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Factors Influencing the Pricing Structure of Dark Fibers for Long Haul Communication

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Title:	Factors influencing the pricing structure of dark fibers for long haul communication.
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Problem description:

The growth of Internet communication and large international data centers have changed the demand of dark fiber. The Internet giants are laying their own cables to support the need of their own data centers and the amount of data they need to move. The benefit of getting one or more of the giants to your country is huge, so how come Norway are not on the list? Norway should be an excellent place to build data centers given its climate and the availability on cheap electricity, but the giants look to Sweden and Denmark instead.

Today most of the Internet traffic in Norway runs through Sweden, and though this works it brings challenges when trying to create a good market for Internet communication in Norway. This has evolved to an increased interest for international dark fiber cables from Norway.

The Internet giants are mainly interested in buying dark fiber pairs, whereas in and out of Norway wavelength products seems to be the focused selling point.
It is believed that this needs to be changed, if Norway wants to be a part of the big market for data centers. Based on this and the general need for increased redundancy, the Norwegian Government has decided to support more International fiber systems.

The next challenge will be to price the dark fiber correctly. The current market has stuck to a cost and meter-based pricing. However, there are multiple other factors affecting the price development.

In this project the focus is on international fiber cables. The main objective is to investigate the price drivers of dark fiber in order to propose a new pricing strategy not solely focusing on cable length and cost pricing for dark fiber.

The main tasks include:

- Briefly overview of the current business model for international dark fiber cables.
- Discuss the need for dark fiber versus wavelength products and present the technologies for long haul fiber transmission.
- Gather information by contacting and interviewing companies involved with dark fiber - both operators and customers, nationally and internationally.
- Create a model demonstrating the factors that affects the pricing of dark fiber.

Responsible professor:	Norvald Stol
Supervisor:	Eirik Larsen Følstad

Abstract

The society today are becoming more and more connected. All new devices are connected to the Internet, transmitting data to the cloud making it possible for users to remotely control anything from anywhere, and virtually bring your data with you all around. The cloud are data storage facilities spread around the world to offer users the best experiences with different devices. Between the facilities data are transferred continuously to maintain redundancy, and to let users access the same data from any location instantly.

This has led to a large expansion of data storage facilities, which needs to be connected to one another. These connections have other requirements than regular users. They want the best of the best to satisfy their customers, which has led to an expansion in cross border fiber cables. In countries where most of the border is to the sea, such as Norway, these cables need to be deployed as a subsea cable.

Developers have multiple factors to consider when planning to deploy a subsea cable. Most factors will be cost drivers in the fiber project but will enhance quality and affect important factors that should be focused when pricing dark fiber. Understanding these factors and their implications are therefore important.

These cables are the physical line containing optical fiber strands ready to transport light signals.

Developers have multiple business opportunities when they are selling access to the fiber. First, they need to figure out if they want to maintain equipment and put light on the fiber or sell the dark fiber strands.

This master thesis explains the fiber system, deployment process and potential cost factors. It studies the market of cross border dark fiber, the driving forces, and discuss pricing factors. This research presents potential customer groups, with varying appreciation of these factors.

The most important price factor discussed is latency, uptime and fiber quality. The investing parameters for obtaining this is also discussed and presented.

Sammendrag

Dagens samfunn blir mer og mer tilkoblet. Alle nye enheter er koblet til internettet, og sender data til Skyen for å gjøre det mulig for brukeren å fjernstyre dem fra hvor som helst. Skyen er en samling datalagrings fasiliteter spredt ut over hele verden for å tilby brukere den beste opplevelsen med de forskjellige enhetene. Mellom disse fasilitetene blir data kontinuerlig overført for å ha redundans, og for at brukeren kan ha tilgang til den samme dataen fra hvilken som helst lokasjon umiddelbart.

Dette har ført til stor utvidelse av datalagrings fasiliteter som trenger å være koblet sammen. Disse forbindelsene har andre krav enn en vanlig bruker har. De vil ha det beste av det beste for å tilfredsstille kundene sine, som har gitt en økning i utlandsfiber. I land som i hovedsak grenser til havet, som Norge, må disse fiberne legges som sjøkabler.

Utbyggere har flere faktorer som må vurderes når en sjøkabel skal planlegges. De fleste faktorene vil øke kostnadene, men vil øke kvaliteten og påvirke viktige faktorer som burde vurderes når mørk fiber skal prises. Det er derfor viktig å forstå disse faktorene og deres betydning.

Disse kablene er den fysiske linjen som inneholder optiske fiber klare til å transportere lys.

Utbyggere har flere forretnings muligheter når de skal selge tilgang til fiberen. Først må de finne ut om de vil drifte utstyr for å lyssette fiberen eller selge mørk fiber.

Denne masteroppgaven forklarer fiberssystemet, utbyggings prosessen og potensielle kostnads faktorer. Den undersøker utlandsfiber markedet, drivkraften og diskuterer prisfaktorer. Studien presenterer potensielle kundegrupper som verdsetter disse faktorene forskjellig.

De viktigste prisfaktorene som blir diskutert er forsinkelse, oppetid og kvalitet.

Preface

This master thesis is an original and independent work by Maja Reimer. The thesis is the final contribution to the Master's degree in Communication Technology at the Norwegian University of Science and Technology (NTNU).

The primary goal of this master thesis is to locate and demonstrate the factors that affect the pricing of dark fiber. In addition, an objective of this master thesis is to give a brief overview of the current business model for international dark fiber cables and discuss the need for dark fiber versus wavelength products and present the technologies for long haul fiber transmission

I want to thank my responsible professor Norvald Stol and my supervisor Eirik Larsen Følstad for their guidance, support and feedback during the process of this master thesis.

Also, I would like to thank the kind people who gladly let me interview them. Chief Technology Officer (CTO) Arnt Erling Skavdal and managing director Cato Lammenes From Tampnet, senior advisor (Seniorrådgiver) Arne Litlere from the Norwegian Communications Authority (NKOM), Chief Executive Officer (CEO) Tor Kristian Gyland from Green Mountain, CTO Dag Aanensen from NO-UK and CTO Helge Gallefoss from Skagenfiber.

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aaS	As A Service
CAPEX	Capital Expenditure
CD	Chromatic Dispersion
CDN	Content Distribution Network
CEO	Chief Executive Officer
CTO	Chief Technology Officer
DDOS	Distributed Denial-Of-Service
DFA	Doped Fiber Amplifier
DTS	Desk Top Study
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
EOS	End Of Service
FCAPS	Fault Configuration Accounting Performance Security
FEC	Forward Error Correction
FRA	National Defense Radio Establishment
IoT	Internet of Things
IP	Internet Protocol
IRU	Indefeasible Right of Use
ISP	Internet Service Provider
ITEM	Department of Telematics
ITU	International Telecommunication Union
MTBF	Mean Time Between Failure
NATO	North Atlantic Treaty Organization
NIX	Norwegian Internet eXchange
NKOM	Nasjonal Communication Authority
NREN	National Research and Education Network
NTNU	Norwegian University for Science and Technology
OCSV	Offshore Construction Vessel
OPEX	Operating Expenses

OSI	Open Systems Interconnection
OTT	Over The Top
PDL	Polarization-Dependent Loss
PLV	Pipelay Vessel
PMD	Polarization Mode Dispersion
RFS	Ready For Service
ROC	Repeated Optical Cable
RTT	Round Trip Time
SLA	Service Level Agreement
SLTE	Special Line Termination Equipment
SNR	Signal-to-Noise Ratio
SOP	State Of Polarization
TCO	Total Cost of Ownership
TIC	Telia International Carrier
TTR	Time To Repair
UK	United Kingdom
ULL	Ultra Low Loss
WDM	Wavelength Division Multiplexing

1 Introduction

In this chapter the motivation and objectives for this master thesis is presented as well as the scope and methodology. This chapter also includes a brief overview of related work.

1.1 Motivation

The development of the connected society, Internet of Things (IoT), leads to an enormous growth of Internet communication and large international data centers, which has changed the demand and market for dark fiber. The Internet giants are laying their own cables to support the need of their own data centers and the amount of data they need to move. The benefit of getting one or more of the giants to your country is huge.

Today most of the Norwegian Internet data traffic runs through Sweden. This makes Norway very dependent on Sweden for international communication. Though this works fine, there are some concerns about this. Sweden has this FRA[1]-law [1] [2], which makes the Swedish government able to monitor all Internet traffic that goes through Sweden, thus they can potentially monitor all the Norwegian transit traffic. This poses a national security risk. The Norwegian government has decided that Norway needs more cross border dark fiber and will support developers that plan on building alternative cross border dark fiber cables [3] [4].

To be able to enter the market, it is important to develop a sustainable business model that contains correct pricing of the cross border dark fiber. The current market is stuck to a cost and meter-based pricing. However, there are multiple other factors affecting the price.

To demonstrate this with a case the, Figure 1 shows four alternative routes from Oslo to Googles planed data center in Denmark. The routes alter from a length of 586 km to 1 399 km. This example is using a market price of 1 Euro per meter per year (Eur/m/yr) [5]. The Round Trip Time (RTT) are calculated by multiplying the length of the route by the speed of light / fiber refractive index = 203,94 m/μ. This shows that the latency, RTT, on the routes varies from 5.75 ms to 13.72 ms. The estimated price also varies from 0.5 mill euro/yr per pair to 1.4 mill euro/yr per pair. As the figure shows the longest route has the highest price and also the highest latency, compared to the shortest route with the lowest price and the lowest latency.

Based on these calculations the route with the highest latency is also the most expensive. In truth, customers will not pay more for a worse product. Thus the pricing does not represent the appreciated customer value, which is a huge dilemma.

[1] National Defense Radio Establishment (FRA) is a Swedish government agency with two main tasks, signals intelligence and support to government authorities and state-owned companies regarding computer security [1].

Longest route:
- Highest Latency
- Highest price

Route	Length [km]	Est price pr pair [Eur/m/yr]	Latency roundtrip (RTT) [ms] (Speed of light / Fiber Refactive Index)
		1	203,94 m/µs
Oslo - Google DK via Sweden (Stockholm) (Telia International Carrier)	1399	1 399 000,00	13,72
Oslo - Google DK via Sweden (Gothenborg) (Level3)	840	840 000,00	8,24
Oslo - Google via Vennesla (Bulk)	749	749 000,00	7,35
Oslo - Google via Fredrikshavn (Skagenfiber)	586	586 000,00	5,75

Shortest route:
- Lowest Latency
- Lowest price

Figure 1: Meter pricing example.

1.2 Objectives

This master thesis has four primary objectives:

- Briefly overview of the current business model for international dark fiber cables.
- Discuss the need for dark fiber versus wavelength products and present the technologies for long haul fiber transmission.
- Gather information by contacting and interviewing companies involved with dark fiber – both operators and customers, nationally and internationally.
- Create a model demonstrating the factors that affects the pricing of dark fiber.

1.3 Scope

This thesis will focus on cross border dark fiber cables out of Norway. Due to the fact that Norway mostly border to the ocean, turning the scope towards subsea cross border cables.
This master will try to explain the factors that affect the pricing of dark fiber and display them in a way that should be beneficial for both developers, operators and customers.

1.4 Methodology

To meet the objective for this master thesis, the methodology used is through a literature study, interviews with companies involved with dark fiber and modelling the pricing factors. These three processes are described in the following sections.

1.4.1 Literature Study

A literature study has been conducted to research the topics in the project description. This includes studying the background of optical fiber and finding the technologies developed in conjunction with this.

1.4.2 Interviews

An interview process has been conducted to gain insight of the dark fiber market. This has been done by contacting operators and customers of dark fiber by phone or email. The actual interviews have been done by personal face to face meetings, over the phone, on skype or by answering questions on email. Getting in contact with operators and customers outside of Norway turned out to be a challenge that could not be resolved.

