15] shows that the three most promising broadband applications were video on demand, home office and videophony. It looks like information services have become more popular from the 1994 survey to the 1997 survey. In addition, from the first to the second survey other application groups have become more interesting than private communications services (videophony).

A telecommunication access line may support the use of many of these groups of applications, so for each group of applications questions were asked on the demand at different prices in order to quantify the demand.

4.3 Potential usage of applications

For every service the respondents were asked to indicate the demand in minutes per day for a given set of prices per hour. Hence a demand curve can be constructed for each application group based on medians from the survey. In Figure 2 a distinction is made between company paid teleworking and teleworking paid by the households themselves, since companies are expected to have a higher willingness to pay than private households.

The demand for telelearning is trickier because it concerns a small share of the households and for a limited time of the year. The household usage will be high some days and zero at other times depending on the type of courses and education frequency. Demand curves for other private broadband application groups are shown in Figure 3. The results show that tele-entertainment follows the same demand curve as telecommuting from a price of five euro per hour, but has a higher saturation level – so the expected demand is much higher at a low price. Tele-entertainment services, which are defined as video on demand, audio/music on demand, multimedia telegame and virtual reality, are very attractive services, but are quite price elastic.

Figure 4 shows medians for round 1 and round 2 and identifies the range from the 25 quartile to the 75 quartile of the answers on demand for broadband connections for different hourly prices. The figure indicates significant reductions in the variance of the answers received in the first round compared to the second round.

Teleworking, information services and tele-entertainment stand out as the most promising broadband applications in the future. The interest for information services can be explained by the rapid development of the Internet and the related narrowband applications. The interest for tele-entertainment is caused by a high degree of usage of existing applications. Teleworking is of special interest and may be one important driver for the broadband market. Teleworking is used by self employed persons with their office at home (SOHO), by one person in the family financed by the company, or by some in the family, but financed internally. Today there is a positive trend towards supporting teleworking at home. For employees with qualified and independent work there are reasons to predict that society and the companies are willing to support and finance extensive use of teleworking with a broadband connection. In that way the employees can work more effectively and in a more flexible way. Society also supports teleworking because of reduced pollution and reduced traffic at rush hour times, etc. Some large companies now offer a home office solution combined with a company paid narrowband access (N-ISDN) for some of their employees.

4.4 Demand forecasts

The respondents were asked to indicate the expected penetration in the residential market for broadband access for the years 2000, 2005, 2010, 2015 in addition to the saturation level. Figure 5 indicates quite a high demand for broadband connections in the residential market. The penetration forecasts for 2 Mbit/s have not changed much from the 1994 Delphi survey. In 1994 the experts predicted, for 2 Mbit access, a penetration rate of 5 %, 10 % and 15 % respectively for the years 2000, 2005 and 2010. In the 1997 survey the forecasts are 4 %, 12 % and 23 % respectively for the years 2000, 2005 and 2010. The difference in the predictions is somewhat larger for faster connections, but the results show the same pattern. While the experts in 1994 expected a

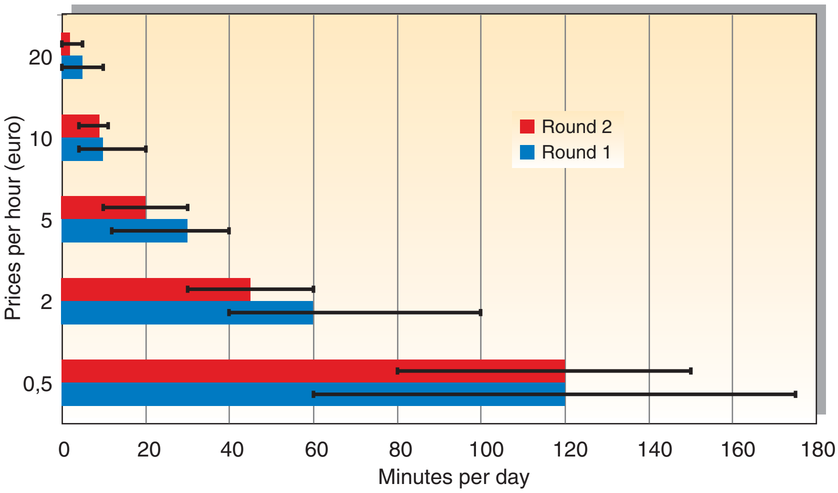


Figure 4 Demand curves for broadband access – all applications

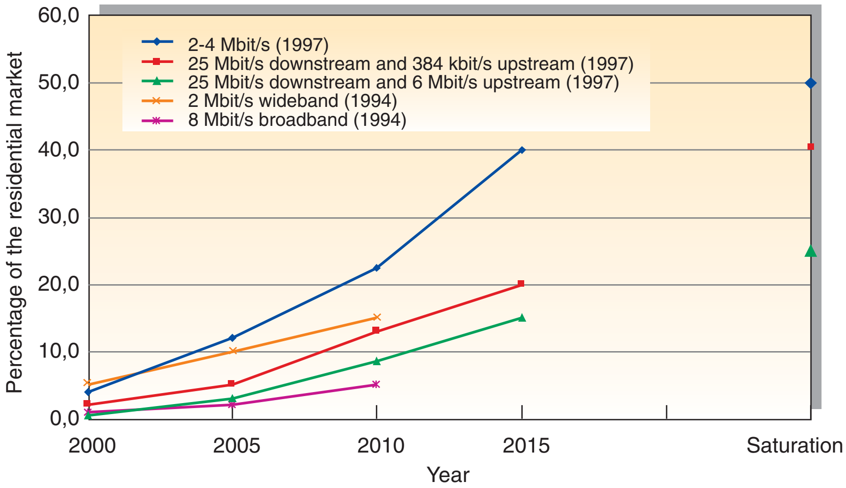


Figure 5 Forecast for broadband access in the residential market

Table 4 Revised broadband forecasts as percentage of the residential market

Access capacity	2000	2005	2010	2015	Saturation
2 Mbit/s	2	12	23	40	50
8 Mbit/s	0.5	5.5	14	22	40
26 Mbit/s	0.1	3	9	15	25
Sum	2.6	20	45	75	*)

**) The saturation for the various accesses will occur at different points in time*

Table 5 Parameter estimates and multiple correlation coefficient for broadband penetration forecast functions

Parameter estimates	a	b	g	M	R^2
2 Mbit/s	- 0.07496	- 0.19266	5	50	98.56
8 Mbit/s	- 4.79468	-0.13249	500	40	99.38
26 Mbit/s	- 4.57674	- 0.15775	500	25	99.37

penetration rate for 8 Mbit/s of 1 %, 2 % and 5 %, the respective penetration forecasts for 25 Mbit/s in the 1997 survey are 2 %, 5% and 13 %.

4.5 Analytical forecasting functions

The development of analytical forecast models for broadband access was a part of the OPTIMUM project. The results from the Delphi survey contain only 2 Mbit/s and 25 Mbit/s accesses. There are reasons to believe that also 8 Mbit/s will be a conventional offered access. Evaluation of the results shows that the sum of the two 25 Mbit/s gives about the same demand as the 2 Mbit/s. During the first ten years the demand for 2 Mbit/s will probably be significantly higher than 25 Mbit/s. Since the total demand for 25 Mbit/s seems optimistic, it has been suggested to transfer 25 Mbit/s with 384 kbit/s return demand to a 8 Mbit/s demand. In addition it has been suggested to split the given demand in a symmetric demand and an asymmetric demand. Since 8 Mbit/s is a lower capacity than 25 Mbit/s it has been suggested to increase demand by 10 %. In addition we will use 26 Mbit/s, which is closer to the new standard than 25 Mbit/s. The forecasts for 8 Mbit/s and 26 Mbit/s for the year 2000 is also reduced to 0.5 % and 0.1 % respectively. The revised forecasts are found in Table 4.

The demand forecasts in the table include both symmetric and asymmetric accesses. The fraction between asymmetric and symmetric will change over time, but during the first years, there will mainly be asymmetric accesses. The models developed in the OPTIMUM project are based on the results from the 1997 Delphi survey. Different analytical forecasting models for fitting the Delphi data are tested. The extended Logistic model with three parameters give a rather good fitting. The model is defined by the following expression:

$$Y_t = M / (1 + \exp(\alpha + \beta t))^\gamma$$

where the variables are defined as follows:

Y_t	Demand forecast at time t
M	Saturation level
t	Time
α, β, γ	Parameters.

The parameters α, β, γ cannot be estimated simultaneously by ordinary least squares regression since the model is non-linear in the parameters. The main objective in the fitting is not to get the best overall fit, but a reasonably good fit for the first years. Therefore, the parameters in the model are estimated by ordinary least squares regression (OLS) for different values of γ. The OLS estimation is based on the following transformation:

$$\ln((M/Y_t)^{1/\gamma} - 1) = \alpha + \beta t$$

The saturation level M and the parameter γ are fixed values in the estimation process. M is found from the Delphi data, while γ is estimated by systematic calculations of RMSE (root mean square error) for a set of different values. The multiple correlation coefficient, R^2, for the models is rather high. The estimated values are given in Table 5.

The broadband penetration forecasts are shown in Figure 6.

4.6 Symmetric and asymmetric demand modelling

The forecasts have to be divided into asymmetric and symmetric demand. Introduction of analytical functions are convenient for describing the share of asymmetric and symmetric accesses. The question is how the symmetric demand will develop compared to the asymmetric demand. The symmetric demand will probably be low for the first years compared to the asymmetric demand. After

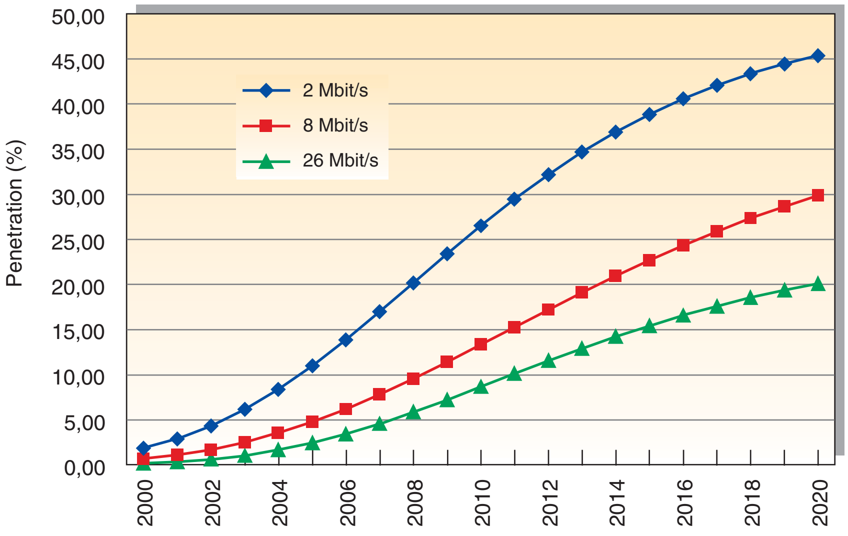


Figure 6 2 Mbit/s, 8 Mbit/s and 26 Mbit/s broadband forecasts some years the symmetric demand will probably have a relatively higher increase. In the end we assume that the proportion of symmetric subscriptions will converge to a given level. One important element is how the PCs are used as broadband terminals, either for communication with specific information sources, or for communication between users. The behaviour may be modelled by constructing analytical functions defining market shares as a function of time between the asymmetric demand and the symmetric demand. The analytical functions should be simple.

It is suggested to use the Logistic model to describe the evolution of the distribution of asymmetric and symmetric demand. The following parameters are defined:

S	Saturation level
S_t	Share of symmetric demand
t	Time
T	Time to 50 % saturation
a	Growth per year
α, β	Parameters in the Logistic model (Model 2).

The model is given by:

$$S_t = S / (1 + \exp(\alpha + \beta t))$$

The Logistic model is symmetric on both sides of $S/2$. The model is uniquely defined if S, α and β are defined. Instead of defining the parameters, we have decided to determine the function by the following assumptions:

1) Define the saturation level S;

2) Define the time (number of years) T, until half saturation is reached;

3) Define the market share S_0 at time 0, which is the year of introduction.

The parameters in the model are found by:

$$\alpha = -\beta * T$$

$$\beta = (1/T) * \ln(S/S_0 - 1)$$

The degree of symmetric demand depends on the offered broadband capacity. The analytical specification differs, depending on connection capacity. The saturation for 2 Mbit/s symmetric demand is suggested to be 40 % in the long run, while the 8 Mbit/s and 26 Mbit/s symmetric demand is suggested to be 30 % and 25 % respectively. The time to reach half saturation for 2 Mbit/s, 8 Mbit/s and 26 Mbit/s is estimated to be eight years, and the starting proportion of symmetric broadband communication demand is estimated to be 2 %. The distributions are shown in Figure 7.

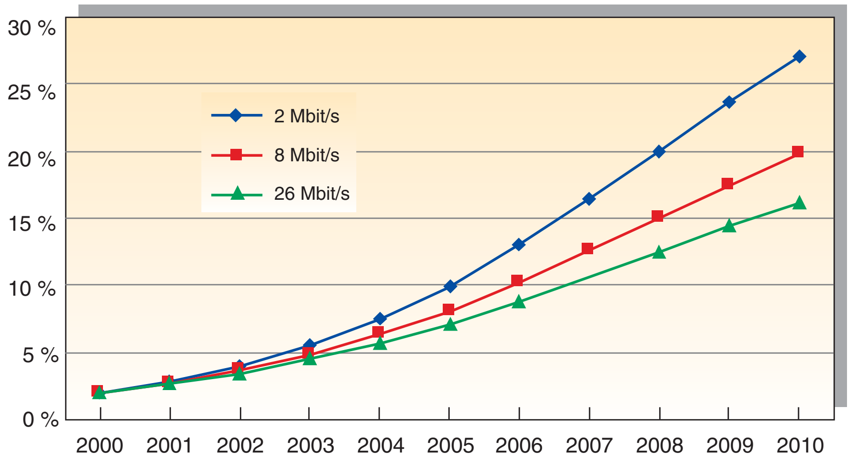


Figure 7 Proportion of the symmetric communication penetration of the total broadband penetration demand. The given assumptions lead to forecasts for asymmetric and symmetric demand as shown in Figure 8

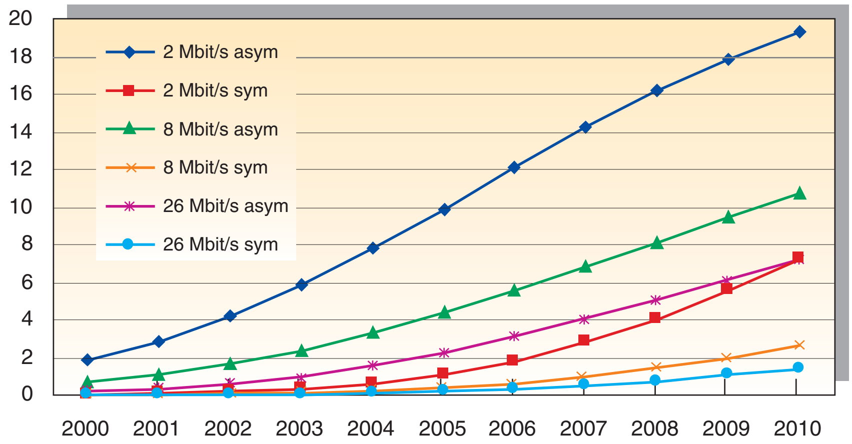


Figure 8 Forecasts for asymmetric and symmetric connections (%)

4.7 Demand for access capacities

The access lines with different capacities may support the use of many of the earlier mentioned applications. Thus, questions were asked on the demand for broadband access for three different access types as a function of annual costs. Figure 9 shows the estimated demand curves for 2 Mbit/s, 8 Mbit/s and 26 Mbit/s broadband connections. The difference between the demand curves is very small and indicates that residential users are not willing to pay much more for a high capacity connection despite the better quality.

4.8 Analytical demand models

As a part of the OPTIMUM project analytical demand models dependent on price were developed. Based on the same arguments as for analytical forecasting functions, 2 – 4 Mbit/s, 25 Mbit/s with a narrowband return channel and a broad-

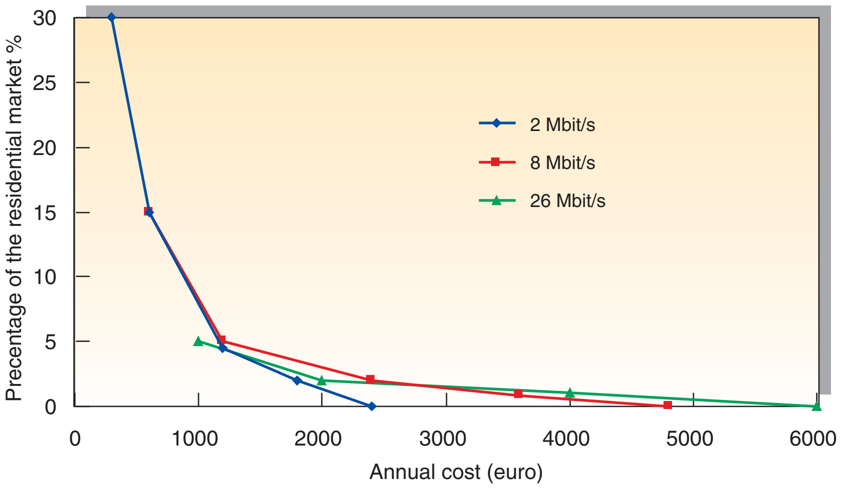


Figure 9 Demand curves for broadband access as a function of annual cost

band return channel are transferred to 2 Mbit/s, 8 Mbit/s and 26 Mbit/s. The suggested demand model based on three parameters is:

$$y = e^{(\alpha+\beta p)^{\gamma}}$$

y	Demand;
p	Price;
α, β, γ	Parameters in the model.

The parameter estimates are found by OLS regression for a given set of γ values. A variant of this model is based on the assumption that the demand is 100 % when the price is 0. Evaluation of the results show that the fitting is not satisfactory. To improve the fit, the parameters α and β are determined such that the demand curve passes through the two initial points, while the γ parameters are determined by minimising the squared distance between the demand curve and the results from the Delphi survey.

Now, let the initial values be:

$$(y_I, p_I) \text{ and } (y_L, p_L)$$

Hence:

$$\beta \;= -\left[(\ln y_L)^{1/\gamma} - (\ln y_I)^{1/\gamma}\right] / (p_I - p_L)$$

$$\alpha \;= (\ln y_I)^{1/\gamma} - \beta\, p_I$$

The parameter γ is found by minimising the following expression:

$$Q(\gamma) = \sum\left(y_i - e^{[\alpha(\gamma)+\beta(\gamma)p_i]^{\gamma}}\right)^2$$

In the non-linear estimation procedure, not only the last equation is minimised but also the first years achieve a reasonably good fit. For all models γ equal to around 10 gives a rather good fit. The framework for the demand curves is described hereafter. It is important to underline that the tariff in this context consists of both a one year subscription tariff and also a usage tariff based on the expected traffic during one year. The methodology described in the previous sections is used to predict the tariff evolution for broadband connections. The predictions are calculated in the following steps:

The tariff p is found by transforming the demand model to the formula:

$$p_t = [(\ln y_t)^{1/\gamma} - \alpha]/\beta$$

The parameters α, β and γ are found by the above equations. Then the tariff predictions for the years 2000, 2001, ..., 2010 are determined by inserting the demand forecasts $\{y_t\}$ in the same years. The tariffs are found in Table 6. The tariff evolution for broadband services in the mass market is shown in Figure 10.

4.9 Willingness to pay for access capacity

Willingness to pay as a function of disposable household income is estimated for broadband access based on answers from the respondents. Disposable income is the household income after tax, ie. the part of the income that is available for saving and purchasing goods and services. Figure 11 shows that households with an annual disposable income in the 10,000 to 15,000 euro range cannot afford to pay more for a high capacity connection. Incremental willingness to pay for broadband access is very small, even for wealthy households.

Table 6 Assumption tariff evolution for broadband services (mass market)

Parameters	2 Mbit/s asym	2 Mbit/s sym	8 Mbit/s asym	8 Mbit/s sym	26 Mbit/s asym	26 Mbit/s sym
Demand, year 2000	1.900 %	0.037 %	0.637 %	0.013 %	0.150 %	0.003 %
Demand, long run	40 %	40 %	30 %	30 %	25 %	20 %
Tariff, year 2000	1800 euro	2700 euro	3240 euro	4860 euro	5192 euro	7788 euro
Tariff, long run	500 euro	750 euro	900 euro	1350 euro	1442 euro	2163 euro

For households with an annual disposable income of between 25,000 and 60,000 euro the willingness to pay for subscription and traffic charges for the highest capacity access is only 2 % of the household's disposable income.

4.10 Price and capacity

The previous sections have shown a low willingness to pay for higher capacity and better quality. The questionnaire also included direct questions on the household's willingness to pay for increased capacity relative to a 128 kbit/s access, ie. an ISDN basic access. Figure 12 confirms a low willingness to pay for incremental increased connection capacity. The difference between the 75 % quartile (25 % answered higher) and the 25 % quartile (25 % answered lower) are shown in the figure as a measure of the variation in the answers. The uncertainty increases with increased capacity.

5 Conclusions

The results from the 1997 Delphi survey show that there will be a substantial demand for broadband services in the residential and SOHO markets during the next ten years. However, the households are not willing to pay too much more for additional broadband applications and additional capacity. Households with low disposable income will not afford to have a subscription, while households with a reasonable disposable income are willing to pay up to 2 % of their disposable income. The possibilities for substitution effects between new and old media (newspapers, magazines, video rental, video games, etc.) are taken into account.

The Delphi survey indicates that customers will be unwilling to pay much more for increased capacity. It is interesting to see that the demand curves for 2 Mbit/s, 8 Mbit/s and 26 Mbit/s are quite similar. The results are supported by the price/quality question where the experts indicate that the households are willing to pay twice as much for a 50 Mbit/s access compared to how much they are willing to pay for an ISDN BA access, and only 2.2 times as much for a 500 Mbit/s access. This is a quite important finding, because a 50 Mbit/s access is possible using VDSL modem for customers with short subscriber lines, while 500 Mbit/s is impossible because of the physical limitation on the twisted pair. To offer 500 Mbit/s access an FTTH solution will

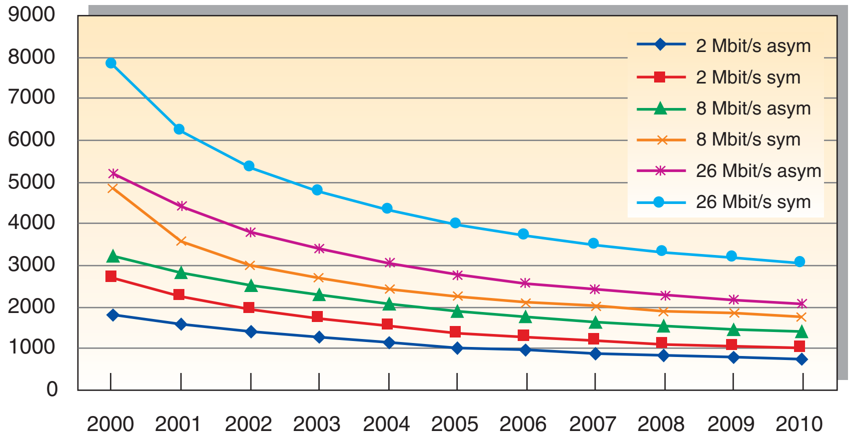


Figure 10 *Tariff evolution for broadband services (mass market) euro*

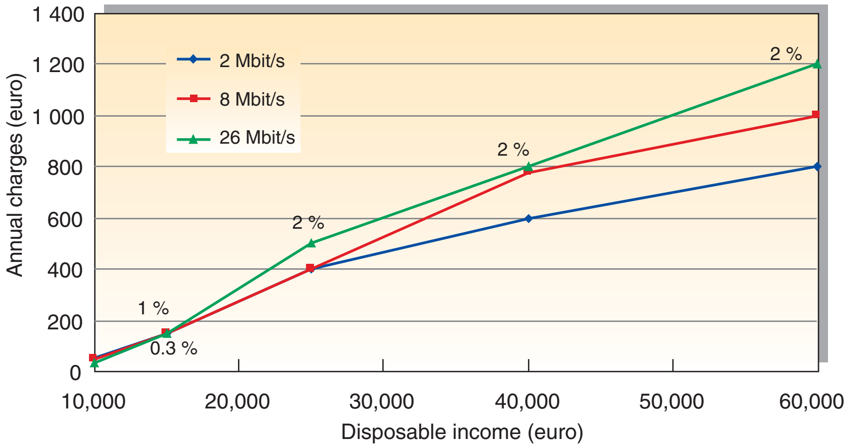


Figure 11 *Income spent on broadband accesses as a function of disposable income*

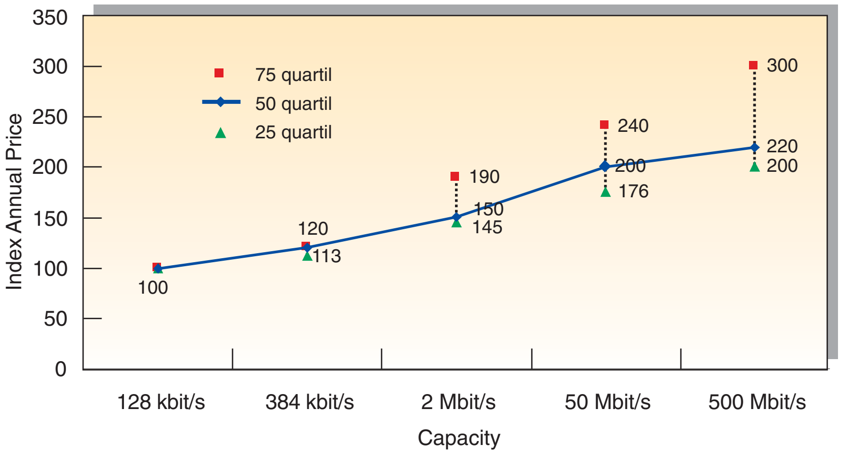


Figure 12 *Willingness to pay for increased capacity relative to 128 kbit/s*

probably be needed, but the customers are not willing to pay more than 2.2 times the price of an ordinary ISDN access!

Comparison of the results from the 1997 Delphi survey and the one carried out in 1994 shows that the results are rather similar. It is interesting to note that the penetration forecasts for a 2 Mbit/s access for the years 2000, 2005 and 2010 are quite close, with the 1997 forecasts being a little bit higher. For higher access capacities we see the same pattern. Usually, the experience when comparing old forecasts of new telecommunication services to new forecasts is that the old forecasts have been too optimistic. The forecasts of the Internet evolution is of course an exception.

Like in the 1994 Delphi survey, the variation in the answers among the experts in the 1997 Delphi survey was significantly reduced from round 1 to round 2. The variation was measured by 25 % and 75 % quartiles. The results indicated that it was unnecessary to carry out an additional round.

To realise the potential broadband demand, a key option is the development of the broadband drivers mentioned in the introduction. Models to predict cost trends for network components show that increased production gives significant reduced cost.

In addition analytical broadband forecasting functions and demand functions are developed together with forecasts for asymmetric and symmetric demand. The analytical forecasting functions and demand functions are modelled based on the results from the Delphi survey.

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Broadband Access Forecasts for the European Market

KJELL STORDAHL AND KJELL OVE KALHAGEN

The first part of the paper gives a review of broadband forecasts and broadband forecasting methods which have been applied during the last eight years to predict the broadband evolution in Western Europe. It is documented that the Delphi survey has developed rather good long-term forecasts based on surveys carried out in 1994 and 1997.

The second part of the paper presents demand modelling and forecasts for different access technologies for the fixed and mobile network based on results from the IST project TONIC[1][2]. The demand modelling and broadband forecasts are important input to four techno-economic business case analyses in the TONIC project. Forecasts for three generic types of Western European countries have been developed: A Nordic country, a Central European country and a Southern European country.

For the fixed network, a model has been developed for forecasting the total broadband penetration in the European residential market. Forecasts are made from 2002 to 2010 based on diffusion models. A specific model is developed to predict the market share evolution between ADSL, VDSL, fixed wireless broadband and cable modem/HFC, and then penetration forecasts for the different access technologies.

For the mobile network, specific forecasting models have been developed to forecast the total mobile access penetration in Europe and for the mobile system generations GSM, GPRS/HSCSD, 3G and 3G/WLAN.

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1 Introduction

Broadband forecasts are important input for a wide range of areas. Specific models are developed to forecast broadband subscriptions and broadband traffic generated in the network [1]. Short-term forecasts are used to estimate the revenue. The forecasts are also input to the budget process and even for following up the budget month by moth.

In addition, the forecasts are used to estimate the investment and operations and maintenance costs. Broadband forecasts are important for predicting purchase of broadband equipment, network components and to predict manpower used for the installations.

However, this paper focuses on long term evolution of broadband technologies. The broadband forecasting models have to take into account various broadband technologies. A battle has started between incumbent operators and cable operators in Western Europe. In some countries the cable operators have rather high broadband market shares since they have started broadband deployment earlier than the incumbent operators. The forecasts show that DSL access technology within a short time will be the dominating technology in Europe. However, in areas were there exist cable networks, the competition is intensive and the broadband penetration higher than normal [2,3]. The situation in Europe is different from North America where forecasts show that cable modem technology based on HFC during the coming years still will have more than 50 % of the market. Fixed wireless broadband access based on technologies like LMDS is for the moment rather expensive. A lot of operators plan to utilise the technology, but it will take some years before the technology is cheap enough to compete with DSL and HFC.

To be able to make the right decisions for the rollout of broadband platforms, overall techno-economic calculations have to be performed. The European Commission has since 1992 supported the following portfolio of techno-economic projects:

- TITAN, RACE 364 (1992–1995)
- OPTIMUM, 2087 (1996–1998)
- TERA[3], ACT 226 (1998–2000)
- TONIC, IST 25172 (2001–2002)

The broadband forecasting models have been an important element in techno-economic modelling.

2 Broadband Forecasting Models for Techno-Economic Analysis of Broadband Roll-out

Important input to techno-economic modelling of broadband rollout is broadband forecasts. Both quantitative and qualitative forecasting

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[1] *TONIC: TechnO-ecoNomICs of IP optimised networks and services*

[2] *http://www-nrc.nokia.com/tonic/*

[3] *http://www.telenor.no/fou/prosjekter/tera*

models are candidates for making broadband forecasts. Actual quantitative forecasting models could be Smoothing models, Time Series models (Box Jenkins approach), Kalman filter models, Regression models, Logit models, Diffusion models and other econometric models. Actual qualitative forecasting methods could be Market surveys, the Scenario method, the Analogy method, Experts methods and the Delphi method.

The question is what type of models can be used for techno-economic analysis of broadband rollout. The forecasting models have to satisfy the following:

1) Because of the nature of investment projects, long term forecasts are important.

2) The forecasting models should also have the ability to be applied with limited or no data at all as input.

In addition there should be possibilities to include relevant expert information.

To establish a new broadband platform, it is necessary to examine a project period of 5 – 10 years. Because of heavy investments the payback could be 5 years or more both in the fixed network using DSL, HFC or LMDS technology, and in the mobile network for UMTS. The mobile business case has also to take into account the mobile licences for UMTS. Hence, long term forecasting models have to be used to evaluate rollout of a new broadband platform.

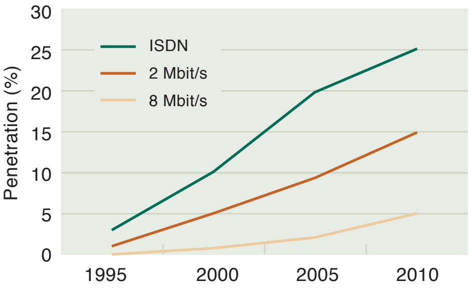

Figure 1 Forecasts of penetration of ISDN, wide- and broadband accesses in the residential market, Western Europe (Delphi survey, 1994)

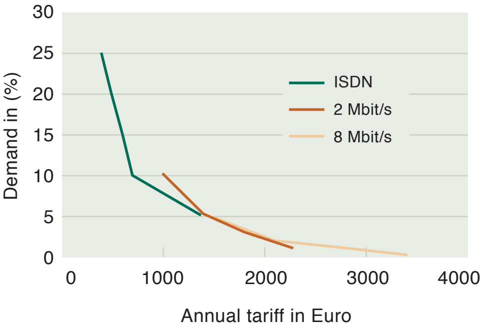

Figure 2 Demand curves ISDN, wide- and broadband accesses in the residential market, Western Europe (Delphi survey, 1994)

In case of no historical data the qualitative forecasting models are of course the most relevant models. Time series models and Kalman filter models are not relevant since they need a substantial number of observations. HFC and DSL were introduced in Western European countries in the period 1999 – 2001. Therefore the number of yearly historical observations in different European countries varies from 1 to 3. The forecasting models used have to utilise limited observations and in addition make long term forecasts.

3 Forecasting Models Used for Broadband Forecasts 1993 – 2000

The EU has since 1992 supported a portfolio of techno-economic projects, with the objective to analyse and evaluate broadband rollout. This chapter gives a review of the forecasting methods used in the techno-economic projects: TITAN, OPTIMUM, TERA and TONIC.

3.1 TITAN

Quantitative forecasting models could not be used in TITAN (Tool for Introduction Strategies and Techno-Economic Evaluations of Access Networks) since the project was carried out a long time before broadband services were introduced in the residential market. Even parts of broadband technology, which are used now, were not known. In the first phase of the project, internal expert evaluations were performed to make predictions of the future broadband market. The applications teleworking, telelearning, telegames, teleshopping, teleinteraction and information/thematic channels were examined. In 1994 a postal two-round Delphi survey was carried out among 100 experts from 10 different Western European countries. The experts had to answer questions about the demand for broadband applications, the demand for access capacity and willingness to pay. The access capacities were segmented in ISDN, wideband accesses (2 Mbit/s) and broadband accesses (8 Mbit/s).

The Delphi results contained demand forecasts for ISDN, 2 Mbit/s and 8 Mbit/s accesses in the years 1995, 2000, 2005 and 2010. The results are shown in Figures 1 and 2.

Figure 1 shows the demand curve for ISDN, wide- and broadband accesses. The experts in the Delphi survey had to estimate the demand based on rather high annual tariffs. For wideband the tariff interval was [1000 – 2300 Euro], while the interval was [1500 – 3400 Euro] for broadband accesses.

The differences between the demand curves are small and show that the users are not willing to pay much more for higher capacity. One reason is the relatively high tariff levels.

Ranking of broadband applications is shown in Table 1. The demand curve and price elasticity was estimated based on results from the Delphi survey. The results are documented in [4–7].

3.2 OPTIMUM

A new Delphi survey was performed in OPTIMUM (Optimised Network Architectures for Multimedia Services) to predict the future evolution of the broadband market. The survey was an on-site two-round Delphi survey carried out on the Techno-economic Workshop arranged by OPTIMUM in 1997. In 1994 a set of applications were described. Now, the relevant applications were grouped in the following application classes:

1 Tele-entertainment (Symmetric and asymmetric)
  - Multimedia telegames
  - Virtual reality
  - Video on demand
  - Audio/music on demand

2 Information services (Asymmetric)
  - Information retrieval
  - Electronic magazines
  - Information retrieval by intelligent agents
  - Electronic newspapers

3 Teleshopping (Asymmetric)
  - Teleshopping
  - Advertising

4 Private communications services (Symmetric)
  - Videophone
  - Teleconferencing

5 Teleworking (Symmetric and asymmetric)
  - Videophone
  - Joint editing/publishing
  - Teleconferencing
  - Teleparticipation
  - Information retrieval
  - Multimedia application

6 Telelearning (Symmetric and asymmetric)
  - Video-on-demand
  - Videophone
  - Virtual reality

7 Telecommunity (Symmetric and asymmetric)
  - Telesurveillance
  - Videophone
  - Telediagnostics

The questionnaire starts with a description of the applications. The capacity classes defined were 2–4 Mbit/s with 384 kbit/s and 25 Mbit/s with 384 kbit/s and 6 Mbit/s return, respectively. The main questions in the survey were:

- Usage as a function of charge;
- Penetration as a function of charge;
- Penetration as a function of time (forecast);
- Demand as a function of disposable household income.

The experts in the Delphi surveys were asked to select the three most interesting broadband applications. Table 1 shows the ranking of the application in the Delphi survey in 1994 and 1997. The table shows that the Delphi survey in 1994 and 1997 predict that home office/teleworking and tele-entertainment/video-on-demand will be important future broadband applications.

The broadband penetration forecasts from the Delphi surveys in 1994 and 1997 are described

Applications 1994	Answers 1994	Application classes 1997	Answers 1997
Video-on-demand	28 %	Teleworking	28 %
Home office	27 %	Information services	25 %
Videotelephony	18 %	Tele-entertainment	24 %
Remote education	8 %	Teleshopping	7 %
Multimedia telegames	7 %	Private communications services	6 %
Home ordering system	4 %	Telecommunity	4 %
Interactive TV/specialised channels	4 %	Telelearning	3 %
Electronic newspapers	3 %	Others (Telebanking)	1 %
Advertising and marketing	1 %		
Telecommunity	0 %		

Table 1 Evaluation of applications. Percentage score

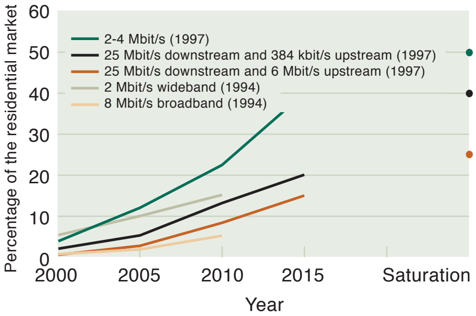

Figure 3 Broadband penetration forecasts for the residential market in Western Europe (1994 and 1997)

in Figure 3. The 2 Mbit/s penetration forecasts in the two surveys are rather close, while high access capacity predictions are lower in 1994 compared with 1997. The Delphi survey from 1994 predicted 13 % broadband penetration in year 2005, while the survey from 1997 predicted 20.5 % broadband penetration.

In OPTIMUM the demand classes were revised to 2, 8 and 25 Mbit/s downstream access capacities. The demand curves based on the Delphi results are shown in Figure 4. The figure shows limited broadband demand when the annual tariff exceeds 1000 Euro. The willingness to pay for access capacity was examined with reference to ISDN. The results are shown in Figure 5.

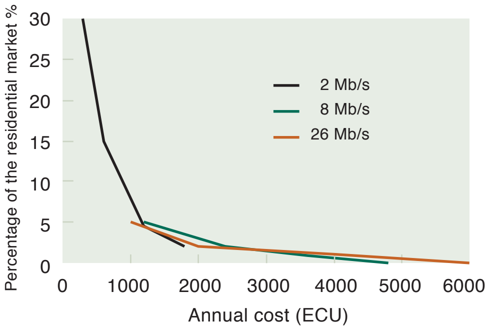

Figure 4 Demand curves as a function of annual cost in Euro (ECU) for broadband subscription (1997)

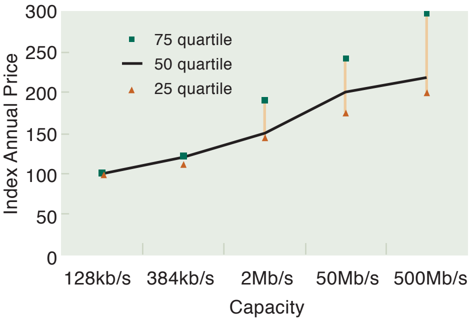

Figure 5 Willingness to pay for increased capacity relative to ISDN (128 kbit/s)

[8–10] describe results from the 1997 Delphi survey in more detail.

3.3 TERA

TERA (Techno-Economics Results from ACTS) utilised the demand data from the 1997 Delphi survey. Diffusion models were examined to describe the evolution of broadband penetration. A four parameter Logistic model was used to the modelling. The model is defined by:

$$Y_t = M / (1 + \exp(\alpha + \beta t))^{\gamma}$$

where the variables are defined as follows:

Y_t is demand forecast at time t
M is saturation level
t is time
α, β, γ are parameters

The model was used to forecast the demand for 2, 8 and 25 Mbit/s accesses. The results are shown in Figure 6.

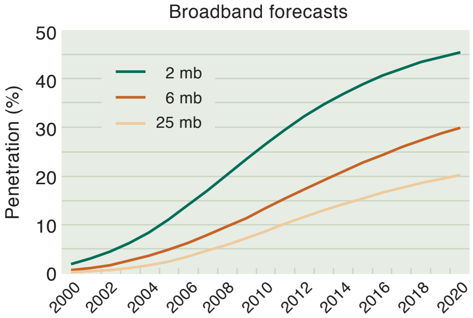

Figure 6 Demand forecasts for 2, 8 and 25 Mbit/s accesses in the residential market in Western Europe (1999)

Since there was no reason to adjust the Delphi forecasts, the Delphi observations were used as input to fit the parameters in the Logistic model. In addition a specific model was used to predict market share between asymmetric and symmetric accesses. The model was described by:

$$S_t = S / (1 + \exp(\alpha + \beta t))$$

Where the parameters are defined by:
S is saturation level
S_t is share of symmetric demand
t is time
α, β are parameters in the Logistic model (Model 2)

Figure 7 describes the market share evolution of symmetric accesses

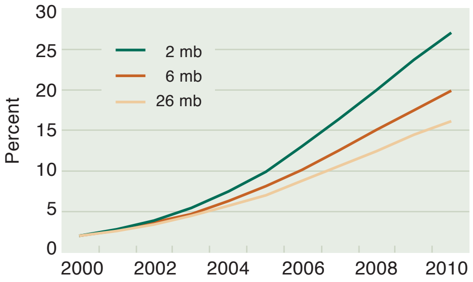

Figure 7 Market share evolution of symmetric broadband accesses in the residential market

Results are described in more detail in [10–17].

4 Forecasting Models Used for Broadband Forecasts in TONIC

A model has been developed to forecast the total broadband penetration in the European residential market. Forecasts are done from 2001 to 2010 based on diffusion models. Specific models are developed to predict the market share evolution between ADSL, VDSL, fixed wireless broadband and cable modem/HFC, and then penetration forecasts for the different access technologies.

Especially the evolution of broadband in Germany, Sweden and Denmark speeds up the broadband demand in Europe. Germany reached 2 million DSL accesses already at the end of 2001. The wide use of (narrowband) Internet, the flat rate tariff and the broadband competition are important drivers for broadband. Introduction of wholesale and the possibility to hire copper lines (LLUB) increase the competition. Also different broadband technologies compete to catch significant market share. Monitoring on the demand data shows that the cable operators have been dominating the first years. However, the broadband penetration at this stage is not very high.

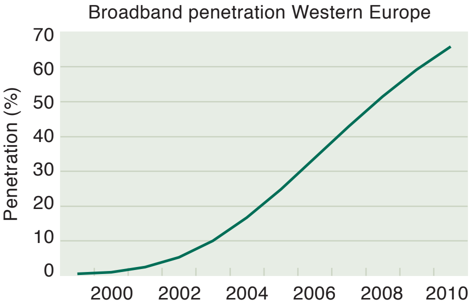

Figure 8 Long-term broadband penetration residential markets Western Europe

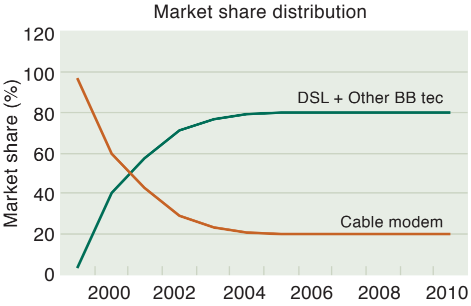

Figure 9 Predicted market share evolution between cable modems (HFC) and DSL + other broadband technologies

4.1 Data Sources and Modelling

Information has been gathered from a lot of different sources. The project partners have collected up-to-date data of the broadband evolution, demographic data and tariff data. Other important sources have been consultant reports from Jupiter [18], Strategy Analytics [19] and OVUM [20]. The Tonic project has developed new forecasts based on the collected information [21–23]. It has been difficult to use the forecasts from the consultant reports since the forecasts predict too high a market share for cable modem and the HFC technology, probably influenced by the situation in North America.

The first step has been to make penetration forecasts for the total broadband demand in the residential market. A four parameter logistic model has been used for the forecasts. The saturation level in the model has been estimated based on coverage for broadband in various countries in Europe. In non-dense rural areas, the expenses in rolling out broadband are too high, because too few households give payback to the necessary investments. The other parameters in the model are estimated based on historical data and also some expert evaluations.

Then predictions of the evolution of market share between different broadband technology have been developed based on a set of Logistic forecasting models. Migration between technologies are handled when VDSL and Fixed wireless broadband are catching market shares from ADSL and cable modem. The penetration forecasts for the broadband technologies are found by multiplying the predicted market share with the total broadband penetration.

4.2 Residential Broadband Penetration Forecasts for Western Europe

Figure 8 shows the long-term Western European residential broadband subscription forecasts. The demand is expressed in percentage of total number of households. The figure shows a penetration of nearly 25 % at the end of 2005.

4.3 Cable Modem (HFC) Market Share Evolution

Figure 9 shows that the market share for cable modems (HFC) starts on nearly 100 % in 1999 but loses about 40 % of the market during the first two years. The long-term forecasts show saturation for cable modem on a 20 % level. Even that level may be a little bit too high for Western Europe. These forecasts contradict the long-term forecasts from various consultant companies, which predict higher cable modem penetration.

4.4 Market Share Evolution for DSL

Figure 10 shows that the market share evolution of DSL reaches a turning point around 2005. Then the DSL market share is predicted to decrease because of other competing technologies.

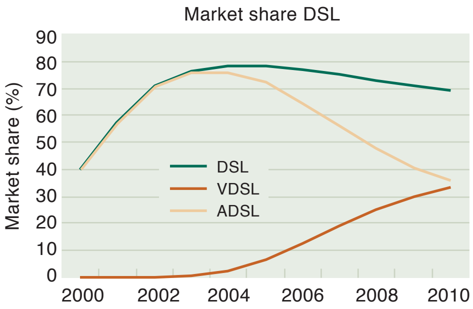

Figure 10 Market share evolution of DSL and the distribution between ADSL and VDSL

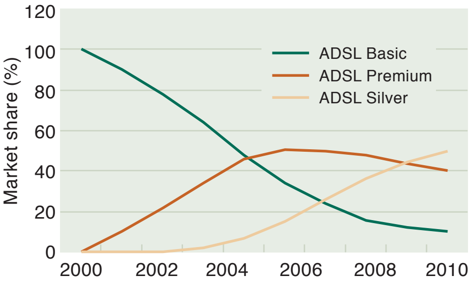

Figure 11 Predicted market share evolution for ADSL basic, premium and silver capacity.

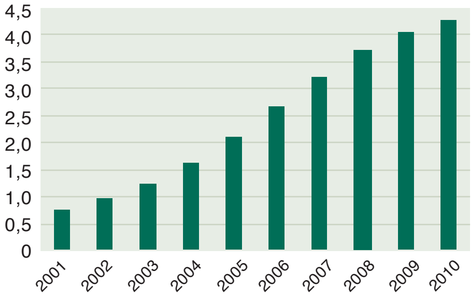

Figure 12 Evolution of predicted average downstream capacity in Mb for ADSL subscriptions

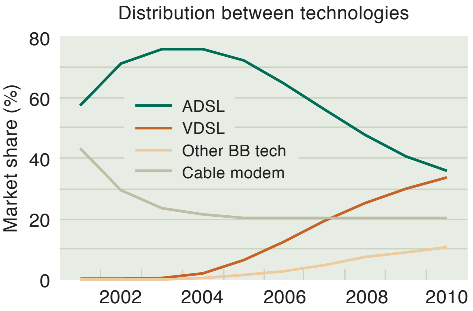

Figure 13 Market share distribution and prediction of ADSL, VDSL, cable modem and other broadband technologies

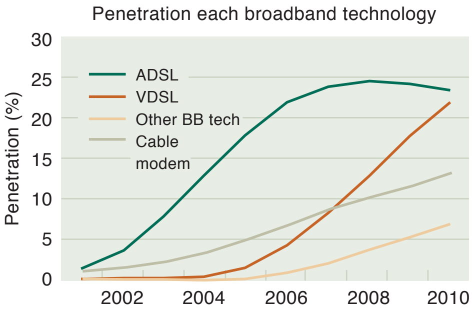

Figure 14 Broadband penetration forecasts for ADSL, VDSL, cable modem and other broadband technologies

Separate forecasts are developed for VDSL market share evolution. The figure shows that VDSL starts slowly in 2003, but increases rather significantly and reaches 30 % penetration in 2010. At the same time VDSL is at the same subscription volume as ADSL. Physical limitations especially the length of the subscriber line influences the market potential for VDSL.

4.5 Market Share Evolution for Different ADSL Access Capacities

The ADSL is divided into the following access capacities:

• Basic-Residential:	512/128kb
• Premium-Residential:	2048/256kb
• Silver-Residential:	6144/640kb

The expected market share evolution is shown in Figure 11. The figure shows that “Basic” is dominating the first years starting with nearly 100 % market share in year 2001. In 2005 “Premium” reaches the same level as “Basic”. The demand for “Silver” is expected to start around 2003.

The mean downstream capacity for “Basic” is assumed to be 0.75 kb. For Premium and Silver the respective figures are 3 Mb and 6 Mb. Based on the assumed figures and the market share distribution, the evolution in average downstream capacity for ADSL is described in Figure 12. The figure shows that the average downstream capacity is 0.75 Mb in 2001. The capacity increases to about 2 Mb in 2005 and about 4 Mb in 2009 for ADSL subscriptions.

4.6 Distribution Between Technology

To be able to predict penetrations for each technology, the overall market share for each technology is needed. Figure 13 shows the market share evolution between different technologies.

The resulting penetration forecasts for each technology are given in Figure 14.

4.7 Broadband Forecasts for Country Groups

The TONIC project has also developed segmented country forecasts for Europe. Requirements for the country grouping have been to have reasonable homogeneous country groups and in addition mainly countries represented in the TONIC project. The following country groups were selected both for the fixed and the mobile network services:

- Nordic countries (Finland, Norway)
- Large central European countries (France, Germany, UK)
- Southern European Countries (Greece, Portugal)

4.7.1 Nordic Countries (Finland, Norway)

The Nordic country group is represented by Finland and Norway, since the countries are partners in the TONIC project. *It is important to underline that Sweden and Denmark, which have a rather high broadband penetration, are not included in the presented results*. The broadband evolution in Finland and Norway is rather similar. The number of households in the two countries is 2.45 mill and 2.01 mill, respectively, while GDP per capita is about 27,000 Euro and 38,000 Euro. At the end of 2001 the broadband penetration in Finland was 3.7 % consisting of 2.9 % DSL and 0.9 % Cable modem. At the end of 2001 the broadband penetration in Norway was 3.5 % consisting of 2.0 % DSL and 1.5 % Cable modem.

Figure 15 shows the broadband penetration forecasts for the Nordic country group. It assumed that saturation is lower in the Nordic countries compared with central European countries because the proportion of low density areas is larger in the Nordic countries.

The predicted market share evolution between broadband technologies is shown in Figure 16.

4.7.2 Large Central European Countries (France, Germany, UK)

France, Germany and UK represent the large central European country group. The number of households in the three countries is 27 mill, 38 mill and 26 mill, respectively, while GDP per capita is about 27,000 Euro, 28,000 Euro and 24,000 Euro. At the end of 2001 the broadband penetration in France was 2.6 %, consisting of 2.0 % DSL and 0.6 % Cable modem. At the end of 2001 the broadband penetration in Germany was 6.1 % consisting of 5.8 % DSL and 0.3 % cable modem.

Figure 17 shows the broadband penetration forecasts for the large central European country group. It assumes that the forecasts are close to the European mean forecasts.

The predicted market share evolution between broadband technologies is shown in Figure 18.

4.7.3 Southern European Countries (Greece, Portugal)

The Southern European country group is represented by Greece and Portugal, since the countries are partners in the TONIC project. The broadband evolution in Greece and Portugal is rather low so far. The number of households in the two countries is 3.7 mill and 5.1 mill, respectively, while GDP per capita is about 13,000 Euro and 12,000 Euro. At the end of 2001 the broadband penetration in Greece was 0.4 % consisting of 0.1 % DSL and 0.3 % cable modem.