The interviewed subjects have been:

- CTO Arnt Erling Skavdal and managing director Cato Lammenes from Tampnet [6].
- Senior advisor Arne Litlere from the Norwegian Communications Authority (NKOM) [7].
- CEO Tor Kristian Gyland from Green Mountain [8].
- CTO Dag Aanensen from NO-UK [9].
- CTO Helge Gallefoss from Skagenfiber [5].

1.4.3 Modelling the Pricing Factors

This process has been conducted by studying the business model for dark fiber cables and using this and the information gathered through the interview process to locate and demonstrate the pricing factors.

1.5 Related Work

A study worth mentioning related to this master thesis is a study done by the University of Huddersfield named “An Economic and Social Evaluation of the UK Subsea Cables Industry” [10], researching the value of the United Kingdom (UK) subsea cable industry. This research identifies the emerging of new actors (stakeholders) which previously only delivered content. The companies mentioned include Microsoft and Google as the new actors interested and driving the subsea telecom expansion.

Another relevant study named “Economical analysis, dark fiber usage cost model and model of operations” [11] study provides analysis of fiber network deployment and operation. It focuses on how to finance an expansion of the National Research and Education Network (NREN) in Eastern European countries. This study discusses the cost efficiency of deploying new technology in a new dark fiber network compared to a legacy network.

1.6 Outline

This master thesis is divided into seven chapters, the topics of each chapter are as follows:

Chapter 1, Introduction: This chapter introduces the motivation and objectives for this master thesis as well as the scope and methodology. It also includes a brief overview of related work.

Chapter 2, Fiber Systems: This chapter covers the technical details of optical fiber systems. Including, among other topics, a brief history, capacity calculations and description of latency.

Chapter 3, Deploying and Operating Fiber Optical Subsea Cable Systems: This chapter explains the process of planning, deploying and operating a subsea fiber cable. It covers important factors to note while planning a path, methods to use when deploying and the maintenance aspect of operating the cable.

Chapter 4, Market: This chapter describes the market for dark fiber and factors driving new cables. It discusses who potential customers and providers are and how they act in today's market.

Chapter 5, Business Model: This chapter present the business model for dark fiber cable providers.

Chapter 6, Investment, Value and Pricing Factors: This chapter present the factors found from studying the business model and interviewing cable developers, operators and customers. The effects are presented and discussed.

Chapter 7, Conclusion and Future Work: This chapter concludes the findings of this thesis and suggests future work.

2 Fiber Systems

This chapter will give a short introduction to digital communication and optical fiber cables. It explains important physical properties of these cables and how it is possible to mitigate these, to be able to deploy cables thousands of km. Capacity and latency are also explained in this chapter, which is important factors when discussing value of a fiber cable.

2.1 History

In the early days the first distant communication was used to warn or inform about war, enemies or emergencies. As the information purposes were defined, the information rate or “bit rate requirement” were quite low, so was the distances of fire and smoke signals.
The first semaphore systems used optical vision-based communications, where symbols gave ability to communicate more information.
Later Morse created a system of short and long signals, which gave the possibilities to communicate full written words and sentences, over the distance of an electrical cable, at the speed of the telegraphist keying in the Morse-signals. In 1850 the first subsea telegraph cable crossed the English Channel. When electrical cables showed the ability to efficient communicate over long distances, the development of the voice-based communication system by Graham Bell in 1876 lead to a new dimension. This boomed the requirement for long haul communication. In 1956 the first electrical transatlantic Telephone cable was deployed [12] [13].

Today these breakthroughs are historical, so is the first optical fiber cable for high capacity data communication over longer distances in the early 1980’s, and the TAT-8 in 1988 which was the first transatlantic optical fiber cable available for traffic [12]. The first subsea optical fiber cable from Norway to Denmark was built in 1992. In 1994 the world record for long haul fiber was set by Nils Flaarønningen[2] at 420 km [14].

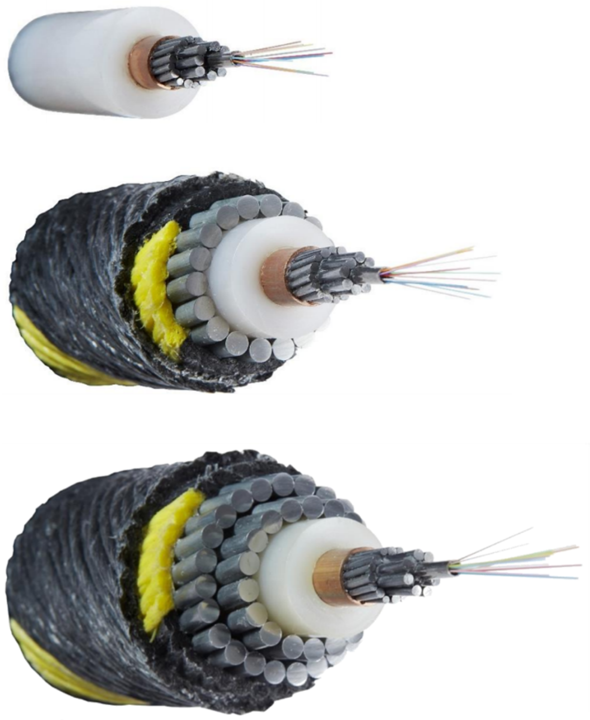
The need for communication has always been there, but now the need for communication and data- storage and -handling grows faster every year. Telenor has made their own forecast based on Cisco’s prognosis predicting that the volume used in a month today will be the same volume that will be used in a day in 2028 [15].

While the earlier investments in intercontinental fiber systems were facilitated by the large Telecommunication companies. Today solutions are both demanded and facilitated, planned and financed by Internet content providers, like Google, Amazon, Facebook and Apple.

[2] Research director, Alcatel Telettra Norway.

2.2 What is an Optical Fiber Cable

An optical fiber cable consists of one or more thin flexible fibers with a glass core through which light signals can be sent. The fiber strand, which is thick like a hair-straw, is protected by tiny tubes surrounded with different grades of protective materials, dependent on the cable´s specification and application. Figure 2 shows a subsea optical cable with double steel armoring, also known as heavy armoring. Land based fiber and fiber cables for pulling in ducts and tubes requires less protection and have often only polyethylene protection.



Courtesy of Nexans Norway

Figure 2: Unarmored, single armored and double armored optical subsea fiber cable [17].

Fiber optical systems are used for efficient communication and are replacing electrical copper-based cables in most communication applications. The fiber optical cable has significant preferences to the electrical cable, in particular related to high frequency capability, noise immunity and low dampening (signal loss), thus longer distances can be reached with higher bandwidth. Still the most critical challenges and also where the most research and development are spent, are into technology and methods for increasing capacity and reducing the signal loss.

Signal attenuation are in general compensated with amplification, and increased fiber quality. Ultra Low Loss fiber (ULL) is reducing the attenuation dramatically.

New transmission technologies provide both higher bandwidth per light-wave sent over the fiber, and systems letting more light-waves to be sent in parallel over the same fiber.

Traditionally the physics of light and light propagation in different media gives various challenges as dispersion, where the different light waves (colors) will have different reflection/refraction properties, and thus the light will be received with an individual delay. Until recently this dispersion phenomena have caused detection challenges causing limitations on throughput. This has led to fiber design filtering for compensating such challenges.

The later developments in coherent fiber optics have turned the dispersion problem to a fascinating feature, actually enhancing the detection precision by taking into account the dispersion characteristics of the actual fiber.

Designing a long haul cross border subsea fiber optic communication system, will require careful selection of technical, physical and economic factors. It is therefore the intention to give a brief overview of some of these factors considered as important in this aspect. Further basic details are arranged in Appendix B to describe fiber types, single mode vs multimode, dispersion and coherent detection.

2.3 Transmission Signal Budget

To provide for high quality communication, the end to end system must be working within its specifications. Meaning that the signal sent must be of a proper quality and that the received signal must be of a such quality that it matches the specification of the receiving equipment. The specification of both sending lasers and receiving photoelectrical equipment varies, and are tuned to different applications like short haul, long haul etc.

For a fiber optical cable system of up to 200-300 km, transmission equipment capable of handling signal loss budget of up to 50 dB without amplification are within reach.

Such systems are typically based on Opto-electrical transmission equipment which has a sensitivity or calculation value of (at least) -50 db. As an example, it will be possible to manage an unrepeated subsea fiber system of 270 km, using a standard available ULL G.562B with an attenuation of 0,18 dB per km.

50 dB / 0,18dB/km = 270 km

For the longer distances signal amplification and regeneration are necessary. InterContinental cables have distances of 6 000 to 13 000 km.

In this thesis cross border fiber systems for distances of 200 km to 7 000 km are discussed, and thus both amplification or repeated optical cables and unrepeated optical cables as well as ULL fiber are essential.

2.4 Ultra-Low Loss

Signal loss, dampening or attenuation in a fiber cable is caused by impurity from pollution of the glass base material. Wide spread minor reflections from impurities along the full cable length cause less signal to traverse the entire fiber length to the receiving end, and thus signal loss.

The new ULL cables have specifications granting down to 0,1460 dB per km [16], this is essential for long unrepeated fiber links. The more commonly used ULL cable ITU-T G.652B is provided with an attenuation characteristic of 0.179 dB per km [5].

2.5 Fiber Amplifier

Fiber optical cables have a signal loss due to impurity in the core. For each km of a cable the signal is reduced, and the noise will gradually make the signal unreadable. In order to maintain a reasonable Signal-to-Noise Ratio (SNR) signal amplification is needed. The current main way of amplifying optical signals is with Doped Fiber Amplifiers (DFA), where multiple techniques exist [17].

The most common technique is an Erbium Doped Fiber Amplifier (EDFA) [18] which leverages a reaction when light hits the natural element erbium. The fiber core is coated, or doped, with erbium ions which will absorb light of specific wavelength and emit on a different wavelength. The result is that light with a specific wavelength receive an energy gain with the cost of a different light.

Another technique is called Raman amplifier [19]. This leverages another natural phenomenon called Raman scattering. The scattering occurs when light of specific wavelengths is sent through the fiber core, and results in an energy gain for a different wavelength.

The common denominator for DFAs is the reduced need of external electrical power. Providing light with additional wavelengths makes it possible to pump the energy of the signal.

Older amplification methods where based on optical to electrical conversion of the signal, and then to retransmit it by a new sending laser. This was very undesired as it imposed more delay, had limitations on tech upgrades, was worn out and caused risk for electrical failures. All optical has lightspeed and does not impose delay other than that caused by the refraction index for the actual material.

2.6 Fiber Capacity

The capacity of a fiber cable has multiple factors. The factors include the bitrate on each of the laser beams, the number of wavelengths per fiber strand and the number of fiber strands per cable. The different factors can create limitations on each other.

2.6.1 Bitrate

The bitrate on one wavelength in a fiber strand, is dependent on the laser and photoelectric receivers' capability. Today's equipment supports typically 10 to 100 Giga bit per second (Gbps) even 400 Gbps. 400 Gbps on a single wavelength fiber were achieved by Huawei in 2014 [20].

2.6.2 Multiplexing

To maximize the utilization of a fiber strand it is possible to send multiple light signals with different wavelengths through it. Utilizing the physics of light and light reflection in glass it is possible to separate the different lights at the endpoints of a fiber strand. Sending multiple bit streams through one communication channel are called multiplexing. The technique used in fiber optics is called wavelength division multiplexing (WDM). It is possible to add many lights to a fiber strand creating a dense wavelength division multiplexing (DWDM).

The number of different wavelengths in one fiber strand is limited by the capacity of the terminal equipment at the endpoints. Commercially available systems today use up to 128 and 160 wavelengths [21], but systems supporting 200 wavelengths [5] are expected. The limits to the number of wavelengths seem not to have been seen yet.