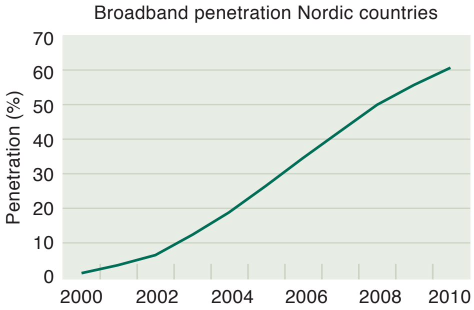

Figure 15 Broadband penetration forecasts

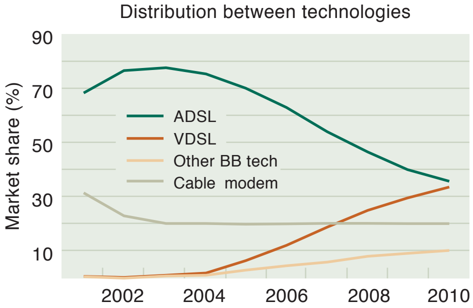

Figure 16 Market share evolution of broadband technology

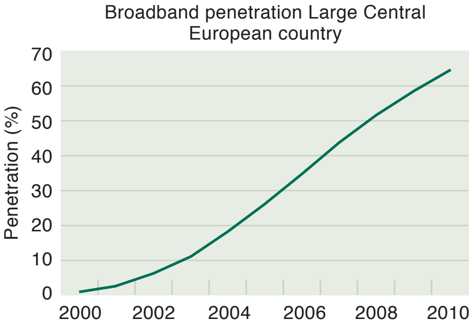

Figure 17 Broadband penetration forecasts

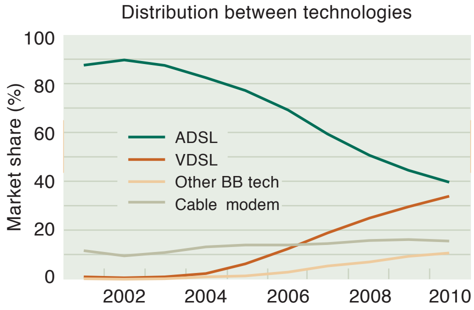

Figure 18 Market share evolution of broadband technology

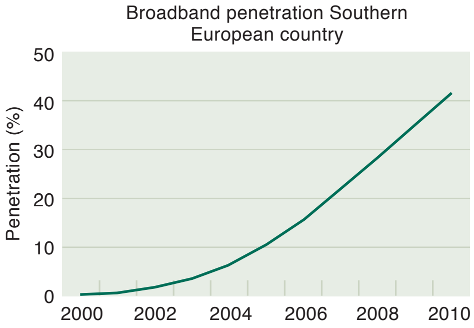

Figure 19 Broadband penetration forecasts

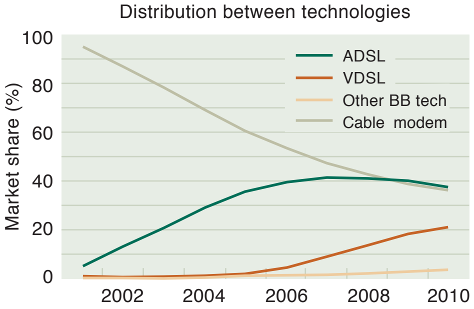

Figure 20 Market share evolution of broadband technology

At the end of 2001 the broadband penetration in Portugal was 1.4 %, consisting of 0.02 % DSL and 1.4 % cable modem. Figure 19 shows the broadband penetration forecasts for the Southern European country group. The figure shows that the evolution is more defensive compared with Central European and Nordic countries.

The predicted market share evolution between broadband technologies is shown in Figure 20.

5 Forecasting Models Used for Mobile Forecasts in TONIC

Demand forecasts for different mobile technologies for Western European countries are presented. The forecasts are established for three different groups of Western European countries. The countries in each group are similar with respect to GDP per capita, GSM penetration today, and forecasted UMTS penetration in 2007. Specific forecasts are developed for each country group.

In particular, after formulating projections on total mobile subscriber penetration, we make forecasts for the different penetration rates for the following mobile system “generations”:

- 2G – digital mobile systems such as GSM
- 2.5 G – HSCSD, GPRS, EDGE
- 3G – UMTS
- 3.5G – ubiquitous roaming among 3G and WLAN[4] systems

It is assumed that a “higher” mobile subscription has interworking access to “lower” mobile subscriptions. 3G have for example possibilities to interwork with 2G and 2.5G. The system generation 3.5G is in fact an UMTS subscription which also has WLAN possibilities. The TONIC Project has developed a set of forecasting models based on extracted external information and on members’ expertise for the establishment of basic assumptions. The results of this work are inputs to the forecasting models.

The demand models and tariff predictions serve as important input to business cases I and II.

5.1 Data Sources and Modelling

Information has been collected from different consultancy reports. The three most important reports are from Strategy Analytics [24], Analysys [25] and OVUM [26]. In addition the TONIC project partners have collected up-to-date information about mobile penetration, demographic data and ARPU levels.

As for the fixed network, a four parameter logistic model has been applied to the forecasts. The saturation level in the model has been estimated based on the number of mobile subscribers and subscriptions. The other parameters in the model are estimated based on historical data and also some expert evaluations.

5.2 Western European Mobile Market Forecast

The statistics show that the 2G subscribers have increased from about 15 % to 70 % during the period 1997 – 2001. One important driver the last years is the prepaid subscriptions, which constitute a significant part. Based on evaluation from the TONIC project and external consultant reports, assumptions of average mobile penetration for Western Europe are assumed, see Table 2.

A four parameter Logistic model is used to generate penetration rates from 1997 to 2010, as shown in Figure 21.

The total subscriber penetration in Western Europe is split into four mobile system generations, namely 2G, 2.5G, 3G and 3.5G. Assumptions about the relative market share for each of the systems were discussed and adopted. We assume that the share of 2G is decreasing to 2 % in 2010, while the respective shares at that time will be 28 % for 2.5G, 37 % for 3G and 33 % for 3.5G. Our assumptions for 3G taking off in 2003 are based on the fact that the initial horizon of early 2002 today appears ambitious, and most operators admit to at least a 6–12 months’ delay.

Table 2 Subscriptions and subscribers assumption for mobile penetration in Western Europe

Penetration/year	2005	2010	Saturation
Subscribers	81	90	95
Subscriptions	100	120	130

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[4] *Based on the technical architecture developed within the IST-MIND project (WLAN is Hiperlan2).*

Based on the assumptions for the evolution of the total subscriber penetration combined with the assumptions regarding each of the mobile systems, we have calculated the penetration forecast for the four different mobile generations. These penetrations are shown in Figure 23.

We can see that the predicted subscriber penetration levels for 2G and 2.5G systems are equal in year 2004/2005. 3G subscriber penetration is 3 % in 2003, increasing to about 33 % in 2010. 3.5G subscriber penetration will reach almost 30 % in 2010.

Figure 24 shows subscription penetration for different mobile systems based on assumptions in Table 1 and the evolution of market shares given in Table 2. It is assumed that mobile subscribers will have more than one mobile subscription.

We see that total mobile subscription penetration will reach 120 % in 2010. 2.5G subscriptions will reach almost 40 % in 2010. 3G subscription penetration is almost 4 % in 2003, increasing to 40 % in 2010. 3.5G subscriptions will increase from 1 % in 2005 to nearly 40 % in 2010.

5.3 European Public WLAN Access in Hot-Spot Areas

The number of hot-spot locations that will be WLAN-enabled is one of the critical uncertainties for the 3.5G subscriber forecasts. Analysys have based their forecasts on the assumption that property owners will react positively to the service propositions currently being in place by operators and that roaming arrangements between public WLAN operators will emerge from 2002 onwards. Analysys have estimated the rollout in hot spots by considering the number of potential locations by type illustrated in Figure 25.

If these assumptions are correct, the number of hot spots with WLAN access will reach over 90,000 locations across Europe by 2006. Figure 25 shows that the overall value of the market is likely to be highly sensitive to the ability of service providers to persuade the owners of cafés, restaurants and hotels to host public WLAN services.

5.4 Mobile Forecast for Each Country Group

5.4.1 Nordic Countries

The Nordic country group is represented by Finland and Norway.

The mobile evolution in Finland and Norway is rather similar. For a long time Finland has been the country with the highest mobile penetration. In the same period Norway has been among the top three. Because of heavy sale of prepaid

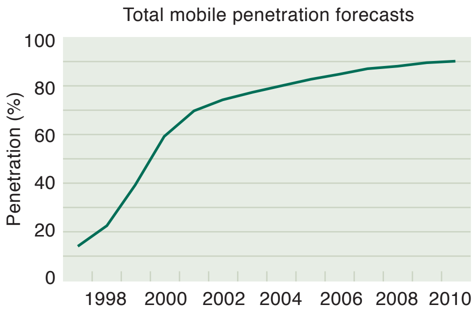

Figure 21 Mobile subscriber penetration forecasts for Western Europe

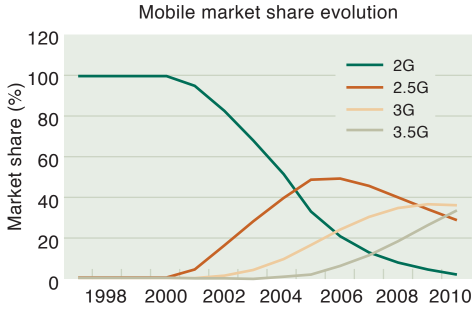

Figure 22 Shares of different mobile systems for Western Europe

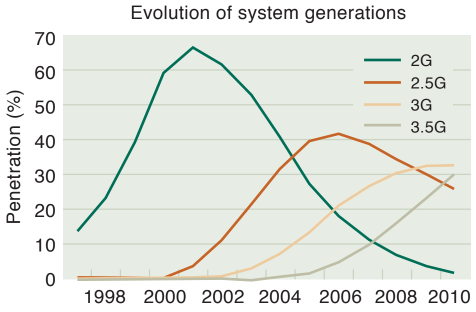

Figure 23 Subscriber penetration forecasts for different mobile systems for Western Europe

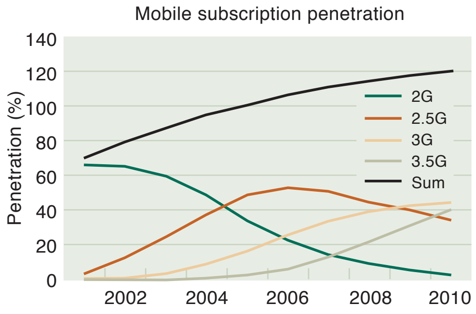

Figure 24 Subscription penetration forecasts for different mobile systems for Western Europe

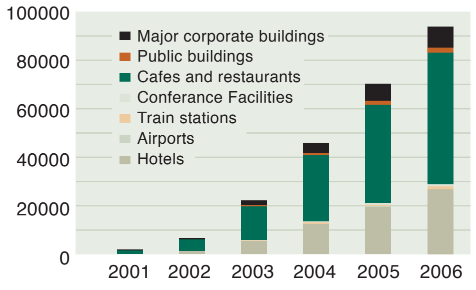

Figure 25 Public WLAN access locations, by type of location (source: Analysys)

mobile card the mobile penetration starts to be more even in several European countries.

The number of inhabitants in the two countries is 5.16 mill and 4.45 mill, respectively, while GDP per capita is about 27,000 Euro and 38,000 Euro. At the end of 2001 the mobile penetration was 80 % in both Finland and Norway.

Figure 26 shows the market share evolution of mobile system generations for Nordic countries.

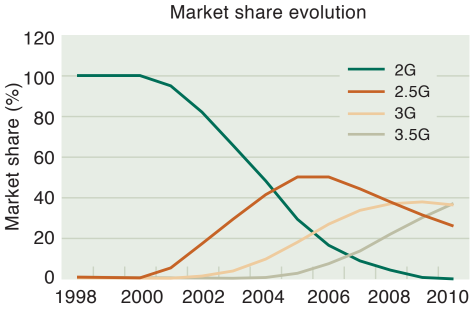

Figure 26 Market share evolution of mobile system generations

Figure 27 shows that the 2G penetrations in 2010 is 0 %, while 2.5G are 25 % and 3.5G is 37 %. The market share is multiplied by the total mobile penetration forecasts for the Nordic countries.

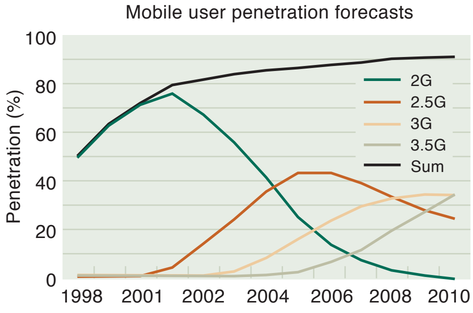

Figure 27 Mobile penetration forecasts for the Nordic country group

5.4.2 Large Central European Country (France, Germany and UK)

France, Germany and UK represent the large Central European country group. The number of inhabitants in the three countries is 59 mill., 82 mill., and 59 mill., respectively, while GDP per capita is about 27,000 Euro, 28,000 Euro and 24,000 Euro. At the end of 2001 the mobile penetration was 58 % in France, 67 % in Germany and about 75 % in the UK. It is assumed that the mobile evolution for the large Central European countries is close to the evolution for Western Europe.

Figure 28 shows the market share evolution of mobile system generations for large Central European countries. The figure shows that the 2G penetrations in 2010 is 0 %, while 2.5G is 30 % and 3.5G is 33 %. The market share is multiplied by the total mobile penetration forecasts for the Nordic countries. The results are shown in Figure 29.

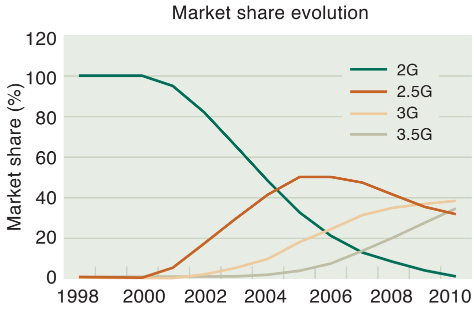

Figure 28 Market share evolution of mobile system generations

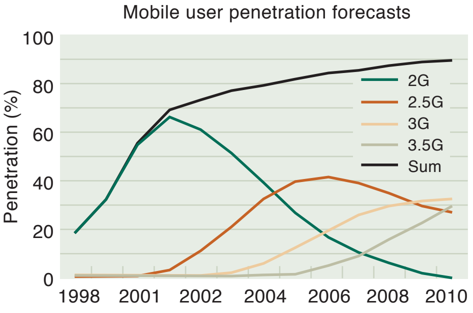

Figure 29 Mobile penetration forecasts

5.4.3 Southern European Country (Portugal and Greece)

The Southern European country group is represented by Greece and Portugal. The mobile evolution in Greece and Portugal has increased very significantly during recent years. At the end of 2001 the mobile penetration was 70 % in Greece and 79 % in Portugal. The number of inhabitants in the two countries is 10.9 mill and 10.4 mill, respectively, while GDP per capita is about 27,000 Euro and 38,000 Euro.

Figure 30 shows the market share evolution of mobile system generations for the Southern European country group.

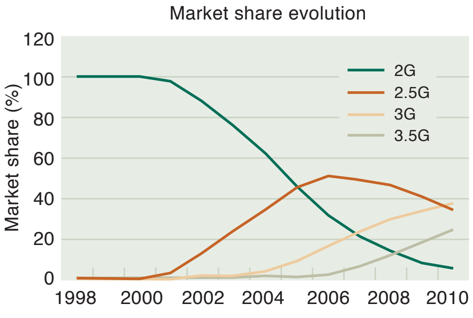

Figure 30 Market share evolution of mobile systems generations

Figure 31 shows that the 2G penetrations in 2010 is 5 %, while 2.5G is 33 % and 3.5G is 25 %. The market share is multiplied by the total mobile penetration forecasts for the Southern European country group. The results are shown in Figure 31.

6 Conclusions

An overview of broadband forecasting models used during the last eight years in a portfolio of techno-economic projects supported by the European Commission has been presented. The forecasts have mainly been based on expert surveys, especially Delphi surveys, before the broadband services were offered. Also diffusion models are used based on results from Delphi surveys and historical demand data. Table 3 gives a comparison of broadband penetration forecasts for Western Europe in 2005. The table shows that the forecasts are mainly on the same level. One exception is the forecasts done in 1994. However, at that time much higher annual tariffs on broadband were expected compared to what we see today. The main conclusion is that the long term forecasting models used seem to give rather good results. If the flat rate tariff regime is changed during the next years because of heavy traffic in the core network, it may be possible that a level of 20 % penetration will be more probable for year 2005.

The paper presents a methodology to forecast broadband penetration based on migration between the competing broadband technologies ADSL, VDSL, HFC (cable modem) and fixed wireless broadband.

The TONIC forecasts show that DSL access technology within a short time will be the dominating technology in Europe. The situation in Europe is different from North America where forecasts show that cable modem technology based on HFC during the next years will still have more than 50 % of the market. Fixed wireless broadband access based on technologies like LMDS are for the moment rather expensive.

Demand forecasts for different mobile technologies for Western European countries are presented. The forecasts are established for three different groups of Western European countries. The following mobile system “generations” have been considered:

- 2G – digital mobile systems such as GSM
- 2.5 G – HSCSD, GPRS, EDGE
- 3G – UMTS
- 3.5G – ubiquitous roaming among 3G and WLAN[5] systems

The predicted Western European subscriber penetration levels for 2G and 2.5G systems are equal in year 2004/2005. 3G-subscriber penetration is 3 % in 2003, increasing to about 33 % in 2010. WLAN subscriber penetration is predicted to reach almost 30 % in 2010.

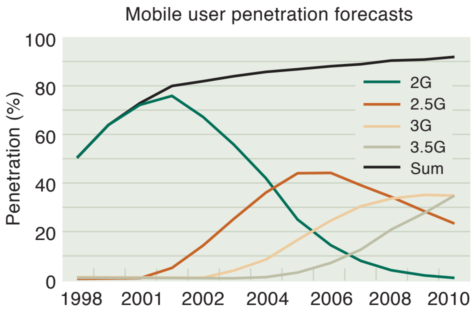

Figure 31 Mobile penetration forecasts for the Southern European country group

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Table 3 Broadband penetration forecasts, Western Europe 2005

	Penetration
TITAN forecasts (Delphi survey, 1994)	11.3 %
OPTIMUM forecasts (Delphi survey, 1997)	20.5 %
TERA forecasts (Diffusion models, 2000)	20.5 %
TONIC forecasts (Diffusion models, 2002)	24.9 %

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[5] *Based on the technical architecture developed within the IST-MIND project (WLAN is Hiperlan2).*

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Long-term broadband technology forecasting

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The paper gives an overview of the relevant broadband technologies, describes their market positions and possibilities. Diffusion models are used to make long-term broadband forecasts for the Western European residential market. The forecasts are separated for the main broadband technologies ADSL, ADSL2+/VDSL, Cable modem and other technologies (FTTx, BWA) based on market share predictions for each technology. The long-term forecasts are evaluated and compared with other broadband forecasts for the Western European market.

1 Introduction

In 2004 the Norwegian Government gave the following statement on broadband:

> *The Government looks at deployment of the broadband network as establishment of a national infrastructure, which during the coming years will be as important for evolution of modern Norway as the telephone network, power line network, railway network, roads, water and sewage network earlier have been for the Norwegian Society.*

The same statement applies also to other countries. The broadband network provides new possibilities and advantages for the business and public sector by giving access to an advanced high capacity electronic infrastructure. The technology and the network will be a fundament for application of information technology, for innovation, rationalisation and value creation. In addition broadband will change the behaviour of households in the private sector significantly over the next years.

The broadband network is the last step of the evolutionary part of the telecommunication network starting with telegraph, telephone, telex, fax, low capacity data network (packet and circuit switched), Nordic mobile systems, GSM, GPRS, Internet and leased lines.

The broadband networks in North America and Western Europe were mainly established just before 2000. During the first two years the HFC technology was dominant in both areas, but in most countries of Western Europe, DSL has now taken over as the leading technology.

Still there are many challenges for rolling out broadband. A lot of different broadband technologies are available. In most countries a lot of competitors are involved in the market. Regulatory bodies have opened the broadband market by introduction of Local Loop Unbundling (LLU) giving other operators the possibility to lease the incumbent's copper pair. Nowadays the regulatory bodies examine the market to check if the incumbent has Significant Market Power (SMP) and will in that case use some regulating tools to reduce the incumbent's market position. The main actors in the broadband market are: incumbents, operators owning different types of infrastructure (fibre, radio, twisted copper), virtual operators, energy companies, wholesalers, Internet Service Providers (ISP), service providers, manufactures, vendors.

To be able to make the right decisions in this very dynamic market, it is vital to make broadband forecasts. This paper concentrates on long-term broadband forecasts, which are used for project investments and investments for establishment of broadband technology platforms.

During a period of 12 years (1992 – 2004) long-term forecasts have been developed as part of techno-economic broadband assessments for analysing various broadband technologies through the European programs RACE, ACTS and IST, by the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC financed by the European Commission. *This paper documents broadband forecast modelling performed by the CELTIC project Ecosys.*

2 Making long-term broadband forecasts

10 – 20 years ago it was much more straightfoward to make forecasts in the telecom market. In Europe, it was limited competition and the incumbents were controlling the market. There were only a few services available and a limited number of technologies and networks, and the telecommunication demand time series were rather stable and regular. At that time it was easier to apply advanced economic and mathematical/statistical models for long-term forecasts.

This paper will describe the methods developed to forecast the long-term demand for broadband access. In order to make the forecasts, it is necessary to have an overview of the relevant broadband technologies and understand the strengths and weaknesses of each technology. The paper gives an overview of alternative technologies and shows the variety and the complexity of technologies.

It is of course important to sample the historical evolution of the demand for each technology and analyse the data. However, when long-term forecasts are modelled, it is also important to have a good understanding of the abilities of each new technology. The paper shows that techno-economic analysis of the relevant technologies is crucial for evaluating the long-term potential of the technologies. In ([2], [10], [17], [19], [22], [27], [28]) techno-economic analysis of broadband technologies is a substantial part of the forecast modelling.

An important part of the techno-economic analysis is the forecasting models for cost predictions of network components and technologies [1].

The position of the dominating broadband technologies is influenced by the supply side because mass production generates low production costs and low tariffs for the subscribers for having a useful business case. The rollout and coverage of the various technologies are also of great importance. Finally, the rest market, which cannot be covered by the dominating technologies, gives possibilities for alternative technologies.

3 Broadband technologies

In the early 1990s the following capacity classifications were recommended:

- Narrowband: [– 128 kb/s]
- Wideband: < 128 kb/s – 2 Mb/s>
- Broadband: [2 Mb/s –]

However, the concept wideband has disappeared and broadband is now defined as capacities larger than ISDN. During the last few years a lot of new broadband technologies have been developed. Figure 3.1 gives an overview of various broadband technologies.

The first platform for mobile communications was established when the Nordic countries in 1980 introduced the Nordic Mobile Telephone System (NMT). In 1993, the second generation (2G) mobile system, GSM, was established in Europe. Later, GPRS with the possibility for data communication was introduced, and recently an enhancement of GPRS – EDGE – offering even larger access capacity. Recently the third generation mobile system (3G), UMTS – WCDMA, has started the rollout in many countries opening for much higher bandwidth in the access. It is well known that license auctions in many countries of Western Europe generated extremely high costs for many mobile operators. The Nordic countries held a “beauty contest” and managed to keep the license fees on a normal level. New mobile technologies with considerably higher capacity are being developed. One of them, the High Speed Downlink Packet Access (HSDPA) is a relevant future mobile technology.

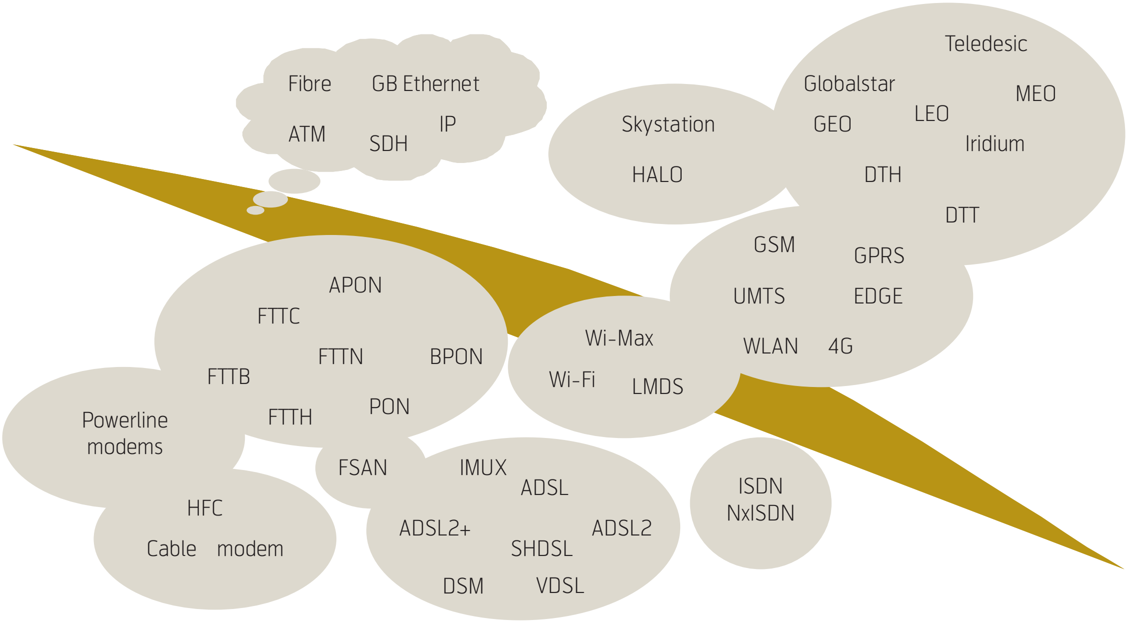

Figure 3.1 Different broadband technologies

Parallel to the mobile and fixed network broadband evolution, new technologies have been developed for nomadic applications. WLAN has been introduced on a lot of hot spots, like gas stations, airports, railway stations, hotels, cafés, bars, restaurants, etc. In addition new technologies for fixed broadband radio transmission like WiFi, WiMax are under way. The hot spots are also called IP zones since they use the IP network as a backbone network for the broadband traffic.

Local Multipoint Distribution System (LMDS), WiFi and WiMax are fixed wireless broadband access systems for the fixed network. LMDS was already four years ago a promising broadband technology. However, the system did not succeed, because of too expensive components and too low production volumes. The new fixed wireless broadband access systems (WiFi and WiMax) are now in a similar position. Especially WiMax has the possibility either to give high capacity or to have a long reach. The system may be an interesting technology in areas not covered by DSL technology.

The Direct To the Home satellite solution (DTH) also give possibilities for broadband communication. However, the number of satellites and the transponder capacity are limited. In addition, the signals interface and return unit are too expensive for the residential market. Hence, the potential for the systems will be part of the business market, which so far is not covered by cheaper broadband technologies.

The Digital Terrestrial Television network (DTT) constitutes a broadband alternative. The local television masts can be used for downlink broadband transmission. In Norway, Bømlo has been established as a pilot area for the system. The downlink is using a dedicated frequency on the DTT system while the return channel is ISDN or GPRS on the mobile. Within some time a dedicated frequency on the DTT for the return channel will be specified.

Another business concept was the balloon sky station. The plan was to place balloons in the air to cover large populated areas. The capacity would be relatively higher than for satellites, but the maintenance cost is large and uncertain.

Another interesting broadband technology is the power line technology (PLC). The concept of transmitting broadband signals through the power lines has high revenue potential, especially for the power line companies. So far the technology has generated too high radiation effects, and specific improvements are necessary to have a new competitive broadband technology. The European Commission is now supporting the PLC technology, trying to generate heavier competition in the European broadband market. However, there are still uncertainties regarding the future radiation effect of these systems.

Countries like Norway and Germany have a very high ISDN penetration, Norway probably the highest ISDN penetration in the whole world. The ISDN network has the possibility to transfer broadband traffic. Telenor introduced in 2004 the service NxISDN with the possibility to use more than one twisted copper pair. *The service called SMAKS offers up to 256 kb/s as a flat rate service (no traffic charge), which covers 100 % of Norway*. The service is offered only in the business market, since the monthly tariff is rather high.

Because of increased capacity demand, an extensive part of the transport networks in Europe are covered by fibre. Fibre is also deployed in some parts of the access network. In many access areas fibre rings with service connection points have substituted parts of the conventional copper tree structure. New operators are entering the broadband market and deploy their own fibre infrastructure in parallel with the incumbent. Some operators have installed Fibre To The Home (FTTH) and Fibre To The Building (FTTB) with in-house Ethernet solutions. Especially in Sweden, FTTB have been deployed extensively to large building complexes. FTTH – fibre to individual houses is much more expensive, because of digging and civil work expenses. The solutions offer the triple play concept for TV, Internet and telephony at the same time. So far the fibre technology has potential to catch

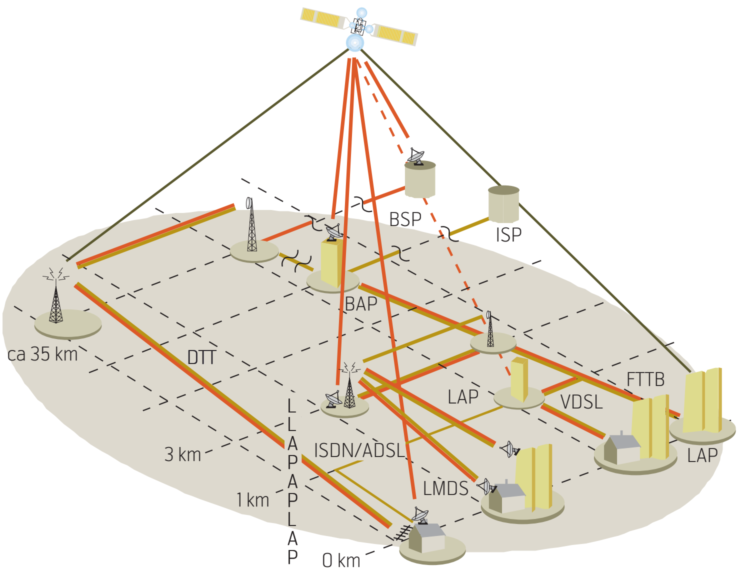

Figure 3.2 Physical network structures for some important broadband services

medium and large size companies, which already need high broadband capacity. Further, the FTTB is a competing broadband technology in dense access areas where fibre is deployed to large building complexes. Another technology is Fibre To The Curb (FTTC) where fibre is deployed deeper in the access network. The deployment strategy for green field areas is usually to deploy tubes with the possibility to install fibre for future demand for both the business and the residential market. The fibre solutions will be even more competitive in the future with significantly increasing capacity demand.

The Passive Optical Network (PON) solutions do not offer a subscriber access, but represent alternative broadband technology for transmitting the traffic in the access network. In the future also Coarse WDM (CWDM) systems can be used in the same way.

The Hybrid Fibre Coax (HFC) system, also denoted cable modem, was the first real broadband technology to be established in the residential market. The technology is still the dominating one in North America but has lost its position to the DSL technology in Europe. The system uses parts of the traditional cable television network by splitting the network into separate small islands with cable tree structure, which are connected with a fibre droop from the head end to the separate coax islands. A return channel is also established.

Finally, the Digital Subscriber Line (DSL) utilising the traditional twisted pair, is the broadband technology with the highest market share on a worldwide scale. There is a set of different DSL technologies which are continuously evolving. There are some important factors to bear in mind regarding the DSL technology:

1. The broadband access could be symmetric (SHDSL) or asymmetric (ADSL)

2. The access capacity decreases with the length of the subscriber line

3. The access capacity increases with the copper diameter

4. The signal to noise proportion increases with the electrical power on the suscriber line

5. New coding is used to improve the signal to noise proportion. The system is called rate adaptive system or READSL

6. The access capacity or the subscriber line length can be increased by doubling the frequency (from 1.1 MHz to 2.2 MHz). The new technology is called ADSL2+.

7. Further increase of the frequency is utilised with VDSL and long range VDSL.

8. ITU develops recommendations for frequency plans for the various DSL technologies to minimize the noise and cross talk on the copper bundles.

9. New electrical power plans for dedicated copper lines improve the capacity and line length of the other copper lines in the bundle.

10. Dynamic Spectrum Management (DSM) is expected to offer a significant performance improvement of the DSL technology. The system is based on establishment of a control centre, which dynamically allocates spectrum sizes to each copper line depending on the signal to noise proportion. See the paper in this journal "Dynamic Spectrum management – a methodology for providing significantly higher broadband capacity to the users" [6].

11. Usually both households and businesses have a set of twisted pairs as broadband connection. It is possible to use more than one twisted pair by using the concept of wire bonding in order to increase both capacity and line length for the customer.

Figure 3.3 illustrates the possibilities with different DSL technology.

In [7] in this journal there is a comprehensive description of the evolution towards the next broadband network platform. The paper addresses major trends and technology development in networking, which is of crucial importance for making good broadband technology forecasts.

So far the DSL technologies for the residential market are dived into two main groups regarding downstream capacity:

- ADSL class
- ADSL2+/VDSL class

It is assumed that ADSL has a downstream capacity of up to 8 Mb/s with ADSL2+/VDSL from 10 Mb/s upward. A new procedure is now going to be implemented. It is called dynamic bandwidth control giving the subscriber the possibility to choose the needed bandwidth at the right time. Anyhow, it is important to plan the demand for low and high access capacity when the broadband network is dimensioned.

The most important broadband technologies are:

- ADSL
- ADSL2+/VDSL
- HFC (Cable modem)
- FTTH/FTTB
- WLAN/WiFi/WiMax

In this paper it is assumed that broadband traffic on mobile terminals and fixed network PCs mainly complement each other. In addition it is assumed that fixed wireless broadband access systems are relevant alternatives for covering sparsely populated areas and also supplements for nomadic movements.

The ability and the possibilities of the different technologies have been analysed in [23], [29], [33], [34], [35], [38].

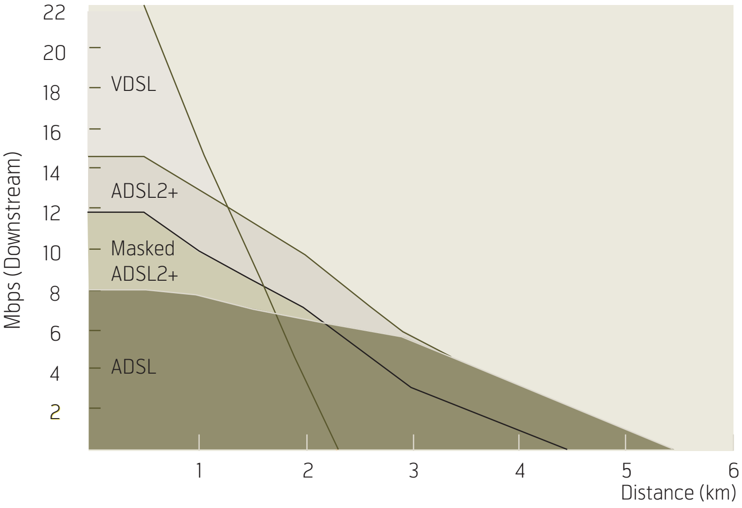

Figure 3.3 Downstream capacity and line length possibilities for various DSL technologies

4 Broadband rollout

The broadband rollout has a crucial impact on the broadband *penetration*. To be able to evaluate the penetration, we need to know the broadband *coverage* of the country. Suppose that the rollout at time t gives the broadband coverage C_t, and that the penetration at that time is P_t. *Take rate* is the proportion between demand and coverage in an area. A Country consists of a set of areas where broadband is rolled out and a set of areas without any broadband availability. Let the take rate at time t be T_t. Then

$$P_t = T_t \, C_t$$

The above equation tells us that the penetration depends on the broadband take rate, which reflects the genuine demand based on the broadband application availability, the broadband tariffs, the service quality, etc. This is commented on in more detail later in this paper. In addition the penetration is dependent on broadband coverage.

The same relation is valid not only for the total broadband penetration, but also for the penetration of different broadband technologies. Figure 4.1 shows the European mean coverage for DSL and HFC (Cable modem) respectively, distributed on urban, suburban and rural areas.

The areas are defined as:

- Urban areas: areas with population density greater than 500 inhabitants/km^2
- Suburban areas: areas with population density between 100 and 500 inhabitants/km^2
- Rural areas: areas with population density less than 100 inhabitants/km^2

The figure shows that the DSL coverage in Europe is much higher than the HFC coverage, which also reflects the penetrations of the two most dominating technologies in Europe.

The figure also shows that HFC has a limited coverage in sparsely populated areas. The reason is the original coverage of cable TV networks in Europe. The cable television networks were mainly deployed in dense areas, because deployment in urban areas was rarely cost-effective. Hence, there are definite limitations of the potential for HFC in Europe because of cable TV coverage. Techno-economic

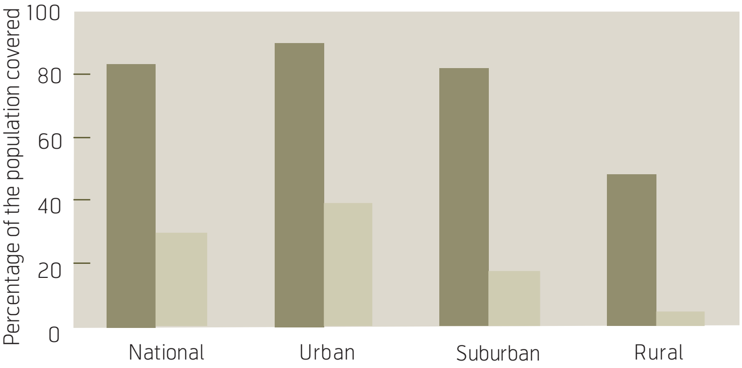

Figure 4.1 DSL and Cable modem coverage in urban, suburban and rural areas in Western Europe (EC: Connecting Europe at High Speed: National Broadband Strategies Dec 2003[13], IDATE)

calculations show that further expansion of cable TV networks is not a good business case. One important reason is the possibility for the households to buy small dishes and subscribe via a DTH satellite operator like Viasat or Canal Digital instead of connecting an expensive expansion of a cable TV network. Therefore, the expansion of the HFC coverage will only be performed by upgrading the established cable TV infrastructure to two-way broadband and not by expanding the original network.

A conclusion is that the rollout plans and the rollout possibilities for different broadband technologies are important factors for future broadband coverage and for the broadband penetration forecasts.

5 The broadband rest market

The European Commission and also Governments in the European countries are following the broadband deployment very closely. The reasons are all the benefits broadband communication and the broadband network create for society. Broadband supports the ICT evolution and generates innovation, rationalisation, new working possibilities and additional value for households and companies. Therefore, the Commission and the national Governments support the broadband deployment and also give economic assistance and advice for rolling out the broadband network. In countries like Sweden and Canada, the Governments have given substantial economic support to the broadband deployment. Other countries rely on a more market driven broadband rollout where the actors and operators take care of the deployment. At this stage of the rollout part of the traditional market and the rest market are the last parts to be covered.

The broadband rest market in European terms is usually defined as the coverage which cannot be realised cost efficiently by the DSL technology. This is a difficult issue, since the size of the rest market continuously changes because of improvements of the DSL technology. 2 – 3 years ago the rest market was a rather significant part. In Norway the size of the rest market at that time was estimated to be about 25 %. However, mini DSLAMs (very small DSLAMs) were developed, reducing the rest market significantly. Further improvement of the DSL technology is expected, which will limit the rest market even more.

The DSL rest market is limited by the size of the access area and also by the length of the copper line. The number of subscribers in an access area must exceed a limit in order to get a DSLAM in the area. In addition, the line length must not exceed a given length in order to offer a subscriber a DSL access.

More extensive analysis of broadband technologies and rollout in rural areas and in the rest market is found in [13], [16], [26], [36].

Where DSL technology is not relevant, other broadband technologies will be installed to offer broadband in the rest market. Relevant technologies are:

- WiFi
- WiMAX
- DTT (digital terrestrial television network)

6 Techno-economic assessments

The long-term broadband forecasts are based on results from techno-economic calculations.

The techno-economic calculations evaluate the “economic value”, i.e. expressed by net present value or pay back period of rollout of different broadband technologies. The assessments have been carried out for rollout on a national level and on specific areas like urban, suburban, rural and especially the rest market to examine the potential of the different broadband technologies.

The main results from the techno-economic calculations show that it is difficult for new broadband technologies to capture significant market share in areas where cable modem and/or DSL are already deployed. The reason is low subscription prices for the established technologies, which is explained by large mass production on a worldwide basis.

The potential for the upcoming technologies will be in market segments which are sparsely populated and not covered by cable modem or DSL. Even expensive wireless broadband access systems may be offered to the business market in these areas.

There is a close link between techno-economic calculations and the broadband forecasts. To be able to perform the techno-economic calculations, it is important to use the forecasts as input. An evaluation of the technologies is then carried out. The next step is to adjust the forecasts for different technologies and perform new techno-economic calculations. This process is continued until the results are quite stable.

To be able to carry out these calculations, a very advanced techno-economic tool is needed.

Within the European programs RACE, ACTS and IST, the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC have in the 1992 – 2003 period, developed a methodology and a tool for calculating the overall financial budget of any access architecture. The tool handles the discount system costs, operations, maintenance costs, life cycle costs, net present value (NPV) and internal rate of return (IRR). The tool has the ability to combine low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters for performing evaluation of various network architectures. In [43] are found more detailed descriptions of techno-economic modelling and the tool.

Telecommunication demand forecasts are input to the tool and to the techno-economic calculations. The Tonic tool is widely used to analyse economic consequences of implementing new network platforms. Important parts of the tool are:

- Service definitions
- Subscription and traffic forecasts
- Service tariff predictions
- Revenue model
- A topology model mapping geographic areas with given penetrations into the tool
- Network component cost data base including more than 300 network components
- Network component cost prediction model
- Investment model
- Operation and maintenance model
- Model for economic calculations
- Risk analysis model

The following steps are needed in the techno-economic evaluations of the network solutions:

The services to be provided must be specified. The market penetration of these services over the study period will be defined. The services have associated tariffs. From the combination of yearly market demand forecasts and ARPU predictions the tool calculates the revenues for each year for the selected service set.

Next, the architecture scenarios to provide the selected service set must be defined. This requires network planning expertise for design of the network and the relevant network components. However, the tool includes several geometric models facilitating the network planning by automatically calculating lengths of cables and ducting. These geometric models are optional parts of the methodology and the techno-economic tool can be used without them. The result of the architecture scenario is a so-called shopping list. This list contains the volumes of all network cost elements (equipment, cables, cabinets, ducting, installation etc.) for each year of the study period and the location of these network components in different flexibility points and link levels.

The costs of the network components are calculated using an integrated cost database containing data gathered from many European sources. Architecture scenarios together with the cost database give the Capital Expenditure (CAPEX) for each year.

The tool contains a forecasting module for cost predictions of network components. The module includes extended learning curve forecasts, which are based on worldwide mass production as an important explanatory variable. See the paper "Models for forecasting cost evolution of components and technologies" [1] in this issue.

In addition Operational Costs (OPEX) is calculated based on operations and maintenance parameters for the component and the maintenance system. The OPEX costs are divided into different components, such as cost of repair parts including civil work and operations and administration costs. Typically the OPEX are driven by services, say by number of customers and number of critical network elements.

CAPEX costs together with the OPEX costs give the life-cycle costs of the selected architecture scenario. Finally, by combining service revenues, investments, operating costs and general economic inputs (e.g. discount rate, tax rate), cash flows and other economic factors the NPV, IRR, Payback period etc are calculated. The methodology is described in more detail in [43].

New mobile systems have been examined by techno-economic analysis regarding market opportunities and rollout strategies ([20], [31], [32], [39]).

7 Broadband penetration status

Data sources

Broadband information has been gathered from a lot of different sources. Project partners in the CELTIC project Ecosys have collected up-to-date data from the broadband evolution. Other important sources have been consultant reports from Point topic [9], OVUM [11], Jupiter [14], Forrester [18] and a set of reports from the European Commission ([12], [15], [21]). It has been difficult to use the forecasts from the consultant reports because the main part of the reports underestimates the expected broadband evolution. One exception is however the last report from OVUM.

An evaluation of the broadband reports from the consultant companies from the 2000 – 2004 period is the continuous underestimation of the expected broadband evolution in Western Europe. During the first part of the period the DSL technology was significantly underestimated because the first forecasts probably took to much account of the HFC broadband evolution in North America.

Parallel broadband forecasts have been developed independently through the European programs RACE, ACTS and IST, by the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC financed by the European Commission. This paper documents broadband modelling performed in the CELTIC project Ecosys.

In the TONIC project broadband forecasts were modelled and presented in two deliverables (Western Europe, 2001) [40] and (Country groups, Western Europe, 2002) [30]. These forecasts have been developed based on principles shown in this paper. These forecasts are significantly higher than all forecasts developed by consultant companies in the period 2001 – 2003. Next section shows that there is a very high growth in the broadband penetration in 2004, which clearly indicates significantly higher penetrations than what was expected by the consultant companies.

Broadband status

Updated broadband statistics from Point topic from Q4 2003 (ultimo 2003) to Q1 2004 (first quarter 2004) and Q2 (second quarter 2004) are presented in this section [9]. The broadband demand status of all Western European countries is shown. *The statistics include the sum of the business market and the residential market*. The next chapters present forecasts for the residential market only. *In addition the statistics cover DSL and Cable modem, but not other broadband technologies*. The reason for using Point topic statistics is that the statistics are updated with Q2 2004 data.

The broadband penetration relative to the number of households from end 2003 to the first half of 2004 for all countries in Europe is shown in Figure 7.1.

The figure shows that Denmark, Netherlands, Switzerland and Belgium are in front, while runners up are Iceland, Norway, Sweden and Portugal. However, during the last year Sweden has lost her position as one of the top three broadband countries in Western Europe. The large countries France, Germany, Italy and UK have a penetration of about 15 % in the first quarter of 2004. However, Germany is now losing her position, in spite of an aggressive DSL rollout the first years. France and Italy have a significant growth and also a hard competition among the broadband operators.

The mean penetration, *sum business and residential market* for the Western European countries was 14.5 % at the end of 2003 and 17.1 % after Q1 2004. Second quarter 2004 the penetration is 18.9 % – an increase of 4.4 % in six months. The mean penetra-

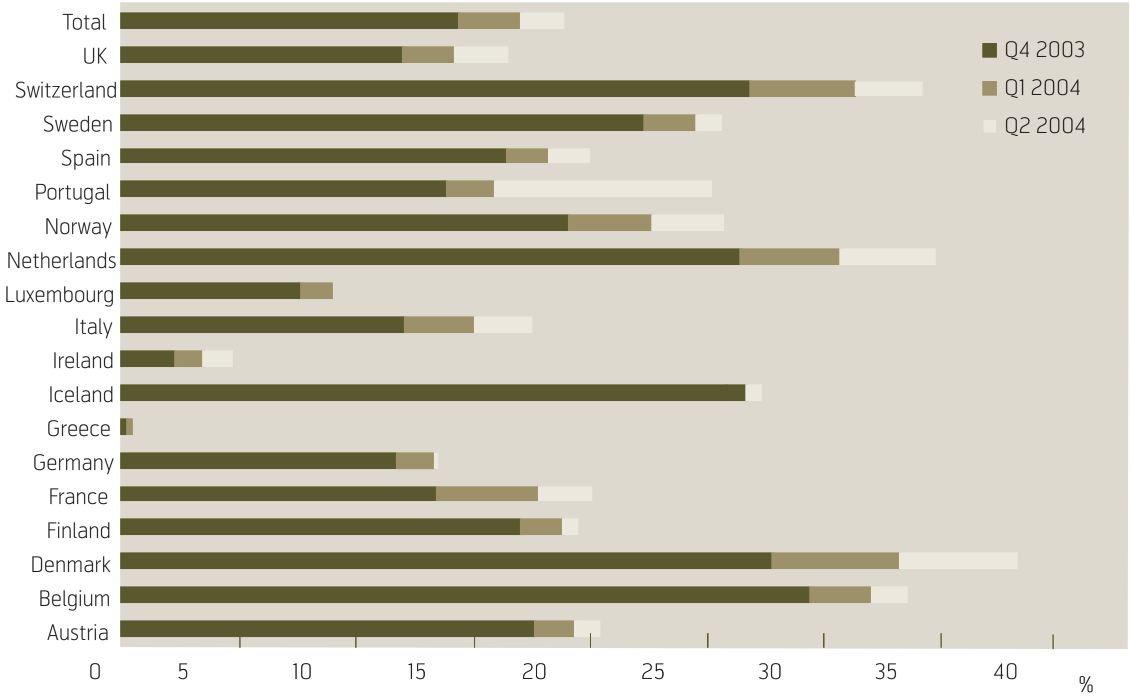

Figure 7.1 Broadband penetration (DSL and cable modem) as sum of residential and business accesses Q4 2003 – Q2 2004 for Western European countries

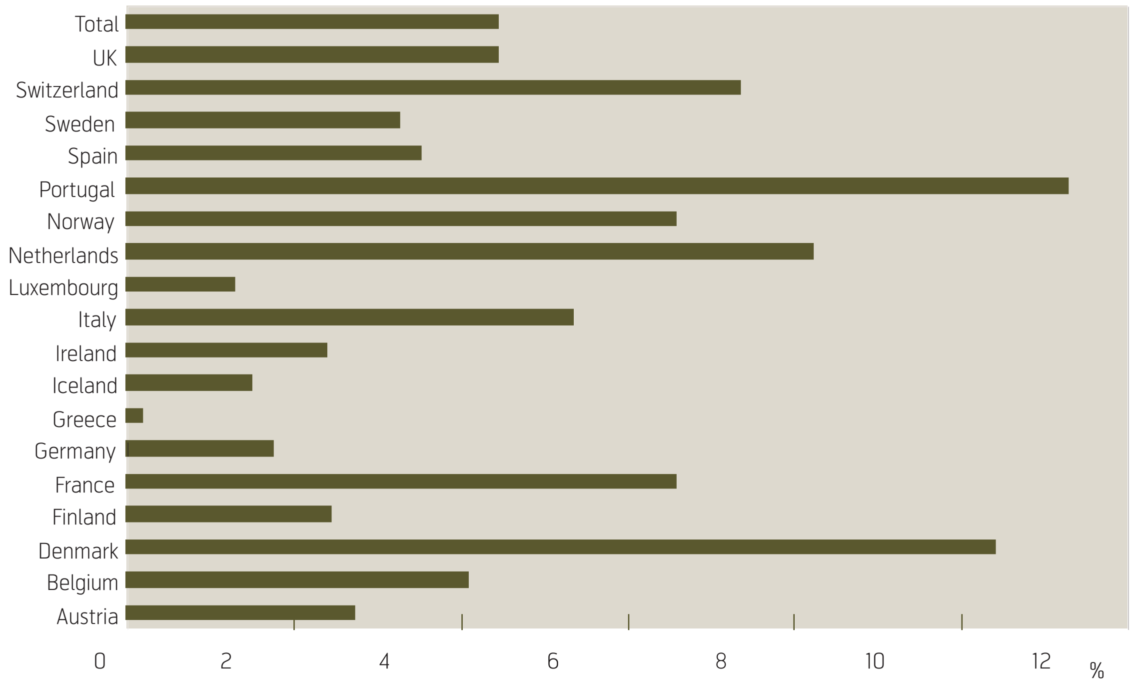

Figure 7.2 Broadband penetration (DSL and Cable modem) growth as sum of residential and business accesses from Q4 2003 to Q2 2004 for Western European countries

tion for the Western European *residential market* was 11.4 % at the end of 2003. Hence, 3.1 % of the penetration is caused by the business market, which constitutes a market share of about 22 %. The business market has a faster growth than the residential market. Q2 2004 penetration data for the pure residential market, Western Europe, is not available at the moment. Based on the given market share, the residential penetration (DSL + Cable modem) is estimated at 15.0 % medio 2004. Penetrations by other technologies have to be added. At the end of 2003, the broadband penetration of other technologies in the residential market was 0.2 %.

The half-year broadband penetration growth, Q4 2003 to Q2 2004 for sum residential and business market for the West European countries is shown in Figure 7.2. The figure shows that Portugal, Denmark, Netherlands, Switzerland, France, and Norway had a very significant broadband growth during the first six months of 2004.

The mean growth in broadband penetration among countries in Western Europe from Q4 2003 to Q2 2004 for the sum of residential and business access is 4.44 % measured per households. The adjusted quarterly growth for the residential market is 3.5 %. If the broadband market evolve with the same speed the rest of the year, the yearly growth of the residential market is estimated to be 7.0 %.

8 Broadband technology forecasts

Drivers for broadband evolution

Important drivers in the broadband market are of course the applications. The evolution of applications generates continuously higher broadband penetration. The evolution of narrowband Internet is an important part of the picture. Now, a significant part of these subscribers are converting to broadband each year. Another important factor is the PC penetration. The PCs are broadband terminals and until now, the broadband subscribers need a PC. In Norway the PC penetration is about 80 %. However, in some European countries the PC penetration is low and may be a barrier for the broadband evolution. Figure 8.1 shows the PC penetration in some OECD countries.

One important aspect is the distribution of broadband content. Interesting applications are: Streaming, Surfing, Peer-to-Peer, Music-on-demand, Video-on-demand, Games, *e*Learning, Electronic newspapers, Electronic books, Gambling, Broadcasting, etc. The operators and service providers are also bundling the services. The HFC and FTTx operators offer triple play.

Other important drivers are national objectives for offering schools, community centres, libraries, etc. high speed broadband. In the national communication plan for Norway, *e*Norge2005, all schools shall have minimum 2 – 10 Mbit/s broadband access by 2005.

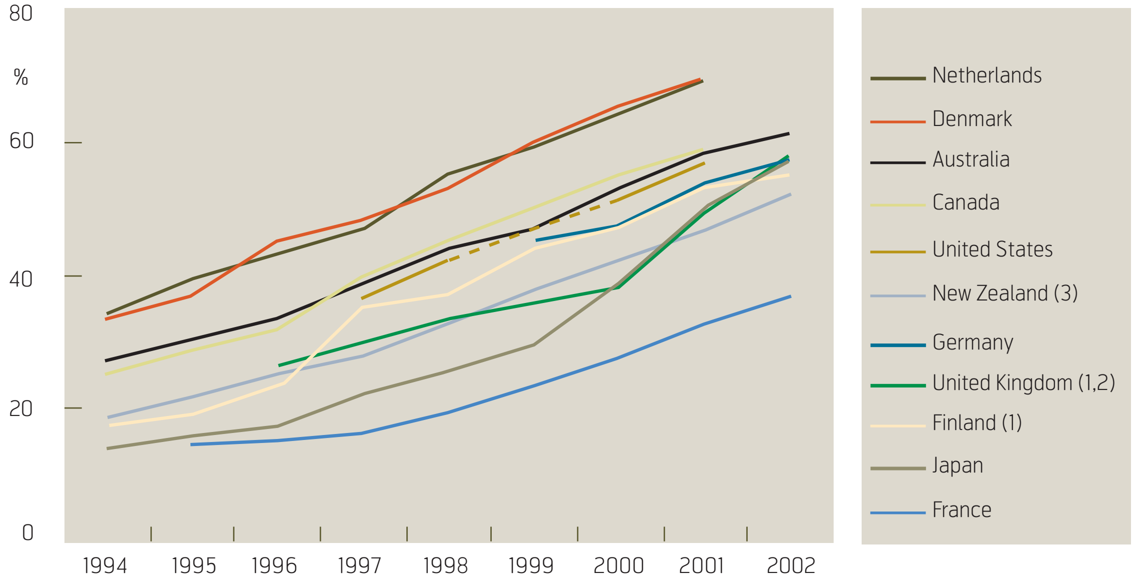

Figure 8.1 Access to home computers. Selected OECD countries (EU Community Survey on Household Use of ICTs, 2002) [21]

Larger schools shall have minimum 10 – 100 Mbit/s connections. In addition the Government is monitoring the broadband coverage very carefully. Some Governments in Western Europe may follow Sweden and Canada, who have supported the broadband rollout with significant investment means. If the broadband rollout in the rest market is too slow, public means may be used to support broadband deployment in these areas.

Another very interesting broadband driver is voice over IP (VoIP). Since broadband access gives the possibility for voice communication, different players are establishing IP-based voice communication on the broadband accesses. Several operators with large core networks, like the incumbents, are developing VoIP with high service quality. Other players in the broadband market establish VoIP services without investing in their own infrastructure. Telio was the company in Norway who offered VoIP without their own infrastructure.

Broadband classification of technologies for the residential market

The broadband technologies are described in chapter 3. For the residential market the technologies are divided into four main groups:

- ADSL
- ADSL2+/VDSL
- Cable modem (HFC)
- Other technologies

Other technologies are mainly: Fixed wireless broadband access systems (FWA), Fibre to the home, Fibre to the building systems, Power line systems, Direct to the home satellite with return channel, and Digital terrestrial television systems.

Broadband technology modelling

The broadband forecasts for the different technologies are modelled by beginning with the broadband penetration forecasts development for the total broadband demand in the Western European residential market. Based on experience from the last few years, diffusion type models have proved to have the best abilities for long-term forecast modelling. A discussion on the forecasts is found in the last chapter of this paper. Also Technology Future Inc. uses diffusion type models for long-term technology forecasts. See [5] in this journal. In [5] and [12] it is shown that the aggregated long-term demand for a set of information and telecommunication services, ICT, in the household segment has a diffusion pattern. [25] gives an overview of different diffusion models used to model telecommunication demand. In this analysis a four parameter Logistic model has been applied for the long-term forecasts.

In this paper the analysis is mainly based on mean values from the Western European market. The models will be improved by modelling the demand in homogeneous groups of European countries. Then more dedicated information will be used regarding rollout speed and coverage of various technologies for the different countries.

Predictions of market share evolution between different broadband technologies have been developed based on a set of Logistic forecasting models. Migrations between technologies are handled when ADSL2+/VDSL and other broadband technologies are catching market shares from ADSL and cable modem. Finally, the broadband penetration forecasts for the technologies are found by multiplying the total forecasts with the market share forecasts for the technologies.

Broadband coverage

The number of cable TV subscribers in 2003 was about 55,000,000 in Western Europe. Since the roll-out of the cable TV has become saturated, new subscribers will mainly be connecting to the existing networks. OVUM [11] predicts about 2 % additional cable TV subscribers per year. At the same time the number of households increases by 0.8 % per year. OVUM estimates that the penetration of cable TV subscribers will increase to 36 % in 2008.

Figure 8.2 shows the cable modem and DSL coverage in Western Europe (Dec 2003). The difference between cable TV coverage and cable modem coverage is due to the heavy expenses in upgrading cable TV networks to a two-way broadband network (HFC). Some of the networks are rather small and some other networks may be of poor quality and not usable for upgrading. Therefore, the cable modem coverage will probably not be very much higher.

On the other hand, the DSL coverage will continue to grow. Figure 8.2 shows that the DSL mean coverage is about 80 %, but much less in rural areas. The DSL is deployed very intensively in Western Europe and is going to have a coverage of more 95 % in the long run. The limitations for coverage are too long copper lines and/or too small local exchange areas. The predictions are estimated by using a Logistic model with 97 % saturation level. However, new technology will probably reduce the size of this rest market. Figure 8.2 gives predictions for the DSL and cable modem coverage.

Residential broadband penetration forecasts for Western Europe

Figure 8.3 shows the evolution of residential broadband penetration from 1999 to 2003.

The figure shows that the broadband penetration evolution during the first years was close to an exponential growth. The demand is expressed in percentage of total number of households. The observations indicate that Logistic models are relevant alternatives for forecasting the penetrations.

Figure 8.4 shows the long-term Western European residential broadband subscription forecasts. The saturation level in the model has been estimated based on historical data, demographics and also expert opinion. The other parameters in the model are estimated.

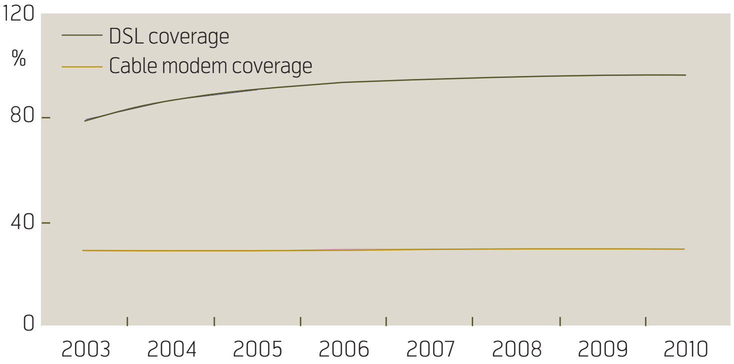

Figure 8.2 DSL and cable modem coverage

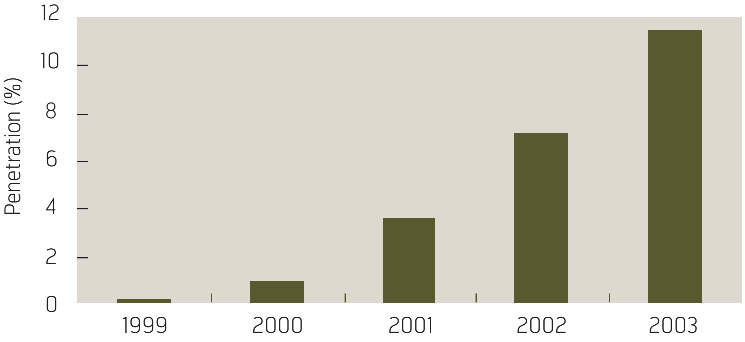

Figure 8.3 Residential broadband penetration, Western Europe, 1999 – 2003

The figure shows fast increase in the broadband penetration in Western Europe during the next years and the point of inflexion around 2005 – 2006. The situation among countries in Western Europe is of course very different. Greece has a very limited penetration, while the Nordic countries and Belgium, Netherlands and Switzerland have a very high penetration.

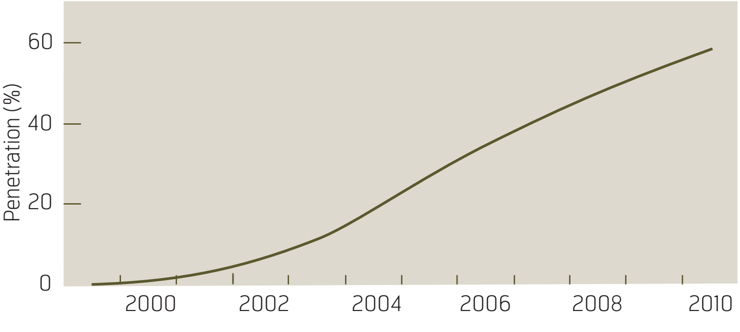

Figure 8.4 Broadband penetration forecasts for residential market, Western Europe

Market share evolution

The market share evolution of cable modem 1999 – 2003 is shown in Figure 8.5. The figure shows that the market share for cable modems (HFC) starts with nearly100 % in 1999, but cable operators lost more than 60 % of the market in the first two years. As mentioned earlier, the cable modem market share has decreased significantly compared with the dominating position in 1999. At that time the number of broadband subscribers was very limited.

The cable modem market share depends on the coverage. Figure 8.2 shows the predicted mean coverage for DSL and cable modem in Europe. The cable modem penetration in the residential market was 3.1 % in Western Europe at the end of 2003. The coverage was 29.0 % and the take rate 10.7 %. The DSL penetration was 7.9 % and the coverage 79 %, which gives a 10.0 % take rate.

The total broadband take rate in cable modem areas is higher than the take rate in other areas. One reason is a more intensive competition in these areas. Cable modem areas are also rather dense areas, where households probably have a higher willingness to pay for broadband subscriptions. In addition the broadband rollout started earlier in cable modem areas. It is estimated that the broadband take rate at the end of 2003 is 3 % higher in cable modem areas than in other areas. The DSL take rate at the end of 2003 in cable modem areas is estimated at 5.3 %, while the DSL take rate in areas without cable modem is estimated at 12.7 %. In addition other technologies start to take minor market shares.

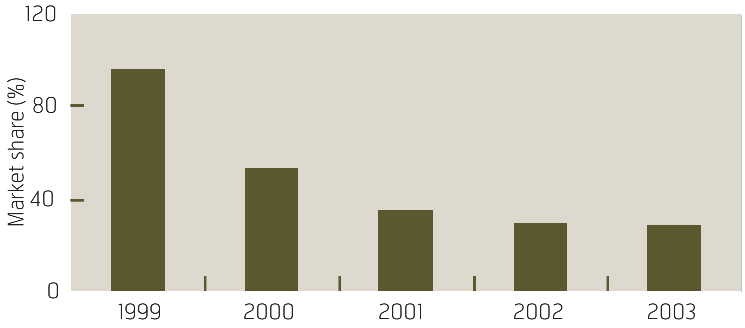

Figure 8.5 Cable modem market share evolution in Western Europe

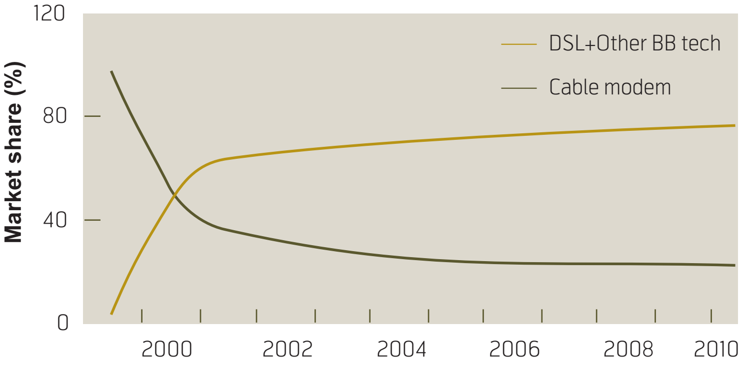

Figure 8.6 Predicted market share evolution between cable modems (HFC) and DSL + other broadband technologies

Figure 8.6 shows the market share forecasts for cable modem in Western Europe.

It is assumed that cable modem operators manage to maintain their broadband position in cable modem areas. Based on the coverage predictions until 2010 for DSL, cable modem and other technologies, the long-term market share for cable modem is estimated to be about 22 %.

The predicted market share evolution for cable modem is modelled indirectly by subtracting market share forecasts for DSL and other broadband technologies from 100 %. The market share forecasts for DSL and other broadband technologies are modelled by a four parameter Logistic model where the long-term market share is set to be 100 % – 22 % = 78 %. Forecasts for the two evolutions are shown in Figure 8.6.

However, there are some uncertainties regarding the market share forecasts. The cable operators bundle the broadband services and the cable television services (TV channels). Therefore, it is difficult for other operators to compete. When ADSL2+ and VDSL are introduced, other operators have the possibility to offer cable television services based on the multicast functionality and traditional broadband services. New operators have the possibility to offer triple play by offering broadband, cable television and telephony. Thus, it may be more difficult for the cable operators to maintain their rather dominating position in the cable areas.

The long-term forecasts show saturation for cable modem on a 22 % level. Even that level may be a little bit too high for Western Europe.

Now, the question is what role the new broadband technologies are going to play in the coming years. The most important technologies for the residential market are FTTB, FTTH, FWA (WiFi, WiMax) and possibly PLC (Power Line Connections). The market share for the new technologies has been reasonably low in the period 2000 – 2003. The market share is shown in Figure 8.7.

By end 2003 there were about 375,000 FTTB/FTTH broadband accesses in Western Europe, while the number of FWA was about 31,000 and the PLC accesses were about 12,000. A significant part of the FWA accesses are business customers. The total number of broadband households was 18,400 million at the end of 2003.

Techno-economic calculations have shown that new broadband technologies have problems surviving in the broadband market. The main reason is a lack of significant mass production possibilities. If a technology enters the market too late, then the mass production potential is reduced and the network components will not be cheap enough.

The broadband penetration in the West European market was 11.4 % at the end of 2003. In the course of the next two years the broadband penetration is predicted to be more than 25 %. Therefore it is crucial for the upcoming new technologies to enter the market and to catch more significant market shares before the established technologies will be even more dominating.

Techno-economic calculations show that it will be extremely difficult to produce broadband solutions with lower CAPEX and OPEX than DSL and cable modem. The best strategy for the new technologies is to enter the rest market before the established broadband technologies reach this part of the market. Because of long line length and high rollout costs for DSL, the FWA solutions may be an alternative in parts of the rest market. In 2010 the DSL coverage is estimated to be about 97 %. Hence, the FWA solutions should have a chance of catching the additional 3 %.

However, there is also a question of service capacity and quality, not only a question of price. In the long term, new demands for very large capacity will be generated. Therefore, FTTH and FTTB and even FTTC (Fibre To The Curb) will be attractive broadband solutions. Especially Sweden and Denmark are in front in the rollout of these access solutions. Strategies for fibre rollout will be:

- To deploy fibre to large building complexes
- To deploy fibre to the homes when building out green field areas
- To renew old infrastructure because of failures

Figure 8.8 shows that the development of market share for new broadband technologies is rather slow. It is difficult to make forecasts for the market share evolution even if we have some observations. The fibre accesses will continue to evolve because of new capacity demanding applications. In addition, the market will be covered by different broadband solutions because of political decisions combined with a market driven approach.

Based on the given arguments, the market share for the new technologies is assumed to be about 7.5 % in 2010. A four parameter Logistic model models the market share evolution. The market share forecasts are shown in Figure 8.8.

The next step is to separate the DSL services ADSL, ADSL2+ and VDSL. The DSL services are described in detail in chapter 3. So far ADSL2+ and VDSL are rarely introduced in the Western European access networks. Telenor started already in 2001 a large VDSL trial with 700 households. During the next years ADSL2+ and VDSL will be deployed gradually.

Techno-economic calculations show that an ADSL2+/VDSL rollout based on cherry picking gives fairly good business cases for the network operators. The rollout strategies are described in more detail in the paper "rollout Strategies and Forecasts for VDSL/ADSL2+" [3] in this journal. One indicator

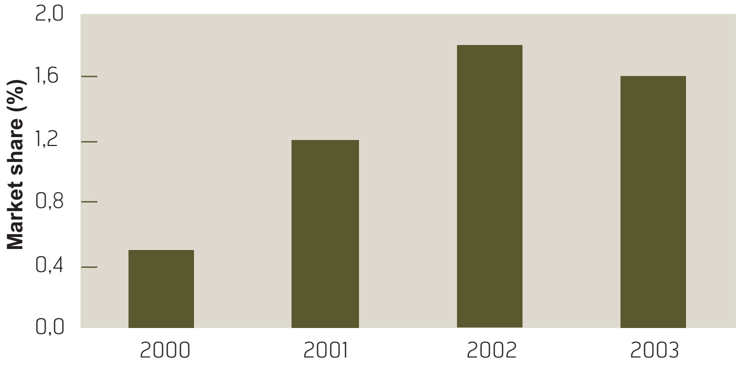

Figure 8.7 Market share other broadband technologies than DSL and cable modem

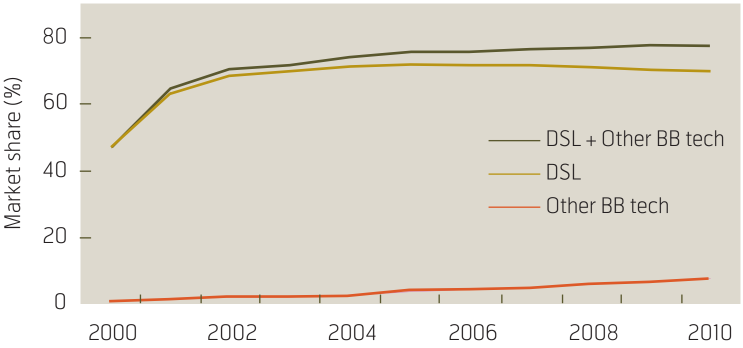

Figure 8.8 Market share forecast for DSL and other broadband technologies

for the evolution is the new DSLAM exchanges, which have interfaces for both ADSL line cards and ADSL2+ line cards. It is important to note that the production cost of ADSL and ADSL2+ cards are at the same level. Therefore, there will be a significant increase in the high capacity demand for DSL. Since there are no historical demand data, it is of course difficult to predict the future market share evolution of ADSL2+ and VDSL. However, because of low additional production costs, especially for ADSL2+, there will be a very significant increase in the coming years.

ADSL2+ and VDSL offer higher broadband capacity than ADSL. During the next few years new high capacity broadband applications will be introduced. Now, streaming applications are very popular in some market segments, but the access capacity limits the usage. The incumbents are working hard to create new income possibilities on broadband to compensate for the loss on ISDN/telephony. New concepts of broadband contents are underway. ADSL2+ and VDSL will offer TVoDSL and in addition VoD and individual choice possibilities of events and old TV programs. Specific content applications will be: entertainment, online games, gambling, *e*learning, music on demand, “voice books” on demand, electronic newspapers and journals etc. Other broadband applications are: “teleshopping” and auctions, surfing, downloading and exchanging software, back-up services, remote broadband storage, home office, video and multimedia conferences, file and information exchange, data base upgrades and tele-surveillance. The peer-to-peer applications in the residential market are about to start to evolve. There will be a significant increase in demand in the coming years for exchange of personal content like digital pictures, digital film sequences – either personal or streamed, videograms, greetings cards, email with broadband content, personal video and multimedia conferences – for example birthday video conferences.

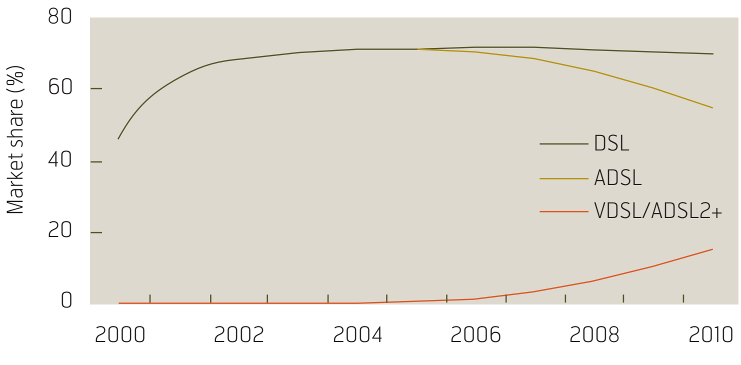

Figure 8.9 Predicted market share evolution for ADSL and ADSL2+/VDSL

One of the first steps for the incumbents is to introduce TVoDSL. The technology will be based on multicasting. However, the market segment in this area is limited because DTH satellites, the CATV network and some FTTH/FTTB operators already offer TV distribution. The next step will be to introduce the more advanced broadband services and applications. The evolution and speed in developing new broadband products will influence the demand for ADSL2+/VDSL.

The ADSL2+/VDSL market share forecasts are based on the assumption of a diffusion type evolution starting in 2004. The premises for the forecasts are that the main part of the Western European operators start to use the cherry picking strategy without additional infrastructure investment. The coverage of ADSL2+/VDSL is about 50 %. It is assumed that operators at the end of the period (2010) will also be deploying fibre deeper into the access network and expand the coverage to about 65 %. Premises for the market segmentation for Western Europe is 90 % HFC coverage inside a radius of 2 kilometres from the exchange (DSLAM). Hence, the potential for ADSL2+/VDSL in 2010 will be 60 % minus 20 % multiplied with the estimated HFC coverage of 22.4 %. The future tariffs for ADSL and ADSL2+/VDSL and the content delivered are of course important factors for the market share of the different services. So far, there is limited information about what consumers will choose. Multinomial logit models have been used to examine ADSL and VDSL demand in the Norwegian market. Significant demand for VDSL was identified [8]. It is assumed that 35 % of the consumers in 2010 will choose ADSL2+/VDSL instead of ADSL where possible. The latter assumption is uncertain, especially because we do not know the future tariffs nor the broadband content of the services. Then the market share for ADSL2+/VDSL is estimated to be about 15 % in year 2010. Figure 8.9 shows the market share forecasts for DSL, ADSL and ADSL2+/VDSL.

Market share and penetration forecasts for different broadband technologies

An overview of the market share forecasts for the different technologies is given in Figure 8.10. The figure shows that the DSL technology in the future will be the dominating broadband technology in Western Europe and that the ADSL2+/VDSL services will gradually substitute ADSL. However, the evolution is reduced because of long subscriber line lengths and the need for heavy investments in the access network for parts of the subscribers. The figure shows that the cable modem market share decreases significantly in the period 2000 – 2010, while the market share for new technologies increases.

The penetration forecasts for the broadband technologies are found by multiplying the total penetration forecasts with the market share forecasts for the technologies. The forecasts are found in Figure 8.11. The figure shows that ADSL is the dominating broadband technology in the period 2000 – 2010, but the penetration decreases at the end of the period. The main reason for this is substitution effects with ADSL2+ and VDSL, which have shown a very strong growth from 2007 to 2010. In parallel the cable modem penetration increases even when the market share is reduced. Also the penetration of other broadband technologies increase in the period.

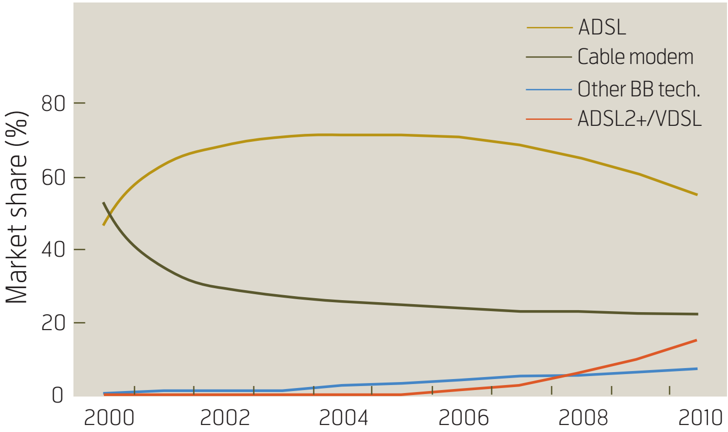

Figure 8.10 Market share forecasts between ADSL, ADSL2+/VDSL, Cable modem and other technologies for the West European market

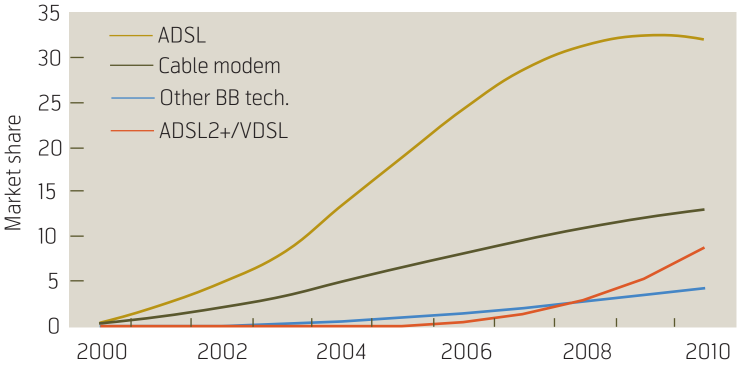

Figure 8.11 Penetration forecasts for broadband technologies in Western Europe

9 Forecast uncertainties

There are a lot of uncertainties connected to the forecasts. Since the broadband forecasts are developed through qualitative and quantitative information, statistical modelling and also subjective input to the modelling, it is difficult to express the uncertainty by a pure statistical model.

However, it is important to analyse the impact of the broadband forecasting uncertainty. The long-term forecasts are mainly used as input for rollout decisions of different broadband technologies and for establishing new network platforms. Techno-economic assessments are used to calculate net present value, internal rate of return and pay back period for the various projects.

A relevant method for evaluating forecast uncertainty is to apply a risk analysis [42]. The paper "Analysing the impact of forecast uncertainties in broadband access rollouts by use of risk analysis" [4] in this issue shows how risk analysis can be used for this type of evaluations. In [24 and [37] risk analysis on broadband investment is combined with option theory for evaluation of uncertainty to decide the right time for broadband rollouts.

10 Broadband forecasts comparisons

Comparison of forecasts is a subject on its own. In this chapter some comparisons of long-term broadband will be shown and discussed. However, the intention is not to give a complete picture of all long-term broadband forecasts produced.

In 1994 the RACE 2087/TITAN project performed a Delphi survey among 100 experts from 10 Western European countries on the future broadband residential market [44]. Demand curves for broadband accesses and applications together with forecasts for long-term broadband demand for the Western European market were estimated based on the Delphi methodology. In 1997 a new Delphi survey was carried out in the AC 226/OPTIMUM project [41]. At that time no broadband demand data were available, since the broadband services were not yet introduced in the residential market. The forecasts from the two surveys are shown in Figure 10.1.

The aggregated penetration forecasts per household from the first Delphi survey (1994) based on the sum of 2 Mb and 8 Mb accesses were estimated to be 14 % in 2005 and 20 % in 2010. Now we see that these 10 year old forecasts have been a little bit pessimistic. However, at that time neither the DSL technology nor the HFC/cable technology were known.

The aggregated forecasts from the 1997 Delphi survey predict 18.2 % penetration in 2005 and 48.5 % in 2010. These forecasts are rather good. The 2005 forecasts are probably a little bit lower than the expected penetration for 2005, and the 2010 forecasts are so far in the right range. The figure shows that high broadband capacity (25 Mb) forecasts are too

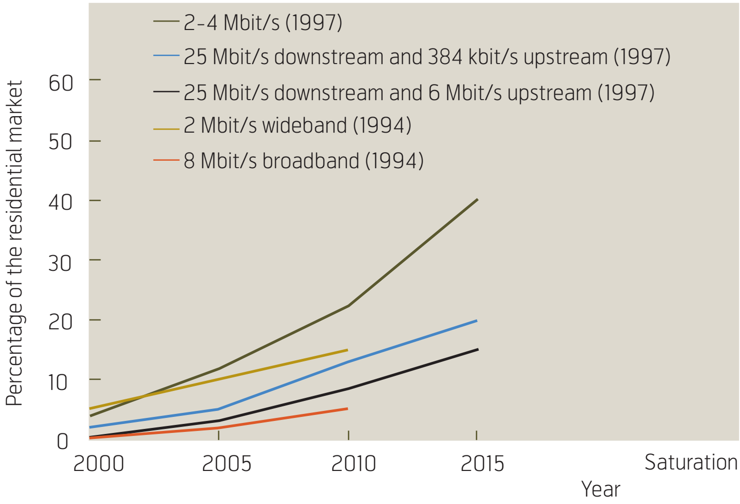

Figure 10.1 Broadband access penetration forecasts per household in the residential market from Delphi surveys performed in 1994 and 1997

optimistic. ADSL2+ and VDSL, which were not specified at that time, are evolving now, but not very fast. The broadband forecast from AC364/Tera is based on the results from the 1997 Delphi survey with some adjustments [41].

Now many companies are making long-term forecasts for the broadband evolution. New broadband forecasts were developed in IST 2000-25172 TONIC in 2001 [40]. It is of course easier to make broadband forecasts when historical demand data are available. This paper presents some of the forecasts. Figure 10.2 gives a comparison of the following forecasts for the Western European residential market:

- Tera (1998)
- Tonic (May 2001)
- Jupiter (2003)
- Forrester (June 2003)
- Jupiter (April 2004)
- OVUM (May 2004)
- Ecosys (August 2004)

The broadband penetration ultimo 2003 was 11.4 %. The Tonic (2001) forecasts and the Tera (1998) forecasts underestimate the penetration in 2003 by 1.7 % – 3.2 %. However, the yearly growth in the period 2003 – 2008 is larger than the Jupiter (2003 and 2004) forecasts and the Forrester (2003) forecasts.

Chapter 7 in this paper gives an overview of the quarterly DSL and cable modem increase Q1 and Q2 for the sum of the residential and business markets in 2004. The adjusted half year growth for the residential market is estimated to be 3.5 %, which gives a yearly growth of 7 % for DSL and cable modem. Taking into account the growth of other broadband technologies, the broadband penetration in Western Europe will increase from 11.4 % to 18.5 – 19 % at the end of 2004.

Jupiter (2004), OVUM (2004) and Ecosys (2004) forecasts for 2004 seem to have the right predictions for 2004. However, Jupiter (2004) have more pessimistic long-term forecasts. The long-term forecasts can be divided into two groups:

Group 1: Tonic (2001), Ecosys (2004), OVUM (2004): High long-term forecasts

Group 2: Tera (1998), Jupiter (2004), Forrester (2003), Jupiter (2003): Low long-term forecasts

In Group 2 Tera (1998) shows a much stronger growth at the end of the studied period than the others. The Jupiter (2004) forecasts, which probably will be on the right level ultimo 2004, have a turning point at the end of 2004. It explains the deviations from Group 1 long-term forecasts. Netherlands, Belgium, Denmark and Switzerland have the highest broadband penetration in Western Europe, with a level for the sum of residential and business of about 35 %. Still the broadband growth in these countries is increasing, which indicates a much higher turning point than 19 %.

Therefore, it is reasonable to believe that the Group 1 forecasts are the best forecasts.

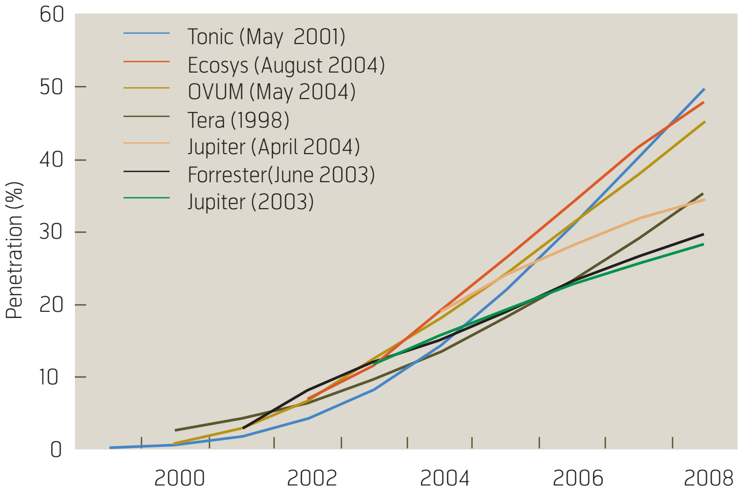

Figure 10.2 Comparison of long-term broadband penetration forecasts per household

11 Conclusions

Long-term broadband technology forecasting is not a very easy subject. Experience has shown that it is nearly impossible to make long-term forecasts without understanding the evolution of new broadband technologies and new broadband network platforms. Knowledge of broadband technologies regarding possibilities and limitations is important for the forecasting.

In order to make good long-term broadband forecasts, techno-economic analysis of the relevant broadband technologies has to be performed. Each technology generates investments and operations and maintenance costs for the rollout, which is dependent on the characteristics of the various access areas in the countries. Techno-economic analysis has the ability to show the economic value of the various technologies. Therefore, the techno-economic analysis is crucial for technology rollout strategies and for broadband forecasts.

Long-term broadband forecasting models for the Western European market take into account the penetration status for the various technologies until 2003/ medio 2004. Then long-term forecasts are developed for the period 2004 – 2010. The broadband forecasts are segmented in separate forecasts for ADSL, ADSL2+/VDLS, cable modem and other broadband technologies.

The analysis shows that ADSL, cable modem/HFC and FTTC/FTTB solutions for large building complexes are the cheapest broadband technologies. In many countries in Western Europe the cable modems/ HFC have limitations because of low CATV coverage. Other broadband technologies have to fight for market share where the mentioned broadband technologies are not deployed. Especially the rest market, with too long copper lines is a potential market for these technologies.

The broadband subscription growth in Western Europe is estimated to be 7 % in 2004 and the long-term forecasts for 2008 probably close to 50 %.

So far the broadband forecasts are mainly based on Western European mean values. The forecast modelling can be improved by making separate broadband forecasts for each country by including explanatory variables such as broadband coverage, broadband roll plans, service offer, tariffs etc.

The experience from using Delphi surveys for making long-term broadband forecasts, before broadband demand data were available, has been very good. However, it is difficult to make general conclusions based on the results from two Delphi surveys.

Comparisons of earlier forecasts from consultant companies and forecasts from the EU Commission funded techno-economic projects RACE 2087/ TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC show that the forecasts from techno-economic projects seem to be more offensive and probably give better forecasts.

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Models for forecasting cost evolution of components and technologies

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Learning curves are used in the industry to predict reduction in production time or production cost as a function of produced volume. The causes of cost reductions are better control of the production process, new production methods, new technology, redesign of the product, standardization and automatisation.

Wright and Crawford first developed the learning curve model for aircraft production [1, 2, 3]. This model is a simple exponential function where the decrease of production time is a function of number of produced units.

This paper describes an extension of the learning curve model [4, 5, 6]. The motivation for this extension was the need to model the cost evolution of new telecommunication network elements in business case studies. To be able to use the cost prediction model in economic calculations, it is important to forecast the cost evolution as a function of time, not as a function of produced units. The model is a combination of the learning curve model and a diffusion model which models the life cycle of the component.

Within the European research programs, the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC have worked out a methodology and a tool for calculating the overall financial budget of any telecommunication service and network project. The tool handles the discount system costs, operations, maintenance costs, demand forecasts, tariffs etc. The output of the tool is the life cycle costs, expected net present value (NPV) and internal rate of return (IRR). An important part of the tool includes the extended learning curves and cost prediction of network components.

The tool has been used to evaluate the life cycle costs of the different *telecommunications network technologies* with different maturity, and the results are fed back into more general forecast models (based on existing infrastructure, competition level etc.) of the market share of the technologies. In that sense the elasticity of technology volumes and cost levels are derived. In addition the tool is used for telecommunications network profitability studies, risk analysis and business scenario evaluations within many telecommunication companies and in several international research projects [7–15].

1 Background

In the European program RACE, project 2087/TITAN identified the need for modeling cost of network components and infrastructure deployment as a function of time [4, 5, 6]. One of the project objectives was to develop a methodology and tool for doing strategic business case studies. In studying future strategic telecom projects new and older cost components with a different degree of maturity have to be considered. It was decided that every cost component should be characterized with its own cost evolution. To be able to do this with a large number of cost elements, a model was developed and implemented in the tool. The model combines the learning curve and the logistic function into a closed form with a set of parameters, which have a clear meaning. This model is called the extended learning curve model and includes parameters representing:

- Cost of the product in the reference year;
- Relative accumulated production volume sold at the reference year;
- Main part of the life cycle time to the product;
- Cost decrease when the production volume is doubled (Learning curve coefficient).

In addition a fifth parameter can be used, which describes the asymmetry of the diffusion growth of the product.

2 Wright and Crawford learning curve models

The Wright-Crawford model is a simple exponential function where the decrease of production time is a function of number of produced units. The initial value of the function is the production time of the first unit. The parameter in the model is the learning curve coefficient K, which denotes the reduction in production time when the production volume is doubled. By assuming that the cost of production is proportional to the production time, the learning curve model describes the cost decrease per produced unit as a function of production volume. In the literature the learning curve is also used for describing individual learning. In an industrial process such individual learning is not the primary cause for cost reduction but a combination of several factors such as:

- More effective labor force
- Better control of the production process
- More effective organization
- Introduction of new production methods
- New technology
- Redesign of the product
- Standardization
- Automatization

Many of these factors are dependent on each other and are therefore not easily separable. For example, the development of software to support production of a product can be composed of better control of the production process, introduction of new production method and standardization of the production process.

T.P. Wright first proposed the concept of learning curves in 1936 to describe the production time of aircraft [1]:

$$T_n = n^{-\alpha} \cdot T_0 \qquad (2.1)$$

where T_n is the average production time for n units, given by

$$T_n = \frac{t_1 + t_2 + \ldots + t_n}{n} \qquad (2.2)$$

where t_n is the time to complete the n^{th} unit, T_0 the time to complete the first unit and n is the number of completed units.

J.R. Crawford applied the same formula, but interpreted T_n as the completion time for the n^{th} unit [2]. Wright's law describes the cumulative effect of learning, while Crawford's formula only refers to scale effects. A disadvantage of Wright's law is the appearance of strong autocorrelation, affecting the statistical estimation of its parameters, a problem that always arises when trying to correlate accumulated values.

In the literature many extensions and modifications of the Wright-Crawford's law has been proposed [3] but for our purpose the simple expression is used as a basis for deriving cost as a function of time. In principle we interpret P_n as the cost of the n^{th} component sold in the market of a specified component with a given functionality (e.g. GSM mobile phones), or a component from a specified product generation or series.

Suppose that component cost (price) P_n is somehow proportional with production time T_n for the n^{th} component, then we have from (2.1):

$$P_n = n^{-\alpha} \cdot P_0 \qquad (2.3)$$

Where
- P_n is the cost of production of the n^{th} component;
- P_0 is the cost of production of the very first component;
- n is the total number of produced units (possibly in a production series);
- α is a parameter in the model.

If the production volume is doubled, then:

$$P_{2n} = (2n)^{-\alpha} \cdot P_0 \qquad (2.4)$$

The relation between P_n and P_{2n} is given by:

$$P_{2n} = K \cdot P_n \qquad (2.5)$$

K is the factor by which the price is reduced when the production volume is doubled. K is called the learning curve coefficient and is related to α by

$$K = (2)^{-\alpha} \qquad (2.6)$$

or

$$\alpha = -\log_2 \cdot K \qquad (2.7)$$

The learning curve coefficient is a number less than 1. It is usually expressed in percentage and typical values are between 70 % and 95 %. The value depends highly on which product group we are taking about, the lower the value the steeper the learning curve. In Figure 2.1 the learning curve with K set to 80 % or α set to 0.32 is shown.

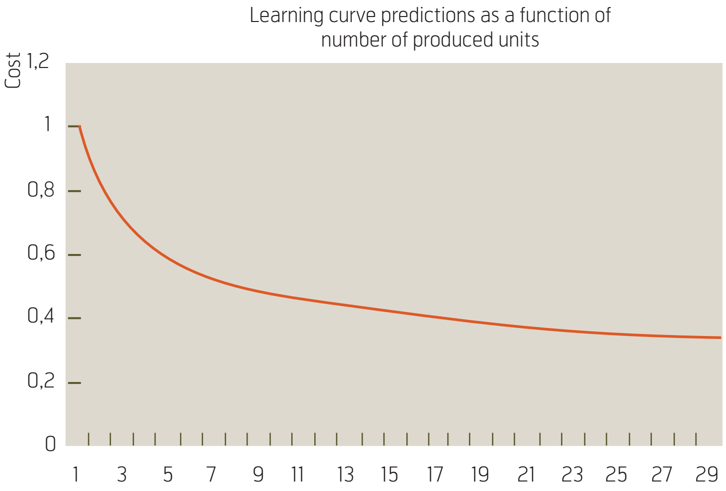

Figure 2.1 Wright-Crawford learning curve model

3 The Logistic model and component cost as a function of time

We know that the production volume n and the production cost per unit P_n is a function of time. Thus the learning curve can be written as:

$$P(t) = n(t)^{-\alpha} \cdot P_0 \tag{3.1}$$

where $n(t)$ is the global volume (for the world production of a component) and P_0 is the cost of the very first component.

The description of the growth over time of the accumulated volume of a cost component can be modeled in many ways. In the situation where very little is known, because the component is new or not even introduced to the market, a standard demand Logistic curve with four parameters is chosen. This curve has the needed generality for most types of growth processes and has a sound theoretical basis. The Logistic model chosen is defined by:

$$n(t) = M[1 + e^{(c+d\cdot t)}]^{-\gamma} \tag{3.2}$$

where

- M is the total market potential
- c, d and γ are parameters
- t is time

The model predicts the yearly-accumulated production volume. If the production volume for several years is known, it is possible to estimate the parameters M, c, d and γ. An iterative estimation procedure where OLS (ordinary least squares regression) is one part of the method can be used for estimating the parameters [17].

However, in new network architectures there are a lot of rather new or completely new network components. Then there is no time series of the yearly production volume. In that case we need another procedure for estimating the parameters. Such a procedure is described in the next chapters.

4 Introduction of relative production volume and growth period as substitution for general parameters in the Logistic curve

Formulas 3.1 and 3.2 contain both the total market size M and the production cost of the first unit P_0. Both of those inputs are sometimes difficult to obtain.

Dividing the learning curve cost in eq. 3.1 by the value at the reference year, M and P_0 disappear and $P(0)$ means the cost in reference year 0. The subscript r indicates that we now have introduced normalized logistic functions (Annex 1) where *$n_r(0)$ is defined as the relative accumulated volumes sold at the reference year*.

$$\frac{P(t)}{P(0)} = \left[\frac{n_r(t)}{n_r(0)}\right]^{-\alpha} \tag{4.1}$$

This formula with the derived expression for α from (2.7) inserted can now be written:

$$P(t) = P(0) \cdot [n_r(0)^{-1} \cdot n_r(t)]^{\log_2 \cdot K} \tag{4.2}$$

Now we have the three parameters $P(0)$, $n_r(0)$ and K. The normalized logistic formula with γ set to 1 is now:

$$n_r(t) = \left[1 + e^{(c+d\cdot t)}\right]^{-1} \tag{4.3}$$

Instead of using the parameters c and d in the Logistic model only the *growth period* ΔT has to be introduced in addition to the *relative accumulated production volume* $n_r(0)$ sold at the reference year as already defined. It is easier to understand and also easier to have an opinion about the size of these parameters than the parameters c and d.

By setting the t equal to 0 in eq. 4.3 and rearranging the expression, c is expressed by $n_r(0)$.

$$c = \ln[n_r(0)^{-1} - 1] \tag{4.4}$$

The growth period, ΔT, is now defined as the time from the component reaches 10 % of the total production volume until it reaches 90 %. Then, the following expression for d can be derived:

$$n_r(t_1) = 0.1 \tag{4.5}$$

$$n_r(t_2) = 0.9 \tag{4.6}$$

By definition

$$\Delta T = t_2 - t_1 \tag{4.7}$$

which after some manipulation (Annex 2) gives:

$$\Delta T = \frac{-2 \cdot \ln 9}{d} \tag{4.8}$$

$$d = \frac{-2 \cdot \ln 9}{\Delta T} \tag{4.9}$$

Inserting c and d in the normalised diffusion curve we get the following formula:

$$n_r(t) = \left(1 + e^{\left\{\ln\left[n_r(0)^{-1} - 1\right] - \left[\frac{2\cdot\ln 9}{\Delta T}\right]\cdot t\right\}}\right)^{-1} \tag{4.10}$$

It is clear from Figure 4.1 that the meaning of ΔT and $n_r(0)$ are very intuitive and much easier to work with than the abstract parameters c and d.

5 Life cycle for different products

The growth period ΔT of equipment or products depends of course on the technical development in the different industrial areas. Especially for consumer electronics like mobile phones the lifetime has become shorter and shorter over the last years. If the diffusion curve (S-curve) is used to describe the accumulated growth of a specific series of equipment, say the ZyXEL Prestige 600 series of ADSL modems or the Nokia 7110 Model of mobile handsets, the growth period ΔT of the models is short (1–5 years) due to new models introduced to the market with new capacities and functionality. If the formula is used to describe the accumulated growth of all units in all series of the product, like fixed telephones, the life time would be much longer, as illustrated in Figures 5.1 and Figure 5.2. For example, the growth period of Television in Canada was about 10 years. In general, due to the better production process, the life cycle of the different electronic products has decreased significantly during the last two decades.

In Figure 5.2 we can observe ΔT of more than 20 years for growth of several goods in Finland (all devices and all production series).

6 The extended learning curve

The expression for $n_r(t)$ in (4.10) is now to be substituted into the learning curve formula (4.2) yielding the final expression for cost versus time in closed form (Annex 2). The expression is called *The extended learning curve model.*

$$P(t) = P(0)\cdot$$

$$\left[n_r(0)^{-1}\cdot\left(1+e^{\{\ln[n_r(0)^{-1}-1]-[\frac{2\cdot\ln 9}{\Delta T}]\cdot t\}}\right)^{-1}\right]^{log_2\cdot K} \qquad (6.1)$$

The parameters in the extended learning curve model are defined by:

- $P(0)$ the production cost in the reference year 0,
- $n_r(0)$ the relative accumulated volume in year 0,
- ΔT the time for the accumulated volume to grow from 10 % to 90 %
- K the learning curve coefficient
- 0 is the reference year.

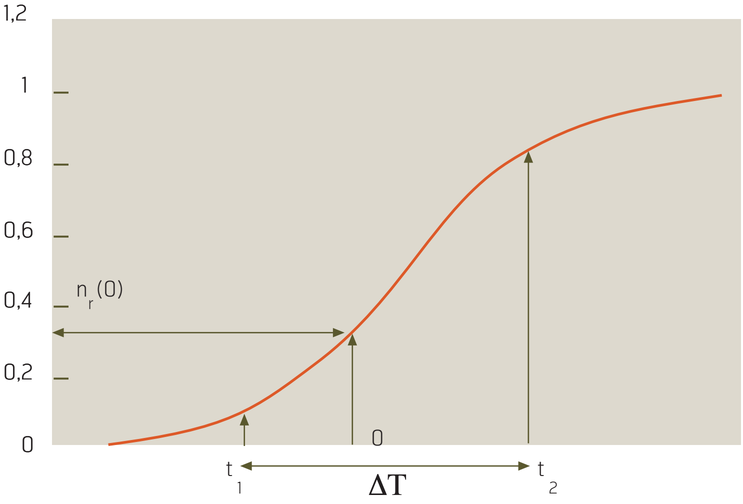

Figure 4.1 The logistic model showing $n_r(0)$ and ΔT

In order to illustrate this relation, and to get a normalised component cost, we put $P(0) = 1$ and $K = 0.90$. By keeping $n_r(0) = 0.001$ constant and letting the parameter ΔT range from 2 to 20 years, we can illustrate the evolution of the normalised cost versus time for different ΔT, as shown in Figure 6.1.

Figure 6.2 shows the impact of $n_r(0)$ on the normalised cost, keeping $\Delta T = 5$ years as a constant.

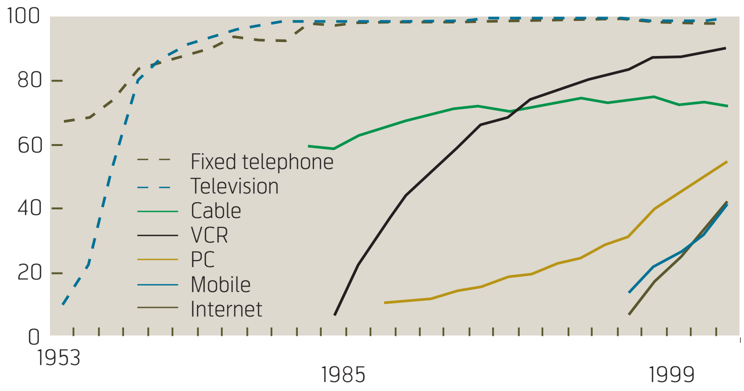

Figure 5.1 Historical diffusion of selected goods in Canada, source: Sciadas 2002b [18]

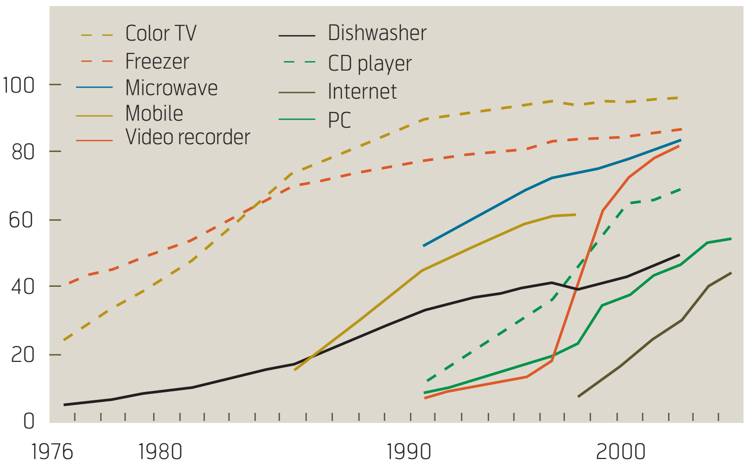

Figure 5.2 Historical diffusion of selected goods in Finland, source: Statistics Finland 2003 [18]

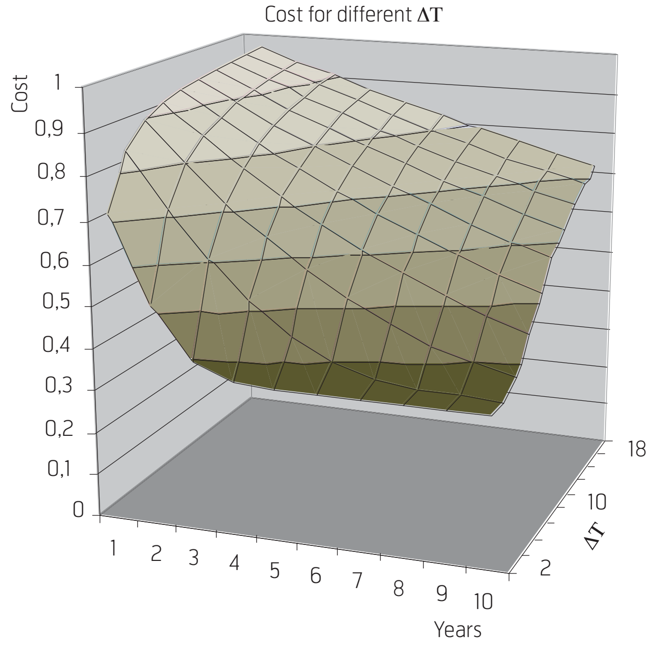

Figure 6.1 The impact of ΔT on the normalised cost, keeping $n_r(0) = 0.001$ and K = 0.9

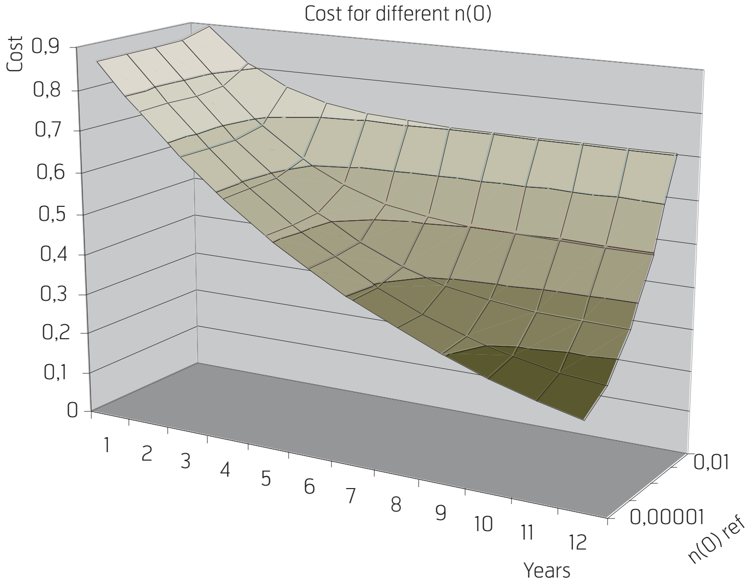

Figure 6.2 The impact of $n_r(0)$ on the normalised cost, keeping ΔT = 5 years and K = 0.9

LearningCurveClass	K_Value
CivilWorks	100.0 %
CopperCable	100.0 %
Electronics	80.0 %
SitesAndEnclosures	100.0 %
FibreCable	90.0 %
Installation (constant)	100.0 %
AdvancedOpticalComponents	70.0 %
Installation (decreasing)	85.0 %
OpticalComponents	80.0 %

Table 7.1 The learning curve classes (Learning curve coefficient)

From the previous expression it is clear that the asymptotic price level when *t* approaches ∞ does not depend on ΔT, and is given by:

$$P(\infty) = P(0) \cdot \left[\frac{1}{n(0)}\right]^{log_2(K)} \tag{6.2}$$

In addition, for small *t* the slope of the price curve is proportional to ΔT^{-1}.