2.6.3 Fiber Pairs

The number of fiber pairs in a fiber cable have few theoretical limitations. Increasing the number of fiber pairs will only increase the size of the cable. The problem occurs on longer distances where there is a need for repeaters. Repeaters often has physical limitations on number of fiber pairs they can amplify. It is possible to install multiple repeaters to support more fiber pairs, but the cost and practicality of this creates a limit. Most wet-plant repeater modules today support either six or eight fiber pairs, but models supporting up to twelve fiber pairs exists in the market [22].

2.6.4 Capacity of Full Cable

Combining the previous factors, it is possible to calculate the capacity of a fiber cable. Showing this calculation, the capacity of the Marea cable [23], completed in 2017, is used. The cable has a capacity of 160 Tbps [24]. It is a 6.500 km long transatlantic cable between the United States and Spain. It has a need of repeaters to go this distance which limits the fiber pairs to eight, or 16 strands. Each fiber strand has a capacity of 10 Tbps, meaning 100 different wavelengths with a bit rate of 100 Gbps.

In 2014 a multi-core, multi-mode fiber was created by researchers achieving a speed of 255 Tbps on a single strand of fiber [25]. The research only tested a one km cable so using this for long haul fibers is not possible yet. This shows the evolution of capacity in fiber strands.

Future equipment able to perform with DWDM with 200 wavelengths, and a single wavelength fiber strand with a bit rate of 400 Gbps is foreseen. It is therefore likely that the capacity of a fiber strand will surpass 80 Tbps in the future, in unrepeated fiber cable systems. A subsea fiber system up to 300 km with 96 fiber strands can then have an expected theoretical capacity of 7,68 Pbps.

400 Gbps/ λ x 200 λ/fiber x 96 Fibers = 7,68 Pbps

2.7 Managed Products

The fiber operator might provide different offerings, packages of products and services. The different products and offerings will have different markets, customers and positions.

There are many differences, but the main differences are related to responsibility for the operator or provider. IRU (see Chapter 5) based products are by definition based on a shared ownership and mutual responsibility. This requires a separate maintenance agreement.

Product examples:

- Fiber strand or pair are packetized with IRU and responsible maintenance agreement for customer infrastructure responsibility
- Fiber pair with a yearly lease and an SLA
- Fiber wavelengths as managed capacity products, as a service
- Fiber Internet Protocol (IP)-capacity as a full-managed-service network capacity service

The typical offering for a fiber infrastructure owner, is dark fiber with IRU agreement. This is an unmanaged product. The maintenance is kept by a separate agreement and can be effectuated by a partner outside of the organization of the infrastructure owner.

2.7.1 Managed Services

For managed products, like IP-capacity and wavelength, not only power and access add to the offering. Managed telecom products must comply with required management definitions for Fault Management, Configuration Management, Accounting Management, Performance Management and Security Management (FCAPS), in accordance with definitions set by Open Systems Interconnection (OSI) [26]. Therefore, these products require a costly organization for proper operation, which again will affect investment, risk, market situation and in the end pricing.

Marketwise it requires a large organization to successfully provide products on more levels in the same market. The products are to some extent in direct competition with each other. As an example, a dark fiber represents a potential threat to wavelength product sale, as all customers of dark fiber at the same route might provide wavelength products and sell their “spare capacity”, thus potentially hurting the market.

One fiber pair can be resold as a managed product with 80 to 200 light waves of 100 to 400 Gbps, meaning that one fiber pair might support 80 to 200 businesses. This illustrate that the market is highly competitive when brokers get access to this.

2.7.2 Network and Routing

When providing full service IP-capacity, this will include peering with other network providers, routing and rule-based filtering of traffic to keep the network operational and secure. Distributed denial-of-service (DDOS) and routing attacks are examples of unwanted activities to mitigate.

This also explains in brief the difference between a telecommunication operator and a pure infrastructure owner, providing dark fiber pairs.

2.8 Latency

Latency is the measurement of time delay in technology. Measuring the time, a signal uses from transmission in point A until it is received in point B. In fiber optics it is mainly three factors affecting the latency of the signal, distance, fiber components and transmission and receiving components.

2.8.1 Round Trip Time (RTT):

RTT, also called round-trip delay, is the time required for a signal pulse or packet to travel from a specific source to a specific destination and back again. In this context, the source is the computer initiating the signal and the destination is a remote computer or system that receives the signal and retransmits it.

2.8.2 Distance and Propagation Delay

Light travels through vacuum at a constant velocity of 299.792.458 m/s which results in an unavoidable latency of 3.33 µs/km. Imperfections in the glass core of a fiber strand give the core a refractive index, slowing down the light. The refractive index for fiber is also wavelength dependent. The latency is therefor closer to 5 µs/km [27]. The only way to reduce this latency is to find the shortest path possible between the two points.

2.8.3 Fiber Components

Different equipment used on long fiber cables, to amplify the signal or reduce the dispersion introduces more latency. Fiber which has dispersion compensating functions can add 20-25% latency [27] on the distance. Amplifying with EDFA also introduces more latency. This is the result of the meters of erbium doped fiber core with a worse refractive index than the regular fiber core. The latency per amplifier is not very high, but on the long-haul, transatlantic, cables the achievement will be noticeable.

2.8.4 Transmission and Receiving

The transmission equipment will also affect the latency. The optical signal needs to be converted from an electric signal to an optic and back to an electric signal for a computer to use it. Different equipment doing this will introduce different latency, a rule of thumb is about 5 µs converting one way resulting in a total of 10 µs [27].

2.9 Optical Fiber Lifespan and MTBF

Subsea fiber systems have a 25-year lifespan [28] [29]. This has become the norm from an economical view regarding down payment and service. All products used in a subsea fiber system have been created with a prerequisite of lasting 25 years without regular service.

This has led to the construction of wet-plant repeaters with multiple failovers, so if one fails it does not need to be replaced. The mean time between failures (MTBF) of these repeaters are 1 500 years [28].

The problem with this is the evolution of technology. When laying a cable with repeaters these repeaters will not be changed for the lifetime of the cable, resulting in a traditional technological bottle neck. Later development has to some extent overcome some of the upgrade dilemma, as the optical repeaters using doped glass substrate are transparent to transmission method.

Unrepeated fiber optic cables (shorter than 3-400 km) do not have wet-plant constraints with respect to tech development. Here, all transmission and management equipment are installed on shore and are easily accessible. Then capacity and technical upgrade is easier to overcome.

Over the course of a cables lifetime the elements will also affect the fiber cable. It is estimated that hydrogen will increase the dampening with 0,003 dB per km after 25 years. The radiation will also affect the cable, adding a 0,002 dB per km dampening after 25 years [28].

3 Deploying and Operating Fiber Optical Subsea Cable Systems

Deploying a fiber optical subsea cable is a time-consuming process. It can require multiple specially built ships and lots of factors needs to be accounted for before deploying the fiber. There are lots of options possible to solve different problems, which is important to understand when cost is discussed later. Operating a cable also has options regarding maintenance, which can affect the cost in different ways.

3.1 Path

To find the best path for a subsea fiber cable is not easy. One might think that laying a cable at the seabed, hundreds or thousands of meters below the surface, makes it possible to go straight from point A to point B. However, one problem is wildlife reserves, both on land and in the sea, which create restricted areas where the cable cannot pass through. Anchoring and fishing areas might also be avoided as they introduce higher risk of damage to the cable.

The seabed itself has huge variations which can be compared to hills, valleys and deep holes. These introduce different problems when laying the cable. In the hills and valleys submarine landslides can occur and damage the cable. If the cable is pulled straight over a deep hole the weight of the cable will create tension which can damage it.

The consistence of the seabed can also affect the path of the cable. Different consistence has different traits which can be desired in some cases and undesired in other. Other factors that can affect the laying process or the operation of the cable are the currents, weather, tides, temperatures and seismology.

A complete survey of the land, sea and seabed is important to perform as early as possible to find the best path for the cable. A surveying ship with a sonar needs to be rented. This ship has to travel along the wanted route to map the seabed. Figure 3 shows this process. The duration of this depends on the distance, as the service speed of these ships are around 13 knots [30], (24 km/h).

Because a surveying ship is expensive and is only able to survey a certain width of the seabed for each pass, it is important to do a Desktop Study (DTS). In a DTS it is important to gather all available information about the area where the cable is going to be laid and find the best path to perform a complete seabed survey. It is important to identify areas which will be difficult to survey, lay the cable and perform maintenance. During this process it is also important to determine if any rules or regulations need to be considered, or if one need any permits lay the cable.

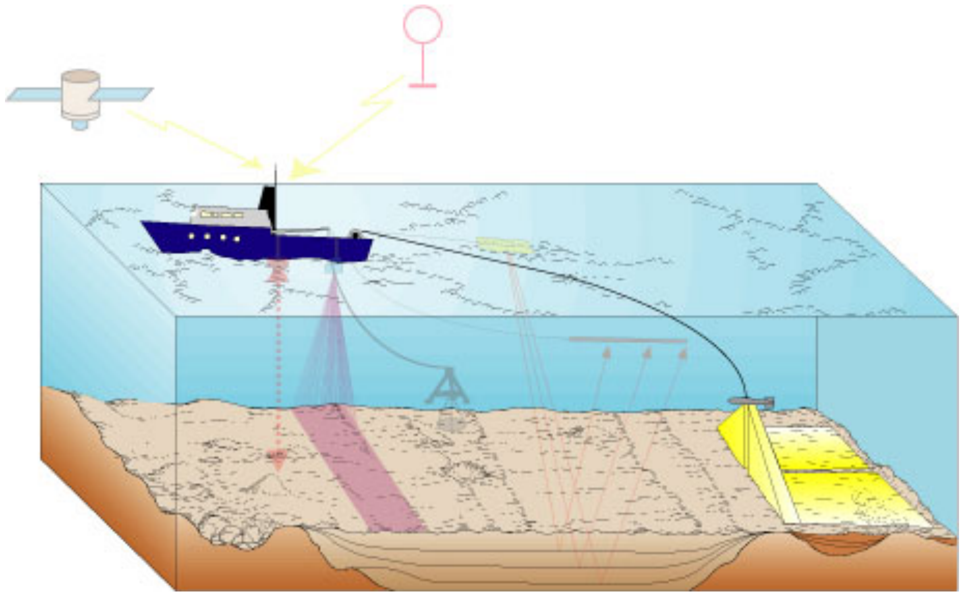


Figure 3: Illustration of ship surveying the sea bed [58].

3.2 Protection

Laying the cable is an expensive and slow process. It requires one or more special built ships depending on the protection used. A list of available ships can be seen in Appendix A. These ships are able to lay between 100 and 200 km of cable a day, with a service speed of only 2-5 knots [31].

The cable might need protection on the seabed. Different hazards and seabed consistence require different protection methods. The methods require special equipment, and in some cases an additional ship to carry and use this equipment. This can increase the cost of laying dramatically, but the correct protection for the environment can greatly reduce the maintenance and operational cost. Thus, minimizing the risk of damage from external factors.

3.2.1 Unprotected

The cable can be laid on the seabed unprotected. This is only used where the environment provides enough protection. These environmental factors can be areas of extreme depth, in areas with fishing and anchoring restrictions or it is off the beaten track.

3.2.2 Trenching

Trenching is a process of laying the cable into the seabed, and it is a two-part process. First the cable is laid by one ship, then another follows with a jet-trench equipment. The jet-trench equipment is dragged behind the ship on the seabed over the laid cable and blows high-pressure jet stream against the seabed, blowing the soil away under the cable. The cable can then sink into the seabed. This is most effective on softer seabed soils, but the more power in the equipment, and the ship pulling it, the harder soil it is able to cut through.

3.2.3 Ploughing

Ploughing is also a technique of burying the cable into the soil. This requires only one ship dragging a specially built plough. The cable is released by the ship and fed through the plough, ending up inside the seabed after the plough. Figure 4 shows this process. This technique can be used on similar soils as trenching but are better on harder soils.