7 Volume and learning curve classes

In the practical implementation of the extended learning curve in the tool mentioned in the introduction, the user chooses or estimates values of every cost component among different classes of the learning curve coefficients *K* and combinations of $n_r(0)$ and ΔT (volume classes). In case the components are new and no historical costs exist, *a priori* values have to be chosen. Illustrations are shown in Table 7.1 and Table 7.2. Typical values of the Learning curve coefficient are from 100 % (meaning no cost reduction) to 70 %, giving 30 % reduction for doubling of production volume.

Typical volume classes are shown in Table 7.2. The grouping can be established by the user of the tool and is not fixed.

The learning curve coefficient *K* classes and the volume classes are chosen according to a pragmatic choice of granularity and can be changed by the user of the tool. Especially the volume classes are chosen to cover the two aspects of cost components: the type and maturity of cost components. For example the twisted copper pair or civil work costs are Straight Line class, POTS may be Old Very Slow class, Fibre costs can be Mature Slow class and new devices for optical switching can be like Emerging Fast class.

The grouping in classes brings the needed granularity for modelling cost evolution of every cost component. The effect of allocating cost evolution to every component in the business case study make the uncertainty of the overall cost picture smaller due to the "large number law" in statistics. In general, over- and under-estimation cancel out by the large number of components.

8 Forecasts by the extended learning curve – some examples

To illustrate how the extended learning curve methodology can be applied, two examples from the telecommunication area are presented in this chapter. The first example shows how ADSL line costs are forecasted based on collected data. A substantial part of the ADSL line costs comes from the DSLAM and the line cards itself (modem is not included). The second example makes cost forecasts for transmission equipment used in the core network. The described costs are not production costs, but costs the operators have to pay for the equipment.

Figure 8.1 shows the development of ADSL line costs in the period 2000–2003. The line costs are shown in brown. Note the significant drop in the line cost from 2001 to 2002. It is difficult to collect international cost data. Some times the data may reflect immediate results from negotiations between manufactures and operators, while some other times there have been no changes in the costs/prices over a long period. The reason can be rather long contract periods. The 2001 cost observation on ADSL line cost is too high compared to both 2000 and 2002 cost, to fit a "natural" decrease during the observed period. The observation has been treated as an outlier. The learning curve model is complex and traditional linear estimation methods cannot be used. The estimation of the parameters is performed by a non-linear estimation procedure, which minimises the root mean square error.

The ADSL line cost forecast modelling gave the estimates:

$P(2000)$ = 212 Euro
ΔT = 8
$n_r(2000)$ = 0.1 %
K = 0.74

Figure 8.1 shows the forecasting results based on the estimation.

The figure shows that ADSL line costs have decreased to about 30 % of the original 2000 costs during a period of only three years. The forecasts also show that there is still a potential for a significant drop in the line costs. The forecasts indicate that the line costs reach a rather stable level after a period of 9–10 years. One reason is the estimated $\Delta T = 8$ years.

It is of interest to evaluate the estimated values. $P(2000) = 212.3$ Euro is one Euro less than the observed value in 2000. The initial production volume in year 2000 is estimated to be 0.1 %. At that time, ADSL was in its initial phase and 0.1 % is a reasonable value. The growth period $\Delta T = 8$ years, from a 10 % production level to a 90 % production level, may be right for ADSL cards with low access capacity. However, if high capacity ADSL cards (up to 8 Mb/s) are included, there is reason to believe that ΔT will be larger. The K factor estimated tells that the cost is reduced by a factor of 0.736 when the production volume on a worldwide basis is doubled. We do not have information about the total international production volume, but the K value seems reasonable.

VolumeClass	$n_r(0)$	ΔT
Emerging_Fast	0.001	5.0
Emerging_Medium	0.001	10.0
Emerging_Slow	0.001	20.0
Emerging_VerySlow	0.001	40.0
New_Fast	0.01	5.0
New_Medium	0.01	10.0
New_Slow	0.01	20.0
New_VerySlow	0.01	40.0
Mature_Fast	0.1	5.0
Mature_Medium	0.1	10.0
Mature_Slow	0.1	20.0
Mature_VerySlow	0.1	40.0
Old_Fast	0.5	5.0
Old_Medium	0.5	10.0
Old_Slow	0.5	20.0
Old_VerySlow	0.5	40.0
StraightLine	0.1	1000.0

Table 7.2 The volume classes

Figure 8.2 shows the development of SDH equipment costs from 2000 to 2003. The SDH equipment costs are shown in brown in the figure.

The observed equipment costs have a nice reduction. However, we see that the relatively yearly reductions are not of the same size as for ADSL line costs. An interpretation is that the maturity of the SDH equipment in 2000 was much higher than the ADSL equipment. This is true because SDH equipment was put into production many years before the ADSL equipment, meaning that the cost evolution of SDH is closer to the tail of the cost curve.

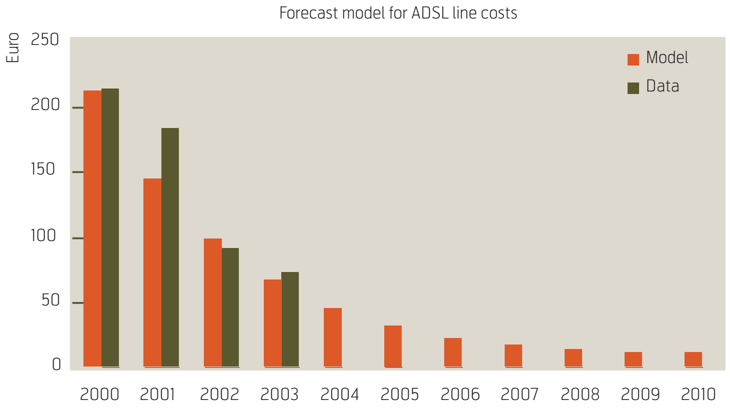

Figure 8.1 Cost observations and forecasts for ADSL line costs

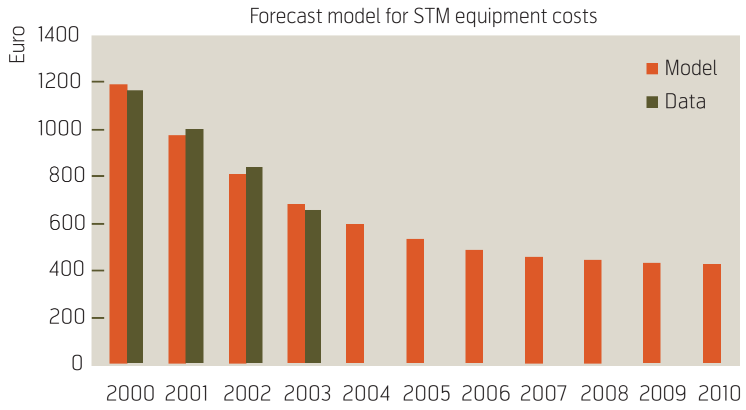

Figure 8.2 Cost observations and forecasts for SDH equipment costs

The same non-linear estimation procedure is performed for the SDH equipment. The estimation gave the following results:

$P(2000)$ = 1188 Euro
ΔT = 8
$n_r(2000)$ = 7.4 %
K = 0.76

Figure 8.2 shows the SDH equipment cost forecasts. The figure indicates quite a small future decrease in costs and that the component cost evolution stabilises around 2007. The estimation shows that 7.4 % of the total volume has been produced. The growth period ΔT is estimated to be eight years. The K factor is estimated to be about the same as for the ADSL line costs. This seems to be reasonable, because both types of equipment are produced today with very similar production methods (10 years is very typical for equipment in a series today). Also the estimated initial cost in year 2000 Euro is reasonably good, only 26 Euro from observed real cost value.

It is difficult to evaluate the forecasts, but the fact that the value of the estimates both for the ADSL line cost and the SDH equipment cost is reasonable based on our additional knowledge is of course a positive element in the evaluation.

9 Conclusions

Wright and Crawford have developed the learning curve model for cost predictions. However, their model is not able to predict the costs as a function of time. In traditional business case modeling, cost predictions for a given period is a necessary input for calculations of net present value, pay-back period and internal rate of return.

The extended learning curve model presented in this paper has the ability to predict cost evolution as a function of time. The model extends Wright and Crawford's learning curve by inserting a Logistic forecasting function for number of produced units. The Logistic function includes *three* parameters for flexible modelling of different production volume evolutions. In addition the learning curve is described with *two* parameters.

Hence, the number of parameters that go into the new model is five. The saturation level of the Logistic function, which is the expected total number of units to be produced, is one parameter. This parameter is eliminated through expression of the relative number (percentage) of produced units. Then the resulting number of parameters in the extended learning curve model is only four.

The traditional objective from a statistical point of view is to estimate the parameters. This is of course a reasonable way to perform the modeling when many observations are made. *However, there are possibilities to include even more knowledge into this process.* Therefore substantial work has been carried out to transform two of the parameters (c and d) in the model, to get *interpretative parameters*.

The following interpretative parameters were identified after the transformation:

- Price in the reference year;
- Relative accumulated volume sold today;
- Main part of the life cycle time to the product – the period between 10 % and 90 % penetration of the product (growth period);
- Proportion of cost decrease when the production volume is doubled (the learning curve coefficient).

In many situations, business case modeling for introduction of new products is performed. Then, no data are available of the production evolution of the new product. Even if no data are available, it is possible to use the extended learning curve model for prediction of the costs. And the reason is *the interpretative parameters*. Without observations, there are possibilities to give *a priori* values of these parameters.

Information about a probable price in the reference year of the product can be collected. The relative volume sold today $n_r(0)$ can be almost 0 or estimated on the basis of some country data. There is no need to know the worldwide penetration. The growth period of the product ΔT has to be roughly estimated.

Remember that the life cycle of the product has decreased significantly during the last two decades (Chapter 5). Based on this type of knowledge it is possible without observations to do some estimates. There exists *a priori* knowledge about the *K* factor for different types of components. This information is available from the equipment provider industry if the component is on the market. The advantage of having *interpretative parameters* in the learning curve model is obvious when cost predictions for new products are developed.

Chapter 8 documented how the extended learning curve model is applied when a set of observations are available. Then, statistical methodology (non-linear estimation) is used to estimate the parameters. Even in this situation, *a priori* knowledge is important. The evaluation of the estimated values turned out to be reasonably good in the two examples presented. However, if for example the main part of the life cycle of those products was estimated to be 40 years, we know that this is completely wrong and we have the possibility to adjust the parameter.

The extended learning curve modeling gives the possibility to include both observations and *a priori* knowledge in the cost forecasts.

The extended learning curve is based on insertion of a three parameter Logistic model which describes a symmetric behavior of the production penetration around a turning point for the function. In Annex 3 a four parameter Logistic model with a non-symmetric pattern is used as input to the learning curve. This variant of the extended learning curve model can give a better flexibility for the estimation of the cost evolution.

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Annex 1 – Relative growth model

We know that the production volume n and the production cost per unit P_n are a function of time. Thus

$$P(t) = n(t)^{-\alpha} \cdot P_0 \qquad \text{(A1.1)}$$

In principle $n(t)$ is the global accumulated volume for the world production of a component at time t and P_0 is the cost of the very first component.

Both of these inputs are sometimes difficult to obtain. These obstacles are easily removed from the learning curve formulation by using relative values, in which case P_0 does not appear.

$$\frac{P(t)}{P(0)} = \left[\frac{n(t)}{n(0)}\right]^{-\alpha} \qquad \text{(A1.2)}$$

Furthermore, the global accumulated volume $n(t)$ may be removed from the expression by observing that

$$\frac{P(t)}{P(0)} = \left[\frac{n_r(t)}{n_r(0)}\right]^{-\alpha}$$

holds true since

$$\left[\frac{n(t)}{n(0)}\right]^{-\alpha} = \left[\frac{n_r(t)}{n_r(0)}\right]^{-\alpha}$$

where $n_r(t)$ and $n_r(0)$ are relative values (i.e. normalized to 1). Rearranging the expression gives:

$$P(t) = P(0) \cdot \left[\frac{n_r(t)}{n_r(0)}\right]^{-\alpha} \qquad \text{(A1.3)}$$

or

$$P(t) = P(0) \cdot [n_r(0)^{-1} \cdot n_r(t)]^{\log_2 \cdot K} \qquad \text{(A1.4)}$$

$n_r(0)$ is the relative component volume at time $t = 0$. The relative accumulated component volume $n_r(t)$ at time t of the component must be modeled in some way.

In the situation with limited number of observations, it is necessary to make a model of the lifetime of every cost component. To be very general we assume that the best general model to describe the relative accumulated volume produced (sold) of a component $n_r(t)$ is the normalized standard demand logistic curve with four parameters. Hence, the Logistic model is defined by:

$$n(t) = [1 + e^{(c+d \cdot t)}]^{-\gamma} \qquad \text{(A1.5)}$$

where

- c, d and γ are parameters;
- t is time.

The model predicts the yearly production volume. If the production volume for the last years is known, it is possible to estimate the parameters c, d and γ. However, in new network architectures, there are a lot of rather new or completely new network components. In this case there is no time series of the yearly production volume. Then we need to be able to interpret the parameters and estimate them based on different *a priori* knowledge.

Annex 2 – Reformulation of the Logistic curve in the symmetric case

In general the Logistic curve is described by abstract parameters, which give no direct meaning. In a situation where hundreds of cost components have to be characterized, it is important to be able to have a more direct feeling about the reasonable sets of parameters to be applied. In the following we first make the reformulation in the symmetric case with the γ set to 1.

Instead of using the parameters c and d in the Logistic model, the *growth period* ΔT and the relative production volume $n_r(0)$ at a reference time 0 are introduced. It is easier to understand and also easier to have an opinion about the size of these parameters than the parameters c and d.

$$n_r(t) = [1 + e^{(c+d \cdot t)}]^{-1} \qquad \text{(A2.1)}$$

c expressed by $n_r(0)$:

Setting $t = 0$ in (A2.1), we get:

$$n_r(0) = (1 + e^{c})^{-1} \qquad \text{(A2.2)}$$

Some rearrangements give:

$$c = \ln[n_r(0)^{-1} - 1] \tag{A2.3}$$

which expresses c in terms of the relative accumulated volume at year 0.

***d* expressed by ΔT:**

We define the growth period as the time from the component reaches 10 % of the total production volume (saturation) until it reaches 90 %. Then the following equations are defined:

$$n_r(t_1) = 0.1 \tag{A2.4}$$

$$n_r(t_2) = 0.9 \tag{A2.5}$$

Thus

$$\left[1 + e^{(c+d\cdot t_1)}\right]^{-1} = 0.1 \;\&$$

$$\left[1 + e^{(c+d\cdot t_2)}\right]^{-1} = 0.9 \tag{A2.6}$$

$$1 + e^{(c+d\cdot t_1)} = 10 \;\&\; 1 + e^{(c+d\cdot t_2)} = \frac{10}{9} \tag{A2.7}$$

$$e^{(c+d\cdot t_1)} = 9 \;\&\; e^{(c+d\cdot t_2)} = \frac{1}{9} \tag{A2.8}$$

$$e^{c} \cdot e^{d\cdot t_1} = 9 \;\&\; e^{c} \cdot e^{d\cdot t_2} = \frac{1}{9} \tag{A2.9}$$

By dividing the right hand side by the left hand side of (A2.6) we get

$$e^{d\cdot(t_2-t_1)} = \frac{1}{9^2} \tag{A2.10}$$

$$d \cdot (t_2 - t_1) = -2 \cdot \ln 9$$

By definition

$$\Delta T = t_2 - t_1 \tag{A2.11}$$

$$\Delta T = \frac{-2 \cdot \ln 9}{d} \tag{A2.12}$$

$$d = \frac{-2 \cdot \ln 9}{\Delta T} \tag{A2.13}$$

which express d in terms of ΔT.

Substitution of the expressions of c and d into the logistic curve gives

$$n_r(t) = \left(1 + e^{\left\{\ln\left[n_r(0)^{-1}-1\right]-\left[\frac{2\cdot\ln 9}{\Delta T}\right]\cdot t\right\}}\right)^{-1} \tag{A2.14}$$

where $n_r(0)$ and ΔT are the only parameters.

Annex 3 – The extended learning curve model based on asymmetric production growth

The Logistic curve for various values of the parameter γ is illustrated in Figure A3.1.

The parameters c and d can be derived as in the symmetric case giving:

$$c = \ln\left[n_r(0)^{\frac{-1}{\gamma}} - 1\right] \tag{A3.1}$$

and by defining δ:

$$\delta = \frac{\left[\left(\frac{10}{9}\right)^{\frac{1}{\gamma}} - 1\right]}{\left[10^{\frac{1}{\gamma}} - 1\right]} \tag{A3.2}$$

where δ is a function of γ only.

Finally, we get the expression for δ as a function of ΔT:

$$d = \frac{\ln \delta}{\Delta T} \tag{A3.3}$$

Hence, the final expression for price versus time in general is:

$$P(t) = P(0)\cdot$$
$$\left[n_r(0)^{-1} \cdot \left(1 + e^{\left\{\ln\left[n_r(0)^{\frac{-1}{\gamma}}-1\right]+\left[\frac{\ln\delta}{\Delta T}\right]\cdot t\right\}}\right)^{-\gamma}\right]^{\log_2 \cdot K} \tag{A3.4}$$

The parameters in the formula are defined by:

$P(0)$, the price in the reference year 0;
$n_r(0)$, the relative accumulated volume in year 0;
ΔT, the time for the accumulated volume to grow from 10 % to 90 %;
K, the learning curve coefficient;
γ, the asymmetry of the logistic curve.

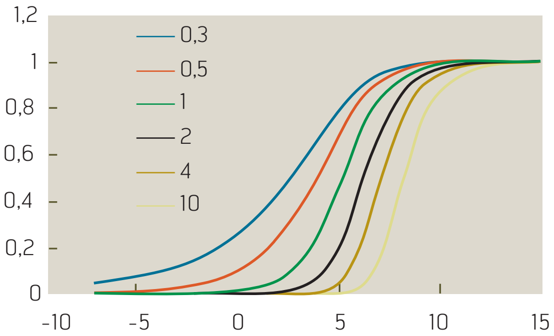

Figure A3.1 Diffusion curves for different values of γ (from 0.3 to 10)

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For a presentation of Kjell Stordahl, please turn to page 2.

Forecasting – An Important Factor for Network Planning

KJELL STORDAHL

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The paper gives an overview of forecasts and forecast methodology used for network planning. Specific attention is given to how forecasts are applied for development of strategies and planning. An extensive list of references is annexed for more detailed studies.

1 Is Forecasting Necessary for Network Planning?

Network planning is an important activity for the operators. In order to utilise the resources and investment means in the best possible way, it is of crucial importance to have insight in future telecommunication demand. A professional forecasting process will show the expected evolution of the telecommunication demand.

Questions to be solved in the network planning process are:

- Choice of technology and network components
- Design of network structure
- Routing principles and redundancy in the network
- Dimensioning of nodes and routes in the network
- Timing of network expansion
- Implementation of additional functionality
- Introduction of new and enhanced services
- Integration of functionality on various OSI levels
- Replacement strategies for old network components/old technology
- Long-term strategy planning for network evolution

Important forecasts to support the planning process are:

- Forecasts for service demand
- Forecasts for enhanced services demand
- Identification of demand for new services
- Subscription/access forecasts for the services
- Traffic volume forecasts for services and applications
- Busy hour traffic forecasts for services and applications
- Forecasts based on market segmentation
- Forecasts taking into account competition and market share
- Forecasts separated into national level, regional level and local level
- Forecasts allocated to the various networks
- Forecasts allocated to transport network, regional network and access network

Specific forecasts are defined by combining the items on the list.

For example, Telenor SHDSL subscription forecasts for the business market for one specific local access area are based on the following:

- Estimation of potential DSL accesses for different market segments, especially type of industry (SIC code) and size in the specific area
- Forecasts of the DSL business penetration in the area
- Forecasts of the evolution of demand of symmetric business access demand in the specific area
- Prediction of expected market share in the specific area

There are different players in the telecommunication market. Because of open network provisioning additional operators have been established in the market. The access network is available based on Local Loop UnBundling and several operators hire the copper pair from the incumbents. In addition wholesale has been introduced to create a more open and competitive telecommunication market with new service providers. The telecommunication market is more complex and there are even more need for forecast modelling taking into account the new environments.

There are always economic risks related to network planning. The forecasting process should generate reduced risks by identifying the new and enhanced applications and make predictions of access and traffic demand generated by the new and traditional services in environments where the competition and evolution of expected market share are described.

Of course there are significant uncertainties related to the forecasting process. Hence, an important part of the process is to describe the uncertainty and try to incorporate the uncertainty evaluations into the network planning process.

2 Network Evolution and the Forecasts

The circuit switched telephone network has evolved through certain milestones from being an analogue network to a network consisting of only digital exchanges. The next step was the introduction of ISDN. Now, Telenor has the highest ISDN penetration in the world. During the last few years the IP based Internet has evolved significantly. In Norway the Internet penetration is more than 60 %. Before the residential broadband take off, the main capacity in the transport network was made up by leased lines and PSTN/ISDN traffic. A significant part of PSTN/ISDN traffic has been narrowband Internet traffic.

Now we see conversion of narrowband Internet traffic to broadband ADSL traffic. New services and applications are established and new demand generated. The broadband platform will be enhanced either through ADSL2+ or VDSL, which in turn include broadband entertainment services in the fixed network. In parallel HFC networks from the cable operators UPC and Telenor Avidi have been deployed and Fixed broadband radio systems like LMDS are established.

Today there is a significant conversion of voice traffic from the PSTN/ISDN to mobile networks. The mobile platform is evolving from GSM to GPRS, possibly to EDGE and to UMTS. In addition WLAN hot spots are deployed.

The business market has evolved through data line switched and data packet switched network without considerable success, to leased lines, Internet and DSL. Now, new services like symmetric DSL (SHDSL), fast- and GB Ethernet are introduced.

The market, the established services, the enhanced and new services and applications create telecommunication demand. Market forecasts are important and necessary for taking the right decisions for network evolution. The forecasts help to get the right timing from introduction of new network platforms and services. More detailed description of the forecasts are shown in [1, 3, 5, 7-8, 11-13, 26-27, 30-31, 34-35, 37, 51, 55, 57, 63, 65, 74, 82-83, 85-87].

3 Techno-Economic Tool for Strategic Evaluations of New Technology and Network Structures

To be able to make the right decision for rolling out a new network platform, a comprehensive techno-economic analysis has to be carried out.

Within the European programs RACE, ACTS and IST, the projects RACE 2087/TITAN, AC 226/OPTIMUM, AC364/TERA and IST-2000-25172 TONIC have developed a methodology and a tool for calculation of the overall financial budget of any access architecture. The tool handles the discounted system costs, operations, maintenance costs, life cycle costs, net present value (NPV) and internal rate of return (IRR). The tool has the ability to combine low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters for performing evaluation of various network architectures [40–46, 58–59, 66, 71–72].

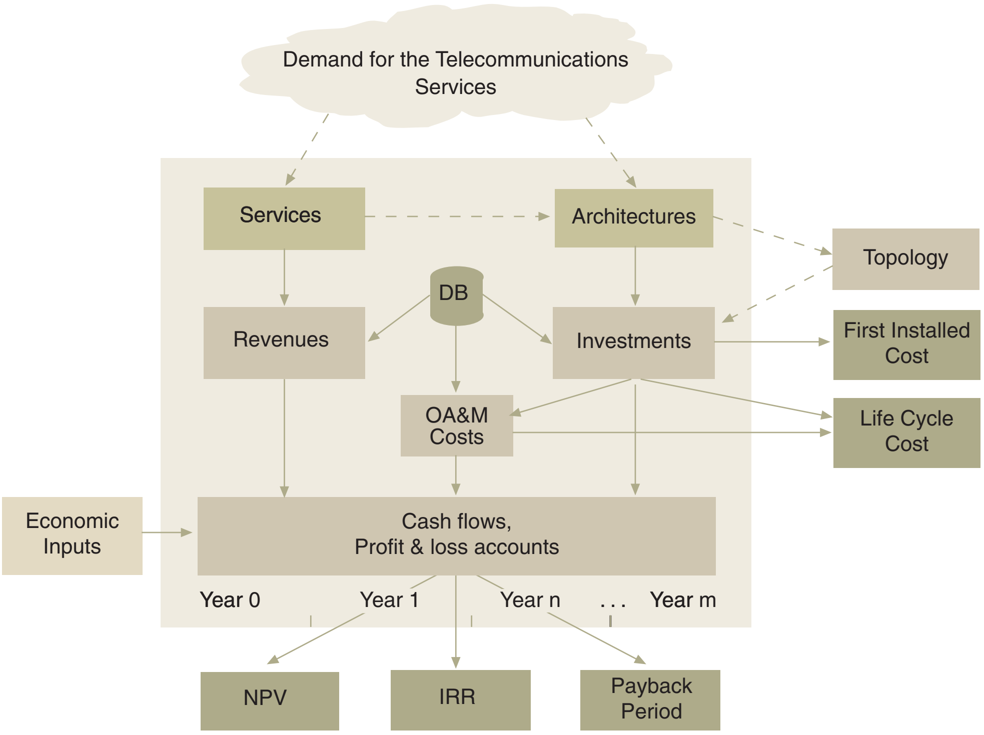


Figure 1 TONIC techno-economic tool for investment projects analysis

Figure 1 shows a techno-economic tool used in different international EU projects.

The figure shows that telecommunication demand is an input to the tool and to the techno-economic calculations. The TONIC tool is widely used to analyse economic consequences by implementing new network platforms. Important parts of the tool are:

- Service definitions
- Subscription and traffic forecasts
- Service tariff predictions
- Revenue model
- A topology model mapping geographic areas with given penetrations into the tool
- Network component cost data base including more than 300 network components
- Network component cost prediction model
- Investment model
- Operation and maintenance model
- Model for economic calculations
- Risk analysis model

The following steps are needed in the techno-economic evaluations of the network solutions:

The services to be provided must be specified. The market penetration of these services over the study period will be defined. The services have associated tariffs, i.e. the part of the tariff that is attributed to the network under study. From the combination of yearly market penetration and yearly tariff information TONIC calculates the revenues for each year for the selected service set.

Next, the architecture scenarios to provide the selected service set must be defined. This needs network design expertise and is mostly outside of the framework of TONIC methodology. However, TONIC includes several geometric models, which facilitate the network design by automatically calculating lengths for cables and ducting. These geometric models are optional parts of the methodology and TONIC can be used without them. The result of an architecture scenario definition is a so-called shopping list. This list indicates the volumes of all network cost elements (equipment, cables, cabinets, ducting, installation etc.) for each year of the study period and the location of these network components in different flexibility points and link levels.

The costs of the network components are calculated using an integrated cost database developed within the TONIC project, containing data gathered from many European sources. Architecture scenarios together with the cost database give investments for each year.

The OA&M costs are divided into different components like cost of repair parts including civil work and operations and administration costs. Typically the OA&M costs are being driven by services, say by number of customers and number of critical network elements.

Investment costs together with the OA&M costs give the life-cycle cost for the selected architecture scenario. Finally, by combining service revenues, investments, operating costs and general economic inputs (e.g. discount rate, tax rate) OPTIMUM, cash flows and other economic factors (NPV, IRR, Payback period etc) are calculated.

4 Strategic Evaluations of New Technology and Network Structures

The possibility to introduce new services, enhanced services, new applications, additional traffic growth and generation of additional revenue is important for network operators. Strategies for introduction of new technologies and network platforms open the possibilities for generation of additional revenue. Some examples of introduction of new technology during the last 20 years are:

- Establishment of NMT
- Deployment of optical fibre and fibre technology in the network
- Digitalisation of the PSTN
- Introduction of ISDN
- Establishment of GSM
- Introduction of Internet
- Establishment of ATM network
- Establishment of IP networks
- Establishment of SDH transmission technology
- Introduction of ADSL

The next step is enhancement of the ADSL platform to ADSL2+ or VDSL and for the mobile network UMTS, WLAN and 4G. Important input for making the right decisions of introducing new technology has been demand forecasts for new and enhanced services. The forecasts and tariff predictions give revenue forecasts, which are used together with techno-economic analysis to support decisions of introduction of new technology.

The traffic forecasts are also fundamental for dimensioning the networks and establishing optimal network structures.

Techno-economic evaluations of new network technology is analysed in [2, 4, 14–15, 18–25, 28–29, 33, 36, 38–39, 48, 50, 52–54, 60, 68, 70, 76, 81, 84, 88–89].

5 Subscriber/Access Forecasting

Network planning of the access network depends heavily on subscriber forecasts. Until recently, substantial investments in the local telephone exchanges have been based on forecasts of the subscriber growth in the local area. The subscriber forecasts indicated time for expansion of the telephone exchange. In addition the subscriber forecasts were used together with queuing models to estimate the busy hour traffic volume in the exchange. When the data traffic was limited, Erlang's dimensioning rule was used for traffic dimensioning taking into account the distribution of residential and business customers. 30 years ago the business customer traffic was dominating and the busy hour was around lunch. Now, traffic from residential customers is dominating on the main part of the Norwegian exchanges. During the last few years the busy hour has been moved from after the main television news programme to the 21.00–22.00 period, mainly because of the Internet traffic.

ISDN was introduced in the Norwegian market 10 years ago. There have been significant substitution effects between ISDN and PSTN in this period. The ISDN forecasts consist of: 2B+D residential, 2B+D business and 30B+D business. Also multiple ISDN line forecasts will be implemented.

The ISDN forecasts have been important for planning and providing new network components.

Because of competition and substitution effects between services, the penetration of PSTN and ISDN have saturated the Norwegian network. Now, the new PSTN and ISDN forecasts reflect a smaller number of subscribers. There are two main reasons for the decrease:

- Some residential customers substitute their main telephone subscriptions with mobile subscriptions

- Some residential customers substitute their PSTN/ISDN Internet connections with ADSL.

These forecasts are crucial for network planning. The forecasts show as a function of time the spare capacity in the network regarding traffic capacity and number of connections.

The subscriber forecasts have been important also for restructuring the access network. The forecasts are used for planning and establishing service connection points in the access network and for dimensioning the access lines and fibre rings between the service connection points.

Subscription forecasts have been developed for (narrowband) Internet, ATM, ADSL, SHDSL, SHDSL point-to-point, Fast Ethernet and GB Ethernet and leased lines. The subscription forecasts give valuable information for planning, dimensioning and expanding the network structure.

However, it is important to take into account significant substitution effects between the services. The ISDN and PSTN forecasts are mutually dependent. The ADSL forecasts influence significantly the narrowband Internet forecasts and ISDN and PSTN forecasts. Lost PSTN and ISDN market shares for the incumbent increase the leased line demand forecasts. Subscription forecasts for 2.5G and 3G increase the leased lines forecasts. Increased ADSL subscriber forecasts and demand for LLUB increase the leased line forecasts because of expansion of the traffic capacity between DSLAM and broadband access point, and because of additional traffic in the transport network. Subscriber demand forecasts for SHDSL and SHDSL point-to-point and point-to-multipoint will lower the leased lines forecasts, since the new services are leased lines substitutes with cheaper tariffs and a degraded service quality.

To be able to control the dependencies, forecasting models for the different services are linked together.

6 Traffic Forecasting

An important part of network planning is design of network structures. The PSTN/ISDN consists of the access network including local exchanges, region networks including group exchanges and the long distance network including long distance exchanges and national exchanges. To maintain a high degree of reliability, independent routes are established between local exchanges and group exchanges on the one hand and between group exchanges and long distance exchanges on the other hand. Between the long distance exchanges there is a logical mesh network. However, even when there is a mesh network there is a simpler physical network taking into account the logical mesh network abilities. The physical network is based on deployed fibre rings and SDH transmission equipment.

Network planning designs optimal structure of the network with the nodes (exchanges) and the routes by minimising the costs for a given redundancy. Important factors are the exchange sites, the route length and the capacity on the routes. Specific network planning tools have also been developed to minimise the investments. Different tools have been developed for the access network and for the transport network. The tools can be applied for establishing new network structures or for expanding the network.

The traffic forecasts are important input for designing the network and for dimensioning the exchanges and capacity on the different routes and as input to the network planning tools.

The busy hour traffic forecasts quantify increases/decreases in the traffic. The dimensioning calculations based on queuing theory add some extra capacity to control random variation in the traffic load during the busy hours. When the traffic on a route or in an exchange approaches the capacity, an expansion will be carried out. The expansion of the capacity will be based on the forecasts for a given planning period.

The forecasting procedure described is used not only for the PSTN/ISDN but for other networks like PSDN, Frame relay/ATM, Digital Cross Connect, various IP networks, networks for mobile operators and leased lines. There are different possibilities for making traffic forecasts. One possibility is to measure the traffic and use the traffic measurements as a historic database for the forecasts. One problem is rerouting of the traffic based on new network structures or because of change of interconnection sites in the network. Such changes affect the traffic measurements, which have to be adjusted before the forecasts can be developed. Another possibility is to analyse the total traffic growth in the given network and make the forecasts on the aggregated level.

A detailed description of the traffic forecasting procedure for the transport network is described in [1]. The traffic forecasting procedure for the transport network is rather complex since the network carries business and residential traffic from all the other networks.

7 Capacity Forecasts

Models for making traffic forecasts during the busy hour have been described. However, the capacity needed to carry the traffic is higher. Additional capacity has to be dimensioned taking into account stochastic variations around the mean traffic in the busy hour. Usually Erlang's blocking formula is applied for voice traffic, while Lindberger's approximation is useful for dimensioning the data traffic capacity [90]. The traffic will probably be transported on SDH systems where packet overhead is added. In addition the systems' average load factor is less than the maximum capacity. Finally there will in general be some extra dimensioning since the expansion of the network is planned and deployed stepwise. A planning period is defined as the time between two expansions. The duration of the planning period is found by taking into account the repeating costs by performing the expansion and the unused investment means during part of the period. The optimal planning period is found by minimising the total costs. The estimation of additional capacity depends on the planning process and the technical systems and will vary from one incumbent to another.

8 Forecasting Methodologies

A variety of forecasting models are used for predicting the evolution of the telecommunication market. An important task is collection and analysis of statistics – historical data. A lot of resources are used to maintain rather large customer based systems. An extraction of data from these systems is used to create subscription statistics, which is a base for subscriber forecasts. In addition specific measurement systems are established to extract traffic measurements on specific points in the networks and also on the aggregated level.

The forecasting models take into account historical data. The most common models for *access forecasts* are:

- Diffusion models
- Regression models
- Econometric models
- ARIMA models
- Kalman filter models
- Smoothing models

The access forecasting models have to take into account substitution effects between services as pointed out in chapter 5. Even the competition between the incumbent and the other operators influences not only the access forecasts but also the BOT and leased lines forecasts. Telenor is using a rather comprehensive composite model where the substitution effects between PSTN, ISDN, Leased lines, ADSL, VDSL/ADSL2+, HFC, FTTH, FWA are included. Important factors in the model are the predicted technology coverage for the coming years, the predicted market shares etc.

The most common models for traffic forecasts are:

- Regression models
- Econometric models
- ARIMA models
- Kalman filter models
- Smoothing models

In addition specific forecasting procedures can be used. The traffic is generated by sources and moves in a network from source to a set of sinks. To dimension the network, it is important to know the traffic behaviour from the edge routers or the local exchanges. The traffic streams are mapped in a traffic matrix. Each element in the matrix denotes the traffic between two exchanges. Suppose the number of exchanges is

N. Then an NxN matrix describes the traffic between all exchanges. Specific forecasting procedures can be used to forecast the traffic in the network or the matrix. The procedures are used when the network structure is stable during a certain period.

The best known traffic matrix forecasting procedure is *Kruithof's method* [103]. The method makes traffic matrix forecasts based on the observed traffic matrix, let us say at time 0, and forecasts of the outgoing traffic and forecasts of the incoming traffic from an exchange, let us say at time t. The outgoing traffic corresponds to the row sums in the traffic matrix and the incoming traffic corresponds to the column sums. There will be inconsistency between the row sums at time 0 and the forecast row sums at time t and in the same manner for the column sums. To reach consistency, Kruithof's method tries to take into account both the traffic structure at time 0 and the row and column forecasts in the best possible way. Hence Kruithof's method uses an iteration procedure to get a compromise between the traffic matrix structure at time 0 and the forecasts. The iteration procedure upgrades the rows in the traffic matrix to correspond with the row sum forecasts. Then the iteration procedure upgrades the columns in the traffic matrix to correspond to the column forecasts. After some iterations the adjusted traffic matrix elements correspond to the row and column forecasts, which gives a traffic matrix forecast at time t.

An *extension of Kruithof's method* can be performed by making point-to-point forecasts for each element in the traffic matrix together with forecasts of the outgoing traffic and incoming traffic from each exchange and then adjust the traffic elements in the matrix based on the exchange forecasts using the same iteration procedure.

A further extension of Kruithof's traffic matrix forecasting procedure has been developed. *The weighted least squares method* is based on the fact that the relative uncertainties in the traffic element forecasts are larger than the row and column sum forecasts. The method calculates the adjusted traffic element forecasts by taking into account the relative uncertainty in the traffic element forecasts and the row and column sum forecasts. The different forecasts are found by weighting the forecasts according to their uncertainty using weighting least square method.

Extended least square method takes also into account the total traffic forecasts for the whole traffic matrix. The total traffic is defined as the sum of the row sums or the sum of the column sums in the matrix, which of course are identical. The method is based on the statistical principle to use as much information as possible. Hence, forecasts of the traffic elements, the row sums, the column sums and the total traffic are used. The model is described as follows:

- C_{ijt} is the traffic between i and j at the time t
- $C_{i.t}$ is the traffic from i at time t
- $C_{.jt}$ is the traffic from j at time t
- $C_{..t}$ is the total traffic at time t

The forecasts at time t is given by C_{ijt}, C_{ijt}, $C_{ij}t$ and $C_{..t}$ respectively. The extended weighted leased square forecasts are denoted by $\{E\}$ and found by solving the following minimisation problem:

The square sum Q is defined by:

$$Q = \Sigma\, \alpha_{ij} \cdot (E_{ijt} - C_{ijt}) + \Sigma\, \beta_i\, (E_{i.t} - C_{i.t}) \\ + \Sigma\, \gamma_j\, (E_{.jt} - C_{.jt}) + \Sigma\, \delta\, (E_{..t} - C_{..t})$$

where $\{\alpha_{ij}\}$, $\{\beta_i\}$, $\{\gamma_j\}$ and δ are given constants. The square sum is minimised given that adjusted forecasts $\{E\}$ are consistent, i.e. satisfy the condition that the row sum is equal to the row sum forecasts of each element and the column sum is equal to the column sum forecasts of each element and the sum of the elements in the whole matrix is equal to the total forecasts. A natural choice of the weights is the inverse of the variance of forecast uncertainty of the forecasts. One way to find estimates of the forecasts' uncertainty is to perform ex-post forecasts and then calculate the mean square error. The solution of the minimisation problem is found by using Lagrange's multiplicator method adding the constraints based on consistency in the adjusted forecasts. By using the method we get $N(N + 3) + 2$ equations when N is the dimension of the traffic matrix. The solution of the system of equations gives the traffic matrix forecasts.

The forecasts methodologies are described in more detail in [91–103].

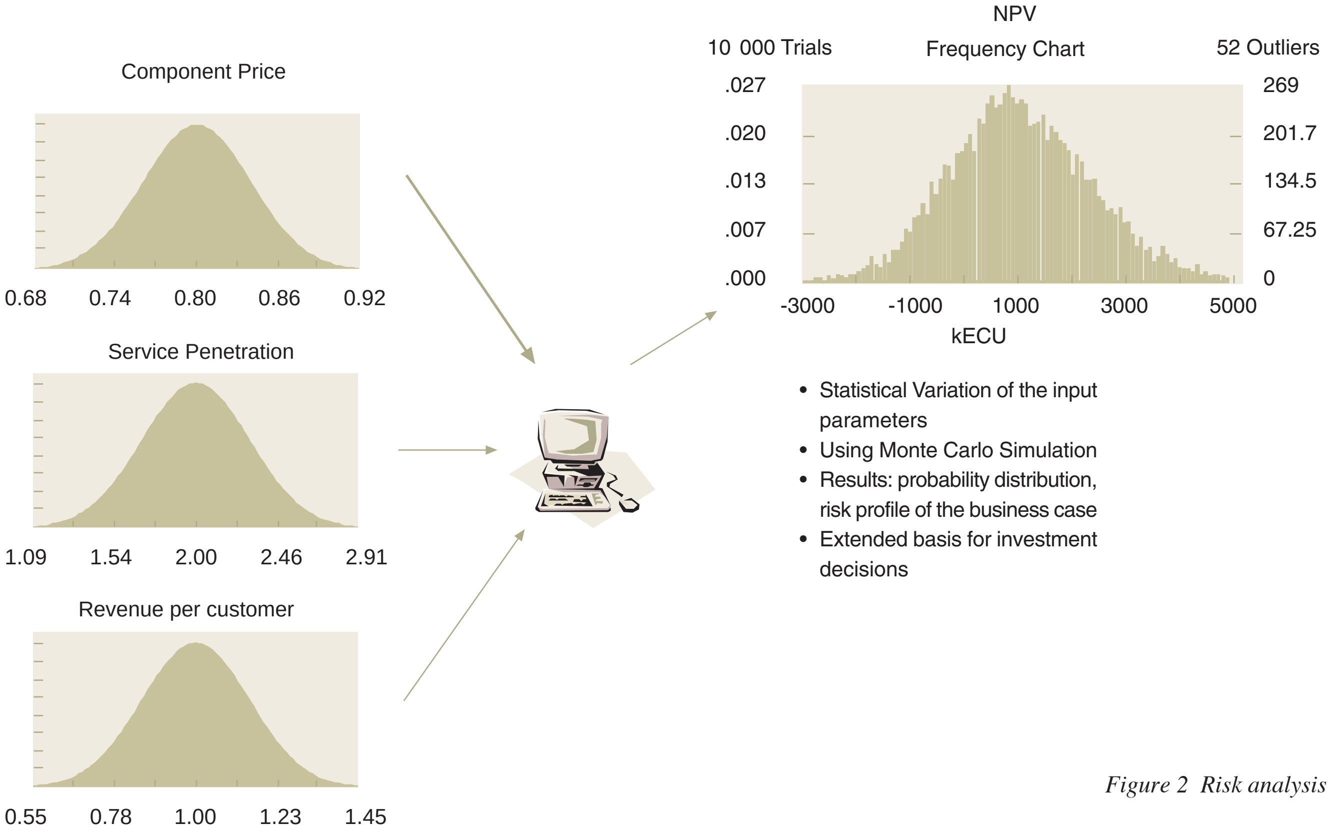
9 Forecasts Uncertainty and the Risk

There are always uncertainties connected to forecasts. Network planning decisions have to be made based on expectations of future evolution. The uncertainty in the evolution can be classified in the following main groups:

- Uncertainty in market (penetration and market share) forecasts

- Uncertainty in tariff forecasts (predictions)

- Uncertainty in network component cost predictions.



- Statistical Variation of the input parameters
- Using Monte Carlo Simulation
- Results: probability distribution, risk profile of the business case
- Extended basis for investment decisions

Figure 2 Risk analysis

The effect of uncertainty in the predictions should be quantified to examine the consequences. The first step is to find the most critical variables in the project. The next step is to perform calculations based on variation in the critical variables to identify the consequences.

One possibility is to apply sensitivity analysis. Another and more advanced method is to use the risk analysis. The output in an economic risk analysis is net present value (NPV), internal rate of return (IIR) and pay back period. One of the outputs or all of them simultaneously can be used in risk analysis.

Instead of using the expected forecast, say at time *t*, a probability distribution of the forecast at time *t* has to be used. Similar probability distributions have to be constructed for all critical variables. Usually truncated Normal distributions or Beta distributions are used.

A Monte Carlo simulation with 1000 – 5000 trials is performed. In each trial, a random number is picked from the predefined probability distributions; one for each of the critical variables. The simulation gives as output the cumulative distribution of NPV, IIR and pay back period and the ranking of the critical variables according to their impact. This uncertainty ranking is based on the percentage to the contribution to the variance of the NPV or the rank correlation with the NPV.

A commercial spreadsheet application Crystal Ball has been integrated with the techno-economic tool. A graphical interface in Crystal Ball makes it possible to specify the distribution functions directly from a palette type of menu inside the techno-economic model.

The risk analysis has been applied on a set of different cases studying strategies for rolling out new network technology [6, 9–10, 16–17, 32, 37, 47, 49, 56, 61–64, 67, 69, 73, 75, 77, 78–80].

10 Conclusions

The paper documents that forecasts and forecast methodology are important factors in the network planning process and strategy process for rolling out new technology platforms. Since the forecasts are uncertain, it is recommended to use risk analysis to evaluate the risk generated by forecasts and predictions of other critical variables. For more detailed studies the papers in the reference list should be studied.

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Traffic forecast models for the transport network

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Topics: 1A

1 Introduction

The line switched voice traffic has traditionally been a significant part of the traffic in the transport network. However, during the recent years Leased lines ordered by different operators and also the Leased lines ordered from the business market have expanded the transport network capacity. A new capacity wave has also started: the data traffic moving from narrowband to broadband. The data traffic is increasing exponentially and will during some years be the dominating traffic in the transport network. Important traffic drivers are broadband applications carried by HFC, ADSL, VDSL, LMDS, UMTS and WLAN.

This paper analyses the traffic and capacity evolution of the transport network of an incumbent operator having the possibility to integrate different type of traffic into the network. A traffic volume indicator is developed for traffic increase in the transport network. The access forecast modelling has been developed based on parts of the results from the projects ACT 384 TERA IST-2000-25172 project TONIC [1 – 11].

2 Market segments

Services
Traffic from the services is transported on different network platforms or on leased lines. Important services for the transport network are: POTS/ISDN, Internet, Leased lines, PSDN (packet switched data network), Frame relay, ATM, IP Virtual private network(VPN), ADSL/SDSL, VDSL/LMDS, Fast Ethernet, Gigabit Ethernet, Lamda wavelength, Dynamic bandwidth allocation.

Market segments
An incumbent operator is leasing transport capacity to other operators. In addition the incumbent offers transport capacity to the residential and the business market. The incumbent operator offers transport capacity either via own service provider or as wholesale. A segmentation of the market will be:

Residential market: POTS, ISDN, Internet, ADSL, VDSL, LMDS, HFC

Business market: POTS, ISDN, IP VPN, Internet, PSDN, Frame Relay, ATM, ADSL, SDSL, VDSL, LMDS, Leased lines, Fast Ethernet, Gigabit Ethernet, Lamda wavelength, Dynamic bandwidth allocation.

Operators: ADSL, SDSL, VDSL, LMDS, Leased lines, Fast Ethernet, Gigabit Ethernet IP-VPN, Lamda wavelength, Dynamic bandwidth allocation. (mobile operators, ISPs, other operators)

Network platforms
Relevant network platforms are: POTS/ISDN, PSDN, Frame Relay/ATM, Digital Cross Connect, Various IP Networks including IP networks for mobile operators, Leased lines. POTS/ISDN is a line switched network. Leased lines have no concentration effect at all, while the other network platforms also have packet switched concentration.

3 Traffic from the residential market

The residential market generates different type of traffic: Voice traffic, Dialled Internet traffic, ADSL traffic, VDSL/LMDS traffic

The voice traffic has nearly reached saturation. During the next years, the line switched voice traffic will be rather stable before parts of the line switched voice traffic are substituted by IP voice. *The dialled Internet traffic* reaches maximum within a few years. Then the dialled Internet traffic will continuously be substituted by broadband traffic. A battle has already started between broadband operators to capture parts of the broadband market.

Broadband access forecasts have been developed in the IST-2000-25172 project TONIC. Figure 1 shows the market share evolution of ADSL, VDSL, FWBB (Fixed wireless broadband) and HFC/cable modem for West European countries.

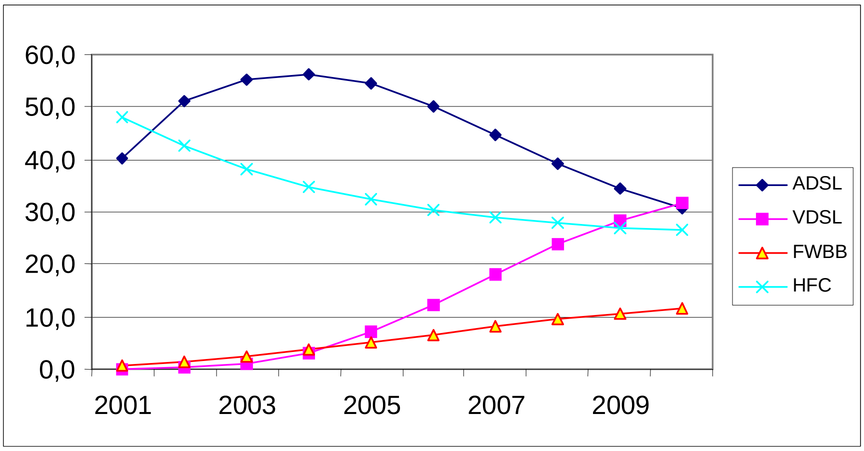

Figure 1 Market share distribution and prediction of ADSL, VDSL, FWBB and HFC(cable modem) for West European countries

Figure 2 shows total broadband penetration. Combination of the figures gives the broadband penetration for each technology.

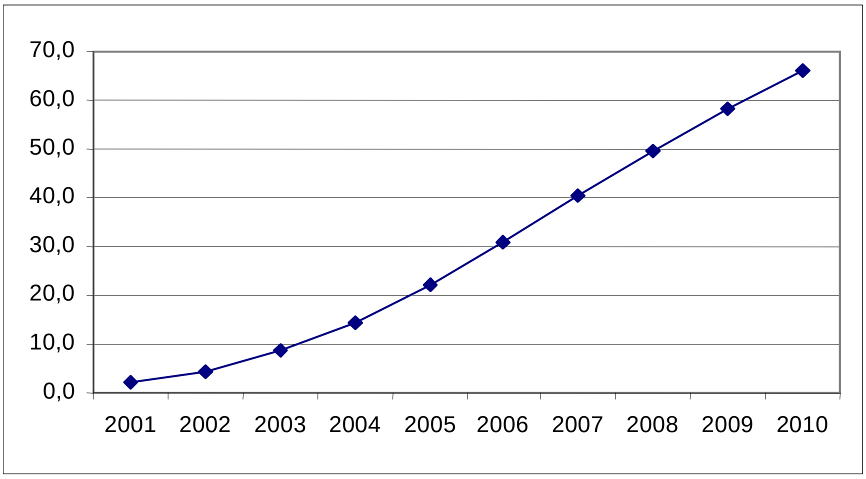

Figure 2 Broadband penetration forecasts for the residential market

Now, the question is which traffic is carried in the incumbent's transport network. Usually the cable TV/HFC traffic is carried outside the transport network, while a part (market share) of the penetration of each of the other technologies will be carried in the incumbent's transport network.
A traffic volume forecast indicator,$V_R(t)$, for the residential busy hour traffic into the transport network is given by:

$$V_R(t) = N_t \ \Sigma_{i=1,2,3} \ b_{it} u_{it} A_{it} C_{it} M_{it} p_{it} \qquad (1)$$

where

i = 1 denotes voice traffic
i = 2 denotes Dialled Internet

i = 3 denotes ADSL
i = 4 denotes VDSL
i = 5 denotes FWBB
N_t is number of households in year t
b_{it} is busy hour concentration factor for technology i in year t
u_{it} is packet switching concentration factor for technology i in year t
A_{it} is the access capacity utilisation for technology i in year t
C_{it} is mean downstream access capacity for technology i in year t
M_{it} is incumbent's access market share for technology i in year t
p_{it} is the access penetration forecasts (%) for technology i in year t

Market share and access penetration
The factor N_t M_{it} p_{it} represents a forecast of number of households connected to the incumbent's transport network in year t using technology i. Suppose the incumbent operator have 40% of the ADSL market share and expects to be in the same position the next years, then M_{3t} = 0.40 for t = 2001, 2002, - - -.

Mean downstream access capacity
The downstream access capacity, $C_{1t,}$ for voice traffic is 64kbs and will be the same the next years. However the downstream access capacity, $C_{3t,}$ for ADSL is changing. Figure 3 shows how the mean downstream access capacity is increasing. Now, the operators offer a set of different access capacities. There will be an evolution from low access capacities to higher access capacities especially because of new and enhanced applications. In addition new functionality such as, bandwidth on demand, will be introduced by the operators. For VDSL the access capacity will be about 24Mbs. However, only part of this capacity will be individual, while the capacity for dedicated TV channels will be a common resource for all households.

The market share evolution for different ADSL access capacities is described in the IST-2000-25172 project TONIC. Mean access capacity is calculated according to the distribution of different access capacities for each year. The results are shown in figure 3.

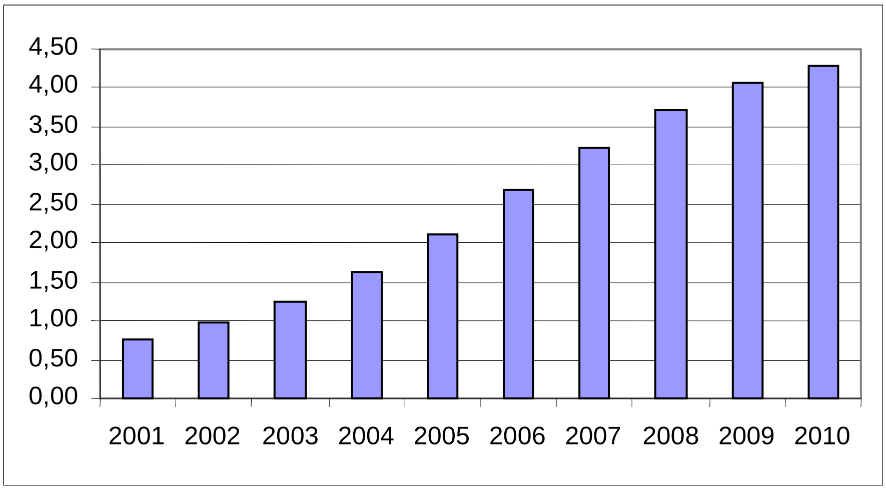

Figure 3 Evolution of predicted average downstream capacity in Mbs for ADSL subscriptions

Access capacity utilisation
A broadband customer is not utilising the maximum capacity all the time. The access capacity utilisation factor indicates average capacity use taking into account the proportion of time during the conversation performing downloading and the proportion of time for upstream. The factor also reflects the degree of using the specified bandwidth.

Busy hour concentration
The busy hour concentration effect is well known. Usually about 10% (b_{1t} = 0,1) of the customers make phone calls in the busy hour. Traditionally Erlang's blocking formula (assuming exponential interarrival time and holding time) is used for dimensioning. The busy hour concentration factor is increasing because of Internet. For broadband connections the busy hour concentration factor is significantly higher because of heavy users, longer holding times, flat rate and evolution of new applications.

The busy hour for residential narrowband and broadband traffic is in the evening.

Packet switching concentration

The line switched services POTS and ISDN have no packet switching concentration ($u_{1t} = 1$). The other services have significant concentrations. Internet use constitutes of sessions based downloading, thinking and upload. The traffic will be packet according to the use. Traditional Internet use gives low packet switching concentration. Applications like music on demand and video on demand generate high packet switching concentration. The evolution of the packet switching concentration factor is complex.

Uncertainty in the concentration factors

Figure 4 shows possible evolutions of combinations between busy hour concentrations and packet switching concentrations. There are significant uncertainties in the evolution. The basis for the predictions in figure 4 is 0,15 (15%) busy hour concentration and 0,20 packet switching concentration in 2001. *Four alternatives* are defined having a linear yearly increase:

Busy hour concentration: 0,15 in 2001 to respectively 0,195 – 0,24 – 0,285 – 0,33 in 2010
Packet switching concentration: 0,20 in 2001 to respectively 0,335 – 0,47 – 0,605 – 0,74 in 2010

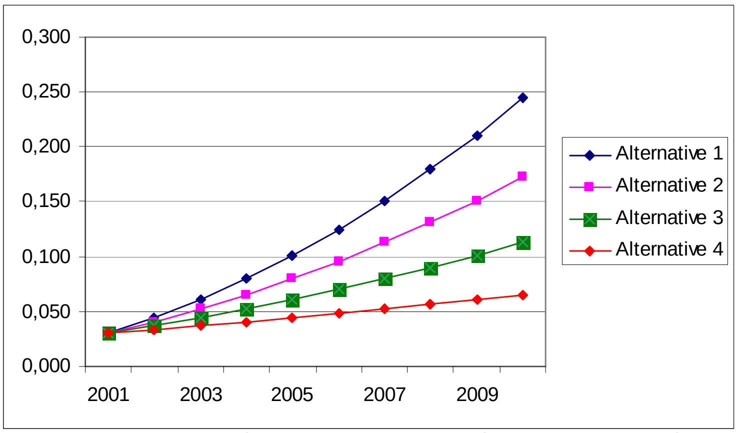

Figure 4 Description of possible evolutions of concentrations of ADSL traffic as a function of busy hour and packet switching concentration

Figure 2 – 4 show a nearly exponential evolution of broadband penetration, capacity increase and traffic concentration the coming years. The most probable prediction will be between alternative 2 and 3. The traffic volume indicator described in equation (1) has a much stronger exponential evolution because of multiplicative effect the same factors.

4 Traffic from the business market

The business market generates following type of traffic/capacity: Voice traffic, Dialled Internet traffic, PSDN, ATM, Frame Relay, DSL traffic, IP Virtual Private Networks (IP VPN) traffic, Leased lines, Fast and Gigabit Ethernet.

There are significantly substitution effects between DSL, IP VPN, Leased lines, fast and Gigabit Ethernet, which have to be taken into account in the forecasting process. Leased lines are used to establish fixed connections between sites often based on head office and branch offices or between different enterprises. The established network forms a local network with high service quality. There are no busy hour concentration or packet switching concentration. Leased lines constitute a significantly part of the transport network capacity. Some part of leased lines capacity will be transferred to IP VPN or DSL because of cheaper tariffs and in spite of reduced service quality/SLA.

A traffic volume forecast indicator, $V_B(t)$, for the business market busy hour traffic is given by:

$$V_B(t) = N_t \, \Sigma_i \, b_{it} \, u_{it} \, A_{it} \, C_{it} \, M_{it} \, p_{it} \qquad (2)$$

where the different traffic/capacity types i are defined in the first paragraph of the chapter.

5 Traffic generated by other operators

Different operators like mobile operators, ISPs, other fixed network operators lease necessary capacity in the transport network. The capacity demand depends on type of services offered and the market share to the operators and of cause the probability for using the transport network to the incumbent.

The mobile operators are important transport network customers using leased lines in the transport network. These operators generate during the next years following traffic:

- 2G traffic (Digital mobile systems such as GSM)
- 2.5G traffic (HSCSD, GPRS, EDGE)
- 3G traffic (UMTS)
- 3.5G traffic (Ubiquitous roaming among 3G and WLAN systems)

The access forecasts for the different systems have been developed in the IST-2000-25172 project Tonic.

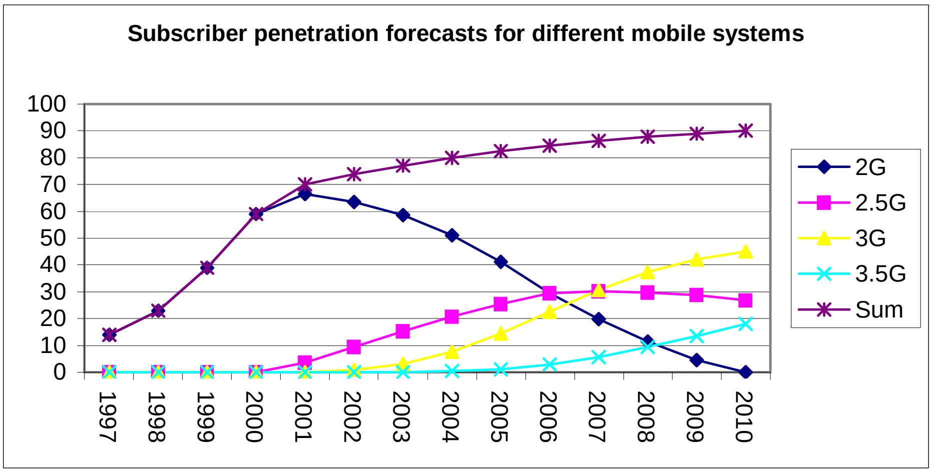

Figure 5 Subscriber penetration forecasts for different mobile systems

Subscription forecasts for the mobile systems, allowing the subscribers to have more than one subscription have also been developed. The traffic capacity for data applications per user is increasing from 40 kbs to 1,92 Mbs from 2G to 3G, while WLAN offers up to 54Mbs. The traffic forecast model for mobile traffic is similar to the traffic in the fixed network. The busy hour concentration factor and the packet switching concentration factor are extremely important for the dimensioning. The services/applications are defined in different service classes: conversation, streaming, best effort and the capacity is reserved according to service level agreements.

The traffic forecasting model, $V_M(t)$, for mobile operators is given by:

$$V_M(t) = N_t \ \Sigma_i \ b_{it} \, u_{it} \, A_{it} \, C_{it} \, M_{it} \, p_{it} \qquad (3)$$

Here N_t is number of persons, not number of households. M_{it} denotes the market share to the operator and i = 1, 2, 3, 4 the system generations 2G, 2.5G, 3G and 3.5G. The penetration forecasts p_{it} are shown in figure 5. The capacity C_{it} is a mean capacity. A 3.5G subscriber has the possibility to use a data rate up to144kbs using UMTS but a significantly higher capacity in WLAN hotspot. The number of hot spots available and the proportion of time the subscriber uses WLAN compared with UMTS give the mean capacity C_{4t}. The factor, $A_{it,}$ indicates the real utilisation of the capacity.

Let $V_O(t)$ be the busy hour traffic forecasts for the other operators, then the total of busy hour traffic forecasts, V(t), is given by:

$$V(t) = V_R(t) + V_B(t) + V_M(t) + V_O(t) \qquad (4)$$

There are definitely possibilities to reduce V(t) since the business traffic has busy hour before/after lunch, while the residential traffic has busy hour in the evening. Since the operators are using leased lines, the capacity is equal during the day and night. Let $V_{BL}(t)$ be the Leased line capacity and $V_{BP}(t)$ be the packet switched traffic in the business market. Then $V_B(t) = V_{BL}(t) + V_{BP}(t)$. The residential broadband traffic is larger than the packet switched business traffic in the busy hour. Suppose that $\Delta = 0{,}2$ (20%) of the packet switched business busy hour traffic is transferred during the residential busy hour. Then the adjusted busy hour traffic forecasts $V^*(t)$ is:

$$V^*(t) = V_R(t) + \Delta V_{BP}(t) + V_{BL}(t) + V_M(t) + V_O(t) \tag{5}$$

6 Capacity forecasts

Models for making traffic forecast during the busy hour have been described. However, the capacity needed to carry the traffic is higher. Additional capacity has to be dimensioned taking into account stochastic variations around the mean traffic in the busy hour. Usually Erlangs blocking formula is applied for voice traffic, while Lindbergers approximation is useful for dimensioning the data traffic capacity [12]. The traffic will probably be transported on SDH systems where packet overhead is added. In addition the systems load factor in average is less than the maximum capacity and finally there will in general be some extra dimensioning since the expansion of the network is planned and deployed stepwise. The estimation of additional capacity depends on the planning process and the technical systems and will vary from one incumbent to another.

7 Conclusions

A traffic volume indicator has been developed to estimate busy hour traffic increase in the transport network. The indicator estimates the traffic entering the transport network. The traffic volume indicator does not include redundancy and protection capacity in the core network. Telenor is using the traffic volume indicator forecasts as input to transport network planning process – evaluating new network structures, expansion of the network and introduction of new core network technology.

The indicator depends of the application evolution and also the tariff regime for broadband services. So far most countries use flat rate for broadband traffic. However, specific applications will overload the transport network heavily if no actions are performed. There exist no incitements to control the size of the traffic in the transport network. A probable solution will be to introduce tariff on high capacity traffic and on bandwidth on demand and specific applications. The traffic forecasts used assume that a new tariff regime for broadband services will be implemented within the next two years.

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METHODS FOR TRAFFIC MATRIX FORECASTING

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1. INTRODUCTION

Efficient forecasting methods reduce the uncertainty in network planning. By using forecasts with high precision as input to network planning programs, important investments can be reduced in the planning procedure. In this paper a set of new methods for making traffic matrix forecasts are introduced. The most frequently used methods for traffic matrix forecasting are Kruithof's method and the method based on direct point to point forecasts. In [5] a new method for traffic matrix forecasting called the weighted least squares method was introduced. In [1] an extension of Kruithof's method was proposed by the Norwegian Telecommunications Administration. The revised (new) CCITT Recommendation E.506 [2] gives an overview of the following traffic matrix forecasting procedures:

- Direct point to point forecasts
- Kruithof's method
- Extension of Kruithof's method
- Weighted least squares method

In this paper an additional traffic matrix forecasting method is also introduced. This new method is an extension of the weighted least squares method. All these methods are based on traditional forecasts as input. The forecasts may be constructed by various forecasting models e.g. smoothing models, regression models, state space models, ARIMA models, growth curves etc. Another way to attack the problem is to formulate the relations between the aggregated forecasts and the point to point forecasts inside the forecasting procedure. This is only possible in state space modelling. A description of such a procedure for making traffic matrix forecasts is given in [6].

2. DIRECT POINT TO POINT FORECASTING

This method is based on making separate forecasts of the elements in the traffic matrix without taking into account the aggregated forecasts like originating traffic (row sums) and terminating traffic (column sums) and the total traffic.

Usually it is possible to make better forecast for aggregated traffic than for traffic on a lower level. In such situations other forecasting methods should be preferred. Evaluation of the relative forecasting precision $\sigma(X)/X$, where X is the forecast and $\sigma(X)$ is the forecasting error, may be carried out before choosing the method to be used.

3. KRUITHOF'S METHOD

Kruithof's method [3] is well known. This method uses the last known traffic matrix and forecasts of row and column sums to make forecasts of the traffic matrix. This is carried out by an efficient iteration procedure.

4. EXTENSION OF KRUITHOF'S METHOD

It is possible to extend Kruithof's method by taking into account not only the forecasts of row and column sums but also forecasts of point to point traffic. Kruithof's method is then used to adjust the point to point forecasts to get consistency with the forecasts of row and column sums. The extended Kruithof's method is superior to Kruithof's method.

5. WEIGHTED LEAST SQUARES METHOD

Weighted least squares method ([4],[5]) is again an extension of Kruithof's method. The extended Kruithof's method assumes that the forecasts of row and column sums are true and adjusts the point to point forecasts to get consistency. The weighted least squares method is based on the assumption that both point to point forecasts and row and column sum forecasts are uncertain and makes traffic matrix forecasts by weighting the forecasts according to their uncertainty.

6. EXTENSION OF WEIGHTED LEAST SQUARES METHOD

The extended weighted least squares method is a completely new method. The method is based on the statistical principle to use as much information as possible both for analysis and forecasting. Hence, not only colomn and row sums but also the total sum of the traffic in the matrix are included in the forecasting model. The model is described as follows; let

- C_{ijt} be the traffic between i and j at time t
- $C_{i\cdot t}$ be the traffic from i at time t
- $C_{\cdot jt}$ be the traffic to j at time t
- $C_{\cdot\cdot t}$ be the total traffic at time t

The forecast at time T is then given by C_{ijT}, $C_{i\cdot T}$, $C_{\cdot jT}$ and $C_{\cdot\cdot T}$ respectively. The extended weighted least squares forecasts are denoted by E and defined in the same way. The forecasts are found by solving the following minimization problem:

The square sum Q is defined by:

$$Q = \sum_{ij} \alpha_{ij}(E_{ijT} - C_{ijT})^2 + \sum_i \beta_i(E_{i\cdot T} - C_{i\cdot T})^2 + \sum_j \gamma_j(E_{\cdot jT} - C_{\cdot jT})^2$$
$$+ \delta\,(E_{\cdot\cdot T} - C_{\cdot\cdot T})^2 \qquad (6.1)$$

where $\{\alpha_{ij}\}$, $\{\beta_i\}$, $\{\gamma_j\}$ and δ are given constants or weights.

The square sum Q with given forecasts { C } and a set of constraints is minimized as follows:

$$\min_{E_{ijT}} Q(E_{ijT} \mid C) \qquad (6.2)$$

given

$$E_{i\cdot T} = \sum_j E_{ijT} \qquad i = 1,2,\ldots\ldots.. \qquad (6.3)$$

$$E_{\cdot jT} = \sum_i E_{ijT} \qquad j = 1,2,\ldots\ldots.. \qquad (6.4)$$

$$E_{..T} = \sum_{ij} E_{ijT} \tag{6.5}$$

A natural choice of weights is the inverse of the variance of the forecasts. One way to find an estimate of the standard deviation and thus the variance of the forecasts is to perform ex-post forecasting and then calculate the root mean square error.

If there are reasons to believe that the total forecast is fairly certain, then the last constraint may be substituted with:

$$C_{..T} = \sum_{ij} E_{ijT} \tag{6.6}$$

The solution of the minimization problem is found by Lagranges' multiplicator method. By using this method we get a set of n(n+3) + 2 equations when n is the dimension of the traffic matrix.

A computer program has been developed to find the extended weighted least squares forecasts. The program has a relatively good input/ output module and is simple to use.

7. EVALUATION OF THE EXTENDED WEIGHTED LEAST SQUARES METHOD

7.1. A simplified model

In order to examine the performance of the extended weighted least squares method, an analysis has been carried out in a case where it is possible to obtain an explicit solution of the minimization problem. No assumption is made concerning the dimension of the traffic matrix. It is assumed that the forecasted traffic elements are of the same size and that the forecasted row and column sums are of the same size. In addition three different weights - one for traffic elements, one for row/column sums, one for the total sum - are used.

The dimension of the traffic matrix is n. The forecasts of traffic elements, row/column sums and total traffic are denoted by c_1, c_2 and c_3 respectively, while the (adjusted) extended weighted least squares forecasts are denoted by e_1, e_2 and e_3. The weights are defined in the same way as w_1, w_2 and w_3.
Hence the extended weighted least squares forecasts are found by solving the minimization problem:

$$Q = n(n-1)w_1(e_1-c_1)^2 + 2nw_2(e_2-c_2)^2 + w_3(e_3-c_3)^2 \tag{7.1}$$

$$\min_{e_1,e_2,e_3} Q \tag{7.2}$$

given the constraints

$$e_2 = (n-1)e_1 \tag{7.3}$$

$$e_3 = n(n-1)e_1 \tag{7.4}$$

By using Lagranges' multiplicator method the minimization problem can be transfered into solving five equations with five unknown. The explicit solution of this problem is:

$$e_1 = \frac{c_1w_1 + 2c_2w_2 + c_3w_3}{w_1 + 2(n-1)w_2 + n(n-1)w_3} \tag{7.5}$$

where e_2 and e_3 are given by equation (7.3) and (7.4).

7.2. Asymptotic behaviour

The asymptotic behaviour of the extended weighted least squares forecasts is studied by looking on the limiting values of { w } in equation (7.5). It is easy to show that:

$$e_1 = c_1 \qquad \text{when } w_1 \to \infty \tag{7.6}$$

$$e_1 = c_2/(n-1) \qquad \text{when } w_2 \to \infty \tag{7.7}$$

$$e_1 = c_3/(n(n-1)) \qquad \text{when } w_3 \to \infty \tag{7.8}$$

The values of the aggregated forecasts e_2 and e_3 are expressed in the equations (7.3) and (7.4). In particular, if one weight goes to infinity all the extended weighted least squares forecasts are only a function of the corresponding c-forecast. If on the other hand, one of the weights is equal to zero, the extended weighted least squares forecasts are a function of the two remaining c-forecasts and their corresponding weights. By setting $w_3 = 0$ we obtain as a special case the weighted least squares forecasts.

7.3. The weights as a function of the variances

In order to apply the forecasting method in the right way, it is important to investigate how the forecasts change as a function of the weights. In section 5 it was suggested to give the various forecasts weights according to their uncertainty. A fairly good solution is to use the weights in equation (6.1) respectively (7.1) equal to the inverse of their forecasting variance.

In the simplified model the inverse of the variance of the forecasts of the elements, of the row/column sums and of the total sum are identical to the corresponding weights w_1, w_2 and w_3. Let the variance of c_1 be σ^2. Now, suppose that the forecasts of various elements in the traffic matrix are independent. Then $\mathrm{Var}(c_2) = (n-1)\sigma^2$ and $\mathrm{Var}(c_3) = n(n-1)\sigma^2$. Usually this is not true. There are reasons to believe that there are covariances between the forecasting errors in the traffic matrix. To describe this effect two additional parameters k_1 and k_2 are introduced so that

$$w_1 = (\mathrm{var}(c_1))^{-1} = [\ \sigma^2\ ]^{-1} \tag{7.9}$$

$$w_2 = (\mathrm{Var}(c_2))^{-1} = [\ k_1(n-1)\sigma^2\ ]^{-1} \tag{7.10}$$

$$w_3 = (\mathrm{var}(c_3))^{-1} = [\ k_2 n(n-1)\sigma^2\ ]^{-1} \tag{7.11}$$

Inserting equations (7.9), (7.10) and (7.11) into equation (7.5) gives

$$e_1 = p_1\Delta_{11} + p_2\Delta_{21} + p_3\Delta_{31} \tag{7.12}$$

where { p } is a probability distribution as a function of { k } given by :

$$p_1 = \frac{k_1k_2}{k_1 + k_1k_2 + 2k_2}\ ,\quad p_2 = \frac{2k_2}{k_1 + k_1k_2 + 2k_2}\ ,\quad p_3 = \frac{k_1}{k_1 + k_1k_2 + 2k_2} \tag{7.13}$$

and { Δ } is a function of { c } given by:

$$\Delta_{11} = 0\ ,\quad \Delta_{21} = \frac{c_2}{n-1} - c_1\ ,\quad \Delta_{31} = \frac{c_3}{n(n-1)} - c_1 \tag{7.14}$$

The { Δ } function can be interpreted as increments in the traffic element forecasts caused by the aggregated forecasts. For instance, Δ_{31} shows the increment in the element forecasts if only the total forecast is taken into account. The { p } distribution determins the weights given to the various forecasts. For instance, if $p_3 = 1$ then all weight should be put on the total forecast ($k_2 = 0$) which corresponds to the situation described by equation (7.8). If $p_1 = 1$ then all weight should be put on the row and column sum forecasts ($k_1 = 0$) which is analogous to using Kruithof's extended method.

Now, suppose that $k_1 = 1$ and $k_2 = 1$. Then the probability distribution { p } is equal to {0.25, 0.50, 0.25} and the extended weighted least squares forecast are given by:

$$e_1 = c_1 + (\tfrac{1}{4})\,\Delta_{11} + (\tfrac{2}{4})\,\Delta_{21} + (\tfrac{1}{4})\,\Delta_{31}$$

In this case 25% of the weight is put on the element forecasts, 50% of the weight is put on the row and column sum forecasts and 25% of the weight is put on the total forecast.

By varying the parameters {k} different values of the probability distribution occur. The table 7.1 shows the variation of the probability distribution as a function of {k}.

Table 7.1 The probability distribution {p} as a function of {k}

	k_2	0.5			1.0			2.5		
k_1	p	p_1	p_2	p_3	p_1	p_2	p_3	p_1	p_2	p_3
0		0	1	0	0	1	0	0	1	0
0.5		0.14	0.57	0.29	0.17	0.67	0.17	0.19	0.74	0.07
0.8		0.18	0.45	0.36	0.22	0.56	0.22	0.26	0.64	0.10
1.0		0.20	0.40	0.40	0.25	0.50	0.25	0.29	0.59	0.12
1.2		0.21	0.36	0.43	0.27	0.45	0.27	0.33	0.54	0.13
1.5		0.23	0.31	0.46	0.30	0.40	0.30	0.37	0.49	0.15
2.0		0.25	0.25	0.50	0.33	0.33	0.33	0.42	0.42	0.17
2.5		0.26	0.21	0.53	0.36	0.29	0.36	0.45	0.36	0.18
∞		0.33	0	0.67	0.50	0	0.50	0.71	0	0.29

8. EXAMPLES

In order to illustrate how the extended weighted least squares method works, a simple example is introduced. Suppose that the original forecasts for a 4 dimensional traffic matririx are given by:

$$C : \quad \begin{bmatrix} 0 & 50 & 50 & 50 \\ 50 & 0 & 50 & 50 \\ 50 & 50 & 0 & 50 \\ 50 & 50 & 50 & 50 \end{bmatrix} \begin{bmatrix} 153 \\ 153 \\ 153 \\ 153 \end{bmatrix}$$

$$\begin{bmatrix} 153 & 153 & 153 & 153 \end{bmatrix} \begin{bmatrix} 684 \end{bmatrix}$$

Then

$$c_1 = 50\ , \quad c_2 = 153 \quad \text{and} \quad c_3 = 684$$

and

$$\Delta_{21} = 153/3 - 50 = \underline{1}$$
$$\Delta_{31} = 684/12 - 50 = \underline{7}$$

Suppose, in this example, that a lot of efforts have been used in developing an advanced long term forecasting model for the total sum. There are reasons to believe that the long term forecasts of the row sums, column sums and of the elements are not sufficiently precise. In this situation the weights are subjectively put like:

$$p_1 = 0.10 \quad , \quad p_2 = 0.20 \quad , \quad p_3 = 0.70$$

By using the equation (7.12) the adjusted element forecast is estimated to:

$$e_1 = \underline{55.1}$$

Usually the various element forecasts, row sums forecasts etc are not identical. Suppose instead that the forecasts are given by:

$$C : \quad \begin{bmatrix} 0 & 61 & 44 & 49 \\ 58 & 0 & 29 & 57 \\ 42 & 30 & 0 & 62 \\ 52 & 55 & 65 & 0 \end{bmatrix} \begin{bmatrix} 157 \\ 144 \\ 139 \\ 174 \end{bmatrix}$$

$$\begin{bmatrix} 150 & 148 & 143 & 170 \end{bmatrix} \begin{bmatrix} 688 \end{bmatrix}$$

Even if these forecasts are not identical, they are of the same size as the former forecasts. The mean of the elements is 50.3 and the mean of the row and column sums is 153.1. Since the various forecasts differ, it is not possible to apply equation (7.12) for calculation of the adjusted element forecasts. Instead, the extended weighted least squares forecasts are found by solving the minimization problem given by equations (6.1) to (6.5).

It is easy to prove that there is a one to one correspondence between the probability distribution $\{p_1, p_2, p_3\}$ and the weights $\{w_1, w_2, w_3\}$. Using this relationship we find that the probability distribution $\{0.10, 0.20, 0.70\}$ corresponds to the weights $\{1.000, 0.333, 0.587\}$. These weights are put into the equations (6.1) to (6.3). Then the solution of the minimization problem gives:

$$E : \quad \begin{bmatrix} 0 & 66.1 & 49.7 & 53.8 \\ 62.1 & 0 & 34.3 & 61.3 \\ 47.0 & 35.6 & 0 & 67.3 \\ 56.3 & 60.0 & 70.6 & 0 \end{bmatrix} \begin{bmatrix} 169.6 \\ 157.8 \\ 150.0 \\ 186.9 \end{bmatrix}$$

$$\begin{bmatrix} 164.4 & 161.6 & 154.7 & 182.5 \end{bmatrix} \begin{bmatrix} 664.3 \end{bmatrix}$$

The extended weighted least squares forecasts are consistent and it should be noticed that the mean of the element forecasts is 55.3 which is not far from the element forecasts (55.1) in the former case. Hence the original element forecasts with mean about 50 are, especially because of $p_3 = 0.70$, forced upwards to about 55.

In most cases, however, it is reasonable to base the weights on quantitative information of the forecast precision. The output from the forecasting building procedure will usually contain forecasts and their corresponding estimated standard deviations. If the standard deviations are not given, they may be estimated by performing ex-post forecasting and then calculate the root mean square error. A natural choice of the weights will then be the inverse of the squared estimated standard deviation. In this case a set of different weights for the element forecasts, the row sum forecasts, the column sum forecasts and the total sum forecast are used together with the original forecasts.

9. CONCLUSIONS

Kruithof's method is well known and even more used for traffic matrix forecasting. If it is difficult or may be impossible to make forecasts of the traffic elements, then Kruithof's method is a reasonable choice. However, if it is possible to forecast the traffic elements, then other traffic matrix forecasting methods should be used. This is due to the fact that Kruithof's method only uses the information of the last known traffic matrix and forecasts of row and column sums. The method reflects different growths in various traffic elements only through the row and column sum forecasts.

Both the extended Kruithof's method and weighted least squares method possess abilities to model different growths in the traffic elements. When applying the extended Kruithof's method the element forecasts are so transformed that they are consistent to the row and column sum forecasts. The weighted least squares method does not postulate that the row and column sum forecasts are "true", but gives the various forecasts (also the element forecasts) weights according to their uncertainty.

The extended weighted least squares method also takes into account the forecast of the total traffic in the matrix. Examples of the total traffic are: international traffic to a group of countries, the sum of all long distant traffic, parts of this traffic etc. It is of great importance to implement such type of information into the forecast modelling. On this level a lot of efforts are carried out in order to make good forecasting models. Hence it is possible, as shown in Chapter 8, to reflect the precision of the work into the model either in a subjective way or in a quantitative way by using the estimated standard deviations.

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Risk assessment and techno-economic analysis of competition between PNO and CATV operators

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The paper presents risk analyses and techno-economic analyses of broadband access network upgrade strategies for Public Network Operators and Cable Operators in a competitive environment in the residential and small business market. The effect of uncertainties in predictions of critical parameters such as demand forecasts and market shares are analysed. The assessed technology options include broadband twisted pair modems, hybrid fiber coax networks and ATM based passive optical networks.

1. INTRODUCTION

The access network is expected to be one of the major battlegrounds of the telecommunication network providers as a full deregulation of the services draws near in Europe. The Public Network Operators (PNO's) are facing competition from Cable Operators in an almost saturated high revenue telephony market. Most PNO's are in turn eager to provide distributive broadband services. Currently this Cable Operator-dominated market is characterised by a potentially high revenue, although the residential demand remains uncertain. The difference in existing access networks of the competitors call for quite different upgrade strategies. This advocates for an in-depth study of the existing competing infrastructures, and technology alternatives, which might be the starting point for upgrades to broadband [1-7].

This paper addresses some of the different challenges faced by the PNO and Cable Operators in adapting their present fixed network to competition. The analysis of broadband upgrade alternatives focuses on one of the most competitive market segments: an urban, apartment block area with short outdoor average loop lengths, in which both the PNO and the Cable Operator have an established infrastructure for their own subscribers. The methodology and tool developed within the project RACE[1] 2087/TITAN[2] has been used to evaluate the selected set of network upgrade alternatives and strategies [10]. The techno-economic analysis approach, which includes assessment of the risk, has enabled specific conclusions and general guidelines to be drawn [8,9]. In this paper extensive risk assessments are performed based on forecasts of the residential and small business market and market shares between PNO and Cable operators for the services: POTS, N-ISDN, CATV, 2Mbit/s Asymmetric Switched Broadband and 2Mbit/s Symmetric Switched Broadband. Other important economic variables like all network component costs, civil work costs, OAM costs, tariffs etc are predicted for each year, but are not varied according to a probability distribution as for the total market and market shares for each service. The analyses shows the market evolution and how the related uncertainties influence on the risks for PNO and CATV operator.

2. THE CASE STUDY

A network evolution during a 10 year period from 1997 to 2007 has been examined. An urban, residential and small business area with the customers living in apartment blocks with an average of 32 dwellings per block has been analysed. The average outdoor loop length from the network concentrator location to the buildings is 400 metres. Network architectures for PNO and Cable Operators have already been established in the area, and the availability of ducts for new cables is low (20% for fibre and 10% for coaxial cable). In the initial year the Cable Operator is assumed to have an existing 450 MHz distribution coax network, whilst the PNO has an existing twisted pair infrastructure for delivering POTS (Plain Old Telephony Service) and N-ISDN (Narrowband Integrated Services Digital Network). For both operators the existing network includes optical access network nodes serving approximately 1.000 subscribers. All of the existing PNO and Cable Operator infrastructures have been fully amortised.

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[1] *RACE: Research in Advanced Communications in Europe.*

[2] *TITAN: Tool for Introduction scenario and Techno-economic evaluation of Access Networks.*

To be presented at Networks '96, Sydney, November 24-29, 1996.

Table 1. General assumptions

General assumptions	
Number of households in area	1.024
Number of buildings in an area	32
Number of households per building	32
Duct availability, feeder	100%
Duct availability, fibre	20%
Duct availability, coaxial cable	10%
Civil works cost per metre	25 ECU
Global cable length, distribution network	7,46 km
Distance, SAP - building	400 m
Global cable length, indoor drop network	20,5 km
Average cable length, drop network	20 m
Discount rate	7,5%
Tax rate	30%

3. THE MARKET FORECAST

The scope of this paper is the study of the broadband upgrade of the above two networks. New services forecasting and demand projections have recently been reported, derived from current spending patterns of households or from market surveys [11]. In this study a common set of services is assumed to be provided by both operators: POTS, N-ISDN, CATV (Cable Television), 2 Mbit/s Asymmetric Switched Broadband (ASB) and 2 Mbit/s Symmetric Switched Broadband (SSB). The CATV service penetrations used here are European averages. The forecasts of the total market of the broadband bearer services are extracted from a Delphi survey on broadband demand, carried out by TITAN in ten European countries [12,13].

Competition is assumed from 1997 on all services, and hence the market will be shared between the PNO and Cable Operator. The competition has been simulated by appropriate adjustments of the service penetrations. The PNO starts with the majority of the market share of the high-revenue narrowband switched services. The Cable Operator initially has the majority of the market share of the low-revenue CATV service.

Figure 1 shows forecasts for the service penetration in percentage of the small business and residential market for each service studied. The forecasts indicate the evolution from 1997 to 2006. In the same period it is assumed that the PNO operator will maintain 75% of the POTS market and the N-ISDN market, the CATV operator will maintain 75% of the CATV market, while the two operators equally share the broadband market: 50% each. In chapter 6 the penetrations and market shares are simulated around their expected valued according to a Normal distribution to examine how changes in penetrations and market shares influence the risks and the economic outcome of the projects.

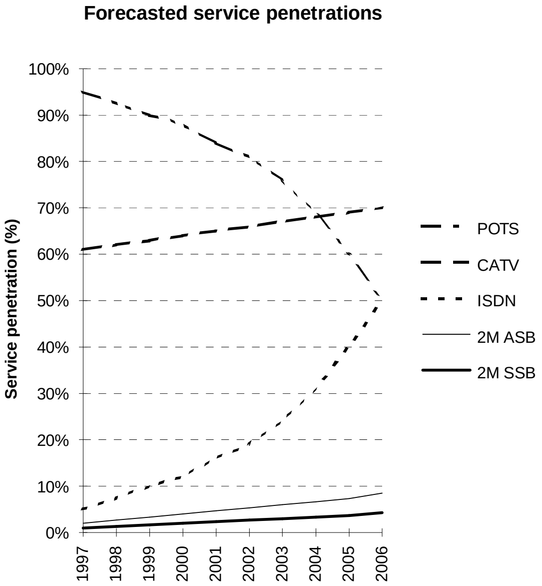

Figure 1. Forecasts 1997 - 2006 of the service penetration (percentage of small business and residential market) for the services POTS, N-ISDN, CATV, 2Mbit/s Asymmetric Switched Broadband and 2Mbit/s Symmetric Switched Broadband

Only the annual subscription tariffs for bearer services have been considered in the analysis. Traffic income is not accounted for, since this is assumed to be trunk network specific revenue. The tariffs used are based on European averages from the TITAN Delphi Survey and other sources. The tariff structure incorporated in the economic analysis includes an evolution of the tariffs during the study period. The evolution of tariffs is strongly related to competition and penetration. The tariff elasticities for the broadband switched services are derived from the Delphi Survey, as described in [14]. The CATV tariff elasticity is modelled by a similar approach. The POTS and N-ISDN tariffs decrease annually by respectively 2% and 4%. The evolution of the annual tariffs are shown in figure 2.

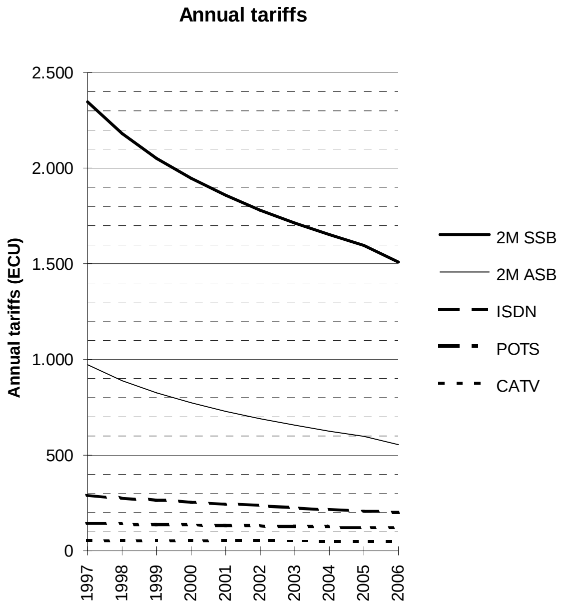

Figure 2. Tariff evolution.

4. BROADBAND UPGRADE OPTIONS

The network operators face great strategic challenges in upgrading the physical layer of the very cost sensitive access network, both with respect to selection of transmission medium and system technology. Optical fibre cable, coaxial cable and twisted copper pairs are the relevant wireline transmission media. Alternative system technologies encompass enhanced copper options like ADSL (Asymmetric Digital Subscriber Line), VDSL (Very high-speed Digital Subscriber Line) and HDSL (High bit-rate Digital Subscriber Line), the fibre option of ATM-PON (ATM based broadband Passive Optical Network) and HFC (Hybrid Fibre Coax) for coaxial cable networks [15].

Two different access network upgrade alternatives have been examined for each of the two operators:

1. PNO, alternative 1: FTTN (Fiber To The Node, 1.000 home passed per node) architecture with enhanced copper.
2. PNO, alternative 2: FTTB (Fiber To The Building) architecture based on ATM-PON
3. Cable operator, alternative 1: FTTN architecture based on HFC with Cable modems.
4. Cable operator, alternative 2: FTTB architecture based on HFC.

4.1 PNO upgrade alternatives

The alternative considered highlight the economic and technological implications for moderate operators which aim to utilise the existing twisted pair copper cables as the basic transmission medium, and aggressive operators which extensively upgrade the network with broadband fibre technology. The former represents a limited degree of service integration, whilst the aggressive upgrade enables an introduction of a full service fibre network. Detailed sketches of the architectures for the PNO alternatives are shown in figures 3 and 4.

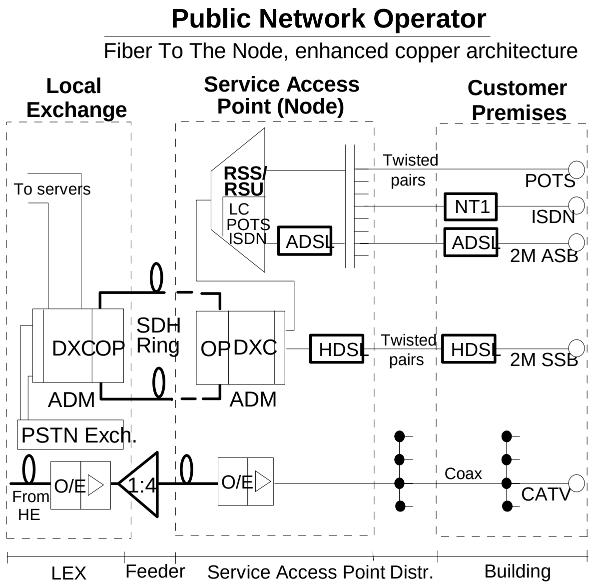

Figure 3: The PNO FTTN upgrade option: FTTN architecture with enhanced copper and a parallel distribution network for CATV.

PNO, FTTN: The PDH ring between the local exchange and the Service Access Point[3] (SAP) is replaced by an SDH ring in 1997. In the distribution network ADSL and HDSL equipment is installed to provide new services like 2 Mbit/s ASB, i.e. Service on Demand (SoD), and 2 Mbit/s SSB. In addition, a CATV distribution network is installed.

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[3] *The Service Access Point refers to the network localisation of the concentrator, as used in several European countries with modern access network infrastructures.*

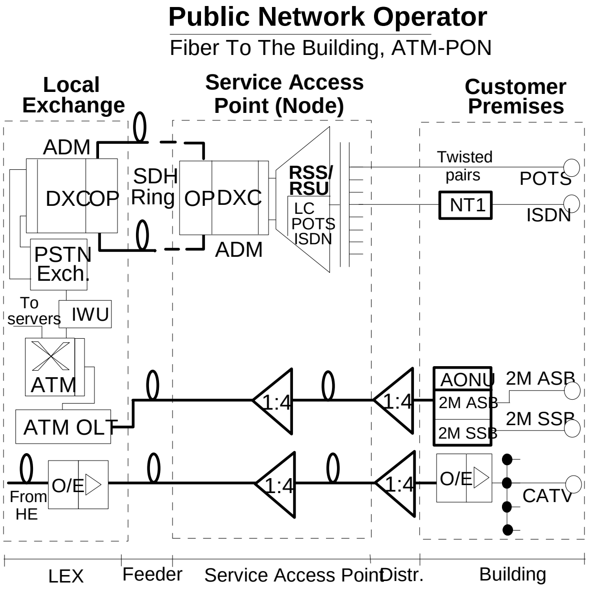


Figure 4: The PNO FTTB upgrade option: FTTB architecture with an ATM broadband passive optical network for broadband services and a parallel distribution network for CATV. (The ATM exchange is not included in the calculations.)

PNO, FTTB: New technology is introduced during the period from 1997 to 2002. The PDH point to point connection to the HUB is replaced by an SDH based ringstructure. The deployment of an ATM-PON in an FTTB configuration is started in 1997 in order to provide new services like SoD and 2 Mbit/s SSB. In addition, a combined fibre-coax network for CATV distribution is installed in 1997.

4.2 Cable Operator upgrade alternatives

The Cable Operator upgrade alternatives represent moderate operators which only partially integrate their network by sharing duct layout, and aggressive operators which fully integrate the network by providing the service set over the same duct layout, transmission medium and network termination units as well. Detailed sketches of the architectures for the Cable Operator alternatives are shown in figures 5 and 6.

Cable Operator, FTTN: The existing coaxial cable infrastructure between the access node serving 1.000 subscribers and the homes are kept during the upgrade period. In 1997 the CATV network is upgraded to bi-directional network with return path. All services are then offered on the integrated coaxial cable network. Cable modems are installed at the customer premises. 10 Mbit/s shared access data modems are for used for 2 Mbit/s ASB.

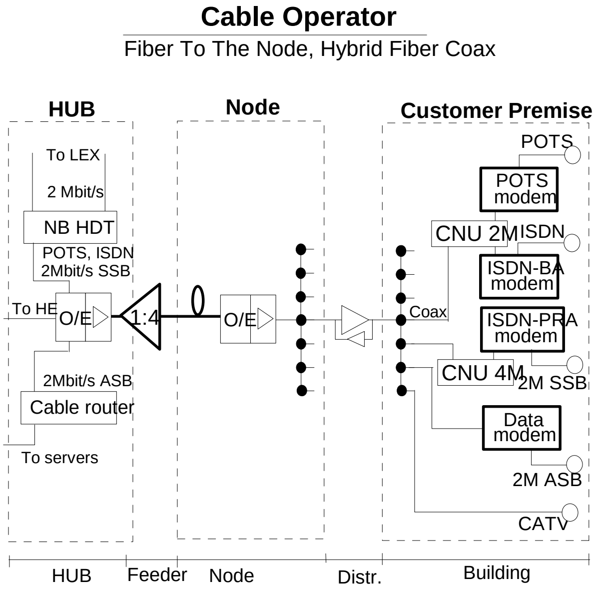


Figure 5: The Cable Operator FTTN upgrade option: FTTN architecture with a HFC network for all services.

Cable Operator, FTTB: Fibre is deployed to the buildings in 1997. This yields a fibre rich network with separate fibres between the HUB (serving approximately 4.000 homes) and the buildings. Cable modems are installed, with 2 Mbit/s dedicated channels access data modems are provided for 2 Mbit/s ASB subscribers.

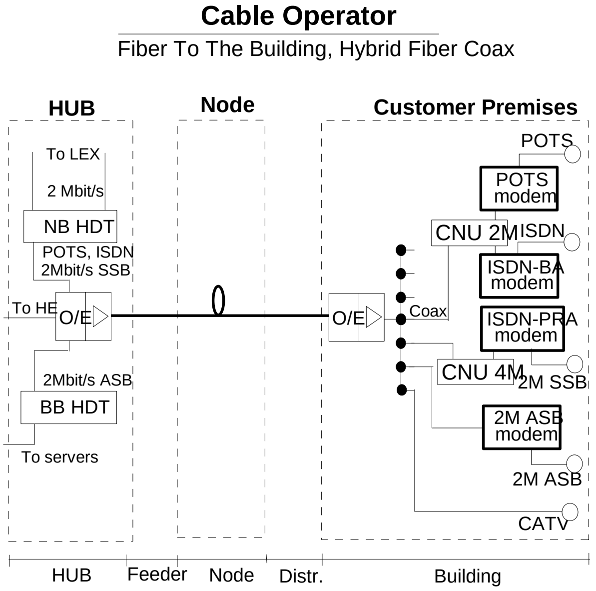


Figure 6: The Cable Operator Fiber To The Building upgrade option: FTTB architecture with a HFC network for all services.

5. THE TITAN METHODOLOGY

The methodology developed by the RACE 2087/TITAN project has been applied to evaluate the broadband upgrade case [10]. The ability to combine low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters is a key feature of this methodology and tool as compared to other similar assessment methods and tools recently reported [16].

In TITAN the network costs are calculated taking the evolution of component costs into account. The cost trends of the various network elements are derived from initial cost, appropriate learning curve coefficients and network penetration assessment over the study period considered. A database including costs at a given reference year for components, installation, civil works and operations and maintenance (OAM) has been developed within the TITAN project. The database contains data gathered from many European sources. The cable infrastructure costs of the network are calculated using a geometric model which involves parameters such as subscriber density, duct availability and type of civil works as inputs. At first the discounted system cost is derived, then OAM costs are calculated using inputs from the cost database, yielding life-cycle costs. Finally the overall financial budget is calculated for the various projects by incorporating revenue estimates from demand and tariff inputs.

6. RISK ASSESSMENT METHODOLOGY

The TITAN tool also contains a methodology for calculating economic risks. The main point in risk analysis is to introduce a probability distribution instead of the expected value for each critical parameter in the model. A simulation program called Crystal Ball based on Latin Hyper Cube simulations is used in combination with the TITAN tool to calculate economic outputs based on various set of the critical parameters. These includes a procedure is made for linking the parameter values in time based on prediction function for the expected value and for the standard deviation.

In this paper, the competition between PNO and Cable operators is modelled by adjustments of the service penetrations. The methodology for risk assessment is used to analyse the effect of uncertainties in predictions of critical parameters. These include:

- The respective market shares (in percentage) of the PNO and the Cable operators
- Total market demand forecasts for POTS, N-ISDN, 2Mbit/s ASB, 2 Mbit/s SSB and CATV.
- Tariffs
- Costs of key network elements

6.1 Risk assessment assumptions

The assumptions used in the risk assessments are shown in figure 1, figure 7 and table 2. For each service penetration and each market share one expected value and one estimated standard deviation are given.

Table 2. Expected values and estimated standard deviations of market shares to PNO operator and Cable operator for each service studied

Expected values and standard deviations		
	Value	*Standard deviation*
PNO market share, POTS and ISDN	75 %	7,5 %
PNO market share, CATV	25 %	2,5 %
PNO market share, 2 Mbit/s ASB/SSB	50 %	5 %
Cable op. market share, POTS/ISDN	25 %	2,5 %
Cable op. market share, CATV	75 %	7,5 %
Cable op. market share, 2 Mbit/s ASB/SSB	50 %	5 %

For each variable the values uniquely defines a Normal distribution. The set of Normal distributions are used to simulate all service penetrations and market shares. Since all service penetrations and market shares are simulated simultaneously, it is necessary to perform a great number of repeated runs for getting a representative output of the economic results of the different upgrade alternatives studied.

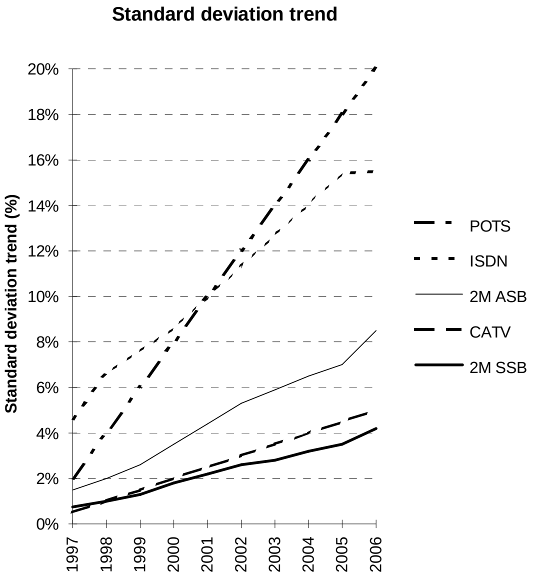


Figure 7. Estimated standard deviations of forecasted service penetration (percentage of small business and residential market) 1997 - 2006 for the services POTS, N-ISDN, CATV, 2Mbit/s Asymmetric Switched Broadband and 2Mbit/s Symmetric Switched Broadband

In the risk analysis the simulated value is obtained by adding to the mean forecasted value the product of the standard deviation values shown in figure 7 and the normal distribution, as shown in figure 8.

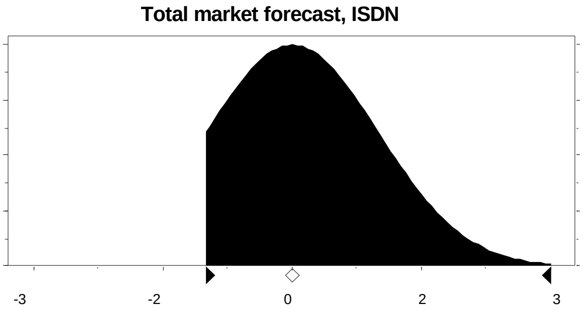


Figure 8. The normal distribution applied to the total market forecast for ISDN.

The forecasted values used here are the Net Present Value[4], the Net Present Value divided by Installed First Costs and Payback period.

7. RESULTS AND DISCUSSION

The risk assessment has been applied to all four technical upgrade alternatives and the following results illustrate the uncertainty in the different techno-economic outputs and the ranking of parameters having the most important effects on the uncertainty.

7.1 PNO, Fibre to the node (FTTN)

Figure 9 shows the frequency distribution of net present value based on the variation of the market inputs.

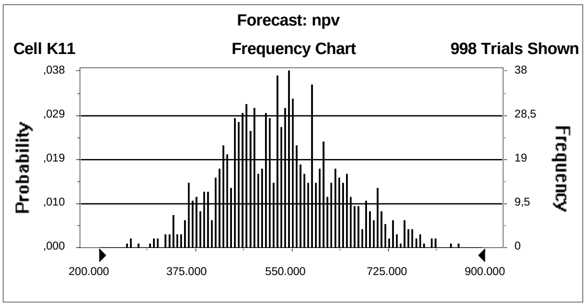
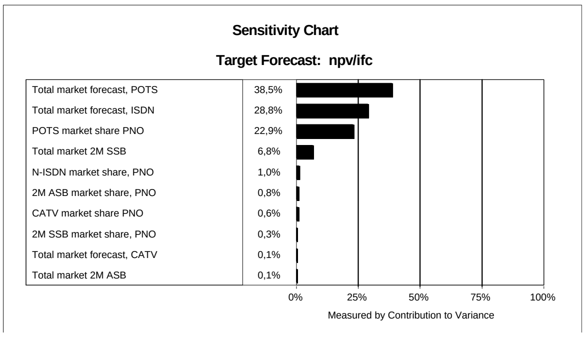


Figure 9. Frequency distribution of the net present value

The expected net present value is about 532.000 ECU. There is a 10% probability that the net present value will be less than 402.000 ECU.

Analysis show that the uncertainty in the total market forecasts for the different services has the strongest influence on the variation of net present value. The most significant effects are contributed by ISDN and POTS. Our study shows that the expected net present value divided by installed first cost is about 1.19. There is a 10% probability that the factor is less than 0.95.

Table 3 illustrates how much the different market variables influence on the variation of net present value divided by installed first cost (NPV/IFC).


Sensitivity Chart

Target Forecast: npv/ifc

Total market forecast, POTS	38,5%
Total market forecast, ISDN	28,8%
POTS market share PNO	22,9%
Total market 2M SSB	6,8%
N-ISDN market share, PNO	1,0%
2M ASB market share, PNO	0,8%
CATV market share PNO	0,6%
2M SSB market share, PNO	0,3%
Total market forecast, CATV	0,1%
Total market 2M ASB	0,1%

Table 3 Ranking of market variables according to their influence on the variation of net present value divided by installed first cost(NPV/IFC)

Table 3 shows that the uncertainty in the total market forecasts for the different services also has the strongest influence on the variation of NPV/IFC. The most significant effects are contributed by the total market for POTS and ISDN. In addition also the uncertainty in the market share for POTS contributes substantially to the variation.