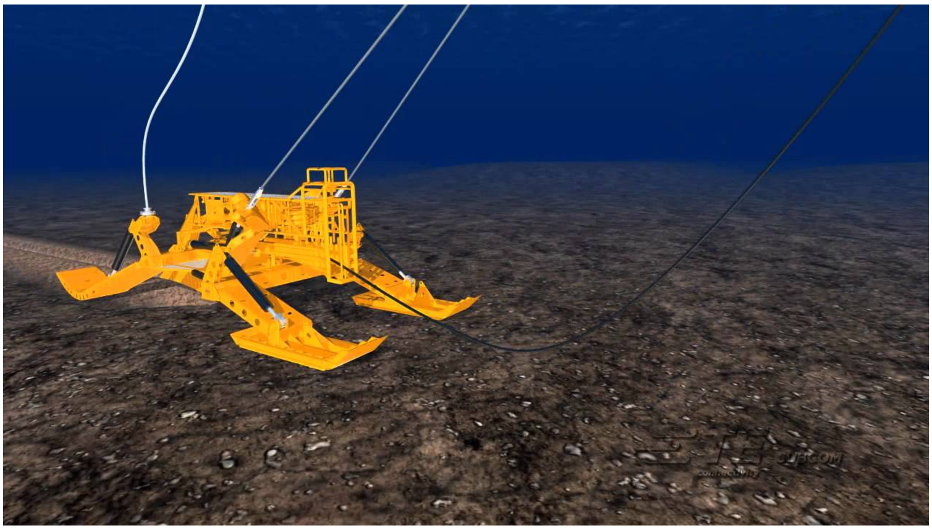


Figure 4: Illustration of ploughing [60].

3.2.4 Rock-Dumping

Rock dumping is, as the term suggest, a method of protection where rocks are laid over the cable. It requires a specially built ship to carry the rock out to the sea, and equipment to drop the rocks quick, but safely over the cable. This protection technique is very expensive and is therefore mainly used where the seabed is very hard, or other methods are not possible.

3.2.5 Concrete Shield Module

A concrete shield is massive plates of concrete blocks tied together. These are placed over the cable as protection, mainly against fishing trawlers. Placing the concrete shield also requires an additional ship to place them over the cable after it is in place on the seabed. This method is mainly used on deeper water and on harder seabed.

3.2.6 Cast Iron

Heavy iron half-tubes are mounted around the cable, Figure 5. It provides more protection than nothing, but anchors and trawlers can still get a hold of the cable and damage it. Divers are needed fulfill this job after the cable is laid. It can therefore not be used on huge depths. This technique is used in areas where digging and other disturbances to the seabed is not allowed, like near wildlife reserves and other restricted areas.

Figure 5: Cast iron from Bell island submarine cable [64].

3.3 Fiber in Power Cables

Another aspect to consider when deploying a subsea optical fiber cable, is laying it within a power cable. If a subsea power cable is planned the cost of adding fiber to the cable are very low. As Figure 6 shows, it is lots of space in a power cable where the fiber can be put.

The problem with this is the maintenance aspect. If a problem occurs on the fiber it is necessary to disable the power cable to repair it. The logistics and extra time this will add, can be costly compared to repairing only a fiber cable.

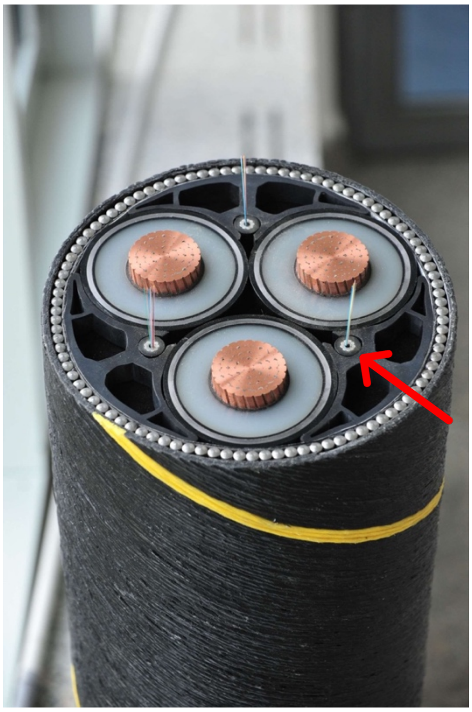


Figure 6: Power cable with fiber (red arrow).

3.4 Operation and Maintenance

In the lifespan of operating a subsea cable, maintenance must be anticipated. There are mainly two kinds of maintenance, planned or preventive maintenance, to avoid later damages and reactive maintenance which is immediate repair as a consequence of an unplanned situation.

3.4.1 Preventive Maintenance

Preventive maintenance has the intention to mitigate or reduce risk for later damage, such as inspecting the cable and maintain a safe cable placement, after storms and sea-bottom changes.
Preventive maintenance can be done by monitoring and analyzing signal quality and by physical inspection of the cable itself.

Monitoring will typically show cable connectivity, but advanced monitoring might also analyze and report signal degradation and abrupt disturbances which might indicate a physical damage or unwanted activity.

Weather and water changes and incidents are also important to monitor at a regular basis. Knowing the water flow and current situation, and monitoring changes to this can be an indicator that something has or might happen to the sea bottom. These changes in current or from submarine landslide might disclose or direct damage the cable.

Physical inspection of the cable route is important to verify if the cable is according to laying requirements or if there are any deviations. The inspection of submarine cables is typically done by a combination of sonar(special) and video. The sonar used can scan through sea bottom and identify the cable in mud and sand. Such a cable inspection is typically done by leasing a ship with advanced inspection equipment. This is costly and therefore done rarely.
Modern submarine drone technology [32] [33] provides new autonomous equipment which goes closer to the cable and sea bottom and thus can utilize more traditional inspection equipment and obtain the same precision as high-grad equipment on a ship some hundred meter above the sea bottom.

Later generation of submarine drones can be programmed to inspect a cable route autonomously. Such inspections can be performed on daily basis, and thus represent a higher protection level.

All deviations must be evaluated and repaired, as a follow-up activity. Planning for an immediate maintenance or repair will reduce outage and need for further unplanned costly repairs.

3.4.2 Reactive Maintenance

Reactive maintenance is maintenance and repair work in accordance with imposed damages. For a subsea fiber cable, a repair normally involves a clean cut and then imposes a new cable segment and two “splices”.
Preparation and readiness for efficient callout of repair team, ship and material is essential. The better preparation and the more equipment that is made available, in local warehouse, the more efficient the repair will be.

Some of the international subsea entrepreneurs provide a repair service agreement, which includes access to a standby repair vessel.

4 Market

This chapter describes the challenges Norway are facing regarding fiber connectivity and connection to the Internet. It discusses the driving forces of developing new cross border cables and explains the potential customers of these cables. The existing cables out of Norway and planned new cables are also presented.

4.1 Challenges

Fiber optic networks have become a part of the critical infrastructure. The government has acknowledged that Norway has few international connections and wishes to encourage more fiber cables to ensure redundancy, diversity and vulnerability [4]. There are currently 100 MNOK on this year's national budget for such stimuli [3]. NKOM shall draw up guidelines for allocation of the support and the Ministry of Transport and Communications are reviewing the applicants and choosing the receivers of the stimuli.

Most Internet traffic today is routed through Oslo, and 90 % [34] of the traffic continues via Sweden, and the majority goes via Stockholm. This gives poor technical performance and represents risk and vulnerability. Further Sweden is not a member of the North Atlantic Treaty Organization (NATO), which is a challenge for the Norwegian defense and military. NKOM has therefore proposed for the government to require telecom operators to be able to run all traffic outside Sweden [4].

South-west Norway has more connections abroad today, and Internet traffic in this region goes through these connections. This is good, but not sufficient, and it does not solve the challenges in relation to Oslo/eastern Norway region and Sweden. The connections of the south-west region go to England, via oil platforms in the North Sea. Their main object was to bring communications to these platforms, and the extension to England was built later as English oil companies also needed communication to their platforms. Because of this, they are not scaled to deal with all the Norwegian communication.

Access to dark fiber in Norway is limited. This is an important prerequisite to increase the interest in establishing more data storage facilities in Norway, as these require better and more connections than those found today. One requirement these facilities has to accommodate is a minimum of three equally good independent routes for redundancy [35].

There are currently no direct connections from eastern Norway to the continent and down to central hubs in Europe like Hamburg, Frankfurt and Amsterdam.

4.2 Capacity vs Availability

With the increasing number of services and products using the Internet, like Internet of Things (IoT) devices, one might think the need of capacity is the driving force. The truth is that the traffic through the Norwegian Internet eXchange (NIX) peaks at 80 Gbps [36], while a single fiber strand can have the capacity of 80 Tbps, shown in Section 2.6. This is thousand times more than are needed today.

Cisco forecast a threefold increase of traffic from 2016 to 2021 [37]. If traffic through the NIX follows this growth rate and this will continue, one fiber strand will have enough capacity for the next 15 years. When fiber cables are laid they have at least eight strands, making them able to take all the traffic far into the future. So, with thousands of times the necessary capacity it will last for the foreseeable future.

One of the driving forces are rather availability in form of uptime. Norway relays on connection going through Sweden and if something should happen with these, Norway would practically be cut off from the global world. The need is redundancy in form of multiple completely independent cables.

This is also required by the cable developer to get customers. If a cable is damaged or malfunction, repair is needed. When repairing a fiber cable, it is necessary to cut it in two an append a new bit of cable. This result in complete transmission stop for all customers even if they do not have any issues with their communication.

Cable developer needs to lay multiple cables or cooperate with other developer to deliver a guarantee of availability. Data storage facilities require redundancy on multiple levels to deliver availability to their customers. They require at least two independent lines which both can sustain all the traffic alone.

The need for multiple fiber connections is likely not caused by capacity, but the need for redundancy.

4.3 Cross Border Dark Fiber Customers

There are different customer groups or buyers in the market for cross border dark fiber connections in Norway. This section presents a list of customers and discusses the customer's perspective related to dark fiber.

In general, the customer groups are infrastructure owners who need cross border fiber infrastructure to support their operation or infrastructure. The requirement and intention will vary among the customers because the different customers will appreciate different quality parameters.

4.3.1 Background

The "Always-on" society with Internet of Things (IoT), data centers, Internet service providers, content and Over The Top (OTT)-providers are the driving forces for increased communication needs. As Internet is global and cloud services are borderless, the demands for international communication means are increasing in capacity and availability.

Today all Internet users are using services mainly hosted outside of Norway, as Google, Amazon, Facebook, Apple, Microsoft and others have their main cloud services hosted in other countries. In Norway most of the Internet traffic are concentrated in Oslo where the service provider networks have their hubs. From Oslo the traffic is lead though existing cable routes in Sweden and further down through Denmark and Germany. This leads to dependency on long routes and many countries for Norwegian Internet communication.

The result of this is high latency and information sent across areas with different laws. Swedish military inspects all traffic crossing their border, meaning most data leaving Norway are inspected. Without extra encryption the data, crossing the border, will not remain confidential and secure. This situation is seen as critical from a service perspective, a security perspective and an efficiency perspective. Customers of a new cross border fiber will benefit of a more direct route to the central hubs in Europe.

4.3.2 Internet Service Providers (ISP)

ISPs are a potential customer of cross border fiber as they offer their consumers general access to Internet. They require high bandwidth and uptime to please their consumers' need of effective Internet access and would like to connect directly to the central hubs in Europe. As the Internet is an open platform ISPs do not require secure lines to offer their products to their consumers.

4.3.3 Telecom Operators

Telecom operators are voice and data carriers. Their main services do not need very high bandwidth but, they need low latency, so their consumers can communicate in real-time. Consumers do not want anyone to be able to eavesdrop on the communication, so the operators want to provide a secure line.

4.3.4 Content Providers

Content providers, or OTT-providers, gives consumers access to content all around the world. They need high capacity between their different locations to be able to provide the content everywhere. The security need is not a necessity, but the content providers want integrity to make sure the content is not edited. These actors will prefer bandwidth before delay.

4.3.5 Operators of Content Distribution Network (CDN)

CDNs provides storage of content around the world so consumers are able to access the content fast and easy, as local content, often referred to as caching. These storages are updated regularly with content from all around the world. This requires large bandwidth and the latency is not very important.

4.3.6 Cloud Service Providers

Highly interactive services as cloud service providers requires low latency. They provide different As A Service (aaS) products like Amazon Web Services [38], Microsoft Azure [39] and Google Cloud [40], where everything is accessed and edited over the Internet and latency becomes very annoying for the consumer. These operations also require bandwidth, but not an excessive amount. Confidentiality and integrity are very important, as consumers can use these services for personal or secret information.

4.3.7 Data Center

Data centers have different requirements. Earlier a data center was “the one and only” data center for a business. All computers and storage were in one place. Today data centers are more decentralized, and the stored data are accessed by multiple businesses and their consumers from multiple locations. The data needs to be available instantly for everyone. Data center providers need multiple locations to be able to accommodate this need. Between the data centers it is necessary to have links with low latency and high bandwidth. These links also need to maintain confidentiality and integrity of the data to secure business sensitive data, so the data centers can accommodate all types of businesses.

4.3.8 Owner and Operator of Private and Business Networks

Private and business networks are between locations, as an internal network. In this thesis these will be represented by defense and military networks. Defense and military networks and applications require high security on their data. As an example, there is an important issue with the fact that traffic through Sweden is recorded and inspected by the Swedish implementation of the FRA-law [1]. This is not appreciated by the Norwegian defense. They have put forward a demand, based on national security [41], that Norway shall be able to operate their own telecom and information network services out of Norway without any dependency to Sweden. According to Sweden not being a member of NATO, Norway is running a risk that Sweden might manipulate and listen to both national as well as NATO sensitive data.

4.3.9 Discussion

A summary of the customers need can be seen in Table 1. Customers of dark fiber have different priorities depending on the application or service they deliver to the consumers. The only factor equal for everyone is uptime, which responds with the “Always-on” society.

Customer Type	Bandwidt / efficeiency	Delay, Latency	Uptime	Security	Application
Internet Service Providers (ISP)	High	Medium	High	Low	General Internett Access
Telecom Operators	Medium	High	High	High	Voice and Data Carriers
Content Providers	High	Medium	High	Medium	Content like Youtube, facebook, News
Operators of Content Distribution Network (CDN)	High	low	High	Medium	Distribution of high quality Film and Media
Cloud Service Providers	Medium	High	High	High	Access to remote applications and storage
Datacenters	High	High	High	High	Loadbalancing, data replication, redundancy
Owner and Operators of Private Networks and Business Networks	Medium	High	High	High	Access to Business critical Application and data. National Security

Table 1: Customer view.

Customers buying dark fiber are often not categorized as only one of these types. Looking for example at Google with their Cloud and GSuite applications offers multiple services to their consumers, both private and to businesses. Their Cloud application also offers CDN solutions and they provide content through YouTube. If they decide to locate in Norway, they will provide an improved version of all these products to their Norwegian consumers. To make this possible they will need high bandwidth, low latency and secure connections to their existing locations.

At the moment, the connection to the European main hub is not sufficient enough from Norway, especially the latency is too high and the security issue with Sweden's FRA-law [1] is also a challenge. New data storage facilities offering these services are not establishing in Norway. According to Tom Andre Sandal CTO NTE Bredbånd, this has led to an ISP in Trøndelag to buy separate fiber connection from Steinkjær to the main European hub, to offer their consumers better performance on services as Microsoft Azure. The new link has reduced the latency and jitter resulting in satisfied consumers and a sales point for new consumers.

The five large companies(Google, Facebook, Apple, Amazon and Microsoft) seeking to provide their consumers with everything are not expanding to Norway even though Invest in Norway (Innovasjon Norge) has had a data center program for 4-6 years now. The Norwegian government has mitigated both power and property taxation on data storage facilities and the companies have built new facilities, but not in Norway as Figure 7 shows. Invest in Norway are pinpointing the fiber situation in Norway as the most important factor inhibiting this investment. Thus, the action from the Norwegian government in stimulating new cross border fiber systems are highly appreciated.

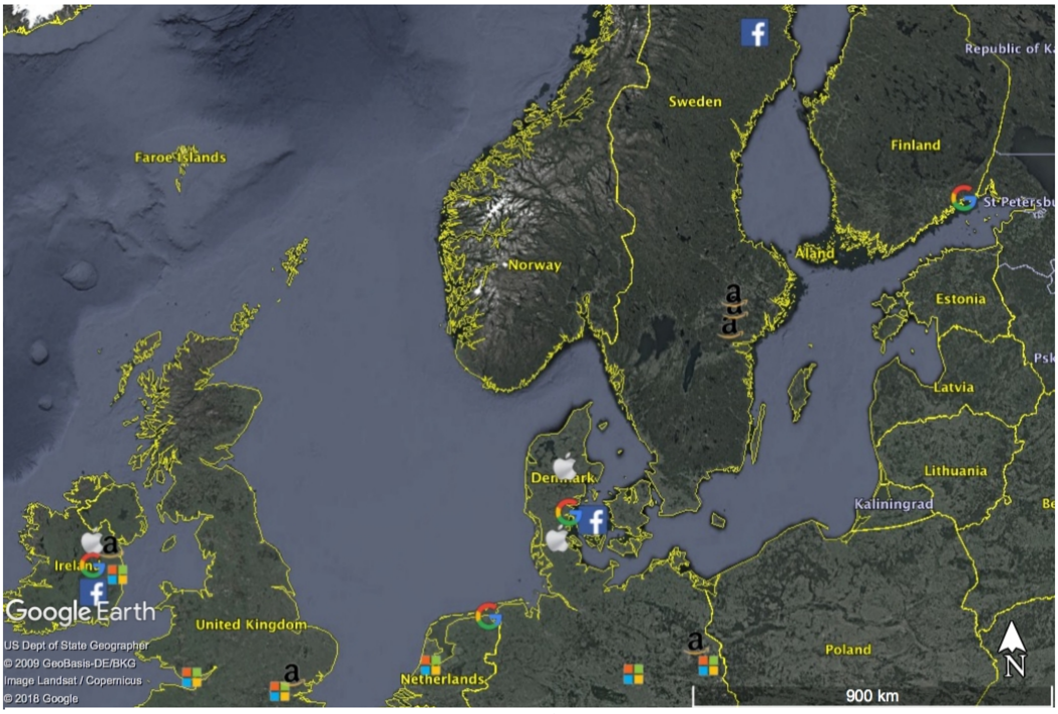


Figure 7: Map of the location of data centers built/planed by Google, Facebook, Apple, Amazon and Microsoft [38] [63] [40] [39] [59].

Through the research and interview process [9] [5] [8] [7] [6], the following two customer groups have been identified for cross border dark fiber. The first group is the mentioned customer types above. These are customers who buy dark fiber for their own benefit, to enhance their product.

Group two are customers which buy dark fiber to resell wavelength or capacity. Examples of these customers are international carrier and infrastructure owners.

Telia International Carrier (TIC) [42] and Leve3 [43] are examples of international carriers. They offer their customers the means to transport data between locations, by selling fiber capacity all around the world. These carriers buy and rent capacity to resell to their customers.
The International Carriers have made their networks by building, buying and leasing fiber and capacity between international hubs (larger cities with large communication needs). In this market the carriers provide services and can be brokers for selling other products, like dark fiber. The International Carriers rely on having the best international

capacity and latency and are constantly buying capacity, redundancy and more efficient routes.

Infrastructure owners builds and owns fiber infrastructure. To be able to provide transmission and redundancy to their customer they need to buy or rent part of the distance, to offer their customers international peering and communication transport products around the world.
When mentioning “Infrastructure owners” all kind of communication infrastructures are thought of, in the context that infrastructure need to be interconnected to provide any services. Meaning that infrastructure owners buy or swap (exchange 1:1) infrastructure elements to be able to provide network and bare connectivity between interesting hubs or connection points.

4.4 Cross Border Dark Fiber Providers

This section presents the cross border fiber cable providers in Norway. Presenting the existing actors and their cables first, and then showing the planned projects for new cross border fiber cables.

4.4.1 Existing Cross Border Cables from Norway

As mentioned previously, 90 % of the Norwegian Internet traffic is today sent from Oslo through Sweden and down to the rest of Europe [34]. It is either sent through Stockholm or Gothenburg before it passes through Malmö and over to Copenhagen. IP only is one of the fiber providers offering this route [44]. The rest of the Norwegian Internet traffic is sent over the existing cross border cables which are listed below. Figure 8 shows all existing cross border cables from Norway.

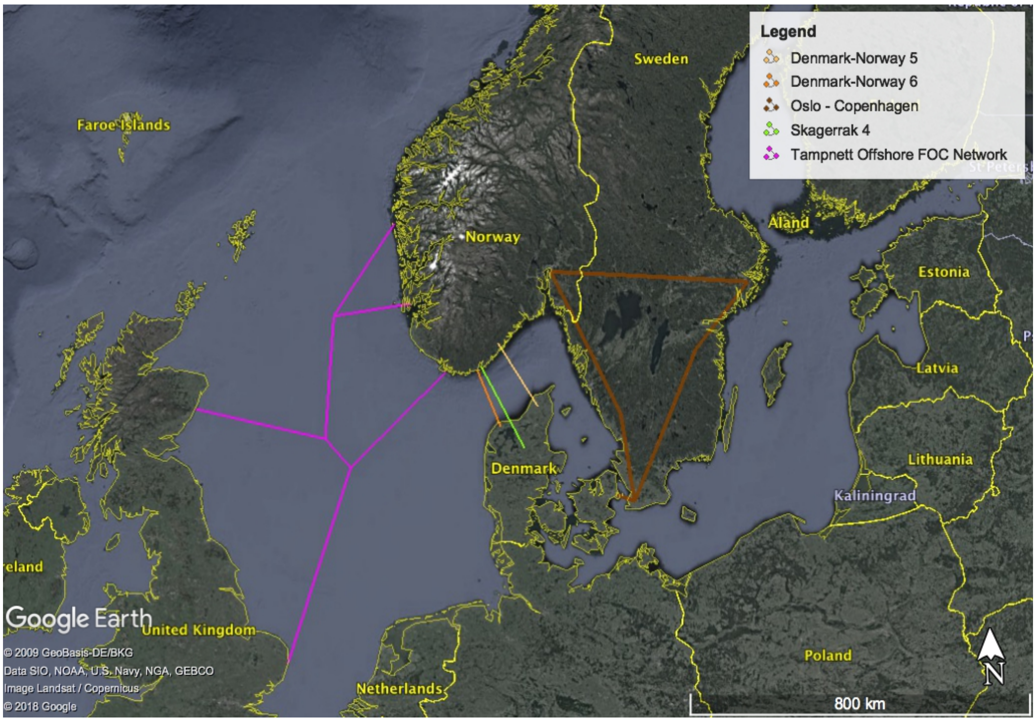


Figure 8: Map of existing cross border cables from Norway [45] [23].

4.4.1.1 Tampnet Offshore FOC Network

Tampnet's vision is to become a global leader in providing high capacity, low latency and reliable connectivity to offshore installations, mobile rigs and vessels. Their mission is to add value to their customers through connecting offshore assets to robust and reliable terrestrial network with high capacity and low latency. Their services shall enable customers to improve on quality, health, safety, efficiency and welfare in their offshore operations [45].