The expected payback period in this case is 4.12. There is a 10% probability that the payback period is greater than 4.69 years. The uncertainty in the total market forecasts for the different services also have the strongest influence on the variation of net present value. In addition the market shares of ISDN and 2M SSB contributes significantly.

7.2 PNO, Fibre to the building (FTTB)

The expected net present value for the FTTB alternative for the PNO is about 400.000 ECU. There is a 10% probability that the net present value will be less than 285.000 ECU. Analysis show that the uncertainty in the total market forecasts for the different services significantly influence on the variation of net present value. The most significant effect are contributed by the total market for ISDN and POTS and also POTS market share.

Figure 10 shows the frequency distribution of the factor NPV/IFC based on the variation of the market inputs.

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[4] The NPV as used here is the discounted accumulated revenues minus the discounted accumulated costs (IFC and running costs). The residual network value is also included in the NPV.

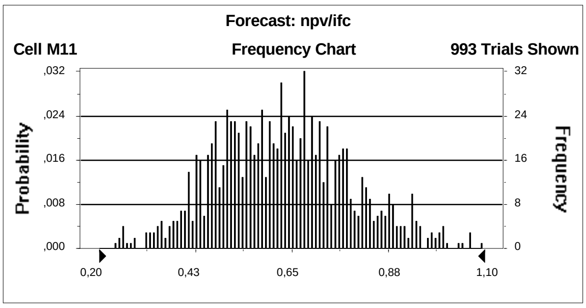

Figure 10 Frequency distribution of net present value divided by installed first cost (NPV/IFC)

The expected NPV/IFC is about 0.63. There is a 10% probability that the factor is less than 0.44.

The uncertainty in the total market forecasts for the different services is the most important factor contributing to the variation of net present value. The most significant effect are contributed by total market for ISDN, 2M ASB, POTS and also the market share for POTS.

Figure 11 shows the cumulative frequency distribution of payback period based on the variation of the market inputs.

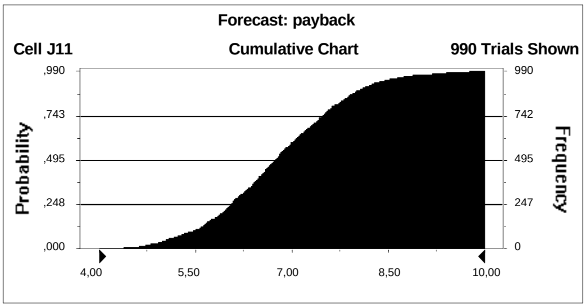

Figure 11 Cumulative frequency distribution of the payback period

The expected payback period is 6.80. There is a 10% probability that the payback period is greater than 8.14 years. The uncertainty in the total market forecasts for the different services again significantly influence the variation of net present value. The most significant effect are contributed by the total market for POTS, CATV, ISDN and also the market share for CATV and 2M SSB.

7.3 CATV, Fibre to the node (FTTN)

The expected net present value is about 215.000 ECU. There is a 10% probability that the net present value will be less than 149.000 ECU.

Table 4 illustrates how much the different market variables influence on the variation of net present value.

Table 4 Ranking of market variables according to their influence on the variation of net present value

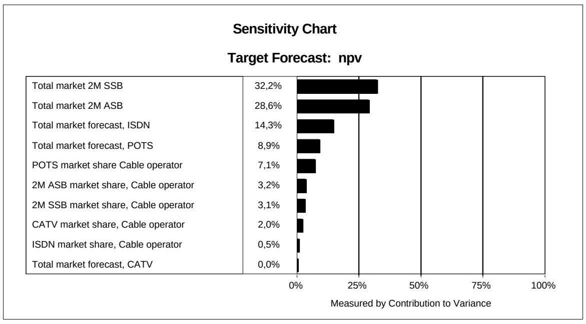

Table 4 shows that the uncertainty in the total market forecasts for the different services has the strongest influence on the variation of net present value. The most significant effects are contributed by the broadband services. The expected NPV/IFC is about 0.70. There is a 10% probability that the factor is less than 0.55. The uncertainty in the total market forecasts for the different services has the strongest effect on the variation of net present value. The most significant effects are contributed by the total market for 2M ASB, POTS and ISDN.

Figure 12 shows the cumulative frequency distribution of payback period based on the variation of the market inputs.

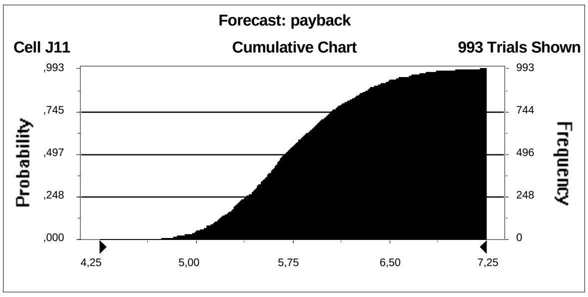

Figure 12 Frequency distribution of the payback period

The expected payback period is 5.75. There is a 10% probability that the payback period is greater than 6.42 years. The uncertainty in the market shares for the different services is in this case the most important influence on the variation of the payback period.

7.4 CATV, Fibre to the building (FTTB)

The expected net present value is about 96.000 ECU. There is a 10% probability that the net present value will be less than 30.000 ECU.

The uncertainty in the total market forecasts for the different services significantly influence on the variation of net present value. The expected NPV/IFC is about 0.13 which is very low. There is a 10%

probability that the factor is less than 0.04. Analysis show that the uncertainty in the total market forecasts for the different services is the most important factor contributing to the variation of net present value. The expected payback period is 12.03. There is a 10% probability that the payback period is greater than 13.62 years. The uncertainty in the market shares for POTS and ISDN and the total market for POTS significantly influence on the variation of the payback period.

7.5 Evaluation of uncertainty factors.

The results in 7.1 to 7.4 describe how variation in market variables influence on the economic outcome.

For the PNO, the main uncertainty is caused by forecasts of the total market for POTS and ISDN. In the model the uncertainties connected to the two variables are generated independently. However, there is correlation between the markets. When the POTS market decreases, the ISDN market increases and vice versa. This effect reduces to a certain extent the total uncertainty. The reason for relatively strong influence is explained by high penetration and in addition the tariffs which are significantly higher than for the CATV service. Also market share for POTS influences net present value and net present value divided by installed first cost significantly, while PNO's market share for ISDN is the most important factor influencing the payback period.

For the CATV operator the forecasts of the total market for broadband services are dominating the uncertainty in the variation of net present value. The variables are also the most important ones for explaining the variation of net present value divided by installed first cost. The penetration for 2M SSB and 2M ASB are low compared with the penetration of CATV, POTS and ISDN, but their standard deviations are relatively high compared with the penetrations. In addition the tariffs are considerably higher than for other services. Also the total market forecasts for ISDN and POTS are of importance both for net present value and net present value divided on installed first cost.

For the CATV operator, the most important contributors to the variation in payback period are the market shares to the services POTS, ISDN, CATV and 2M SSB(only for FTTN). For the FTTB upgrade alternative, forecasts of the total market for POTS and ISDN are of significant importance. The fact is explained with a long payback period, more than 10 years. For the FTTN upgrade alternative, the payback period is less than 6 years. Therefore variables which contribute much to the uncertainty the first part of the 10 years period have the highest weight.

7.6 Evaluation of upgrade alternatives.

The risk analysis show that the net present value of the FTTN solution for the PNP may be reduced by 25% from 532.000 ECU to 402.000 ECU with a 10% probability depending on the market evolution. The respective percentages for PNO FTTB, CATV FTTN and CATV FTTB are: 29%, 31% and 69%. The analysis show about the same behaviour of the factor NPV/IFC for the different alternatives. The NPV/IFC factor is reduced by 20-30% except for CATV FTTB where the decrease is about 70%. The most extreme unprofitable upgrade project is the FTTB for CATV operator which is also underlined by an extremely long payback period. The expected values calculated for the alternative upgrade projects show that FTTN alternatives for both operators have the highest net present values. The NPV/IFC factor range from 1.2 to 0.7 with a payback period from 4.12 to 5.75 years. PNO has the most profitable projects. Since this upgrade projects include all new and old revenues for all services even the FTTN alternatives are quite heavy projects. The FTTB alternative for the PNO is comparable to the FTTN alternative for the CATV operator although slightly less profitable. The FTTB alternative for CATV operator based on the given assumptions, is an extremely unpromising project

8. CONCLUDING REMARKS

The risk assessment and additional analysis show that the FTTN alternative for the PNO is the best economic alternative with the lowest risk. The FTTB project for the CATV operator is the least economic alternative and also a high risk project.

The service forecasts of the total market contribute more to the variation of the results compared to the service market shares to the operators. The ordinary services POTS and ISDN generates more uncertainty than the other services, mainly because of the high penetration. Depending on the technical alternative, type of operator and economic output different set market variables explain the main part of the variation.

In this paper only market variables , forecasts of total market penetration and market shares for a set of services, are simulated according to given probability distributions to evaluate their effect on the economic results for various upgrade alternatives. It is important to study the effect of these variations which are based on a set of assumptions mainly from an European Delphi survey. In supplementary analysis also the cost element like civil work costs, OAM costs, cost of network components and also the tariffs should be simulated in order to identify critical risks.

Acknowledgement

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OVERVIEW OF RISKS IN MULTIMEDIA BROADBAND UPGRADES

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1 ABSTRACT

The first part of the paper gives an overview of the risks connected to a roll out of a broadband infrastructure. Specific attention is put on market risk, competition risk, regulatory risk, technology risk and operational risk. The risk methodology developed in the ACTS projects OPTIMUM and TERA is described. The paper shows how risk methodology can be applied for evaluation of various network architectures. The second part of the paper presents risk and techno-economic analyses of broadband access network upgrade strategies for Public Network Operators in a competitive environment in the residential and small business market. The effect of uncertainties in predictions of critical parameters such as demand forecasts and market shares are analysed.

2 MARKET RISKS

Substantial risks are linked to the predicted evolution of the broadband market. A fundament for the evolution is new and enhanced broadband applications. Uncertain demand forecasts generate significant risks influencing the investments and also other costs. One realisation is an unexpected delay in the demand. Overestimation of the demand implies overestimation of investment costs, where parts of the costs are bundled and not utilised for a period. Underestimation of the demand will generate waiting lines and bad reputation and lost market shares. Also the problems in the roll out, in component and service supply and in service quality will induce bad reputation.

If some customers are lost to a competitor, it is difficult to win these customers back. This risk problem is denoted as the churn problem. The customer can be lost from specific market segments, specific user groups or in specific geographic areas. The risks for lost market shares may also be caused of substituting applications and services.

3 COMPETITION RISKS

The main objective for the regulator is to establish a competition regime where the newcomers should have a fair competition, while the incumbent operator should have significant handicap. The effect will be reduced market share and power for the incumbent operator and a more balanced market between all operators. The risks and the uncertainty are influenced of unpredicted regulations, number of new competitors and alliances between the operators and also service providers. The risks are lost market shares.
The geographic deployment strategy for roll out influences the market shares as well as service mix, service quality, customer support and type of billing systems compared with the other network operators. Another important competitive factor is the tariffs and the tariff strategy. Significant risks for loosing market shares are linked to the tariff evolution for the different competitors.

4 REGULATORY RISKS

Since the public network operators (PNOs) own large parts of the access network, the European regulators have taken some actions to induce competition in the access network. In some countries the PNO have been forced to implement Local Loop UnBundling, LLUB. In other countries specific transmission equipment for permanent access can be hired from the PNO. However there are a lot of uncertainty connected to the actions of the regulator. The regulator may generate changes in some important parts of the telecommunication law. The regulator controls the number of licenses for the operators. The regulator may prevent the incumbent operator for offering given services. The body influences the interconnect tariffs and may also regulate the ordinary tariffs. The regulator controls also the Universal Service Obligation, USO regime.

5 TECHNOLOGY RISKS

A wide range of technologies is available for transport of broadband communication. In the access network a fibre node structure or a coax structure have to be deployed. The last part of the access network can be covered by ADSL or VDSL modems on copper, or by the radio solution LMDS or in the future the universal mobile telephone system, UMTS. Other alternatives are satellite communication combined with a wireline return channel or a hybride fibre coax system, HFC. The technologies may substitute each other or may be deployed as supplements in different parts of the network. In the transport network deployment strategies for substitution between PDH and SDH transmission equipment are carried out. In parallel the fibre capacity is expended by introduction of wavelength division multiplexing, WDM. Another technical problem not solved is the switching. One possibility is to use ATM, another is to use IP and a third one is to implement ATM over IP.

There are substantial risks for implementing the wrong technology at the wrong time. Important questions are:

- - time for optimal roll-out
  - which geographic areas should be covered at the start
  - which market segments should be covered at the start
  - the size of the broadband nodes and the structure is of crucial importance
  - dimensioning of the network and estimated demand controlled expansion
  - selection of optimal technology in different parts of the network
  - strategies for roll out based on competition in specific areas
  - strategies for robust upgrading of the upper part of the access network giving possibilities for utilising different technologies
  - strategies for minimising the upfront costs the first period

To get insight in these problems for understanding the risk, economic evaluations of the different technologies have to be performed by rather comprehensive calculations. One possibility is to use the TERA/OPTIMUM tool. Some examples are shown in this paper.

6 OPERATIONAL AND INVESTMENTS RISKS

Investment and operational costs can be divided in:
- investment costs
- operational and management costs
- maintenance cost
- administrative costs
- cost for support systems
- customer support costs
- marketing costs

Implementation of a new broadband network including new services and applications will generate uncertain cost estimates. The main input is demand forecasts for the total market and estimates for lost market shares because of competition. If the forecasts turn out to be completely wrong, then also the investments will be out of scale. Since forecasts for new services are uncertain there are generated substantial cost risks.

The network components and the technology standards induce risks when an operator starts a roll out before the standards have been adapted. Additional investments and replacement of rather new components may be necessary. There are substantial uncertainty related to the prediction of component costs. The learning curve forecasts show that the component costs decrease as a function of large scale production. However, there is significant uncertainty in the predicted component cost evolution.

In addition specific technology problems may occur. The quality of some components does not satisfy the norms and have to be replaced by other type of components. The selected manufactory has significant problems and does not satisfy the production specifications. The effect is bad quality for the customers, delivery problems, waiting list and a bad reputation. The same risks can be generated if the demand forecasts, planning, dimensioning, projecting or deployment of the network is pure.

7 ECONOMY RISKS

To be able to evaluate a broadband network upgrading, the discounted sum of revenues, investments, operations and maintenance costs etc has to be calculated over 5 – 10 years period. The result can be expressed in net present value, payback period, internal rate of return, installation first costs, life cycle costs, payback each year etc.The economic risks is the sum of all the above mentioned risks. Some of the risk problems mentioned, can be quantified and analysed by using the TERA/OPTIMUM tool which contains an option for risk simulations and assessments.

Important economic risks are caused by:
- higher investment costs than expected
- higher operational and maintenance costs than expected
- higher administrative costs
- higher customer support and marketing costs than expected
- investments restrictions due to lower profit or new priorities
- reduction of service mix
- loose of market shares
- higher revenue reductions due to substitution effect between other services
- lower subscription and traffic demand
- slower broadband application evolution
- restricted regulations.

8 TERA TOOL FOR TECHNO-ECONOMIC EVALUATIONS

Within the European programs RACE and ACTS the projects RACE 2087/TITAN and AC 226/OPTIMUM and TERA have developed a methodology and a tool for calculation of the overall financial budget of any access architecture. The tool handles the discount cost system, operations, maintenance, life cycle costs and the cash balance. This enables a comparison of various optical or hybrid architectures through a global system assessment. The tool has the ability to combine low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters for performing evaluation of various network architectures [1–2].

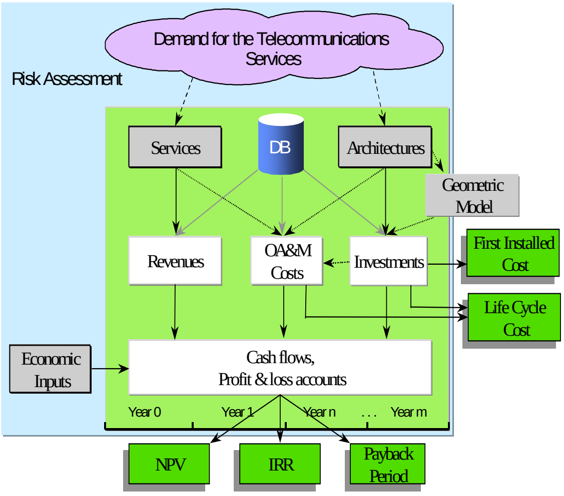

Figure 1 Model for techno-economic assessments

A methodology has been developed based on an expansion of the Wright and Crawford's learning curve models to predict future cost of the network components. Geometric (geographic) models are used to map network structures into the tool. A specific model for operations and maintenance costs has been developed. The tool has also a specific module used for risk assessments [3-4]. In addition forecasts of the demand for the services offered and the relating tariffs is necessary for the calculations. Figure 1 gives an overview of the techno-economic model.

9 METHODOLOGY FOR QUANTIFYING THE RISKS

Choice of probability functions

The uncertainty in the assumptions made has to be quantified with respect to probability functions and limits of the uncertain variables when risk analysis is performed. Since, it is meaningless to operate with negative costs, tariffs or forecasts, the Beta distribution is introduced to solve the problem. Traditionally the Normal distribution can be used, but in cases where there are significant probabilities for generating negative values, the Beta function is recommended.

Simulation performance

When performing sensitivity and risk analysis, the uncertain parameters are described by suitable probability density functions. The techno-economic scenario is then calculated based on a certain number of times using Monte Carlo or Latin Hypercube simulation; each time a random number is picked from each distribution. In general, it is difficult to give an advice of number of simulations since there is a dependency of the complexity in each case study analysed. The best way to control the problem, is to do some test-simulations series and calculate the uncertainty in the output distributions. Based on experience so far, the sufficient number of simulations could be 500 – 10000. Figure 2 illustrates how the risk assessment is performed

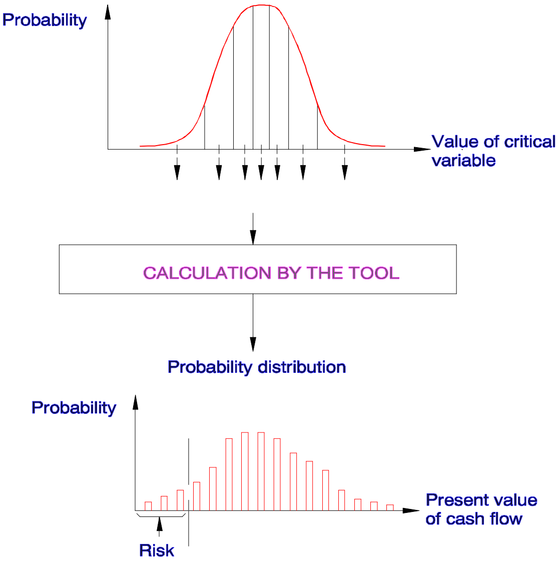

Figure 2 Risk simulations

Methodology for cost predictions and uncertainties

The extended learning curve for prediction of component costs has been developed in the OPTIMUM project. The cost prediction curve is dependent of a set of parameters: Starting cost at the starting time, type of component, penetration at the starting time and penetration growth. The TERA cost data base contains estimates on these parameters for all components and generates cost predictions based on the extended learning curve.

The methodology takes into account the variation in uncertainty for different technology. For example, the uncertainty in the cost of civil works is smaller than the uncertainty in the cost of electronics. In addition a time component increasing the relative uncertainty is implemented in the model.

Methodology for demand forecasts and uncertainties

It was decided to develop analytical forecasting models instead of the usual tables as input to the TERA tool. The analytical functions will be part of the new framework for TERA [5]. It is more convenient to use functions instead of tables as input to the tool. In addition the functions give more flexibility for variations when risk analysis is carried out. The models are based on the results from the last Delphi survey performed at the last OPTIMUM workshop in Aveiro in October 1997. Different analytical forecasting models for fitting the Delphi data are tested. The extended Logistic model with three parameters gave rather good fitting for 2 Mb/s, 8Mb/s and 26 Mb/s. In addition specific forecasting models for symmetric and asymmetric demand penetration are constructed.

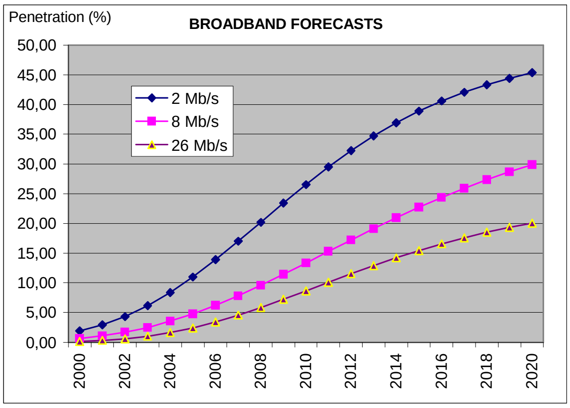

Figure 3 Broadband penetration forecasts

Tariff predictions and uncertainties

The tariffs used are based on European averages given as functions of the penetration according to the demand curves extracted from the OPTIMUM Delphi survey carried out in 1997. The tariffs are service penetration dependant, which is needed in a reasonable risk model. *The tariff includes subscription and traffic costs*. The costs for the terminal and for the content are not included. Uncertainty distributions have been defined, including trends. Limits are imposed in the model on low and high penetration tariffs. For low penetrations, the tariff is kept constant below 2 % service penetration. Because of the uncertainty in penetration, the tariff for each service will vary in each run of the simulation.

10 RISK EVALUATION WHEN THE COMPETITION INCREASES

In this paper extensive risk assessments are performed based on penetration forecasts and lost market shares for the 2Mbit/s, 8Mbit/s and 26Mbit/s services. The 2 Mbit/s service is offered as an asymmetric and symmetric switched broadband service.

The broadband case study

A network evolution during a 10 year period from 2000 to 2009 has been examined. Upgrade boundary conditions for the PNO, like the demographic area, the existing networks, overall service take rate and market shares are included in the case study. One of the most competitive market segments is analysed: a highly density residential and small business area with customers living in apartment blocks. The network architectures for PNO have already been established in the area.

The operator aims to utilise the existing twisted pair copper cables as the basic transmission medium. ADSL and VDSL modems are deployed at the local exchange and at the customer premises to offer broadband access; fibres are used as transmission medium in the upper part of the network – FTTLex architecture. The architecture is stepwise expanded by deployment of fibre and fibre nodes (FTTN128 and FTTN512) combined with VDSL modems further down in the access network.

Competition and lost market shares

The incumbent operator starts by having 100% of the market in year 2000, but is loosing market shares continuously during the study period. In addition the uncertainty in lost market shares is simulated based on different degree of uncertainty.

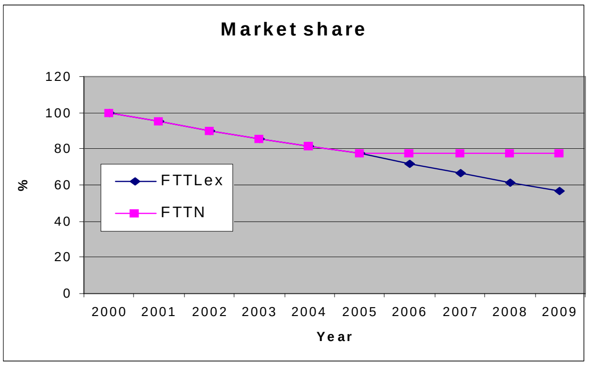

Figure 4 The market share evolution for the public network operator

For each year until year 2005 the market share is reduce relatively with 5%. If the operator deploys FTTN architectures, the market share reach a stationary situation, else the operator continues to 7.5% relative market share each year until year 2009. The market share evolution is illustrated in figure 6.

There are significant uncertainty connected to the competition and the estimated market share. Therefore, the uncertainty in the market share evolution is simulated based on:

- 10% relative standard deviation
- 20% relative standard deviation
- 30% relative standard deviation

In addition uncertainty distributions are implemented in the analysis for:

- Penetration (2, 8, 26 Mbit/s)
- Symmetric/asymmetric (2Mbit/s)
- Tariffs (2, 8, 26 Mbit/s)

Results

The results show that there is a significant probability (on a 10% level) for 50% reduction of the life cycle costs mainly based reduced

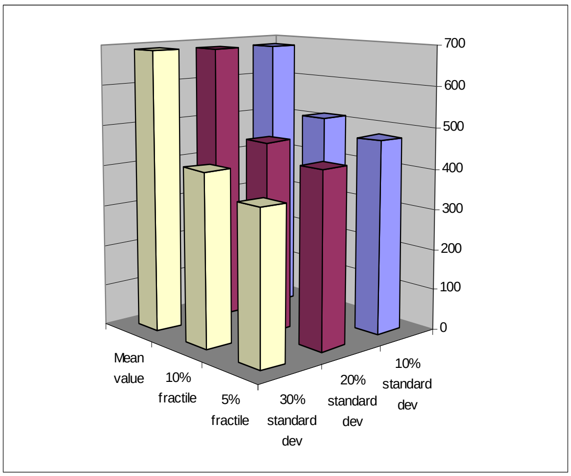

Figure 5 Expected life cycle costs and life cyclce cost on 10% and 5% level based on different degree of uncertainty

penetration and lost market share. The life cycle costs is defined as the total discounted accumulated costs for the projects including both investment costs and OAM costs. When the operator looses market shares both the costs and the revenue are reduced

At the same time there is a 10% probability for a 50% reduction of the net present value. The net present value is defined as the total discounted sum of all costs and all revenue each year. With a fairly high uncertainty in the evolution of lost market share, there is a substantial risk for a negative net present value. Figure 6 shows that there is a 5% risk to get a significant negative net present value if the standard deviation is 30%. If the standard deviation is 20%, the net present value on a 5% level is rather low. However if the standard deviation is 10%, then there are reasonable high estimates for the net present value.

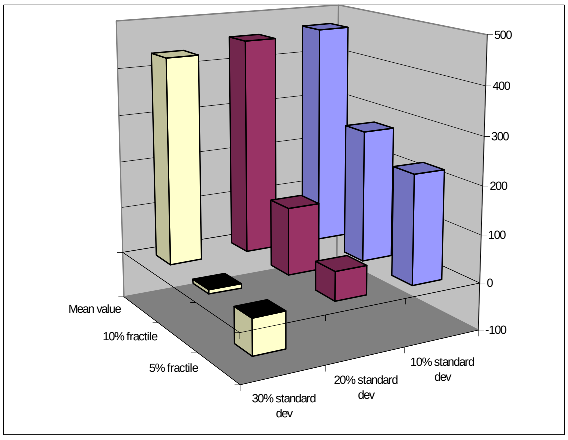

Figure 6 Expected net present value and net present value on 10% and 5% level based on different degree of uncertainty

The results show that large uncertainty in competition and lost market causes significant risks on 5 – 10% probability level. The same results can be shown when there are rather high uncertainty in the tariff evolution and in the estimated penetrations.

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Risk analysis of broadband access rollout strategies in a competitive environment

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Abstract

This paper analyses a set of different broadband access rollout scenarios for an incumbent operator in the most competitive market segments: a dense urban area. The residential market and the SOHO market are examined. The analysis focuses on different evolutionary paths starting with the twisted pair copper network. The strategy of the incumbent operator is to roll out ADSL and VDSL at the right time. The timing for rollout depends on a set of critical factors like the infrastructure and area characteristics, component costs, mass production of network components, applications offered, expected tariff evolution, willingness to pay, demand forecasts and evolution of expected market share. The operator aims to utilise the existing twisted pair copper cables as the basic transmission medium. The architecture is stepwise expanded by deployment of fibre and fibre nodes combined with VDSL modems further down in the access network.

Net present value (NPV) and internal rate of return (IRR) have been calculated in order to estimate each rollout alternative. A cost break down of various rollout alternatives is shown, giving a better understanding of the viability of each rollout. A techno-economic tool developed in the projects AC 226/OPTIMUM and AC 364/TERA have been used for the calculations. To establish a robust optimal rollout strategy, risk analysis has been performed. Risk analysis takes into account the uncertainties in the critical factors demand, tariffs, market share, and cost evolution of specific equipment. Instead of using single values as input to the calculations, probability distributions of each critical factor are used as input. The probability distributions characterise the uncertainties of the predictions to each factor. A risk simulation tool, Crystal Ball, has been used together with the techno-economic tool. For each rollout alternative, a Monte Carlo simulation of 500 runs has been performed for the risk analysis. The optimal ADSL/VDSL rollout strategy is developed, taking into account both the mean values of the NPV and IRR, and the risk involved.

Introduction

Mainly all West-European incumbent operators introduced ADSL commercially during 1999-2000. In North America the number of DSL modem reached 2,0 million accesses third quarter 2000, while the number cable modems reached 3,0 million the second quarter 2000. The battle between the DSL operators and the cable operators has started and the question is how the market share between these technologies is evolving? The incumbent operators face further competition from wholesale and Local Loop Unbundling and also because of LMDS and UMTS operators. The incumbent operator will meet the competition by starting to roll out ADSL and after some years VDSL with the potential of a much broader spectrum of services including video on demand and multimedia applications.

This paper examines various rollout and market share scenarios for the incumbent operator. The timing for rollout of ADSL and VSDL is crucial.

The rollout case study

The rollout case study analyses an exchange area consisting of 34.560 potential customers. A cable operator is deploying a HFC network with cable modems, while the incumbent operator is expanding the network to a DSL network.

The cable operator already offers ordinary TV distribution to their customers in the exchange area, while the incumbent operator offers POTS/ISDN and Internet. The introduction of ADSL gives possibilities to offer a large set of new applications like high speed Internet, various home office applications, multimedia applications, but not high quality interactive entertainment applications. VDSL and HFC are assumed to be competitive solutions, which in addition offers high quality broadband like interactive entertainment applications etc. The churn rate for ADSL is rather high, while the churn rate for HFC and VDSL customers are low. The cost for transition of customers from the cable operator to the incumbent operator and vice versa is high. The reasons are that the customers for a long time have been owned by the operators, either as cable TV customers and/or POTS/ISDN/Internet customers. In addition the customers are strongly linked to the operators by service bundling.

The following services (capacity classes) is offered by the incumbent operator:

Table 1 Capacity classes

Downstream Capacity [Mbps]	Upstream Capacity [Mbps]	XDSL Technology
0.512	0.128	ADSL
1.024	0.256	ADSL
2.028	0.512	ADSL
6.144	0.640	ADSL
24.576	4.096	VDSL

Technical description

The 4 ADSL services are provided from DSLAMs at the local exchange – each DSLAM is supporting up to 768 customers. VDSL services are provided from optical network units (ONUs) places at outside cabinets as well as at the local exchange.

Different vendors use different names for the ONU – sometimes 'DSLAM' is used. Up to 128 users per ONU is assumed. No passive splitters are used in the architecture. An optical fibre cable carrying 24 fibres feed each ONU. Twisted pair copper is used for the remaining path to the customer. In this study, there has been no analysis on crosstalk (NEXT and FEXT) between xDSL sources.

Total broadband penetration (demand)

The broadband forecasts are based on a Delphi survey and additional forecast demand data from the TERA project [1, 2, 4, 5, 8]. The forecasts show the demand evolution in a highly competitive residential market where two broadband operators are rolling out a broadband structure. The total broadband demand forecasts are fitted by an extended Logistic model with four parameters:

$$Y_t = M / (1 + \exp (\alpha + \beta t))^{\gamma}$$

where Y_t is the demand forecast at time t, M is the saturation level and α, β, γ are the additional parameters. The accumulated forecasts shown in figure 1, are calculated based on the assumption of 40% penetration in 2005.

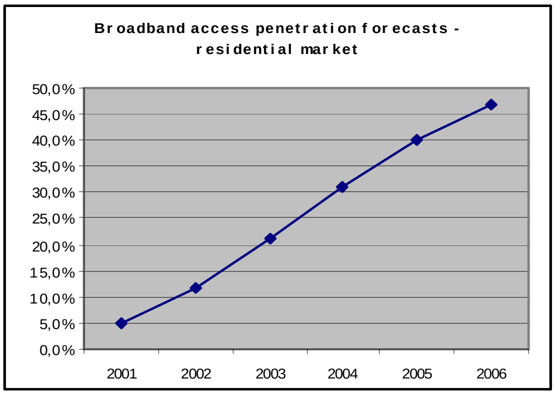


Figure 1 Total broadband penetration forecasts

The total broadband forecasts are split based on technology (operators) and access capacity. The market share evolutions are described in scenario 1 – 7, depending of different roll out strategies.

Tariff evolution/prediction

The broadband tariff structure is rather complex. Important tariffs are: connection tariff, access tariff, service provider tariff, traffic tariff, transaction tariff, and tariff for content (pay per view etc).

Only some few operators have introduced a traffic tariff when the monthly traffic volume exceeds a given limit. In the case study we suppose free traffic charge and are mainly interested in the demand for accesses. The yearly charge for having a 0.5 Mbps is set to 800 Euro.
The tariff model is constructed in the following way: The basic tariff for a 0.5 Mbps is given (800 Euro). The model predicts a relatively 10% decrease of the tariff per year. In addition the model predicts an increase of 40% for each doubling of the downstream capacity for year 2001, while this factor is linearly reduced to 20% in year 2005. The connection tariff is set 150 Euro for 0.5 Mbps and 1 Mbps, while the tariff is 200 Euro for higher capacities

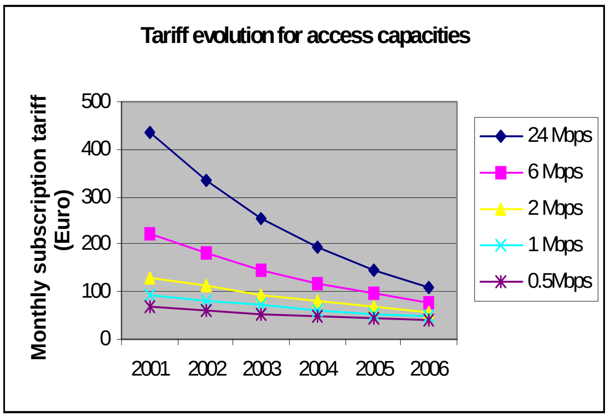


Figure 2 Tariff evolution for access capacities

Figure 2 shows the erosion of the monthly subscriber tariff, which includes access tariff, service provider tariff and the traffic tariff. Usually the operators have a flat rate tariff for the traffic. Charges for specific applications are not included.

Rollout scenarios/Market share scenarios

Seven different scenarios are studied. In three scenarios 5 – 7, the cable operator is rolling out broadband network in 2001. In four scenarios 1 – 4, the cable operator is deploying the broadband network to offer the services in 2002. The various scenarios for 2001 and 2002 reflect the incumbent operators timing for ADSL and VDSL rollout.

Figure 3 shows the prediction of access demand distributed on the access capacities 0,5 – 6 Mbps in the period 2001 – 2006. The figure shows that there will be continuously demand for higher capacity. The demand is generated of new and enhanced broadband applications and the operators have to meet the capacity demand.

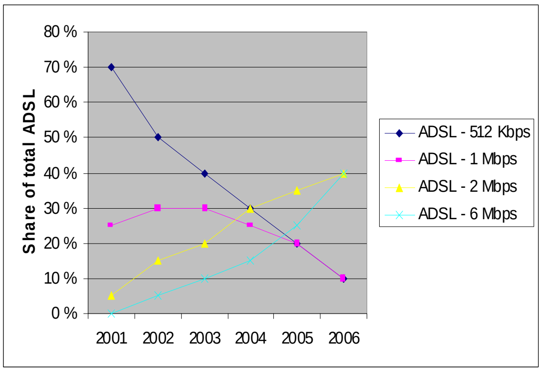
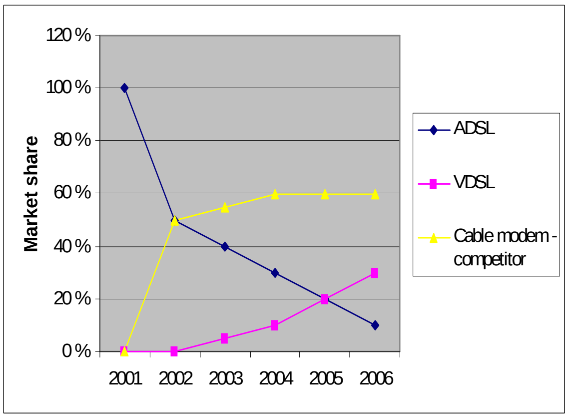


Figure 3 Prediction of demand for ADSL access capacities

Scenario 1

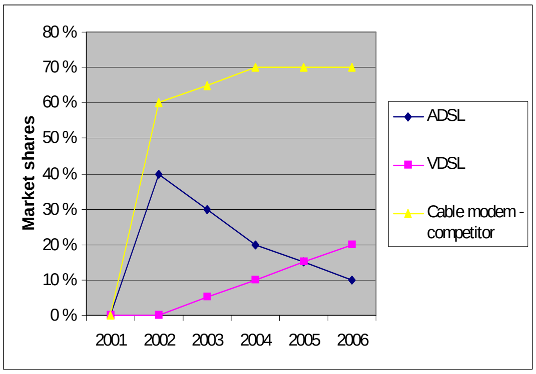
The incumbent operator offers ADSL in year 2001. The cable operator meets the challenge by deploying HFC offering cable modems in year 2002. One year later the incumbent operator offers VDSL in the same area. Figure 4 show the market share evolution. The ADSL market share is reduced from 100% to 50% when the cable operator introduces broadband. The figure shows that the market share for ADSL gradually is decreasing during the study period. At the same time it is difficult for the incumbent operator to take a larger part of the broadband market.



Figur 4 Scenario 1: Market share ADSL, VDSL and cable modems

Scenario 2

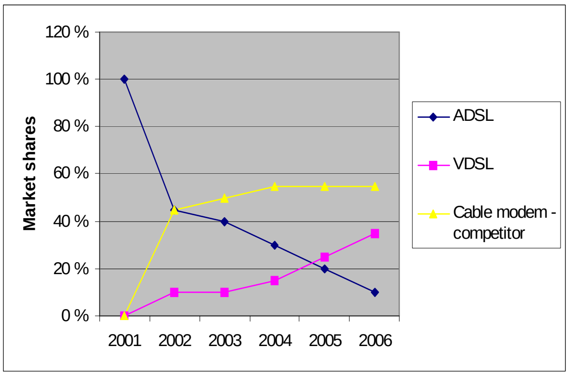
The incumbent operator offers ADSL in year 2002. The cable operator meets the challenge by deploying HFC offering cable modems the same year. One year later the incumbent operator offers VDSL in the same area.
Figure 5 show the market share evolution. The cable operator gets 60% of the broadband market the first year since the operator has a more advanced product. The operator takes more market share during the comming years because of late introduction of VDSL.



Figur 5 Scenario 2: Market share ADSL, VDSL and cable modems

Scenario 3

The incumbent operator offers ADSL in year 2001. The cable operator meets the challenge by deploying HFC offering cable modems in year 2002. The same year the incumbent operator offers VDSL. Figure 6show the market share evolution. The ADSL market share is reduced from 100% to 45% from 2001 to 2002.The figure shows that the market share for ADSL gradually is decreasing.

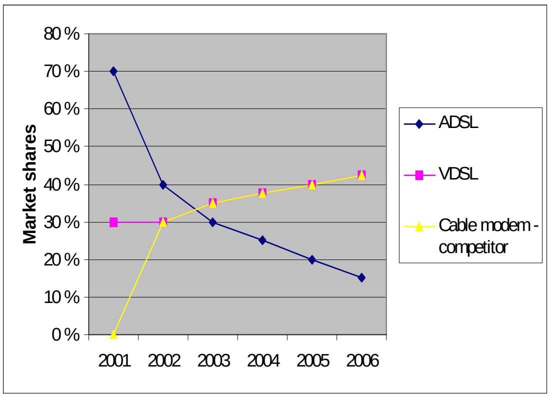


Figur 6 Scenario 3: Market share ADSL, VDSL and cable modems

In spite of introducing VDSL at the same time as the cable operator, the incumbent operator has to fight very hard to get high VDSL market share. It is difficult for the incumbent operator to win larger parts of the market since most of the subscribers have a TV channel subscription by the cable operator.

Scenario 4

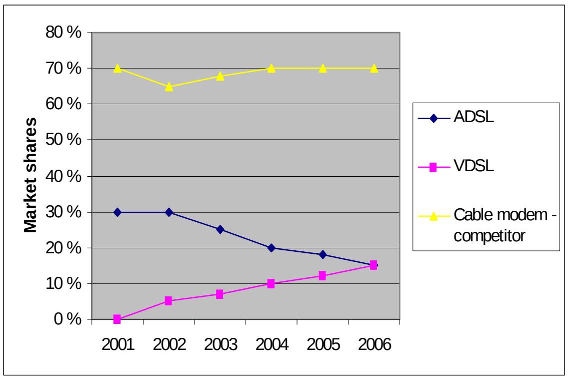
The incumbent operator introduces an offensive strategy by offering both ADSL and VDSL in year 2001. The cable operator deploys HFC, but is offering cable modems only from year 2002. Figure 7 show the market share evolution. The ADSL starts with 70% market share in 2001, which is gradually reduced. The cable operator introduces broadband later than the incumbent operator and have to fight rather hard to get broadband market share at the same level as the incumbent operator.



Figur 7 Scenario 4: Market share ADSL, VDSL and cable modems

Scenario 5

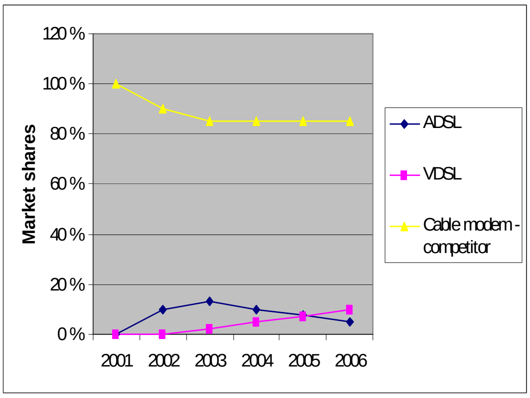
Scenario 5 - 7 describes the situation where the cable operator deploys HFC early and is offering the cable modems already in year 2001. The first scenario shows that the cable operator introduces broadband in year 2001, while the incumbent operator is offering ADSL. The cable operator gets 70% of the market and is able to hold the market share during the study period in spite of introduction of VDSL in year 2002. Figure 8 show the market share evolution.



Figur 8 Scenario 5: Market share ADSL, VDSL and cable modems

Scenario 6

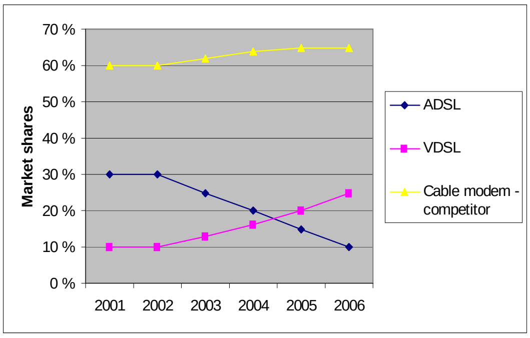
The cable operator introduces broadband in year 2001, while the incumbent operator is offering ADSL in year 2002 and VDSL in 2003. The cable operator gets 100% of the market the first year. Since incumbent operator introduces VDSL two year after the cable operator, in a market where the cable operator during a lot of years has delivered TV distribution, it is very hard take market share. The incumbent operator ends with 15% market share at the end of the study period. Figure 9 shows the market share evolution



Figur 9 Scenario 6: Market share ADSL, VDSL and cable modems

Scenario 7

Scenario iii describes a highly competitive situation where the cable operator in 2001 is offering broadband based on their HFC solution, while the incumbent operator has deployed a VDSL structure in 2001 beeing able to offer the customers both ADSL and VDSL. Since the cable operator has delivered TV distribution for a long period, it is assumed that the cable operator will get 60% of the market in year 2001 and is increasing the market share slightly. The incumbent operator starts with 30% ADSL market share and a 10% VDSL market share. The evolution of market share is shown in figure 10.



Figur 10 Scenario 7: Market share ADSL, VDSL and cable modems

Results

Within the European programs RACE and ACTS the projects RACE 2087/TITAN and AC 226/OPTIMUM and AC364/TERA have developed a methodology and a tool for calculation of the overall financial budget of any access architecture. The tool handles discounted costs of capital investments, operations, maintenance costs, life cycle costs, and revenues as well as net present value (NPV) and internal rate of return (IRR).The tool has the ability to combine low level, detailed network parameters of significant strategic relevance with high level, overall strategic parameters for performing evaluation of various network architectures [6-7, 9-16].

The TERA tool has been used to evaluate techno-economic results of the described scenarios. Figure 11 shows the calculated net present values and the installed first costs for each scenario.

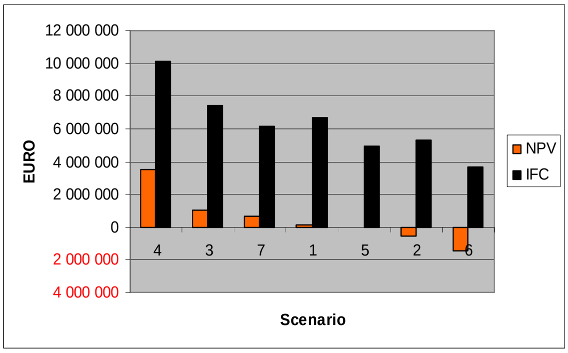


Figure 11 Installed first cost and net present value for scenario 1-7

The figure shows that the incumbent operator has to fight rather hard to get a positive net present value when the cable operator starts to roll out broadband in 2001 (Scenario 5-7). The only possible way to get a significant part of the broadband market is to introduce ADSL and VDSL at the same time as the cable operator. In addition the incumbent operator to a certain degree, has to meet the access tariffs to the cable operator. Scenario 6 shows that the incumbent operator gets a significant negative net present value. The reason is too late roll out of broadband and too low market share.

The cable operators have not financial strength enough to roll out a broadband structure in all relevant areas during a short time. Hence, scenario 1–4 is important to analyse. The figure shows that the incumbent operators have a possibility to get rather good economical results by rolling out a broadband DSL network in “cable-land”. Scenario 4 indicates a very good net present value for the incumbent operator.

The investments depend of the total broadband penetration in the area, the proportion between ADSL and VDSL subscriptions, broadband market share for the incumbent operator and of course the network component costs and the evolution 2001–2006. Figure 11 shows that the installed first costs increases when the incumbent operator gets a larger market share. The proportion between first installed costs and net present value is acceptable for scenario 4, 3 and 7.

Uncertainties and risk modelling

A series of risk analyses has been carried out- one for each of the seven scenarios. One uncertainty variable is introduced for:

- Price evolution of xDSL equipment
- Growth of the total broadband demand (all services, including competitor’s)
- Erosion of monthly access fee

A Monte Carlo simulation with 500 runs is performed for each scenario. In each run of a simulation, a random number is picked from suitable probability distributions; one for each of the 3 uncertainty variables. The simulation gives as output the cumulative distribution of the NPV and the ranking of the 3 uncertainty variables. This uncertainty ranking is based on the percentage to the contribution to the variation of the NPV. From the cumulative distribution, the probability that the project will produce a negative NPV is calculated.

In the following, the uncertainty model is described:

Price evolution of xDSL equipment:

Even though a significant part of the overall investment cost is civil works, this cost is not very uncertain. Therefore the uncertainty is put in new equipment.

The price of each xDSL network component '*i*' (DSLAM, modems etc) follows a learning curve [3, 6, 7, 16]:

$$f_i(t) = f_i\left(n_{0,i}, K_i, P_{0,i}, \Delta T_i, t\right)$$

The uncertainty is modelled as a relative uncertainty $s(t)$:

$$s(t) = 1 + 0.3(b + at)Y$$

Y is calculated as linear transformation of a Beta-distributed variable X:

$$Y = (Y_{\max} - Y_{\min})X + Y_{\min}$$

The price curve including uncertainty is therefore calculated as;

$$\tilde{f}_i(t) = f_i(t)s(t)$$

The reason for choosing a Beta-distribution is the fact that this distribution is confined between a minimum and a maximum value avoiding negative prices, which would be meaningless. In addition, the Beta-distribution may have many different shapes. The rectangular distribution is a special case of the Beta-distribution.

In our calculation, $a = b = 1/5$ and X is Beta-distributed with parameters $\mu = \nu = 4$. $Y = X$ as we have degrees of freedom choosing the parameters a and b. The maximum deviation in the last year is between 0.7 and 1.3. With a 95% confidence, the relative uncertainty in the last year is between 0.79 and 1.21.

The same relative uncertainty curve is used for all components so that the learning curves move in the same direction for each run which is plausible as the component prices will be strongly related (same technology, vendor etc.)

Tariff erosion

The tariff erosion is modelled by a simple percentage reduction. The uncertain tariff erosion is modelled by a linear transformed Beta-distributed random variable as in the price evolution.

The default value is 10%. The minimum and maximum values are 0% and 20% respectively. Thee confidentiality interval of Y is [5%, 15%]. By using the simple linear transformation and the Solver function in Excel, the parameters μ and ν are easily found. In fact μ is found using:

$$\nu = \frac{\mu\left(1 - X_M\right) + 2X_M - 1}{X_M}$$

where X_M is the mode of X found as (10%-0%)/(20%-0%) = 0.5.

Growth in total broadband demand

A general S-curve with asymmetry parameter γ is used to model the total broadband demand.

When γ and the saturation parameter are given, the two remaining parameters are found when for instance the penetration in the first and final year are given. We have chosen 5% penetration in 2001 and 40% in 2006. The penetration in 2001 is kept fixed and the penetration in 2006 is changed randomly. Again, a linear transformed Beta-distribution is chosen. The minimum and maximum values for the penetration are 30% and 50% respectively. $\mu = \nu = 3$ are chosen.

Risk analysis

For each Monte Carlo simulation specific values are generated for:

- Price evolution of xDSL equipment
- Growth of the total broadband demand (all services, including competitor's)
- Erosion of monthly access fee

based on the described risk models. For each simulation run a complete set of techno-economic calculations are performed including first installed costs, OAM costs, revenues, cash flow, IRR, NPV, payback period etc. The set of 500 simulations generates an accumulated distribution for each variable. The accumulated distributions are used to evaluate the risk; i.e. to calculate the probability for the variable to exceed given limits. Figure 12 shows for each scenario the probability to have a net present value less than 0.

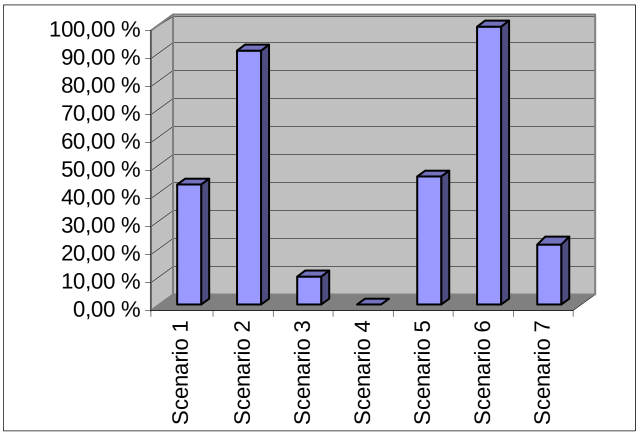


Figure 12 Probability for having a negative net present value

The figure shows that the probability to have a negative net present value for scenario 6 is close to 100%, while the probability for scenario 4 is close to 0%. For the incumbent operator scenario 1, 2, 5, 6 have significant risks for negative net present values. Again, the conclusion is to speed up the introduction of broadband before the cable operator takes the main part of the broadband market.

The question is which of the above mention variables gives the dominated contribution to the net present value uncertainty. Figure 13 answers the question for each scenario. The figure shows that the uncertainty in tariff evolution is the dominated variable – which explains 55% –70% of the variation of net present value. The demand forecasts explains 15% - 35%, while the price evolution of the DSL equipment only contributes with 7% - 17%. The price evolution of DSL equipment seems to be more certain than the tariff evolution. One important argument is that predictions of a sum of component costs are based probably of overestimation of some costs and underestimation of some other costs. The uncertainty in the demand forecasts introduces uncertainty both in the investments and in the revenues, while uncertainty in the tariff predictions only introduces uncertainties in the revenue.