In the North Sea Tampnet has a subsea cable network linking Norway to the United Kingdom. This subsea cable has three landing points in Norway, Farsund, Kårstø and Øygarden, and two landing points in the UK, Aberdeen and Lowestoft. The cable is 1,751 km long and is connected through five off-shore platforms. It was finished in 1999 [23].

4.4.1.2 Skagerrak 4

Statnett owns a subsea cable connecting Norway to Denmark. It has landing points in Kristiansand, Norway, and Tjele, Denmark. The cable is 240 km long where 137 km is subsea cable and it was finished in 2014 [23].

4.4.1.3 Denmark-Norway 6

In 1992 this cable from Arendal in Norway to Hjørring in Denmark was finished. This subsea cable is 130 km long and owned by TDC and Telenor. This cable is marked with an end of service in 2017 [23].

4.4.1.4 Denmark-Norway 5

This subsea cable was finished in 1992 and is 120 km long. It has landing points in Kristiansand, Norway, and Thisted, Denmark. This cable is marked with an end of service in 2017 [23].

4.4.1.5 Svalbard Undersea Cable System

North in Norway there is a 2,714 km long subsea cable from Breivika to Longyearbyen on Svalbard. This cable was finished in 2004 and is owned by Telenor [23]. Unfortunately, this cable does not support any international communication from Norway and are thus not of interest in this thesis.

Cable Name	**Total Length**	**Ready For Service(RFS)**	**End Of Service(EOS)**
Tampnett Offshore FOC Network	1 751 km	1999	2024
Skagerrak 4	240 km	2014	2039
Denmark-Norway 5	130 km	1992	2017
Denmark-Norway 6	120 km	1992	2017
Svalbard Undersea Cable system	2 714 km	2004	2029

Table 2: Existing cross border cables

4.4.2 Planed Cross Border Cable Projects from Norway

Figure 9 shows a map of all planed cross border cable projects from Norway.

Figure 9: Map of planed cross border cable projects from Norway [51] [48] [47].

4.4.2.1 Havfrue/AEC-2

Facebook are building a new data center in Denmark and to connect this with their other data centers they are building a cable together with Aqua Comms and Google. The cable will run from the United States to Ireland and Denmark. The landing point in the United States is in Wall Township, New Jersey. The landing point in Ireland is in Lecanvey. The landing point in Denmark is Blaabjerg. Bulk industry has gotten green light to get a connection to Kristiansand, Norway, and are at this time working on finding potential investors for this project [46] [47]. The cable is planned to be finished in 2019 and will be 7,200 km long [23].

4.4.2.2 England Cable NO-UK

The NO-UK Cable Project vision is to deliver high quality dark fiber connections enabling the establishment of large data centers in Norway. The data centers shall consume green hydro power produced in region and enable Norway to become part of a global edge/core data network by 2020 [48].
NO-UK are planning to build a new cable to the United Kingdom. The landing points will be in Rennesøy, Norway, and Seaton Sluice, United Kingdom. This cable is scheduled to be finished in 2020 and will be 722 km long. At the landing point in Norway this cable will be directly connected to the Green Mountain data center [49] and in the UK

directly connected to the Stellium data center [50]. They are at this time working on financing the project.

4.4.2.3 Skagenfiber

Skagenfiber AS is established to build, operate and own fiber connections between Norway and northern Europe. The company will deliver dark fiber to data centers and telecom companies seeking capacity, redundancy and shortest route to Europe [51]. Skagenfiber are planning to build a new cable from Fredrikstad, Norway, to Fredrikshavn, Denmark. This cable is scheduled to be finished in 2019 and will be 220 km long from landing point to landing point. They are at this time working on financing the project.

Cable Name	Length	Ready For Service(RFS)	End Of Service(EOS)
Havfrue/AEC-2	7 200 km	2019	2044
England Cable	722 km	2020	2045
Skagenfiber	220 km	2019	2044

Table 3: Planned cross border cables

All these projects represent critical infrastructure for Norway, but none are yet financed.

4.4.3 Who Invest and Control International Cross Border Communication Cables

Earlier communication infrastructure was deployed and controlled by the telecommunication companies. Now investments are done to support the growing demand for Internet services and international communication from this. Table 4 shows the main owner of the new cross border cables planned. It shows that the main actors now are Amazon, Apple, Facebook, Google and Microsoft, while the owners of existing cables are AT&T, TDC and other telecom companies. Telecom companies do not want to take the cost as they can offer their consumers the access they need, while OTT actors wants to improve their services to the consumers. They are willing to take the cost to do so as well.

#	Subsea Cable System	RFS Date	System Type	Length	OTT Owners/Customers	Supplier
1	Unity/EAC-Pacific	March 2010	Transpacific	9,620 km	Google	NEC
2	Southeast Asia Japan Cable (SJC)	June 2013	Transasia	8,900 km	Google	NEC
3	GTT Express	September 2015	Transatlantic	4,600 km	Microsoft	TE SubCom
4	AEConnect (AEC-1)	January 2016	Transatlantic	5,536 km	Facebook, Microsoft	TE SubCom
5	FASTER	June 2016	Transpacific	11,629 km	Google	NEC
6	Asia Pacific Gateway (APG)	November 2016	Transasia	10,400 km	Facebook	NEC
7	Seabras-1	June 2017	Transamerica	10,800 km	Microsoft	ASN
8	Monet	Q4 2017	Transamerica	10,556 km	Google	TE SubCom
9	MAREA	Q1 2018	Transatlantic	6,600 km	Facebook, Microsoft	TE SubCom
10	Junior	Q2 2018	Regional	390 km	Google	Padtec
11	Tannat	Q2 2018	Transamerica	2,000 km	Google	ASN
12	New Cross Pacific (NCP) Cable System	Q2 2018	Transpacific	13,618 km	Microsoft	TE SubCom
13	Hawaiki Cable	June 2018	Transpacific	14,000 km	Amazon	TE SubCom
14	Pacific Light Cable Network (PLCN)	Q1 2019	Transpacific	12,800 km	Facebook, Google	TE SubCom
15	Indigo West and Central Cables	Q1 2019	TransAPAC	9,450 km	Google	ASN
16	Hong Kong Guam (HK-G)	Q4 2019	Regional	3,900 km	Google	NEC
17	Curie	Q4 2019	Transamerica	10,000 km	Google	TE SubCom
18	Havfrue	Q4 2019	Transatlantic	8,179 km	Facebook, Google	TE SubCom
19	JUPITER	Early 2020	Transpacific	14,000 km	Amazon, Facebook	TE SubCom
20	HKA	2020	Transpacific	13,000 km	Facebook	ASN
21	SJC2	Q4 2020	Transasia	10,500 km	Facebook	NEC

Table 4: Subsea cable owners/customers [65].

5 Business Model

As this thesis is focusing on factors influencing the pricing structure of dark fibers for long haul communication, it is essential to understand the business model for the investing parties. That is to see their motivation and later to understand how the various factors in pricing might reflect the business for a distributer or provider building and delivering cross border dark fiber. Alexander Osterwalder created a business model canvas which describes an organization's business model by nine different building blocks [52]. Using this canvas as a guide, this thesis will now study the model for cross border dark fiber business.

As seen from the Section 4.4 Norway is a market with very few existing actors. Therefore there is a need for new actors who will typically have a need for funding and will thus seek out potential partners with the same interest to create a shared investment. This shared investment will typically be split by the use of Indefeasible Right of Use (IRU)-contracts, explained in the following.

Indefeasible Right of Use (IRU)

An IRU-contract is a permanent agreement that cannot be undone. It Is a shared agreement between the primary owner of, in this case, the dark fiber and a potential partner of this [11]. When the contract is settled it means that the partner has the exclusive, unrestricted and indefeasible right to use one, a pair or more strands of fiber of the cable. These contracts create a shared ownership which means it also comes with a shared responsibility for repair and eventually dismantling. An IRU agreement are meant to be for the lifetime of the infrastructure. For a fiber cable it is normally 15 to 25 years, with an option to "lifetime renewal" thereafter.

Because of the big difference between a regular lease contract and an IRU-contract it is important to understand the business from two different aspects, which typically are the two phases of deploying and financing a cable project.
These aspects are:

- Pre-installation: when a provider decides to start a subsea fiber cable project, it is normally needed to sell IRU-contracts to fund the project.
- Post-installation: when a distributer is established and has already built the cable and is continuing with sales and maintenance of this. In this case focus will be selling lease-contracts applying from 3-5 years, as running business.

5.1 Pre-Installation

Before a fiber is deployed, there are limited values in a project or a company owning a large fiber project. This fact makes financing a hard task. This is often solved by splitting the cost of the project between a few partners. Each partner gets a part ownership of the cable, which is the main value in the project. By selling out parts of the cable by IRU agreements (described earlier), the value to finance is reduced and there is cash in the company. Thus, financing the rest is possible. Until the fiber is in operation all related cost is Capital Expenditures (CAPEX) [53], or investment cost. The partners owning IRU-agreements will also be able to post the cost of the IRU as CAPEX in their accounting books.

When starting on the process of establishing a dark fiber cross border subsea cable, the provider needs to plan the project in detail to understand what the cost drivers are and create a reasonable business plan.

As described earlier planning the deployment process consists of several activities and decisions to be made. The main activities that affects cost and quality involves feasibility study, desktop analysis, decision on route, cable protection and laying principles, arrangement of vessels for cable lay and preparation, cable and system solution with or without repeaters and doped cable, detailed planning, permissions, right to land and lease agreements. The issues and principles of these areas are mentioned earlier in this thesis in Chapter 2 and Chapter 3.

The customer segment in a business perspective is rather referred to as partners, as they will share the same interest in establishing the fiber project. The IRU-partners are typically larger enterprises, which have parallel interests and will be driving forces in establishing the project, based on their needs for the specific route or link in a broader network perspective. Typically, initial partners for a new cable will be bigger data centers with international partnership with demanding requirements, defense and military with special requirements, international carriers who will broaden their offerings for resale, service providers and OTT (where they are investing in infrastructure).

OTT players (e.g. Netflix) are normally investing in a global service cloud player (e.g. Amazon) by running all their services on their platform. By this, the OTT will have made their services available globally without planning and investing themselves in global infrastructure. Therefore, the larger infrastructure, data center and cloud providers are more important requester of international capacity.

Table 5 shows a business canvas of the pre-installation process.

<table>
<tr><td colspan="6">Pre-installation – subsea cross border cable</td></tr>
<tr>
<td rowspan="2">Key Partners

- IRU-partners
- Contractors:
o Project managing.
o Terrain/ Seabed route planer.
o Cable manufacturer
o Cable entre-preneur and laying vessel.</td>
<td>Key Activities

Plan the cable project

Finance the project.

Lay the cable.</td>
<td rowspan="2">Value Proposition

- Dark fiber connection in the form of IRU-contracts.
- Open for customer requirement</td>
<td colspan="2">Customer Relationship

Direct contact to create partnerships for IRU agreement.</td>
<td rowspan="2">Customer Segment (Partners)

The big actors:
- Data centers
- Defense and military
- International Carriers
- Infrastructure owners
- Cloud Service Provides
- (Service Providers – OTT)</td>
</tr>
<tr>
<td>Key Resources

- Route planning.
- Permission to build.
- The subsea fiber cable.
- Contractor to lay the cable
- Cable vessel.</td>
<td colspan="2">Channels

Marketing – with the help of consulting partners</td>
</tr>
<tr>
<td colspan="3">Cost structure (CAPEX)

Project planning cost.
Terrain/seabed routing cost.
Financing cost.
Building cost (cable man|ufacuting)
Laying cost (cable laying)</td>
<td colspan="3">Revenue Stream

IRU-contracts (up front)
Investors – support of the project.
Bank loans.</td>
</tr>
</table>

Table 5: Osterwalder business canvas - pre-installation.

5.2 Post-Installation

In this thesis, the situation after the cable laying project is finished seen as a different business case. This is an operational phase, and finance is settled. In this phase or in this kind of project, the focus is on running the business. There is little to do with respect to the fiber project, the cable parameter is set and the dependencies with respect to wet-plant and other are done.

The running business is mainly concerned with maintaining the fiber as is and ensuring income by selling lease contracts.

The market for lease contracts of 3 to 5 years are understood to be through integrators and system architects. Here the specific cross border fiber will be part of a communication system, pathed up according to customer's needs. Examples hereof might be international private business networks, defense and military networks extensions, university and research networks. These networks are running between larger cities and are patched up by more different network segments from different infrastructure owners by network architects.

Table 6 shows a business canvas of the post-installation process.

5.2.1 SLA and Maintenance

Lease agreements are managed products and comes normally with a guaranteed availability and repair time. This is called Service Level Agreement (SLA)

The agreed service level will define the reaction time and repair time for fiber customers. For the fiber operator actions must be taken to keep the cost of compliance with the customer SLA to an affordable level. When the operator fails to deliver, the SLA normally set forward claims for economical compensation.
This is where the agreement differs between standard lease agreement and IRU (ownership), for an IRU it is normal to have a joint responsibility and not a customer/vendor SLA agreement.

<table>
<tr><th colspan="6">Post-installation – subsea cross border cable</th></tr>
<tr>
<td rowspan="2">Key Partners

Surveillance providers – drones.

Maintenance and repair providers – divers and cable boats.</td>
<td>Key Activities

Surveillance and maintenance of the cable.

Selling leases.</td>
<td rowspan="2" colspan="2">Value Proposition

-Dark fiber leases – typically 3-5 years.
-Maintenance and repair.
-SLA</td>
<td>Customer Relationship

-Direct contact to sell lease agreements.
-Solution designers
-Reseller</td>
<td rowspan="2">Customer Segment

-Data centers
-Defense and military
-International Carriers
-Infrastructure owners
-Cloud Service Providers
-Private networks</td>
</tr>
<tr>
<td>Key Resources

Marketing/Sales

Maintenance Team, Cable boat, Surveillance drones</td>
<td>Channels

-Marketing – be visible at conferences and fairs.
-Supporting Solution designers</td>
</tr>
<tr>
<td colspan="3">Cost structure

Loan – down payment.
Sales cost.
Maintenance cost.</td>
<td colspan="3">Revenue Stream

Sales – leasing contracts.</td>
</tr>
</table>

Table 6: Osterwalder business canvas - post-installation.

5.3 Comparison

It seems to be a great difference in business proposal when the actor is in possession of an operational cable (post-installation) or if he is working on financing a potential project (pre-installation)

By using IRU agreements, a split ownership is agreed to. In this phase mutual agreements can be done, and the partners can agree on project design and important parameters and essential specifications, forming the best project and features for the interested parties.

In second phase, post-installation, the fiber project is financed and closed, and the fiber is available for traffic. This means that all design and all feature choices are taken. The finished product, dark fiber at given spec is available.

Studying these two aspects expose that they have different products, different responsibility, different pricing and different risk, and thus the customer proposal and customer value might be different.

Customers or partners joining forces before the project is defined will be able to affect the project specifications and recommendations. Thus, this has a value for the specific customer.

Fiber characteristics and fiber route, placement and protection are defined in phase one, pre-installation. When the project has ordered the cable and the laying process has started, there are still areas to affect and tweak to improve quality and selling points. These factors are related to the second phase, post-installation, and are related to maintenance and operation quality and cost. This will be presented and discussed in the following chapter.

All these effects or factors will be evaluated with a cost-benefit approach, and there might be numerous evaluation criteria’s.

6 Investment, Value and Pricing Factors

This chapter present the factors found from studying the business model and interviewing the cable operators and customers [6] [7] [8] [5] [9]. The effects of this are presented and discussed.

6.1 Investment Perspective

According to the business model, the investor or cable owner always look for the most cost optimal solution, or the solution that requires less investment. Most of the investment choices will represent quality effect or other effects to the fiber customer, some more, other less. Some effects might have an opposite consequence in the business case and must therefore be focused on, in a total perspective. One foreseen effect caused by fiber quality, used as an example here is that high quality reduces the sale volume as the quality can be so high that customers need fewer pairs.

The investor sees all quality enhancements as cost drivers, and needs to see that the investment pays off in sales volume or better pricing.

For the customer or buying partner all unnecessary investments will always be seen as extra cost of no interest. Therefore, a trade-off in some sense will be necessary.

6.2 New Route

From an investment perspective, investing in something unique represent a risk but it also represent the greatest opportunity. Before the infrastructure is installed there is no demand, as this is not an option. Thus, foreseeing the demand is problematic, as the existing potential customers have already working alternatives.

The opportunity lies in the new enhanced business proposal, represented by other parameters like shorter route, reduced latency, fewer connection points etc.

Latency is one of the most focused criteria in data communication. Low latency enhances the possibility of remote service productionas well as the market for services, typical cloud services. According to that, a new route with low latency can open for new markets. An example of this is that Norwegian cloud production from Norwegian data centers will have reduced latency towards customers in Denmark, Germany and Great Britain, with the new planned cables from the west coast and Oslo region (see Figure 1). This will provide an increased market value. Partners bundling the low latency cable with their offering will have a comparative lower latency feature or have the ability to produce for a larger market.

Projects that are investing in establishing new cross border fiber systems, representing more direct routes to interesting destinations, creates a uniqueness and seems to be attractive and price driving in the dark fiber market.

Investment

- Cost of new project

Effect for Operator

- Unique position
- Comparative latency parameter

Effect for Customer

- Reduced latency
- New or increased market position
- Comparative lower latency services

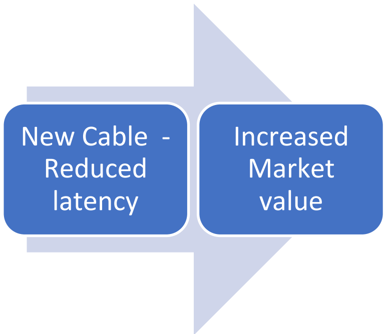


Figure 10:Effect of new route.

6.3 Fiber Quality I

There are different types of fiber quality in the market, and these comes at different prices.

High quality fiber in this context is typically ULL fiber, more information in Section 2.4. With ULL it is possible to obtain better signal over longer distances and thus reduce the need of more complex amplification systems, and system tuning and optimization. As amplified or repeated fiber systems require more installed equipment these systems impose higher complexity and cost. More system elements (repeaters) involved also by nature increase the risk for failures, even though the MTBF, see Section 2.8, for modern subsea systems, with redundant repeaters are extremely high.

ULL fiber has higher cost than traditional fiber. If repeaters can be avoided by ULL it is anticipated that the cost of an unrepeated system still will be lower than a Repeated Optical Cable (ROC) system.

Using ULL to reduce complexity by involving less equipment and lower investment will clearly bring down both investment cost and operational cost/risk, and thus reduce the Total Cost of Ownership (TCO).

In general, a system with lower complexity will have less risk and will therefore be in position to provide a better SLA with respect to technical uptime, which is a feature the customer will pay for.

As mentioned above, there are more advantages when investing in high quality fiber:

- Enhanced reach gives better signal at longer distances
- Less equipment (no repeaters)
- Less system design and tuning
- Less cost than repeated based system equals less TCO
- Less risk for outage

Investment

- ULL fiber costlier, compared to low grade fiber
- Compared to repeater system, ULL is cost efficient

Effect for Operator

- High quality fiber connections
- Less equipment, less risk for outage and problems gives a better SLA
- Lower TCO

Effect for Customer

- High quality fiber connections
- Reduced risk for outage

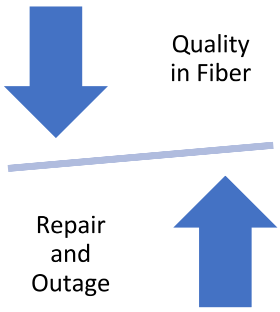


Figure 11: Effect of fiber quality I.

6.4 Fiber Quality II

An unrepeated fiber system allows for more parallel fiber in the cable, compared to a repeated system. As there is no amplification there is no impact to the light beam, which again opens for independent equipment per fiber and ability to catch up on technology development on fiber transmission systems. This flexibility will allow the fiber customer to expand capacity according to individual development in demand and technology. This is especially attractive for a customer having special requirement or wanting to deploy their own transmission and DWDM equipment on the fiber and thus control the wavelength specter by themselves.

Unrepeated fiber systems allow more pairs to be applied, as there is no limitation imposed by the physical wet-plant equipment or power transport.

Investment

- ULL fiber costlier compared to low grade fiber
- Compared to Repeater system, ULL is cost efficient

Effect for Operator

- Basis for higher capacity per fiber strand
- Pure dark fiber gives no technology dependencies for other transmission systems in wet-plant
- Possibly technology upgrades for enhanced capacity during the fiber lifespan, less dependency to amplifiers and wet-plant limitations, where this is avoided.

Effect for Customer

- Basis for higher capacity per fiber strand
- Ability to utilizing high capacity DWDM systems

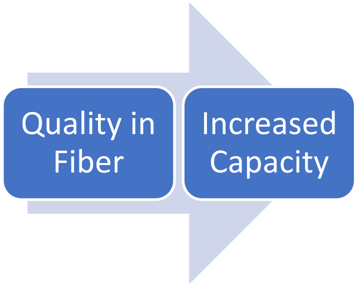


Figure 12: Effect of fiber quality II.

6.5 Planning and Deploying

In the planning process there are choices that can have impact on cable life time, risk for damages and need for repair. This affects cost for maintenance, but also the quality with respect to service stability or uptime, which is important for a good reputation.

During the down time, the cable does not provide any services, and thus makes no revenue for the cable owner or the partners and leasing customers. Thus down-time needs to be avoided by all means.

As mentioned in Section 3.2, there are several ways to protect the cable against wear and breakage. In short burying the cable deeper is costlier but gives better protection against damages from fishing and heavy-duty trawling equipment, which easily can tear an unprotected fiber cable apart.

Repairing a cable is costly and it also reduces revenues, as customer agreements (example SLA) might call for a reduced lease payment, compensation.

The motivation for the cable operator will be to invest in the planning and laying process to reduce the running operational cost. Normally this will be positive for the operational business case and TCO.

In the planning process the cable operator can invest in a safe and well natural protected route with little or no known risks for damages, or he need to take precautions to avoid damages by imposing more or less costly investment as burying the cable in the sea-bottom, covering with rock-dumping, or mounting cast-iron sleeves. These principles are described in Chapter 3. The cable itself can be armored to withstand physical stress and wear. Examples of cable armoring are shown initially in Figure 2. Unarmored, single armored or double armored have dramatically price differences both based on material cost, but also extra processing or production cost and risk.

Investment

- Better cable protection requires investment in preparation, investment in cable armoring and(or) investment in laying process

Effect for Operator

- Less outage
- Less cost for maintenance
- Better sales position
- Reduced TCO
- Better service quality – ability to provide a "higher SLA"
- Better total pricing

Effect for Customer

- Better service stability
- Reduced TCO

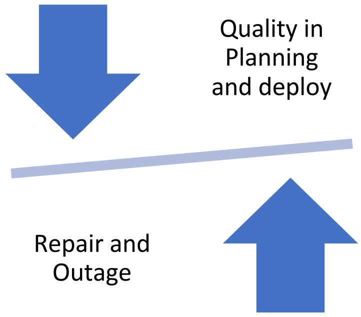


Figure 13: Effect of planning and deploying

6.6 Preventive Maintenance

Preventive maintenance is normally planned with the intention to mitigate or reduce risk for later damage, such as inspecting the cable and maintaining a safe cable placement, after storms and seabed changes, see more in Section 3.4. Such operations are costly but can be well planned and budgeted as part of the Operating Expenses (OPEX) budget.

For the operator this will be a trade-off between on one side preventive maintenance activity level and cost and on the other side reactive immediate repair and possibly more outage.