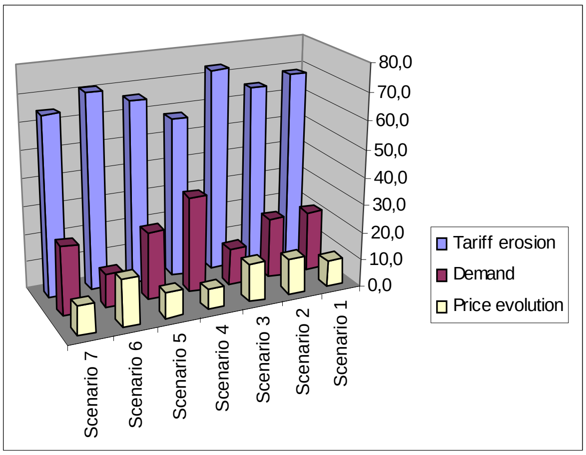


Figure 13 Ranking the sensitivities. Contribution (%) to the net present value uncertainty

Figure 13 also illustrates how the uncertainty in market share and market share evolution has an impact on incumbent operator's net present value. Since the incumbent operator is not controlling the cable operator, there are significant uncertainties and risks related to the timing for broadband roll out.

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Analysing the impact of forecast uncertainties in broadband access rollouts by the use of risk analysis

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In this paper thorough risk analysis is performed on the rollout investment case described in this journal [1]. The concepts of uncertainty and risk are introduced, followed by an extensive overview of various types of uncertainties and risks in telecommunication investment projects. The next part of the paper describes the risk methodology. The risk and sensitivity analysis performed on the scenarios described in [1] is discussed. The focus is on financial risk in this paper.

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1 Introduction

There are many complex and interacting factors with an impact on the economics of telecommunication investment projects. The main factors are the evolution of: applications, technologies, network platforms, service quality requirements, cost evolution, demand for new services, price levels, regulatory environment and competition. Telecom projects are influenced by *future forecasts and predictions* of all these factors.

The network operator's strategy is governed by estimated revenue, expected return on investments and assessed economic risks caused by uncertainties in the forecasts and predictions. Introduction of new technologies, new applications, new network platforms, new architectures etc. depend on the long-term revenue prospects and also on related uncertainties and risks. Strategic decisions play an important role in the near term positioning when the competition is increasing. The environment of the telecommunications market is now changing dramatically and will continue to do so in the coming years.

New applications and services can be implemented by using the existing network platform, or by expanding the network platform, or by introducing new technology and new network platforms. The preferred alternatives depend on the cost of network components and the cost evolution. The price of the given applications depends on investment costs, operation and maintenance costs, and revenue considerations. Demand depends on the expected competition, the market potential for the applications, expected market shares, substitution effects between applications, penetration as a function of time, price and service quality. In addition there are interactions between the main factors.

In this paper, thorough risk analysis is performed on the rollout investment case described in this journal [1]. We begin with an introduction to the concepts of uncertainty and risk, followed by a description of the risk methodology. The risk and sensitivity analysis performed on the scenarios described in [1] is discussed. Focus is on financial risk in this paper.

2 Uncertainty and risk

Uncertainty and risk are unavoidable companions in every business case evaluation. Many high level assumption variables in a business case, e.g. service penetration, ARPU, market share etc. of which the default values are chosen from consensus/brainstorming/expert information etc., are inherently uncertain. The variation of these variables may have a vital impact on the whole value of the project, which means the difference between success and failure. The first questions that arise are how do we describe the uncertainty in assumptions, and what is actually the difference between uncertainty and risk?

To illustrate the concepts of uncertainty and risk, let us start with a simple example. We assume that we have two projects, A and B, with their respective distributions as shown in Figure 1 (for example obtained from simulations).

The question is now: Which project is more uncertain than the other, and which project carries most risk? It is immediately seen from Figure 1 that Project B has the highest level of uncertainty due to its higher standard deviation. However, Project A is the riskier of the two projects as the 5 % percentile is negative, and therefore there is a probability of a negative NPV higher than 5 %. For Project B, however, the probability of a negative NPV is 0 as the minimum value is positive. The 5 % percentile (Value at Risk) is therefore also positive.

A "plain" traditional sensitivity analysis is often used, in which each input variable is changed on a one-by-one basis, in order to identify the most significant variables. However, this is not sufficient if a more complete picture of the overall uncertainty is needed. The multivariable sensitivity and risk analysis approach applied in this paper is based on the well-known Monte Carlo simulation methodology. In

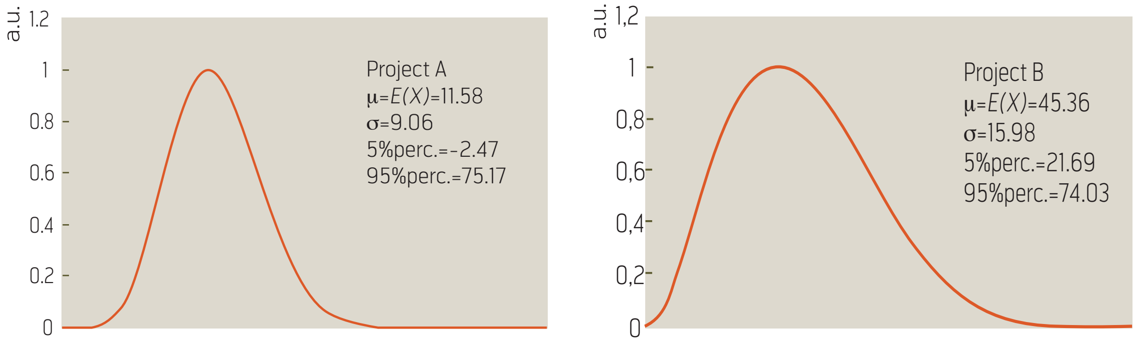


Figure 1 The difference between uncertainty and risk

short, the difference between traditional "plain" sensitivity analysis and risk analysis based on Monte Carlo simulation is that the former only tells you what is *possible*; not what is *probable*!

3 Overview of uncertainties and risks in broadband telecommunication projects

Market uncertainties and risks

Substantial risks are linked to the predicted evolution of the broadband market. A fundament for the evolution is new and enhanced broadband applications. Uncertain demand forecasts generate significant risks influencing the investments and also other costs. One realisation is unexpected delay in the demand. Overestimation of the demand implies overestimation of investment costs, where parts of the costs are bundled and not utilised for a period.

Underestimation of the demand will generate waiting lines and bad reputation and lost market share. Also the problems in the rollout, in component and service supply and in service quality will induce bad reputation.

If some customers are lost to a competitor, it is difficult to win these customers back. This risk problem is denoted as the churn problem. The customer can be lost from specific market segments, specific user groups or in specific geographic areas. The risk of lost market shares may also be caused by substituting applications and services.

Uncertainties are usually expressed by measures like standard deviations and confidence limits. Traditional statistical methods are used to estimate standard deviations and confidence limits for given probability densities. However, the situation is often more complicated when forecast uncertainties are estimated.

Then there are two sets of uncertainties: Uncertainties based on estimation of parameters in the forecasting model and uncertainties caused by the forecasting period. The forecasting uncertainties are either expressed directly from the model when Box Jenkins time series models [3] are used, or in regression models with time, t, as explanatory variable. However, when there are additional explanatory variables the situation is more complex. Then, the uncertainty of the forecasts of each explanatory variable also has an impact on the total forecast uncertainty. In such situations it is difficult to model and estimate the uncertainty as a function of time.

Competition, regulatory risks and uncertainties

The main objective for the regulator is to establish a competition regime where newcomers have a fair competition, while the incumbent operator has significant handicap. The European Commission has recommended that the regulators perform market analysis to identify whether the incumbent is dominating the market or not (Significant Market Position).

The effect could be a reduced market share and power for the incumbent operator and a more balanced market between all operators. The risks and the uncertainty are influenced by unpredicted regulations, the number of new competitors, and alliances between the operators and also service providers.

The geographic deployment strategy for rollout influences the market shares as well as the service mix, service quality, customer support and type of billing systems compared with the other network operators. Another important competitive factor is the tariffs and the tariff strategy. Significant risks of losing market shares are linked to the tariff evolution generated by different competitors.

Since the incumbents own large parts of the access network, the European Commission through European regulators have taken actions to generate competition in the access network by introducing Local Loop Unbundling, LLU. However there is a lot of uncertainty connected to the actions of the regulator. The regulator may generate changes in some important parts of the telecommunication law. The regulator controls the number of licenses for the operators. The regulator may prevent the incumbent operator from offering given services. The body influences the interconnect tariffs and may also regulate the ordinary tariffs.

Technology risks

A wide range of technologies are available for transport of broadband communication. In the access network a fibre node structure or a coax structure has to be deployed. The last part of the access network can be covered by ADSL, ADSL2+ or VDSL on twisted pair copper lines, or by the radio solutios such as LMDS, WiFi, WiMax. Other alternatives are satellite systems combined with a wireline return channel or a hybrid fibre coax system, HFC. The technologies may substitute each other or may be deployed as supplements in different parts of the network. In parallel the fibre capacity is extended by introduction of wavelength division multiplexing, WDM and mainly IP in the core network.

There are substantial risks of implementing the wrong technology at the wrong time. Important questions are:

- Selection of optimal technology in different parts of the network;

- Strategies for rollout based on competition in specific areas;

- Strategies for robust upgrading of the upper part of the access;

- Network design giving possibilities for utilising different technologies;

- Strategies for minimising the upfront costs the first period.

In addition specific technology problems may occur. The quality of some components does not satisfy the norms and have to be replaced by other types of components. The selected manufacturer has significant problems and does not satisfy the production specifications. The effect is bad quality for the customers, delivery problems, waiting lists and bad reputation. The same risks can be generated if the demand forecasts, planning, dimensioning, projecting or deployment of the network are pure.

Operational and investments risks

Investment and operational costs can be divided into:

- Investment costs
- Operational and management costs
- Maintenance cost
- Administrative costs
- Costs of support systems
- Customer support costs
- Marketing/sales costs.

Implementation of a new broadband network including new services and applications will generate uncertain cost estimates. The main input is demand forecasts for the total market and estimates for lost market shares because of competition. If the forecasts turn out to be completely wrong, then the investments will also be out of scale. Since forecasts for new services are uncertain substantial cost risks are generated. Important questions are:

- Introduction time for optimal rollout;

- Which geographic areas should be covered at the start;

- Which market segments should be covered at the start;

- The size of the broadband nodes and the structure are of crucial importance;

- Dimensioning of the network and estimated demand controlled expansion.

The network components and the technology standards induce risks when an operator starts a rollout before the standards have been adapted. Additional investments and replacement of rather new components may be necessary. There are substantial uncertainties related to the prediction of component costs. The learning curve forecasts show that the component costs decrease as a function of large-scale production. However, there is significant uncertainty in the predicted component cost evolution.

Revenue and cost risks

To be able to evaluate a broadband network upgrading, the discounted sum of revenues, investments, operations and maintenance costs etc. has to be calculated over a 5–10 year period. The result can be expressed in net present value, payback period, internal rate of return, installation first costs, lifecycle costs, pay-back each year, etc. Important revenue and cost risks are caused by:

- Lower tariffs than expected;
- Reduction of service mix;
- Loss of market shares;
- Higher revenue reductions due to substitution effect between other services;
- Higher investment costs than expected;
- Higher operational and maintenance costs than expected;
- Higher administrative costs;
- Higher customer support and marketing costs than expected;
- Investments restrictions due to lower profit or new priorities.

4 Risk methodology

The uncertainty in each assumption has to be quantified with respect to a suitable probability density function including "practical limits for variation for performing risk analysis".

Data collection

All relevant information, specific assumptions, natural limits, and types of distribution as well as confidence intervals have to be collected.

Probability distributions

Suitable probability distributions should be identified for each assumption variable. The choice of probability distribution depends on the restrictions on the variable, whether we need some extra degree of freedom such as asymmetry in the distribution etc. In various fields, e.g. physics, economics and social sciences, empirical data or the law of large numbers determine the choice of distribution, e.g. noise in electrical systems, the evolution of stock prices and people's IQ. IQ values are for example modelled by a normal distribution with mean value 100 for a population (age group) and standard deviation 15. However, one should generally be careful using the Normal distribution in simulations if negative numbers are not allowed.

For instance a market share will always be between 0 % and 100 %, the value of a stock is non-negative but can (theoretically) be of infinite value, and penetration and costs cannot be negative, etc.

Usually Beta distribution and Log Normal are used to model important variables in the business cases. Appendix A gives a more detailed description of how the Beta distribution and Log Normal distribution are fitted.

Risk simulation performance

Output variables have to be identified. Usually net present value, internal rate of return and pay-back period are used to evaluate the economic value of investment projects. Also the number of simulation trials has to be decided. Then the number of trials performed in a simulation shows the impact on the output variable.

Thanks to modern easy-to-use software, Monte Carlo simulations can be performed on standard spreadsheet models on a PC. Such software also has splendid report features, in which the user can specify result tables with the complete statistics of the output variables such as mean value, standard deviation, percentiles, etc.

Random numbers are generated in each trial of the simulation according to the selected distributions generated for each of the selected variables for the risk analysis. The simulation therefore calculates a large number (maybe thousands; the number of simulation trials specified by the user) of what-if scenarios. Equally important: the simulation keeps track of the calculations by measuring the impact on the result from the changes in each of the variables.

In the simulation package called Crystal Ball® [2], "normal" Monte Carlo or *Latin Hypercube Sampling* can be used. In Latin Hypercube Sampling, an assumption's probability distribution is divided into intervals of equal probability, whereas in the former approach the random numbers are picked over the entire range for that distribution.

In general, it is difficult to give advice on the number of simulations since there is a dependency of the complexity in each case study analysed. The best way to control the accuracy is to do some test-simulation series and calculate the uncertainty in the output distributions. Based on experience so far, the sufficient number of simulations could be 500 – 10,000.

Figure 2 illustrates the concept of Monte Carlo simulation. The figure shows how random values are drawn from probability distributions representing input variables 1, 2, 3, ... For each trial a value of the output variable, here NPV, is calculated. By repeating this process 10,000 times a frequency chart (histogram) is generated. Figure 2 shows that the histogram forms a probability distribution for the output variable. The final part of the risk analysis is to interpret the information from the input and output distribution.

Risk analysis

When the simulation is finalised, the complete statistics on the output variable distributions, the correlation between output variables is available and can be extracted in a report, which is an Excel workbook with tables. The samples generated for the input vari-

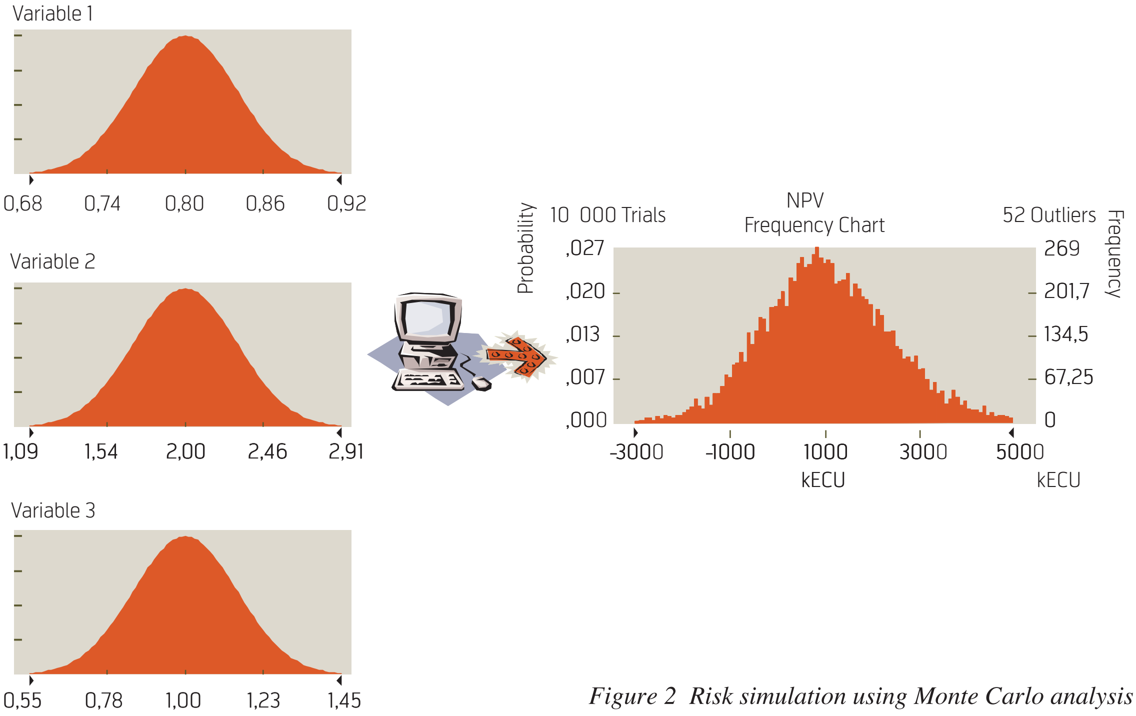


Figure 2 Risk simulation using Monte Carlo analysis

ables can also be saved for further analysis. In addition, the impact of each input variable on the given output variable is measured as well – either in terms of the so-called *Rank Correlation* or the *contribution to the variance*. Both of these metrics will be described in more detail in Appendix B.

An overview of the uncertainties and risks in telecommunication projects is discussed next before moving on to the actual case study in Chapter 5.

5 Risk analysis of ADSL2+/VDSL rollout case study

The six different rollout scenarios described in [1] with different timing and ambition levels of ADSL2+/VDSL rollout are summarised as follows:

Scenario 1: "Market equality, no overlap"
Scenario 2: "Market equality, 50 % overlap"
Scenario 3: "Market equality, 75 % overlap"
Scenario 4: "Incumbent two years delayed"
Scenario 5: "Incumbent one year delayed"
Scenario 6: "Incumbent aggressive rollout "

The base case results [1] are summarised in Figure 3.

To be able to analyse the impact of the uncertainties, the most critical variables have to be identified. In this case study the most important variables are considered to be:

- Adoption rate forecasts
- ARPU
- Broadband content costs
- Sales costs
- Provisioning costs
- Customer operations and maintenance
- Customer installation costs
- Smart card costs
- Line card costs
- Price reduction rate for DSL equipment, i.e. DSLAM rack and linecards.

Table 1 summarises the uncertainty assumptions for each variable. Each selected input variable is described by its default value, upper and lower limit, confidence interval and probability distribution parameters.

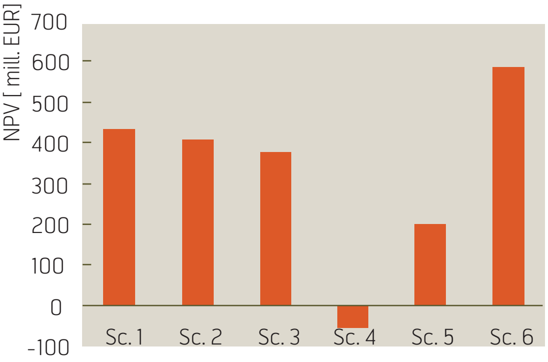


Figure 3 Base case results for the six scenarios

The broadband demand, the costs and revenues are predicted from 2005 to 2011. The main variables can be grouped by demand, ARPU, which gives the expected revenue, and costs like Capex, Opex and content and sales costs.

Most of the values in the table are specified in EURO. The sales costs and the content costs are expressed as a proportion of the total (ISP + wholesale part) and ISP part of the revenues respectively. The sales costs are 30 % of the total revenue each year. The content costs are 60 % (default) of the ISP part of the revenues in the first two years of operation, 5 % less in year 3 and 4 and then decreasing by 5 % in the following years. Figure 4 shows the default ARPU breakdown.

The demand evolution is based on the adoption rate in year 2011. The adoption rate values in the period 2006 – 2010 are adjusted proportionally according to the simulated 2011 value.

The other variables in the table have reference values for 2005. Based on the reference values, predictions are calculated for the 2006 – 2011 period. In a simulation trial, the reference value has a deviation. Then the predicted values (2006 – 2011) will have a deviation proportional to the predicted size (2006 – 2011) multiplied by the reference value deviation. Since the values of the variables are simulated a large number of times, there will be great variation in the deviations, based on the probability distribution used.

10,000 trials of Hypercube simulation were performed for each of the six scenarios, in order to analyse the impact on the net present value (NPV). The Beta distribution has been used for all input variables. A more detailed description of the Beta distribution is found in Appendix B.

First, three sets of simulations (for each scenario) were carried out:

- All ten variables were simulated;
- Only Adoption Rate and ARPU were simulated (the rest were frozen at default values);
- Only Adoption Rate was simulated (the rest were frozen at default values).

Table 2 summarizes the results for all the three simulation types for the six different scenarios in terms of mean value, standard deviation and 5 % percentile. All values are in mill. EURO.

As can be seen, all six scenarios have negative 5 % percentile values when all ten variables were simulated. The reason is the generally high customer-independent investment combined with high uncertainty

Variable name	Minimum value	5 % percentile	Default value	95 % percentile	Maximum value	α	β
Monthly ARPU	90	95	**100**	108	124.7	5.11	11.16
Line card price	1,200	1,400	**1,600**	1,800	2,000	4.94	4.94
Sales costs	25 %	27.5 %	**30 %**	32.5 %	35 %	4.94	4.94
Provisioning costs	50	60	**65**	70	80	11.77	11.77
Equipment price reduction rate	5 %	8 %	**10 %**	12 %	15 %	8.02	8.02
Adoption rate, final year	26 %	29 %	**32 %**	37 %	42 %	4.02	6.04
Customer installations cost	100	110	**120**	130	140	4.95	4.95
Content costs	50 %	55 %	**60 %**	65 %	70 %	4.95	4.95
Smart card costs	20	25	**30**	35	40	4.94	4.94
Customer operations & maintenance	15	20	**25**	30	35	4.95	4.95

Table 1 Assumptions for probability distributions used in uncertainty and risk calculations

in ARPU and adoption rate. The input variables are independent in the simulations, which means that trials with a combination of a low adoption rate and a low ARPU will give a significantly negative contribution to the NPV.

For all the scenarios it was found that the adoption rate and ARPU in that order were by far the most dominant contributors to the uncertainty in NPV. *The contributions to the NPV variance were in the 48 % – 56 % range for the adoption rate and the 33 % – 38 % range for the ARPU for the six scenarios*. The contributions from the remaining assumptions were therefore small in comparison. Especially the network component costs have a very small impact. This is due to fairly good cost prediction models combined with experiences of cost reduction trends of network components for the last years.

Scenario 6 has the largest NPV and also the highest mean value to standard deviation ratio and is therefore the least risky scenario. Scenario 4 has the smallest NPV (default as well as simulated mean value) and in addition the most negative 5 % percentile (and therefore the highest value at risk; VaR). All the scenarios look quite risky with negative 5 % percentiles in most cases.

As expected, the standard deviation decreases with fewer simulated input variables. As the ARPU and Adoption Rate are the two dominant variables, the most dramatic decrease is seen when going from two variables simulated to only one simulated variable. When only the two dominant variables are simulated, the 5 % percentile turns positive in Scenario 6. When only the adoption rate is simulated, the 5 % percentile also turns positive for the first three scenarios. When only simulating the Adoption Rate, we avoid the negative contribution from trials with low values of both Adoption Rate and ARPU. Therefore the 5 % percentile is improved and the risk therefore reduced even further.

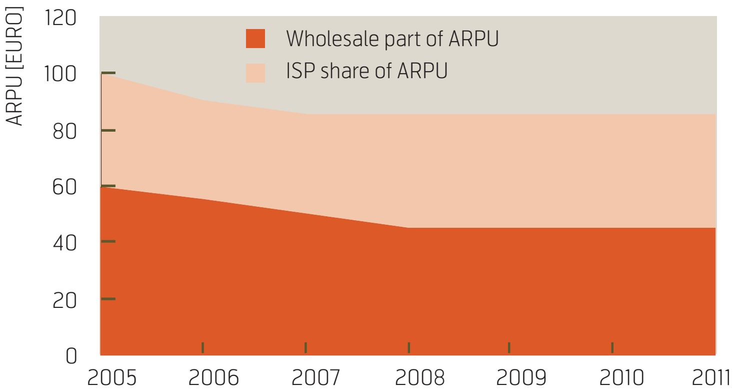


Figure 4 ARPU breakdown

This first batch of simulations was done in order to illustrate that too pessimistic values are generated if we do not take the inherent coupling between ARPU and Adoption Rate into account. This coupling can be modelled by the use of price elasticity models so that the adoption rate will generally increase with a decrease in the monthly tariff. However, such models can be quite complex as other parameters than just price generally influence the adoption rate of services such as brand value, etc. As this kind of price modelling is outside the scope of this paper, we chose to study the impact of introducing a generic negative correlation between the Adoption Rate and the ARPU. The next step was to study the impact of "weak", "moderate" and "strong" correlation using –0.25, –0.50 and –0.75 respectively for the correlation value. The results are shown in Figure 5 where all variables are simulated.

We see that the risk is reduced remarkably as the 5 percentile is increased significantly due to the reduced standard deviation in each simulation.

Scenario	10 variables simulated			Adoption rate and ARPU			Only Adoption Rate simulated		
	5% perc.	95% perc.	σ	5% perc.	95% perc.	σ	5% perc.	95% perc.	σ
Sc. 1	-48.5	1,155.7	364.1	-5.1	1,114.5	339.5	58.6	928.4	263.4
Sc. 2	-70.6	1,138.4	365.7	-27.4	1,097.3	341.2	37.6	909.7	265.6
Sc. 3	-102.3	1,108.3	366.4	-58.9	1,066.1	341.9	4.3	882.5	266.6
Sc. 4	-376.4	438.5	264.8	-341.4	408.4	227.6	-287.4	261.6	166.7
Sc. 5	-212.0	830.8	315.9	-174.2	795.8	293.8	-112.9	624.9	224.1
Sc. 6	-50.6	1,561.9	487.7	6.0	1,507.2	455.9	90.6	1,256.9	356.1

Table 2 Summary of three types of Monte Carlo simulations – by scenario

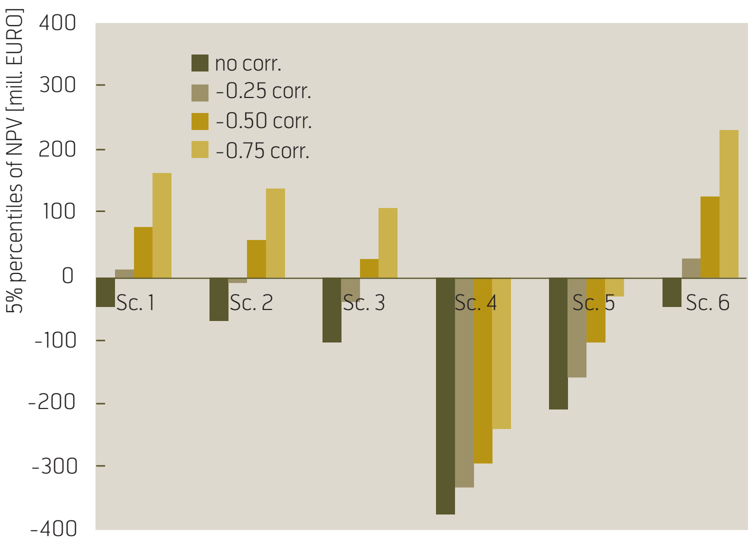


Figure 5 5 % percentiles for various degrees of correlation between ARPU and Adoption Rate. Ten variables simulated

The ranking of the different scenarios with respect to the ranking of NPV and riskiness is however unchanged. Scenario 6 is still the most profitable project and is also the project with the smallest level of risk in terms of mean to standard deviation ratio. Scenario 6 has the highest mean to standard deviation ratio followed by Project 2. We also see that Scenario 4 and Scenario 5 have negative percentiles for all levels of correlation. These two scenarios also have the lowest values of the mean to standard deviation ratio.

For moderate and high correlation, Scenarios 1, 2, 3 and 6 get positive values of the 5 % percentile.

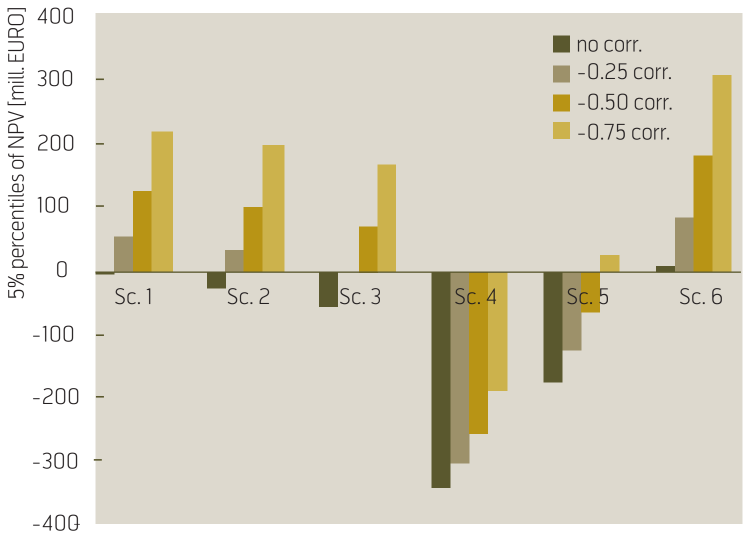


Figure 6 5 % percentiles for various degrees of correlation between ARPU and Adoption Rate. Two dominant variables simulated

The simulation batch with correlation was also carried out where only Adoption Rate and ARPU were simulated. The results are summarized in Figure 6. The same trend and ranking as in Figure 5 are seen but now the standard deviation is even smaller due to the fewer variables simulated.

Scenario 4 and Scenario 5 remain quite risky due to the delay of entry by two years and one year respectively.

It should of course be pointed out that broadband rollouts would be stopped or scaled down if the cash flow is significantly lower than what is expected. Then, the project has to wait until the expected costs decrease or the revenue increases.

For the given assumptions, the strategy of entering the market too late at high coverage as in Scenario 4, is very risky due to lost market shares. The risk picture for Scenarios 1–3 and Scenarios 5–6 is strictly on the pessimistic side, as flexibility in timing is not taken fully into account by considering the given rollout scenarios separately.

An optimal strategy will be to go for a rollout level as in Scenarios 1–3 and scale up the ambition level in coverage as in Scenario 6 only if market conditions are favourable.

6 Conclusions

The objective of the presentation was to show how risk analysis and the related risk framework are used to evaluate business cases on broadband rollout taking the risks into account.

By using Monte Carlo simulations it has been possible to give a more complete picture of the risks in large-scale broadband rollouts. The additional multivariable sensitivity analysis gives the contribution to the NPV variance from all the uncertain assumption variables in the case study. Using the traditional sensitivity analysis concept where all assumption variables are changed one at a time is only useful as a first step in order to pick the dominant ones for further analysis. The reason is that the former concept only shows what is possible – not what is probable.

When not using correlation between variables, all the six scenarios that were investigated had a negative 5 % percentile, i.e. a positive value at risk, and therefore carried significant risk even though four of the scenarios showed a high NPV as well as internal return. By not taking into account the inherent coupling of ARPU and adoption rate what will result is a too high standard deviation and thereby overestimation of the risk. The impact of negative correlation between Adoption Rate and ARPU was therefore studied thoroughly. Correlation showed significant impact on the result due to the reduction in standard deviation. For moderate correlation of –0.5, all but the two most risky scenarios (Scenario 4 and Scenario 5) showed positive values of the 5 % percentile. However the ranking of the scenarios in terms of NPV and riskiness remained unchanged. The mean value/standard deviation is a good measure in order to rank projects according to risk.

The risk analysis showed that the adoption rate had the highest impact on risk followed by the ARPU. The prediction of network component costs generated limited risk compared with the adoption rate and the ARPU. The reason is the existence of fairly good cost prediction models combined with experiences of cost reduction trends of network components for the last years.

The methodology described showed its usefulness in identifying the overall uncertainty as well as giving good indications of the ranking of investment projects with respect to risk. We also believe that an extension of the framework taking into account strategic flexibility (if any) would be very useful.

7 Appendix A

In the following, the uncertainty model is described. We give a short description of the Beta and Log Normal distributions and how to calculate relevant parameters from specified values and ranges of the selected uncertainty variables.

Beta distribution:

The Beta distribution has a number of characteristics that makes it useful for most studies:

- It is confined to a specified interval;
- It has sufficient degrees of freedom – it can be symmetric and bell-shaped or asymmetric and peaked.

A Normal distribution is not useful in the modelling of variables that can only have positive values. A Normal distribution with given mean and standard deviation will have a certain probability > 0 that a negative number will be produced. As a result, either meaningless outputs will be generated or the calculation will end with an error message.

The generalised Beta distribution of a variable in the closed interval $[a, b]$ is given by:

$$p(y) = \frac{1}{\mathrm{B}(\alpha,\beta)(b-a)^{\alpha+\beta-1}}(y-a)^{\alpha-1}(b-y)^{\beta-1} \tag{A.1}$$

where $\mathrm{B}(a, \beta)$ is the Beta function defined by

$$\mathrm{B}(\alpha,\beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)} \tag{A.2}$$

where $\Gamma(z)$ is the gamma function of z, $z \neq 0, -1, -2, -3, \ldots$

In many simulation tools, only the normalised Beta distribution, i.e. $\alpha = 0$ and $\beta = 1$ is available. However, this problem is easily transformed by the linear transformation:

$$Y = f(X) = (b-a)X + a \Leftrightarrow X = \frac{Y-a}{b-a} \tag{A.3}$$

The most expected value (mode) of the Beta distribution is defined as the value of y for which $\frac{dp(y)}{dy} = 0$. By standard calculus, we get the mode

$$\bar{Y} = (b-a)\frac{\alpha-1}{\alpha+\beta-1} + a \tag{A.4}$$

and the mode of the normalised Beta distribution

$$\bar{X} = \frac{\alpha-1}{\alpha+\beta-1} \tag{A.5}$$

It is often easier to relate to a most expected value and a confidence interval of a random variable than the mean value and standard deviation. If q is the confidence interval, Y_L the lower percentile of the confidence interval and Y_H the higher percentile of the confidence interval (by definition $q = H - L$), we must have

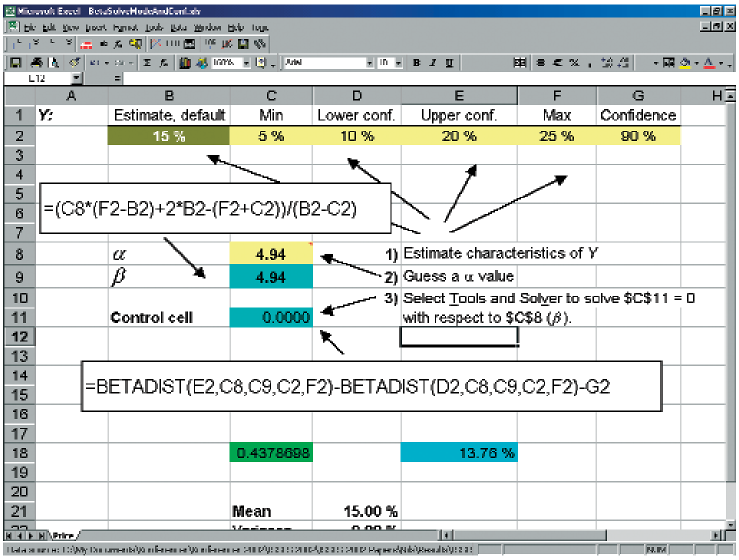
$$\int_{Y_L}^{Y_H} p(y)dy = \int_0^{Y_H} p(y)dy - \int_0^{Y_L} p(y)dy =$$
$$\tilde{\mathrm{B}}(Y_H,\alpha,\beta) - \tilde{\mathrm{B}}(Y_L,\alpha,\beta) = q \tag{A.6}$$

where $\tilde{\mathrm{B}}(Y,\alpha,\beta)$ is the accumulated Beta distribution of Y with parameters α and β. This function is defined as a built-in function in Excel. When the mode is known, we only get one unknown parameter, namely α. We then have:

$$\beta = \frac{\alpha(1-\bar{X}) + 2\bar{X} - 1}{\bar{X}} =$$
$$\frac{\alpha(\bar{Y}-a) + 2\bar{Y} - (b+a)}{\bar{Y}-a} \tag{A.7}$$

α can found by using Solver in Excel.

As an example, we use as default value 15 % for the Beta-distributed variable. The 5 % and 95 % percentiles are chosen as 10 % and 20 % respectively. The minimum and maximum values are set to 5 % and 25 % respectively. Figure 7 shows an implementation in an Excel spreadsheet.



	A	B	C	D	E	F	G
1	Y:	Estimate, default	Min	Lower conf.	Upper conf.	Max	Confidence
2		15 %	5 %	10 %	20 %	25 %	90 %
8		α	4.94				
9		β	4.94				
11		Control cell	0.0000				
18			0.4378698		13.76 %		
21			Mean	15.00 %			

=(C8*(F2-B2)+2*B2-(F2+C2))/(B2-C2)

1) Estimate characteristics of Y

2) Guess a α value

3) Select Tools and Solver to solve C11 = 0 with respect to C8 (β).

=BETADIST(E2,C8,C9,C2,F2)-BETADIST(D2,C8,C9,C2,F2)-G2

Figure 7 Parameter calculation using Solver and Excel

The Beta distribution can have many shapes depending on the size of the parameters α and β. Figure 8 shows the shapes of the Beta distribution for different combinations of α and β.

The Log Normal distribution:

The Log Normal distribution is often used in modelling random variables that can have non-negative values up to infinity (in principle) as for stock values etc. For a Log Normal distribution, the natural logarithm of the variable is Normal distributed. If the logarithm of the variable of interest, X has a mean and standard deviation of μ_{Log} and σ_{Log} respectively, the probability distribution is defined as:

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma_{\text{Log}} x} \exp\left\{ \frac{-[\ln(x) - \mu_{\text{Log}}]^2}{2\sigma^2_{\text{Log}}} \right\} \quad \text{(A.8)}$$

The mode $\bar{X}$, Mean $E(X)$ and variance σ^2 are found by standard calculus as:

$$\bar{X} = \exp(\mu_{\text{Log}} - \sigma^2_{\text{Log}}) \quad \text{(A.9)}$$

$$E(X) = \exp\left(\mu_{\text{Log}} + \frac{\sigma^2_{\text{Log}}}{2}\right) \quad \text{(A.10)}$$

$$\sigma^2 = \exp\left(2\mu_{\text{Log}} + \sigma^2_{\text{Log}}\right)\left(\exp\left(\sigma^2_{\text{Log}}\right) - 1\right) \quad \text{(A.11)}$$

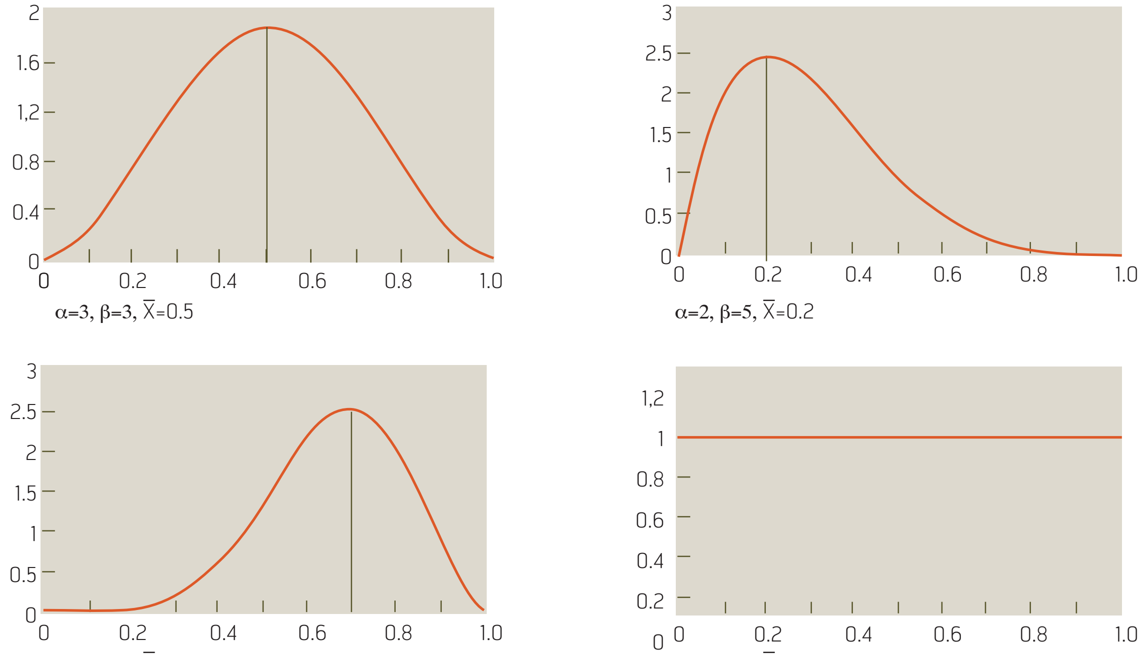
The parameters can be found by using the Solver function, when mode and percentiles, e.g. 5 % and 95 % percentiles are known.

8 Appendix B

In the Monte Carlo simulations approach the input variables are ranked by so-called *rank correlation* or *contribution to variance*.

Rank correlation:

A correlation coefficient measures the strength of the linear relationship between two variables. However, if the two variables do not have the same probability distributions (or at least are very different due to the general non-linear relationships in a model e.g. demand models), *Pearson's correlation* [4] may give misleading results. Therefore the so-called rank cor-



α=3, β=3, $\bar{X}$=0.5

α=2, β=5, $\bar{X}$=0.2

α=6, β=3, $\bar{X}$=0.71

α=1, β=1, $\bar{X}$=undefined

Figure 8 The Beta distribution for various combinations of α and β relation or *Spearman rank correlation coefficient* [5] is used. This is the general measure used in most Excel-based commercial software tools. To calculate the rank correlation between two data sample vectors $\bar{A}$ and $\bar{B}$, the data is ranked in order of size using the numbers 1, …, *n*. Rank-correlation is in any case useful when data is not presented in precise samples, which is the case when the number of simulation trials is moderate or small and hypercube sampling (which is more time consuming than standard Monte Carlo sampling!) is not applied.

The rank correlation coefficient is calculated from the following formula:

$$r = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{B.1}$$

where d_i is the difference between ranks of i^{th} sample of $\bar{A}$ and $\bar{B}$ and *n* is the dimension of the arrays. The data can for example be the ranks in two different competitions among five competitors.

Example

$\bar{A} = [5\ 2\ 4\ 1\ 3]$ and $\bar{B} = [3\ 1\ 5\ 2\ 4]$.

We immediately find

$\bar{d} = [2\ 1\ 1\ 1\ 1]$ and $\bar{d}^2 = [4\ 1\ 1\ 1\ 1]$.

$$\sum_{i=1}^{n=5} d_i^2 = 4+1+1+1+1 = 8;\ n^2 = 25$$

We therefore have

$$r_{\text{Rank}} = 1 - \frac{6\times 8}{5\times(25-1)} = 1 - \frac{2}{5} = 0.6.$$

Contribution to total variance:

Crystal Ball® calculates the contribution to variance for variable *i* as

$$C_{Var,i} = \frac{r_i^2}{\sum_{j=1}^{n} r_j^2} \tag{B.2}$$

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For a presentation of Kjell Stordahl please turn to page 2.

COMPETITION IN THE LOCAL LOOP:
HOW TO MINIMIZE THE MARKET RISKS

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Abstract

Different ADSL2+/VDSL roll out scenarios are examined. Take rate for the competing operators is modelled depending on theirs entrance in various exchange areas. Net present value and internal rate of return have been calculated by use of an advanced techno-economic tool. Based on analysis of the different scenarios, guidelines for roll out ADSL2+/VDSL strategies is developed.

1 Introduction

During the last years a significant broadband demand has been generated in Western Europe. Forecasts show that the expected broadband penetration in the residential market will be about 20% in year 2005 [2,5,6]. The most relevant broadband technologies are: DSL, HFC, FTTH, FWA, WLAN, multiple ISDN lines, DTT and also satellite solutions to cover the rest market. The European Commission has recommended a market driven and technology neutral broadband evolution. Only Sweden, Canada and South Korea have used another strategy by supporting part of the broadband deployment with Governmental investments.

The incumbent operators face competition from the LLU operators, the cable operators and to some extent operators using fixed wireless access and fibre to the home solutions [9,13] In the rest market with sparsely dense population the satellite operators challenge the incumbent operator [1,4,10]. The question is what type of broadband strategy should the incumbent apply for not loosing too large market share.

The incumbent operators have started to roll out ADSL. The second step is to use enhanced technologies like ADSL2+ and VDSL with the potential of a much broader spectrum of services.

2 Broadband technology forecasts

Broadband access forecasts for the residential European market have been developed by the European projects AC364/TERA and IST 25172/TONIC. The forecasts are made by using diffusion models for the total broadband penetration and separate the penetration for each technology prediction based on market share predictions [2,5,6,8,14,15]. New updated forecasts have now been developed. The forecasts are shown in figure 2.1. The forecasts are separated in ADSL, VDSL/ADSL2+, HFC and other broadband technologies.

The CaTV coverage is very different in Western Europe. Some countries, like Netherlands and Belgium, have a nearly 100% coverage, while other countries have a more limited coverage. Because of Direct To the Home (DTH) satellites, the CaTV networks are not expanded. However, the CaTV operators are upgrading their networks to HFC. The study presented in this paper analyses areas where there is no competition from HFC.

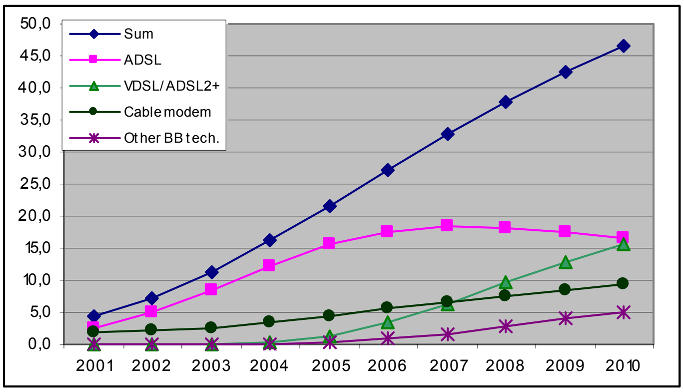

Figure 2.1 Broadband penetration forecasts (%) for the West European market

The penetration is a function of the deployment and the adoption rate. The adoption rate is the genuine demand for broadband. However, the demand cannot be effectuated if the broadband infrastructure is not deployed. Hence, the adoption rate will always be higher than the penetration if coverage is less than 100%. The penetration for a country is estimated by multiplying the mean adoption rate with the coverage.

3 High capacity broadband: ADSL2+ and VDSL

So far the incumbents have offered ADSL in the residential market and ADSL/SHDSL in the business market. The next step is to extend their broadband offer by ADSL2+/VDSL. Telenor have studied VDSL extensively the last 3 years by a large VDSL pilot with 700 subscribers. The technology offers two parallel interactive TV channels and traditional Internet surfing (ADSL) at the same time with 15 Mbit/s capacity up to 1,5 km from the DSLAM. ADSL2+ is predicted to cover distances up to 2 km from the DSLAM with 10 Mbit/s capacity.

A set of different elements is important for ADSL, ADSL2+ or VDSL roll out in various access areas. Important elements are: Size of the access area (number of customers), broadband penetration forecasts, distribution of the copper lines, standardisation of broadband network elements, especially access cards and multi DSLAM, network component prices and functionality, broadband capacity and length capability for ADSL2+ and VDSL and broadband applications offered.

4 Strategic positioning

The challenge for the incumbent operator is to roll out ADSL2+ and VDSL at the right time. The timing for rollout depends on what the LLU operators and other operators using other broadband technology are doing in the same access area.

The broadband operators wait for standardisation of the DSL technology and mass production of new network components to get cheaper prices and lower investments and lower operational costs. On the other hand, the operators are afraid for loosing significant market share. In Sweden Bredbåndbolaget and Bostrøm have announced that they plan to offer VDSL based on hiring the copper lines (LLU) from TeliaSonera. The operators will introduce VDSL in the largest exchanges in the three largest cities in Sweden. The operators plan to use a cherry picking strategy by offering the service to customers, which are situated close to the exchange according to the maximum VDSL coverage without doing any infrastructure investments. It is of cause a good strategic move to start with largest exchanges where the investment per customer is small. In addition the operator reduces the other operators market possibilities significantly in the area.

5 Adoption rate forecasts

In this paper a generic model is used to quantify the market loss for the incumbent by entering the area later than a competitor. The adoption rate is the genuine demand for broadband in an area. The adoption rate will be effectuated if a broadband infrastructure is deployed in the area. The adoption rate for ADSL2+/VDSL has been estimated based on the penetration forecasts given in figure 2.1 adjusting for deployment coverage and assumption of no HFC penetration in the areas considered.

Figure 5.1 shows the adoption rate for the incumbent as a function of delayed introduction of ADSL2+/VDSL in an area.

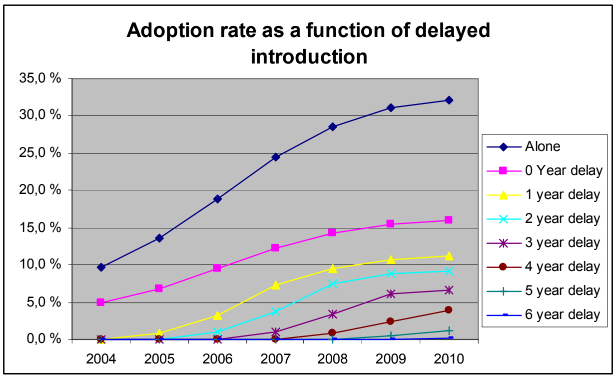

Figure 5.1 ADSL2+/VDSL adoption rate forecasts as a function of delayed introduction

The upper curve shows the adoption rate evolution if only one operator is offering the broadband services in the area. The next curve shows the adoption rate evolution if both the incumbent and another operator enter the area together at the same time. The other curves show the adoption rate evolution based on delayed introductions.

The generic model for reduced adoption rate as a function of delayed introduction assumes that the first operator takes the initial market, while the new operator the first year takes 20% of the market growth, the second year 35% of the market growth and from the third year 50% of the market growth.

6 Market segmentation

The market is segmented in 5 main groups according to the exchange size where the size is defined as number of households with a twisted pair connection to the exchange. Table 6.1 defines the market segments called area 1, area 2, ---, area 5.

Table 6.1 Market segments according to exchange size and volume of households in the segments

Market segment	Exchange size N	Per cent households
Area 1	15.000 < N	10%
Area 2	10.000 < N =< 15.000	15%
Area 3	5.000 < N =< 10.000	20%
Area 4	2.000 < N =< 5.000	20%
Area 5	N =< 2.000	35%

It is assumed that households in dens areas have a higher broadband penetration and also generate higher Average Revenue Per User (ARPU). The relative weights regarding both penetration and ARPU are 1,2 for area 1, 1,1 for area 2, 1,0 for area 3, 0,95 for area 4 and 0,90 for area 5. The most attractive market segment for ADSL2+/VDSL roll out is area 1, followed by area 2 --- etc, because of higher penetration, higher ARPU and lower investment cost per customer.

7 Deployment scenarios

Six different deployment evolutions called scenario 1, --- , scenario 6, are analysed. It is assumed for all scenarios that the ADSL2+/VDSL roll out ends with 60% coverage in year 2010. In addition the investments are based on a cherry picking strategy only offering ADSL2+/VDSL to customers with maximum 2 km copper lines. In this study VDSL is offered to customers with copper lines up to 1,5 km, while ADSL2+ is offered to customers with copper line in the range 1,5 –2 km. The cherry picking strategy is based on no additional infrastructure investments.

The tables show for each year the deployment volume proportion (in percent) of the total number of households both for the incumbent and for other operators. The tables indicate with **bold percentages** that the operator is the first one in the given exchange area, and with **non bold percentages** if the operator is the second one. The deployment strategy for the operators for each scenario is to be the first operator in an exchange area starting with the largest exchanges possible. The operators are not allowed to cover Area X+1-1as a second operator before all the Area X is covered by operator number one.

Scenarios 1-3 show competition situations where the incumbent and the other operators take 50% of the market. Scenario 1 represents a strategy where there is no overlap, i.e. there is non-second operator in the areas. In scenarios 2 and 3 there are respectively 50% and 75% overlap in the exchange areas. Scenario 4 and 5 show situations when the incumbent is respectively two and one year delayed in ADSL2+/VDSL roll out compared with the other operators, while scenario 6 shows an offensive roll out from the incumbent point of view.

Table 7.1 Scenario 1 – Market equality, no overlap

Year	Incumb	Other	Overlap	Incumb	Other	Incumb	Other	Incumb	Other	Incumb	Other
				Area1	Area1	Area2	Area2	Area3	Area3	Area4	Area4
2004	2,5%	2,5%	0%	**2,5%**	**2,5%**						
2005	7,5%	7,5%	0%	**2,5%**	**2,5%**	**2,5%**	**2,5%**				
2006	12,5%	12,5%	0%			**5,0%**	**5,0%**				
2007	17,5%	17,5%	0%					**5,0%**	**5,0%**		
2008	22,5%	22,5%	0%					**5,0%**	**5,0%**		
2009	27,5%	27,5%	0%							**5,0%**	**5,0%**
2010	30,0%	30,0%	0%							**2,5%**	**2,5%**
Sum			0%	5,0%	5,0%	7,5%	7,5%	10,0%	10,0%	7,5%	7,5%

Table 7.2 Scenario 2 - Market equality, 50% overlap

Year	Incumb	Other	Overlap	Incumb	Other	Incumb	Other	Incumb	Other	Incumb	Other
				Area1	Area1	Area2	Area2	Area3	Area3	Area4	Area4
2004	2,5%	2,5%		**2,5%**	**2,5%**						
2005	7,5%	7,5%		**2,5%**	**2,5%**	**2,5%**	**2,5%**				
2006	15,0%	15,0%	5,0%	2,5%	2,5%	**5,0%**	**5,0%**				
2007	22,5%	22,5%	10,0%	2,5%	2,5%			**5,0%**	**5,0%**		
2008	32,5%	32,5%	20,0%			5,0%	5,0%	**5,0%**	**5,0%**		
2009	40,0%	40,0%	25,0%			2,5%	2,5%			**5,0%**	**5,0%**
2010	45,0%	45,0%	30,0%					2,5%	2,5%	**2,5%**	**2,5%**
Sum				10,0%	10,0%	15,0%	15,0%	12,5%	12,5%	7,5%	7,5%

Table 7.3 Scenario 3 - Market equality, 75% overlap

Year	Incumb	Other	Overlap	Incumb	Other	Incumb	Other	Incumb	Other	Incumb	Other
				Area1	Area1	Area2	Area2	Area3	Area3	Area4	Area4
2004	2,5%	2,5%	0,0%	**2,5%**	**2,5%**						
2005	7,5%	7,5%	0,0%	**2,5%**	**2,5%**	**2,5%**	**2,5%**				
2006	17,5%	17,5%	10,0%	5,0%	5,0%	**5,0%**	**5,0%**				
2007	27,5%	27,5%	20,0%			5,0%	5,0%	**5,0%**	**5,0%**		
2008	35,0%	35,0%	25,0%			2,5%	2,5%	**5,0%**	**5,0%**		
2009	45,0%	45,0%	35,0%					5,0%	5,0%	**5,0%**	**5,0%**
2010	52,5%	52,5%	45,0%					5,0%	5,0%	**2,5%**	**2,5%**
Sum				10%	10%	15%	15%	20%	20%	7,5%	7,5%

Table 7.4 Scenario 4 - Incumbent two years delayed

Year	Incumb	Other	Overlap	Incumb	Other	Incumb	Other	Incumb	Other	Incumb	Other
				Area1	Area1	Area2	Area2	Area3	Area3	Area4	Area4
2004	0,0%	5,0%	0,0%	**0,0%**	**5,0%**						
2005	0,0%	15,0%	0,0%	**0,0%**	**5,0%**	**0,0%**	**5,0%**				
2006	10,0%	25,0%	5,0%	5,0%		**5,0%**	**5,0%**		**5,0%**		
2007	22,5%	37,5%	15,0%	5,0%		0,0%	5,0%	**7,5%**	**7,5%**		
2008	35,0%	45,0%	27,5%			5,0%		2,5%	5,0%	**5,0%**	**2,5%**
2009	45,0%	50,0%	37,5%			5,0%		2,5%	2,5%	**2,5%**	**2,5%**
2010	52,5%	52,5%	45,0%					7,5%			**2,5%**
Sum				10,0%	10,0%	15,0%	15,0%	20,0%	20,0%	7,5%	7,5%

Table 7.5 Scenario 5 – Incumbent one year delayed

Year	Incumb	Other	Overlap	Incumb	Other	Incumb	Other	Incumb	Other	Incumb	Other
				Area1	Area1	Area2	Area2	Area3	Area3	Area4	Area4
2004	0,0%	5,0%	0,0%	**0,0%**	**5,0%**						
2005	5,0%	15,0%	0,0%	**2,5%**	**2,5%**	**2,5%**	**7,5%**				
2006	15,0%	25,0%	7,5%	5,0%	2,5%	**2,5%**	**2,5%**	**2,5%**	**5,0%**		
2007	25,0%	35,0%	15,0%	2,5%		2,5%	2,5%	**5,0%**	**7,5%**		
2008	35,0%	42,5%	22,5%			5,0%	2,5%	0,0%	0,0%	**5,0%**	**5,0%**
2009	45,0%	47,5%	32,5%			2,5%		5,0%	2,5%	**2,5%**	**2,5%**
2010	50,0%	50,0%	40,0%					5,0%	2,5%		
Sum				10,0%	10,0%	15,0%	15,0%	17,5%	17,5%	7,5%	7,5%

Table 7.6 Scenario 6 – Incumbent offensive roll out

Year	Incumb	Other	Overlap	Incumb	Other	Incumb	Other	Incumb	Other	Incumb	Other
				Area1	Area1	Area2	Area2	Area3	Area3	Area4	Area4
2004	5,0%	5,0%	0,0%	**5,0%**	**5,0%**						
2005	15,0%	10,0%	0,0%			**10,0%**	**5,0%**				
2006	25,0%	20,0%	10,0%	5,0%	5,0%			**5,0%**	**5,0%**		
2007	35,0%	27,5%	17,5%			5,0%	2,5%	**5,0%**	**5,0%**		
2008	45,0%	32,5%	25,0%				2,5%	5,0%		**5,0%**	**2,5%**
2009	52,5%	37,5%	32,5%				2,5%	5,0%		**2,5%**	**2,5%**
2010	55,0%	40,0%	35,0%				2,5%			**2,5%**	
Sum				10,0%	10,0%	15,0%	15,0%	20,0%	10,0%	10,0%	5,0%

8 Techno-economic assessments

Different deployment strategies are analysed by using a techno-economic tool. The tool developed within the European programs ACTS and IST by the projects AC 226/OPTIMUM and AC364/TERA and IST 25172/Tonic calculates net present value (NPV), payback period and internal rate of return (IRR) for each deployment strategy. The tool contains a cost database with reference costs for network components in 2004 and learning curve predictions of the component cost evolution. The Capital Expenditure (CAPEX) is calculated based on the forecasts, the dimensioning of number of components and the predicted cost evolution. In addition Operational Costs (OPEX) is calculated based on operation and maintenance parameters for the component and the maintenance system. The revenue in the model is found by multiplying the ARPU with the access forecasts. The discount rate is assumed to 10%.

The cherry picking strategy for ADSL2+ and VDSL only offering the access close to the exchange/DSLAM are examined. The techno-economic tool calculates the economic value of the strategies for different roll out times for the incumbent operator based on deployment strategies to the other operators.

9 Results

The business case studied is a country with 60 million inhabitants and 25 million households. The average number of lines per exchange (CO) in area 1, 2, 3, 4, 5 is assumed to be 12.000, 8.000, 2.600, 1.400 and 400 respectively. The ADSL2+/VDSL coverage within 2km is assumed to be 75%. This coverage is different in various European countries because the distribution of the subscriber lines is different.

The main results are shown in figure 9.1 where the net present values are calculated for all scenarios. The figure shows that scenario 1-3 have rather good net present values for the incumbent and of cause also for the other operators (since the incumbent and the other operators use identical roll out strategies). Scenario 1-3 is described in table 7.1-7.3. The scenarios 1-3 have a symmetric rollout between the competitors, ending with 60% ADSL2+/VDSL coverage in year 2010. Both the incumbent and the other operators benefit by being the first operator to enter new exchange areas. The figure shows that the net present value decreases when the incumbent has to use additional spending the cover exchange areas as operator no 2. The analysis shows that the most optimal way for the incumbent and the other operators is to share the market without overlap (Scenario 1). Then the return of the investment is maximised. However, there will be competition in a lot of areas and the operators are not allowed to do such agreements. Scenario 2 and 3 show the net present value when the incumbent and the other operators have respectively 30% and 45% overlap in the rollout.

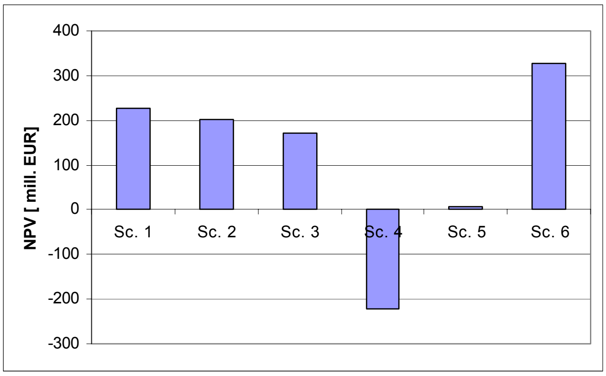

Figure 9.1 Incumbent: Net present values for scenario 1- 6.

Scenario 4 “Incumbent two years delayed” is described in table 7.4. Both the incumbent and the other operators end with 52,5 % coverage in year 2010. However, the incumbent is two years delayed in the rollout compared with the other operators. The consequences are rather dramatic since the other operators enter the largest exchange areas. The incumbent looses the possibility to be operator no 1 in area 1 with the largest potential of subscribers and also significant part of area 2 as the first operator. The move for the incumbent is to concentrate to be the first operator in area 3 and the second operator in area 1 and mainly in area 2. The incumbent has a rather aggressive rollout after the two first years, but it is to late to get good results. The explanation is loss of initial access subscribers by entering the market too late and lower revenue per subscriber by entering areas with less number of lines. The net present value is significant less than zero.

Scenario 5 “Incumbent one year delayed” is described in table 7.5. Now, the incumbent is one year delayed compared with the other operators. The incumbent fails to be the dominating operator on the largest exchage areas, but the handicap is not as significant as in scenario 4. Figure 9.1 shows that the net present value is positive but not more than that!

Scenario 6 “Aggressive incumbent rollout” is described in table 7.6. Now, both the incumbent and the other operators start the rollout in year 2004. The incumbent has the resources and uses an aggressive rollout and ends with a higher coverage than the other operators at the end. Hence, the incumbent also gets a better position by entering the largest exchange areas as fast or faster than the

other operators. The result is a rather large net present value – also compared with scenario 1.
The calculation of internal rate of return for the various scenarios confirms the conclusions based on the assessed net present values. The results are shown in figure 9.2

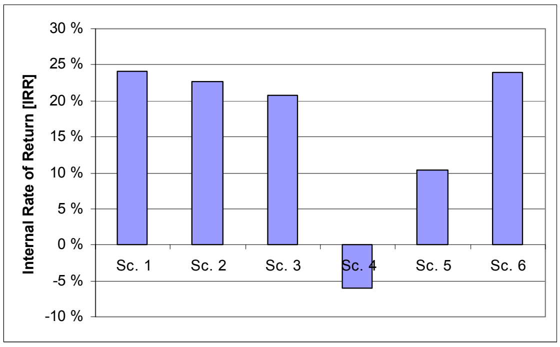

Figure 9.2 Incumbent: Internal rate of return for scenario 1-6

10 Conclusions

The operators have limited resources for ADSL2+/VDSL roll out. The question is how to utilise the resources in an optimal way. Analysis in this paper shows that the first step is to enter the exchange areas by the cherry picking strategy.

To optimise the economic value of the roll out, the operators should start to roll out ADSL2+/VDSL in large areas. However, the roll out depends on being the first operator or the second operator in the area. The analysis show that it is better to enter the second best area as the first operator, than enter the best area as the second operator.

Both the incumbents and the other operators are in fact playing a game to utilise their resources in an optimal way when they are rolling out ADSL2+/VDSL.

This paper also gives some guidelines on how ADSL2+ and VDSL should be rolled out. If the competition is heavy, delay in the roll out causes significant loss.

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Potential new broadband revenue streams

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Abstract

The paper examines new potential revenue streams for the fixed and mobile market. Data representing the evolution of household spending for a sample of European countries have been collected and analysed. Especially, new services have been classified and a framework for forecasting models for potential new broadband revenues has been developed. The paper documents substantial potential revenue possibilities for the mobile and fixed broadband market.

Key Words

New broadband revenues, service classifications, content services, household spending behavior, fixed mobile market share, forecasting models

1 Introduction

The Western European mobile and fixed network markets have grown significantly during the last few years. Several drivers have initiated the very strong growth and new drivers are initiated. Distribution of network based broadband content is in the initial phase. So far the broadband evolution has mainly been driven by facilities like always on, higher speed, fixed price (flat rate) and flexible usage. The degree of payment for broadband content is rather limited for the moment.

The analysis and the results in this paper concentrate mainly on the residential broadband market. The residential market is also the dominant part of the broadband market today regarding both accumulated traffic, number of accesses and revenue.

The main part of the paper analyses the evolution of the household spending for some European countries: France, Finland, Germany, Norway, Spain and UK. The data collection process has been difficult because the needed detailed spending data cannot be extracted from the usual national statistics. The search has shown that in some countries there exists more detailed household spending data than in other countries. Therefore, the results are based on rather incomplete statistics from some countries.

It is natural to analyse the spending budget for households in order to estimate the revenue potential for broadband content both for fixed network broadband services and mobile services. The hypotheses is: Part of the spending categories, which the household now pay for, will in the future be partially substituted by use of services in the mobile and fixed network. The estimated potential will be an upper limit for a long-term evolution. It is important to know that the identified revenue potentials will be shared between different players in the value chain: content creators, content brokers, service providers, network operators and others.

To make this evolution a success, it is important to develop the right business models between the players and also implement tariff procedures and principles for sharing the added broadband value among players.

2 Household budget evolution

2.1 Number of households and the evolution for some selected countries

Table 2.1 gives the number of households in the sample of Western European countries.

Table 2.1 Number of households for a sample of European countries, 1998 - 2003

Number of households in **thousands**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	23990	24277	24567	24852	25140	25427
Finland	2355	2365	2373	2382	2398	2405
Germany	37532	37795	38124	38456	38720	38944
Norway	1809	1846	1876	1905	1937	1969
Spain	12263	12672	13086	13468	13843	14187
UK	25217	25479	25727	25998	26259	26520

The table shows that the number of households increases for all the selected countries. The mean growth from 1998 to 2003 was 6,0%. Spain had the highest growth with 15,7%, while Finland the lowest with 2,1%. The main part of the paper shows revenue potential per household. In section 6 the subscriber broadband access forecasts takes into account the growth in the number of households.

2.2 Price index evolution in some European countries

Usually the statistics contain nominal values, which means what is the amount spentin different years. However, the nominal values do not give the right information for comparing what a household is spending in different years. Hence, the nominal values have to be corrected taking into account the price index values for the same years.

To get comparable spending data across various countries, all data will be adjusted by the price index evolution, setting price index to 100 in year 2000. Table 2.2 shows the adjusted price index evolution for a sample of West European countries, where the index is normalised to 100 in year 2000.

For a better understanding of comparisons, table 2.2 shows the adjusted price indexes with 2000 as reference year.

Table 2.2 Normalised price index evolution in a sample of West European countries, 1998 -2003

Adjusted price index to Reference Year 2000	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	0,98	0,99	1,00	1,02	1,04	1,05
Finland	0,96	0,97	1,00	1,03	1,04	1,05
Germany	0,98	0,99	1,00	1,02	1,03	1,05
Norway	0,94	0,97	1,00	1,02	1,05	1,06
Spain	0,94	0,96	1,00	1,03	1,07	1,10
UK	0,98	0,99	1,00	1,01	1,03	1,04

2.3 Household spending distribution

The household spending is distributed in the following main categories: Food, Alcohol/tobacco, Clothes/shoes, House/dwelling/power, Furniture/household equipment, Health articles/services, Transport, Communications/post, Culture/leisure, Education, Restaurants/hotels, Other services/commodities.

The most important spending categories are:

- Food
- House/dwelling/power
- Transport
- Culture/leisure

Table 2.3 shows the household spending evolution in nominal € values in some European countries

Table 2.3 Household spending evolution in nominal € values, 1998 -2003

Household consumption (at year 2000 prices) in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	30591	31231	31947	32342	32704	32846
Finland	24690	25357	26083	26484	26704	27788
Germany	29800	30600	31200	32100	32100	33250
Norway	29348	33150	34578	35736	36945	37626
Spain	17731	18330	19863	20879	21320	n.a
UK	30873	32475	34011	35452	36851	38151

The values in this figure are not adjusted according to the price index. Therefore, it could be difficult to identify if there has been a real growth in the spending.

All figures in the following part of the paper are adjusted with the price index (100 in year 2000). Table 2.4 shows the household spending evolution in real “year 2000” €.

Table 2.4 Household spending evolution in real “2000” € values, 1998-2003

Household consumption in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	31203	31697	31947	31812	31589	31136
Finland	25819	26211	26083	25813	25627	26440
Germany	30408	31034	31200	31471	31044	31818
Norway	31066	34142	34578	35014	35228	35654
Spain	18964	19074	19863	20370	20000	n.a
UK	31530	32722	34011	35021	35932	36691

2.4 Increased purchase power

Table 2.4 shows the evolution in real year 2000 €. The numbers in the table are mainly increasing, which indicates an increase in the household’s purchasing power. Figure 2.1 shows the percentage increase from 1998 to 2002.

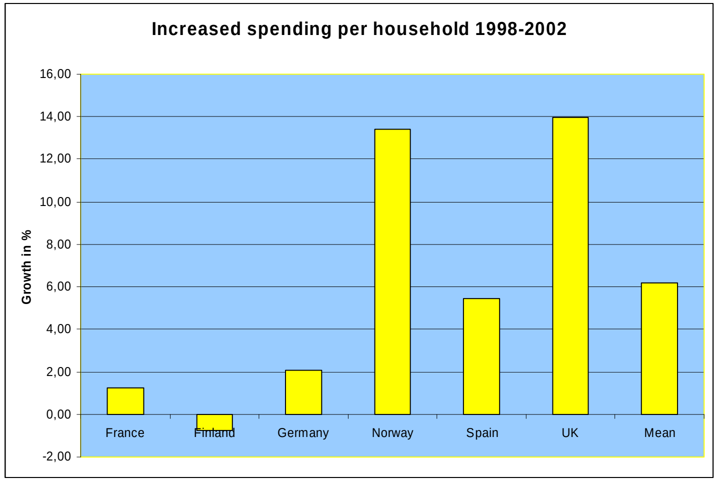

Figure 2.1 ***Increased spending per household 1998-2002 for some European countries***

All countries except Finland have experienced an increase in purchasing power during this period. UK and Norway got a growth of 13-14%, while the other countries had a more moderate growth. The mean growth was about 6,2%. However, taking into account the growth in number of households during that period, the increase in total spending for the selected countries was 14,1%. The values are corrected for inflation.

3. Services and revenues in the telecommunications industry

During the past decade, communication habits of people and the ways of using communications networks have changed tremendously. Multimedia web content is becoming richer every day, and technologies such as e-mail, mobile telephony, and SMS messaging have become an important part of every-day social interaction for the majority of the people in developed countries. Services such as video-on-demand, instant messaging, and different types of VoIP services are currently emerging in the markets.

3.1 Communications and content services

All the aforementioned services can be broadly categorized into two groups, communications and content services. Basically, the difference between the two is whether the people using the services are communicating with other people or servers in the network.

Figure 1 shows a classification of person-to-person communications services. In the figure, the communications services are placed on a matrix based on two different qualities. Firstly, the services are divided into three groups: mailing, messaging, and calling, based on the immediacy of the communication. Secondly, the services are differentiated on the basis of the content that can be conveyed by them, i.e. text, images, voice, or video.

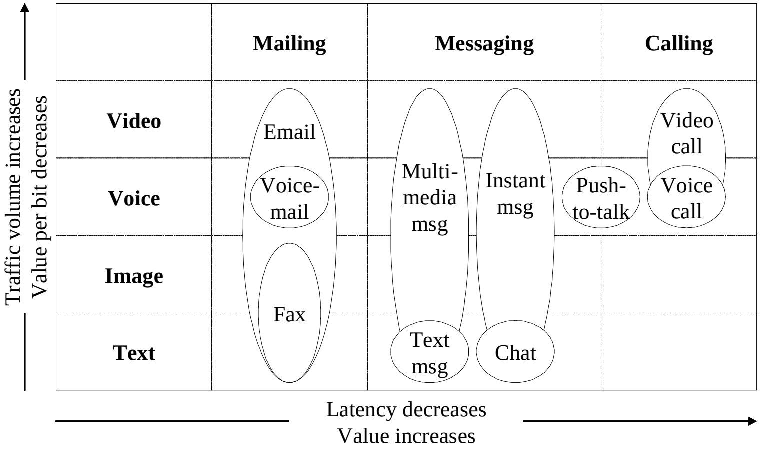

Figure 3.1: Classification of person-to-person communications services

By content services we mean e.g. electronic books, music, movies, and video clips, ordered and delivered over the fixed or mobile networks. In content services we can differentiate between downloading and streaming, having different kind of use models and technical requirements on the network

3.2 Fixed, mobile, and wireless networks and services

The classification introduced in Figure 3.1 does not separate between fixed and mobile services, and all the services in the matrix could be provided over both kinds of networks. Mobility increases the value of communications services by allowing people to maintain their ability to communicate regardless of time or place. Furthermore, it removes the location dependence of communications and makes people more reachable. The increased reach ability increases the value of the network service as the number of on-line users in the network increases.

In addition to fixed and mobile networks, there exist a number of wireless technologies that provide local mobility inside e.g. a home or office building, adding value to the originally fixed service. Table 3.1 shows a categorization of network technologies in these three different domains.

Table 3.1: Examples of technologies in different network domains

	Fixed	Wireless	Mobile
Circuit-switched	PSTN, ISDN	DECT Bluetooth	GSM UMTS CS
Packet-switched	ADSL Cable	WLAN Bluetooth	GPRS/EDGE UMTS PS

Fixed line operators are in a good situation regarding the wireless domain, as the networks are usually deployed as an extension to the fixed (broadband) service. Mobile operators, on the other hand, are more likely to see networks such as WLANs more as a competitor to their current services.

WLANs can provide new revenue opportunities for both fixed and mobile operators, and from both communications and content services. Deployed in homes, offices, and public places, the WLANs extend the reach of the fixed broadband networks, and allow the services to be used more flexibly and freely. Mobile handsets with integrated WLAN radios give the users an opportunity to choose between the mobile and fixed broadband networks when using a certain service.

3.2 Revenue split between fixed and mobile services

Statistics about the telecommunications market size and breakdown between different sub-categories can be found in the annual regulatory reports of EU [EU7th, EU10th]. A summary of these statistics is presented in Figure 3.2 and Figure 3.3.

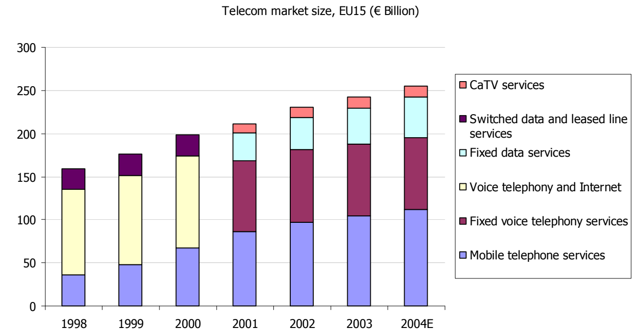

Figure 3.2 Growth of the EU telecommunications markets, 1998-2004 [EU7th, EU10th]

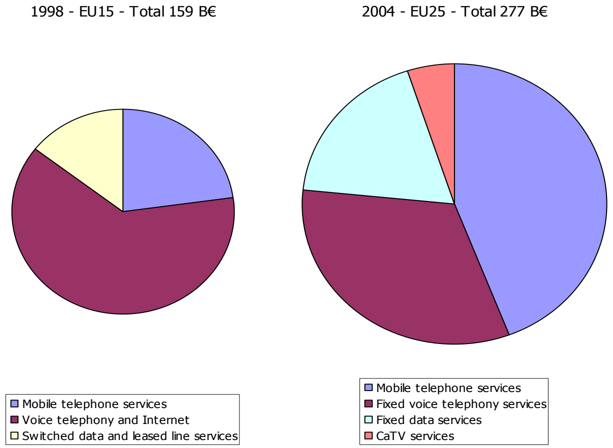

Figure 3.3 Breakdown of the EU telecommunications market, 1998 and 2004 [EU7th, EU10th]

Both figures clearly illustrate the growth of the mobile industry both in absolute and relative terms. The share of the mobile service market has increased from 23% to 44% in just seven years, whereas the fixed telephony market has diminished both in absolute and relative terms. Increasing the economic profitability of the fixed telephone network infrastructure, broadband services are currently experiencing high growth throughout Europe and the world.

4 Potential new revenue for broadband

4.1 Broadband in Europe

Broadband access is booming in Europe. After a few years of strong growth, the market for broadband access further accelerated in 2004. In most countries, broadband access is now a commodity service that is widely available. This resulted in an intensified competition. There are ample choice of services, affordable pricing, higher speeds and growing awareness among the customers. These factors have made broadband access the main alternative for Internet access. Migration from dial-up service took place faster than initially expected and companies are also replacing leased lines with broadband connections.

Although growth over the next years will remain strong, high growth rates for basic access are expected to level off in the long term. By 2009, it is foreseen that 92 million broadband connections will exist. DSL accounts for around 80% of these accesses; the rest is on cable. Beyond the basic Internet access, new services should enrich it, to compensate its dropping prices as well as the decreasing traditional revenue streams.

Most of the growth for broadband is in the residential sector, mainly over a DSL or cable access. Users, initially attracted by entry-level plans are migrating to plans offering higher data rates and greater download allowances. As city consumers are generally the main target for service provider, complete availability of these services in all regions is still not a reality. So, coverage of small cities and rural areas remains to be greatly improved.

Operators hopefully expect revenues from the new offerings enriching the broadband Internet accesses that can be considered as a pillar ensuring competitive business for operators. However, due to the battle of tariffs and competition, revenues will be reasonable. The possibilities to increase them will be very much in relation to the market, business models and ability to deploy the necessary infrastructure after deep analysis of technical possibilities and demand.

In a "virtual society", communications networks are expected to provide resources for education, games, programs and shopping, available in a personalized way. Children find it natural to carry cell phones, iPods, PlayStations. New generations are used to videogames, music downloads, instant messaging and unlimited TV channels, always accessible, any time, any place.

To meet these needs, telecom networks must evolve and telecom service providers have to build infrastructure for voice applications, video and data, delivered with high quality and reliability over broadband networks. New applications as well as general information, movies, music, TV programs, and so on, will stream into the home, workplace and portable devices.

The recently launched value-added services for customers create a rather optimistic situation for operators and service providers expecting revenues to live upon.

4.2 Services

Broadband is no longer just high speed Internet access. It has evolved to become the enabler of a bouquet of IP services. Although Internet access remains the most important application for the short or medium terms, voice and video over broadband can currently be considered as cornerstones of successful broadband strategies.

Operators will provide bundles of services to attract new customers and retain existing clients. However, if the customer experiences poor performances for even one service of the bundle, the entire service package can be rejected. Then, service providers will lose the bundling business opportunity.

Until now, the development of broadband access market has been mainly driven by high speed Internet access. Broadband connections facilitate Internet centric usage types, like surfing, e-mailing, file-sharing, instant messaging. Recently, operators launched additional applications, or enriched existing ones, to increase the appeal of broadband portfolios, expand the potential market and increase revenue streams. Voice and video are still key applications. An increasing number of operators now offer triple play bundles, including voice, video and Internet access.

As a result of intense competition, incumbent operators have included voice over broadband in their portfolio, in addition to the traditional PSTN subscription, to retain their customers. Lower cost is the key selling argument. A number of operators are offering low cost or even free second line services. This alternative

allows increasing the bundle of products and services that together represent value for the customers.
As a revenue opportunity, these services on a second line are rather limited and substantial business cannot be expected out of them. However, with these low cost access, customers can experience the quality voice over broadband can bring. If this quality meets customer expectations, this alternative may easily be adopted.

Video is a major area of activity for broadband operators. Technology allows operators offering quality video services to users over IP connections or on demand. TV over IP is a new market segment for broadband providers. With revenues for fixed voice decreasing, and prices for basic broadband access dropping, new revenue streams are becoming crucial for many players. TV over DSL also contributes to keep customers or even attract some already served by cable operators. These services allow 1 or 2 channels of standard quality to be delivered at the same time, requiring 2 to 4 Mbit/s per channel, depending on the compression method. For competitive TV over IP offerings, multiple TV streams need to be delivered simultaneously, to allow for multiple TVs and a video recorder per household. As HDTV is expected to become popular, bandwidth requirements will increase further.

In addition to voice and video, other applications can provide high value for customers when combined with broadband access, such as a broadband IP VPN, which can be an alternative for a company instead of leased lines. Other applications, like online/multiplayer gaming; video-telephony, e-Commerce, e-Learning, e-Government, e-Health, Domotics, Security services are certainly of interest for business customers and may in some cases interest households.

In the last few years, operators have increased average downstream speed per broadband connections, often with no extra charge for the customer. This increase, enabled by technology advance, pushed by competition and allows bandwidth intensive video content services available for households. The penetration of services like TV over IP has an impact on the average bandwidth per connection.

Some recent services could be used in the home area network, meeting the needs of family members that live far from one another, for them to be able to communicate visually by adding a video feature to the telephone like videophony and the videophonic gatekeeper.
The objective of the videophonic gatekeeper is to connect visitors to a member of a household, wherever he is. It meets the needs of people with mobility problems but also people who are rarely at home during the day. When the visitor arrives, the service displays his/her images on the TV screen, or on the office computer, or soon, on the 3G mobile phone. A connection to the home area network enables communications to be set up with the TV set or with any appropriate set.

4.3 Infrastructure

The broadband needs of residential customers (Internet and audio visual) involve the problem of choosing the access network. For basic Internet services, ADSL is generally sufficient (up to 2Mbit/s and a good coverage), but as many operators want to offer bundles of services, they are looking for ways to increase the bandwidth of their access networks and ways to upgrade their networks to support other DSL technologies.

Many operators in Europe are currently upgrading their networks to ADSL2+, a standard that increases the theoretical downstream speed from 10 Mbit/s for normal ADSL to 25 Mbit/s. More realistic performance levels are 16 Mbit/s to 18 Mbit/s downstream.
A successor of ADSL2+ is VDSL2 for mass market. The high profile, operating at frequencies up to 30 MHz promises 100 Mbit/s of symmetrical speed, is limited to very short loops of up 100 meters. In the low profile, at 8 MHz, the aim is for downstream speeds of 20 Mbit/s to 30 Mbit/s at 750 to1200 meters.

Increasing the bandwidth will allow a much broader range of services to end users. Because of the loop length dependency on DSL technology, the truly high bandwidth TV/Video services will not be available to all customers that can get a DSL service. Therefore, fibre connected access nodes will have to be brought closer to the end user, which will cost a lot of money and time. It seems that this situation will not be completed in a near future.

Cable networks are alternatives to DSL. However, only 1 out of 3 households were able to get a cable broadband access in 2004. This situation is improving, but the reach of cable broadband access will remain inferior to that of DSL. Coverage is also significantly improved. The problems to be solved are more political or financial than technical, but this places cable operators at a disadvantage with regards to economies of scale, in terms of marketing, branding, equipment purchasing and network efficiency.

Fibre metro Ethernet appears to be most suitable for business sites.
Radio-based broadband access technologies for connecting household and business sites can operate in a number of frequencies. Until recently, most broadband fixed wireless access networks were based on proprietary equipment, resulting in high cost and a poor business case for most operators. The WiMax, based on IEEE 802.16 range of standards, may be suitable for equipment interoperability.
Satellite broadband services are mainly marketed in areas where DSL services are not yet available. Power line communications are also a solution, not expensive but with a relatively low performance.

Of course, when planning any access deployment, the solution cost is a fundamental criterion. Depending on the specific deployment model, costs vary due to factors such as a technology maturity and market volume (which will drive product price reductions), solution component efficiency and technology.

Bandwidth demand is driven by the end users and their need for enhanced services. To assess the capacity supply, different technologies can be compared. By optimizing the bandwidth supply to service demand, providers can realize an economical and profitable deployment.

Traffic engineering and bandwidth consumptions are key factors of deployment plans.

4.4 New potential broadband revenue streams

It is natural to analyse the spending budget for households in order to estimate the revenue potential for broadband content both for fixed network broadband services and mobile services. The hypothesis is: Parts of the spending categories, which the household now pays for, will in the future be partially substituted by use of services in the mobile and fixed network. The estimated potential will be an upper limit for a long-term evolution. Telecommunication services are expected to provide support, or even constitute an alternative, to some existing services or activities.

Table 4.1 gives the household consumption on IT equipment. It should be noted that the classification used by COICOP (base of these figures) has not been fully updated and, for instance, IT equipment does not include PCs or other kind of equipment actually used to communicate at the present time.

Table 4.1 Evolution of average household consumption: IT equipment, 1998 - 2003

IT equipment in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	89,81	106,64	121,01	112,96	100,13	105,97
Finland	121,22	121,50	119,68	127,28	n.a	n.a
Germany	146,54	181,67	205,64	199,87	n.a	n.a
Norway	n.a	243,38	297,33	295,50	263,37	246,40
Spain	68,79	69,76	77,00	76,42	60,66	n.a
UK	293,97	291,42	294,77	303,85	271,20	273,44

The table indicates a moderate or negative growth during the last few years. Part of the consumption is necessary for telecommunication usage.

The consumption on telecommunication services is provided in Table 4.2

Table 4.2 Evolution of average household consumption: Telecommunication services, 1998 -2003

Telecommunication services in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	494,88	564,95	610,96	611,26	633,30	646,70
Finland	554,60	676,13	744,21	790,29	804,98	812,22
Germany	544,84	567,01	612,74	718,93	721,18*)	723,44
Norway	524,56	646,18	611,11	678,00	715,38	793,88
Spain	348,53	358,82	373,79	415,25	440,47	n.a
UK	560,41	607,50	669,68	697,01	708,19	735,08

*) Estimated

The table shows a very significant growth in the telecommunication consumption. Figure 4.2 indicates the same.

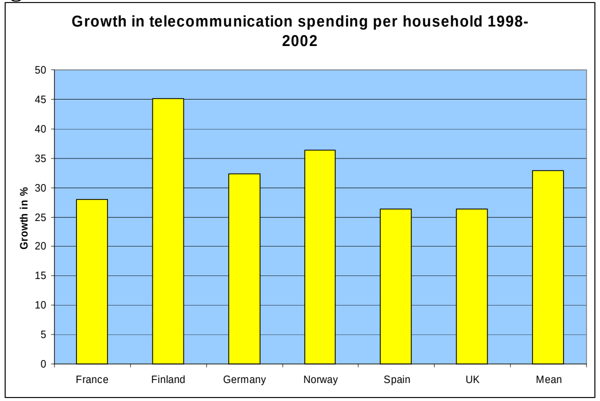

Figure 4.2 Growth in telecommunication spending per household from 1998 to 2002

The figure shows that households in all selected countries had an increase ot more than 25% in telecommunication spending from 1998 to 2002, which mean a yearly increase of more than 6%! The mean increase for households is 32,9% during the period.

The total telecommunication spending for all households in selected countries has increased from 312 mill € to 436 mill € in the period. The total telecommunication spending is adjusted for inflation and takes into account the increased number of households.

In the same way, the following figures give the evolution of average household expenditures on TV, cinema, music, theatre, concerts, gambling, books, newspapers, newsletters and journals, education and learning, and electronic gaming. Parts of these spending categories will most likely on long-term to be substituted by telecommunication services available on broadband accesses.

Table 4.3 Evolution of average household consumption: TV licences and pay TV, 1998 - 2003

TV licences and pay TV in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	171,54	185,73	191,81	193,80	196,34	202,08
Finland	132,32	132,43	141,17	148,97	149,31	147,96
Germany	n.a	266,25	271,64	291,42	311,24	318,06
Norway	176,10	183,88	199,67	212,91	223,79	236,33
Spain	n.a	n.a	n.a	n.a	n.a	n.a
UK	n.a	n.a	n.a	n.a	n.a	n.a

Table 4.4 Evolution of average household consumption: Cinema, theatre, concerts, 1998 -2003

Cinema, theatre, concerts in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France **(Cultural services)**	342,06	356,69	366,34	372,00	375,01	377,27
Finland	102,57	122,38	134,01	142,42	146,11	151,52
Germany	n.a	n.a	n.a	n.a	n.a	n.a
Norway	172,20	179,81	195,25	208,20	218,84	231,10
Spain	121,39	122,16	146,93	152,85	151,12	n.a
UK	625,71	643,29	645,62	671,01	725,10	738,97

Table 4.5 Evolution of average household consumption: Gambling, 1998 -2003

Gambling in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	235,32	240,86	267,48	275,27	284,73	290,42
Finland	496,88	500,00	524,23	511,58	511,17	538,84
Germany	649,17	684,63	707,11	704,37	678,16	675,93
Norway	307,10	284,69	282,22	302,29	308,19	348,74
Spain	157,94	149,98	155,54	173,65	171,46	n.a
UK	417,35	404,05	389,51	385,83	402,63	420,52

Table 4.6 Evolution of average household consumption: Books, 1998 -2003

Books in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	113,36	112,32	114,71	121,66	121,05	118,63
Finland	111,45	111,89	106,62	103,95	100,87	106,42
Germany	175,09	175,76	176,53	173,36	n.a	n.a
Norway	203,73	223,66	230,37	229,59	230,85	242,87
Spain	106,60	97,01	101,65	105,54	101,09	n.a
UK	122,85	133,55	143,27	148,87	155,66	159,59

Table 4.7 Evolution of average household consumption: Newspapers, newsletters, journals, 1998 -2003

Newspapers, newsletters, journals in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	227,96	224,14	218,24	212,20	206,00	199,88
Finland	338,80	351,40	340,08	341,33	329,04	344,59
Germany	336,58	334,09	332,34	314,08	n.a	n.a
Norway	378,98	358,57	357,04	376,68	372,70	366,06
Spain	126,22	111,29	124,91	124,94	118,99	n.a
UK	166,21	168,24	168,42	159,43	154,66	152,49

Table 4.8 Evolution of average household consumption: Education and learning, 1998 -2003

Education and Elearning in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France	179,34	181,33	176,20	174,38	178,34	180,02
Finland	139,43	133,30	125,58	126,05	125,69	126,60
Germany	198,20	202,60	206,96	205,48	211,81	213,04
Norway	106,51	106,81	107,28	115,52	115,37	108,92
Spain	253,33	250,57	244,86	234,80	230,22	n.a
UK	458,87	512,83	537,35	518,39	505,10	501,65

Table 4.9 Evolution of average household consumption: Electronic gaming, 1998 -2003

Gaming in €	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
France (video games, game console)	9,89	11,16	13,60	13,48	16,52	19,91
Finland	n.a	n.a	n.a	n.a	n.a	n.a
Germany (consol/pc/online/mobile)	n.a	36,01	34,05	35,46	39,01	39,07
Norway	37,03	42,85	48,15	55,60	58,94	61,96
Spain	75,25	79,40	87,18	90,72	84,59	n.a
UK (including toys and hoobies)	469,21	513,06	544,33	589,19	669,75	724,66

5 Classification of services

The objectives with classification of broadband services and applications is to make a structure for modelling the evolution of the future broadband ARPU. There are reasons to believe that future ARPU will consist of charges *for installation and usage together with a monthly fee.*

The classification of services and applications can be segmented in three main groups:

- Content services
- Information retrieval and storage
- Person to person and Peer to peer

The segmentation is valid for the residential, while the business market is more differentiated. Home office is a segment in between the residential and the business market – sometimes financed by the companies.

- ***Content services/applications***

Today most of the income streams for content services and applications are not part of the revenue for telecommunications service providers and network operators. However, broadband networks are able to transfer new broadband content applications and capture part of these income streams.

The future content services/applications are:

Purchase of movies and music

- Purchase of movies, VHS, DVD
- Purchase of music, cassettes, CD, DVD

Leasing of movies and music

- Leasing of movies, video on demand
- Leasing of music, music on demand

Cultural services and entertainment

- Video from program library, video on demand
- Events on demand
- TV channels and subscriptions
- On demand: News, sports, adult, life stile programs, health, lifeTV, etc
- Substitutions: Theatre, concerts, opera, cinema, other performances, museums, etc

Lotteries and gambling

- Gambling on automates
- Online gambling
- Online betting
- Video background information
- Video transmission of the gambling event

Books, newspapers, newsletters, journals

- Books (voice)
- Newspapers, dedicated newspapers
- Newsletters
- Journals

E-learning

- Education
- Additional education
- Hobbies

Online games

- Down loading and updating of gaming software
- Online games

- ***Information retrieval (Browsing/surfing)***

Traditional free surfing applications
Surfing on charge (purchase of software, back up services, information)

- ***Information storage***

Network based storage

- Network based storage of photos and films
- Network based storage of other information

- ***Peer to peer and person to person***

Homepage®
E-post with broadband content
Videogram, Greetings cards
Exchange of personal content
Exchange of downloaded content

- Exchange of Shareware software (various small and large programs)
- Film clubs
- Music clubs
- Exchange of general info

Video/WEB telephony
Video conference/ Multimedia conference

- ***Surveillance at home***

Surveillance services for elderly/sick

- ***Home services***

Management home services
Smart home services

- ***Home office***

Different multimedia broadband applications
Data/file exchange
Video/film exchange
Video telephony
Videoconferences

6 Models for forecasting new revenue streams

It is expected that many of the services presented in section 5 will have a significant growth in the future. However, the users will only increase their telecommunication spending based on the increased value created by the new services. The households will still be rational in their telecommunication usage.

6.1 Forecasts for broadband accesses

A key factor for increased spending is access to both the mobile and fixed broadband network. Especially, the growth in demand for fixed broadband accesses will have a significant impact on household spending on new services.

The CELTIC Eureka project ECOSYS and the IST project Tonic have developed broadband access forecasts for fixed network [2, 3, 4, 5, 7, 8, 9, 10, 11, 12]. These forecasts are important for the revenue modelling. Households without access are not able to utilise the new broadband services. Figure 6.1 shows the broadband penetration forecasts for West European countries.

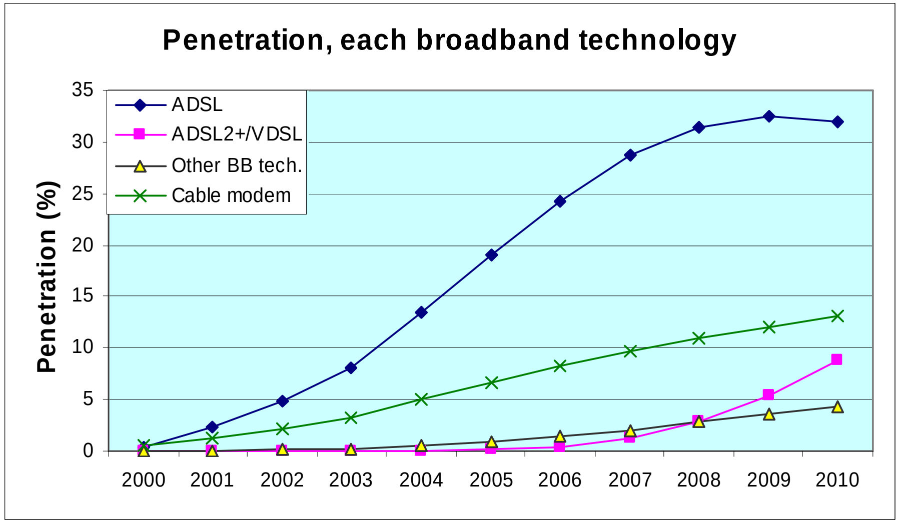

Figure 6.1 Penetration forecasts for broadband technologies in Western Europe

In principle the broadband access forecasts should be separated based on what type of applications is used. Let $f_B(t)$ be the broadband access forecasts for the households. The forecasts reflect total broadband accesses. Some applications like video on demand, streaming, TV, etc need high capacity. Then ADSL2+/VDSL and part of the cable modem forecasts and other broadband technology forecasts constitutes the relevant forecasts.

Figure 6.2 shows the mobile handset/technology penetration forecast for Western Europe. The forecasts are based on forecast models developed in the projects Tonic and Ecosys [1, 6, 7, 11, 12].

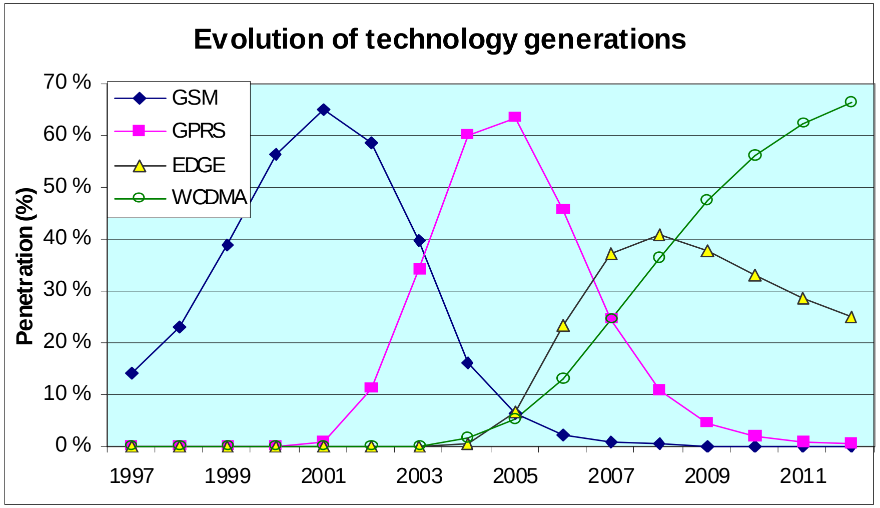

Figure 6.2 Handset (technology) penetration forecasts for GSM, GPRS, EDGE and WDCMA for Western Europe

Persons who have EDGE and UMTS handsets will have possibility to access new applications. For some mobile applications GPRS can also be an alternative. Let $f_M(t)$ be the forecasts.

6.2 Evaluations of the spending potentials in the residential market

To utilise the possibilities, the households need to have access to either a broadband connection or new mobile networks or both.

Section 4 showed the household spending on the following main categories:

- Purchase of films, videos, music
- Leasing of films, videos, music

- TV licences and pay TV
- Cinema, theatre, concerts
- Gambling
- Books
- Newspapers, newsletters and journals
- Education and E-learning
- Electronic gaming

Let the spending categories be numbered $j = 1,2$ - - - N.
Let the annual household spending in each category be: $S_j(t)$ at time t.

Suppose that $\Delta_j(t)$ is the fraction of spending category $S_j(t)$ at time t, which will be substituted by use of telecommunications per household. One way to describe the evolution is to assume these fractions on long-term. Let the long-term fraction for spending category j be $\Delta_j(\infty)$.

Hence, one possibility is make assumptions of the long-term fraction and then make forecasts, which reach that level in the long run.

Questions to be answered are:

- How much of film, video, music market (both purchase and leasing) will be transferred by telecommunications in the long run?
- How much of the book, newspaper, newsletter, journal market will be transferred by telecommunication in the long run?
- How much of the Education market will be substituted by telecommunications
- etc

Another aspect of substitution effects for the telecommunications is also creation of additional values. It is seen from the significant increase in the household spending on telecommunication in the last few years – especially caused by extended mobile usage.

Another important factor for future revenues in this sector is the evolution and growth in the household spending in general. We see the spending over time change between categories, but for some of the countries, there is also a significant growth in the total spending. Part of this growth may be used on telecommunications.

6.3 Potential revenue content forecasts for the residential market

We assume that the additional revenues from the content categories are divided in a broadband part and a mobile part.

Let
- $\Delta_{jB}(t)$ is the fraction of spending category $S_j(t)$ at time t which could be substituted by broadband, $j = 1,2$ - - - N
- $\Delta_{jM}(t)$ is the fraction of spending category $S_j(t)$ at time t which could be substituted by new mobile systems, $j = 1,2$ - - - N

The long-term estimates for broadband and mobile content potential revenue respectively are:

$$– \Delta_{jB}(\infty)\, S_j(\infty),\ j = 1,2 \text{ - - - } N \qquad (6.1)$$

$$– \Delta_{jM}(\infty)\, S_j(\infty),\ j = 1,2 \text{ - - - } N \qquad (6.2)$$

Since applications are rather new, it is natural to model the evolution with a diffusion model. Here, logistic models are used.

Let the Logistic model for broadband and mobile spending categories be respectively $f_{jB}(t)$ and $f_{jM}(t)$. Then the forecasts are expressed by:

$$Y_{jB}(t) = \Delta_{jB}(\infty)\, S_j(\infty) \,/\, (1 + \exp(\alpha_{jB} + \beta_{jB}\, t))^{\gamma_{jB}} \qquad (6.3)$$

$$Y_{jM}(t) = \Delta_{jM}(\infty)\, S_j(\infty) \,/\, (1 + \exp(\alpha_{jM} + \beta_{jM}\, t))^{\gamma_{jM}} \qquad (6.4)$$

where $Y_{jB}(t)$ and $Y_{jM}(t)$ are demand forecasts at time t, $\Delta_{jB}(\infty)\, S_j(\infty)$ and $\Delta_{jM}(\infty)\, S_j(\infty)$ are the saturation levels and α_{jB}, α_{jM}, β_{jB}, β_{jM}, γ_{jB}, γ_{jM} are growth parameters.

The next part of the forecasting model includes:

- $f_B(t)$ broadband access forecasts (households)
- $f_M(t)$ mobile access forecasts (persons)
-

To be able to use the applications there are needs for broadband access and an advanced mobile handset. The forecasts are found in section 6.1. As mentioned the forecasts could be differentiated depending of spending category/applications.

Hence, potential revenue content forecasting model R(t), consisting on a fixed network part and a mobile part is given by:

$$R(t) = [f_B(t)\ \Sigma_{j=1,\ --n}\ Y_{jB}(t)] + [f_M(t)\ \Sigma_{j=1,\ --n}\ Y_{jM}(t)] \qquad (6.5)$$

More precise forecasts are found when the access/handset forecasts are differentiated based on spending category/applications ($f_{jB}(t)$, $f_{jM}(t)$, j = 1,2 - - - N). Then, we get the following forecasting model:

$$R^*(t) = [\ \Sigma_{j=1,\ --n}\ (f_{jB}(t)\ \ Y_{jB}(t))] + [\ \Sigma_{j=1,\ --n}\ (f_{jM}(t)\ \ Y_{jM}(t))] \qquad (6.6)$$

6.4 Tariff considerations

A lot of work has been done on content charging. Different alternatives are: “pay per view”, pay for subscription, pay for usage, combinations etc.

So far only potential revenue forecasts have been developed. Suppose that the charging alternative pay per view is used. If the pay per view for category j is $P_{jB}(t)$ and $P_{jM}(t)$ for broadband and mobile respectively, then the annual usage in year t, $U_{jB}(t)$ are $U_{jM}(t)$ are given by:

$$U_{jB}(t) = f_{jB}(t)\ Y_{jB}(t)/\ P_{jB}(t) \qquad (6.7)$$

$$U_{jM}(t) = f_{jM}(t)\ Y_{jM}(t)/\ P_{jM}(t) \qquad (6.8)$$

6.5 Revenue distribution among players

The content revenue will be shared among different players. The primary source is of course the content owner (C). There may also be content brokers (B) who negotiate with network operators (O) and content owners. In addition there will be service providers (SP) selling the product in the market.

The revenue sharing differentiates between household spending categories and applications and depends on how much resources are used by the players. Let the percentage proportion between the players, i = 1,2, -- m, for each spending category for respectively broadband and mobile be:

- $q_{ijB}(t)$
- $q_{ijM}(t)$

then, it is possible to forecast the revenue for the different players.

The revenue for the broadband and mobile player no i respectively is given by:

$$R_{iB}^*(t) = \ \Sigma_{j=1,\ --n}\ (f_{jB}(t)\ Y_{jB}(t)\ q_{ijB}(t)) \qquad (6.9)$$

$$R_{iM}^*(t) = \ \Sigma_{j=1,\ --n}\ (f_{jM}(t)\ Y_{jM}(t)\ q_{ijM}(t)) \qquad (6.10)$$

6.6 Content revenue and additional revenue

It is important to separate between services for content categories and services, which is not based on ownership to content.

Services based on information exchange and surfing may in the long run give significant revenue possibilities. Examples of such applications are: Surfing, purchasing, electronic commerce, auctions, electronic post with broadband content, videograms, greeting cards, exchange of personal content, exchange of downloaded content (shareware software, film clubs, -), video/WEB telephony, video conferences.

7 Summary and conclusions

The paper documents the evolution of household spending for a sample of West European countries. Specific spending categories in the long run are substitutes to telecommunications are analysed. The results show that the number of households increases significantly over time in Western Europe and the spending per household increases during the period 1998-2003 taking into account the inflation in that period. The conclusion is increased purchasing power for households**.**

The analyses show that the telecommunication spending per household has increased with about 33% during the period 1998-2002 for the selected country sample. All countries examined had an increase of 25% or more. The results indicate that introduction of new and enhanced services for both mobile and the fixed network will continue to rise the telecommunication spending.

Important areas for new telecommunication services are the content services. The analysis show that household are spending much money on leasing and buying videos and music, Pay TV and TV licenses, consumption on cinema, theatre, concerts, gambling, books, journals, newsletters, newspapers, education and learning, and electronic gaming. The tables in the paper show the amount of money, which is used on the different spending categories. Parts of this spending will in long term be substituted to telecommunications.

In addition the paper shows how new content services may be classified and indicate how the spending during the last years are dived between mobile and fixed network services.

New mobile and broadband access forecasts, which are an important part of the new revenue forecasts, are presented. In addition the paper introduce a framework for forecasting new revenue streams.

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