Seabed changes from changes in current and from submarine landslide might disclose or direct damage the cable.

Preventive maintenance is here inspection of the cable route and the cable itself, and to prepare repair and other mitigations to reduce the risk of outage by wear or damage.

Such inspections are normally done by lengthy and costly surveillance missions by expensive ships, carrying expensive equipment for seabed inspections. Submarine drones can be instructed to inspect a cable route autonomously on daily basis, and thus represent a higher protection level, but a higher investment.

Investment

- Preventive maintenance

Effect for Operator

- Reduces reactive maintenance – Fault and Error Correction

Effect for Customer

- Higher quality results in less outage

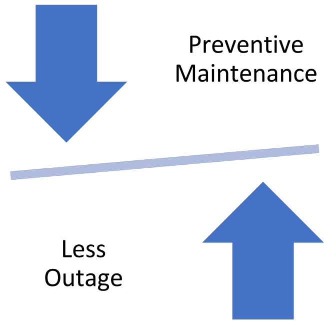


Figure 14: Effect of preventive maintenance.

6.7 Reactive Maintenance

Reactive maintenance is maintenance and repair work in accordance with imposed damages. Repair of subsea cables requires a "big operation" and is therefore costly and time consuming. To keep the time and cost at minimum, preparation and planning is essential. Quick repair or predictive repair times are basis for providing customer SLA at higher levels and higher quality.

Effective routines for repair, including callouts and repair materials will reduce the Time to Repair (TTR).

Some of the international subsea entrepreneurs provide a repair service agreement at a fixed yearly fee, which includes "immediate" access to a standby repair vessel. Per repair or call-out there is a variable cost fee based on day rate and fuel.

Investment

- Preparation work and investment
- Repair material and spares for warehouse
- Yearly fee for support and access to resources and repair vessel

Effect for Operator

- Reduced outage time
- Higher SLA value, with shorter response and repair times
- Less SLA compensation cost
- Predictable Maintenance cost gives less over-shoot due to planned and agreed routines and cost.

Effect for Customer

- Reduced outage time
- High quality

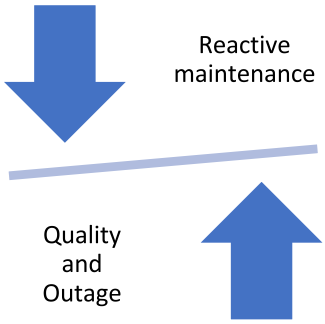


Figure 15: Effect of reactive maintenance.

6.8 Special Offerings - Managed Products

With reference to Section 2.7, the fiber operator might provide different offerings, packages of products and services. The different products and offerings will have different markets, customers and positions. Managed Products with higher SLA requires more effort to deliver and maintain. Managed products cannot be directly compared to dark fiber, but dark fiber is a prerequisite for capacity products.

Managed products are best delivered from an organization having experience as a telecommunication operator, while dark fiber alone can be provided by a pure infrastructure owner, providing dark fiber pairs.

Example for managed products
Investment

- Managed products to be sold require investments in a running business with 24x7 operational organization.

Effect for Operator

- Large competitive business segment

Effect for Customer

- More players in the competitive Capacity market

6.9 Security

The fiber systems can be specified to different levels of security.

Security in general covers unintended access to the physical system, or access to the data and services carried by the physical system. Thus, everything ranging from tampering and sabotage to information access and infiltration are security aspects to be of the fiber operators concern.

NKOM cares about risk where the operators are dependent on other operators or other countries telecom systems on different levels. If a failure in a supplier's system or organization can affect the transmission, they have an unwanted dependency. This dependency can be used efficiently to stop or hinder national security in certain situations, which again is focused by reports as a risk to the nation [41].

From this it is easily seen that the telecom operators and the Norwegian defense and military should have full individual control of all management levels of the network, and this should be operated from within Norway, contrary to the present situation of today.

In addition, it has been pinpointed that most traffic passes through Sweden, which according to the FRA-law [1], give the Swedish authorities the right to full insight in the actual data and information.

New cross border fiber systems should have an open architecture where the data center or telecom operator as a customer, can have full control over their infrastructure by operating the fiber. This is obtained by allowing the operators to install their equipment and manage the equipment at the landing station for the subsea cable, with a collocation agreement. It will also be important that these actors can operate their network equipment independently from each other, to maintain real independence and security.

A secure operation includes a prepared and protected operational environment, where operational dependencies such as power and physical access are prepared to a certain level. This includes redundant power solutions and availability of spare parts for keeping a guaranteed minimum repair-time and thus a high up-time, as up-time and availability is a security aspect.

For maintaining secure access to the physical installation, it should not be possible for unauthorized personnel to get access. An agreed security level including access- or key-management is essential.

Access to data are prohibited but might be done through directives as the FRA-law in Sweden.

Investment

- Invest in secure collocation infrastructure for hosting national operators and secure organizations in accordance to external requirements
- Provide cross border connections not involving Sweden.

Effect for Operator

- Unique position

Effect for Customer

- National security

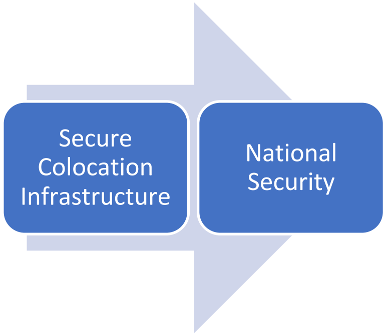


Figure 16:Effect of security.

6.10 Redundancy I

If the fiber infrastructure owner can provide a parallel, redundant infrastructure this is anticipated to be a significant value position, as this gives one stop shopping for the customers. This will have an important value for the customer not having established communication.

For the infrastructure owner, investing in parallel infrastructure represent a significant budget increase, but might lead to a unique market position, and thus a larger sales volume. This will also bound and focus the relation with the customer, as the account will represent a greater budget per customer.

Investment

- Redundancy means parallel infrastructure, higher cost, double investment for owner and operator

Effect for Operator

- Cost
- Potential uniqueness, better market position
- Potential sales
- Larger volume

Effect for Customer

- Better solution
- Preferred Solution
- Bigger investment/agreement

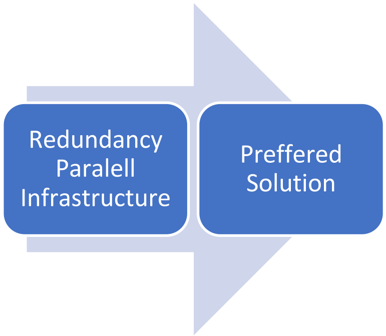


Figure 17:Effect of redundancy I.

6.11 Redundancy II

For customers who have already active traffic on an alternative route, buying access as redundant access is often seen as a “not mandatory route”, meaning the budget is lower than the primary route. To withstand this, arguments of better quality will be essential. As examples, lower latency, better SLA, higher capacity potential per fiber strand. Still there might be a risk for price erosion in the market, as there will be a known over-capacity and need for sale to keep business running.

Investment

- Double investment

Effect for Operator

- More capacity than market requires

Effect for Customer

- Known available volume leads to price erosion

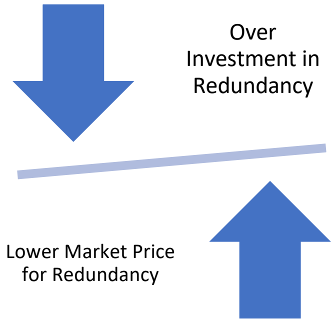


Figure 18: Effect of redundancy II.

6.12 Discussion

From the factors that can differentiate the various cross border fiber providers, it is here shown that different focus in the investment and preparation can give comparative advantages in a sales process.

The optimum choice seems to be to find the route that makes up the missing link in the sum of shortest paths in between high traffic nodes. Shortest route implicates lowest latency, which seems to be the most important value parameter. Thus, infrastructure positioned for efficient transport of traffic between high traffic nodes or hubs in the emerging network will be able to obtain the best prices.

Most customers will see a great value in high uptime or guaranteed repair times. This helps the customers to plan their service level, by calculating the need for other parallel solutions and redundancy. It can be expected that customers having a sole point to point perspective, or where the unique low latency is of high importance, will value the quality and repair parameters high, as their service are more dependent on this very link.

Data center and cloud services are a growing international industry. Cloud services need to propagate through the network to run efficiently as close to the user as possible, to provide best user experience. Thus, data and applications might be constantly moving and updating between data centers. This and other cloud requirement will require exchange of large data sets or volumes to match with accessible storage, compute, and analysis power. To handle these situations in an optimal way, large capacities between data centers will be established for data center development and for data interchange and for making the services globally available with low latency. It is therefore expected that data centers will require dark fiber end-to-end, to have full control of their communication capacity, to obtain the required flexibility, security and other required quality and manageable parameters, which sums up the main reasons for data centers to invest in dark fiber access rather than managed products like wavelengths or capacity. Data centers will need high capacity, low latency and high availability or redundancy.

Security is and will be of high importance for industries and governmental business and defense. Based on this, there might be even more focus on not to send traffic through Sweden. Providing international cross border links avoiding Sweden seems to be a selling point.

Unrepeated high-quality fiber links give the most flexible infrastructure and will provide for the dark fiber customer the widest flexibility and capacity and utilization of new transmission systems. It is expected that customers will pay more for an open system without spectrum limitation. Special line termination equipment and repeaters are examples of equipment that might cause spectrum limitations.

Complete one-stop-shopping solutions with end-to-end delivery and parallel redundant infrastructure might be of high value for customers not having comparable infrastructure in place.

The cost of adding more fiber strands in a fiber project is low, as the cost of fiber in an subsea cable is a fraction of the cost of the cable, and the cable is understood to be ¼ to ½ of the total project CAPEX (investment cost). By this, filling up the cable with fibers gives meaning, as it seems to have little direct cost impact, but a immediade high sales potential.

Broader availability of international cross border subsea fiber might also lead to price erosion in areas where the market is presented with more capacity and alternative routes than it can assimilate.

If more capacity and routes are available in the market, the competitive market will see reduced pricing. The customer might buy not double but quadruple parallel infrastructure, due to higher availability and lower pricing. If this is the new marked direction we can see redundancy solution with higher number of parallel links. The requirements for uptime and general quality will then be reduced per singular cable – but statistical the total uptime and quality will be better as log as the cables are statistically independently with respect to risk for outage. In this regime quality will not be a prioritized factor.

In this thesis, based on understandings from the interviewed experts, the market for dark fiber is mainly for professional data center or large infrastructure owners. The data centers need high capacity and flexibility for the inter-data center production. The infrastructure owners also need dark fiber to match the existing infrastructure, and to run the same set of services and management transparently through the entire network. Other users most often require capacity and will not prioritize to operate the physical fiber themselves, thus requiring managed products like IP-capacity or to some extent wavelengths.

Due to security reasons some business will require or have external requirements to secure full control of all parts of their network. This might be requirements due to national security and defense, high privacy requirements or business nature. Requirements like this is often set to prevent any dependencies from other parties who might be corrupted or infiltrated in different ways and thus represent an operational risk to the other party's communication and information. These customers might have few options, and one option will be to build completely private infrastructure to fulfill their precise requirements. Thus, these customers will be willing to invest in a cable project or in other ways secure that a project will come through as a cooperation, because this will be a reduced cost compared to being responsible for the full project themselves.

7 Conclusion and Future Work

In this chapter a conclusion of the master thesis will be presented. The conclusion will present a summary of the findings and suggest some future work.

7.1 Conclusion

This thesis has presented and discussed cross border subsea fiber systems and projects, fiber and fiber systems and how to deploy subsea fiber. It has focused on areas where design decisions might impact quality and value, in order to find factors that can be vital in pricing and in price comparison.

Today, long-haul fiber is priced per meter, and thus what seems to be the most important competitive factor, latency, seems not to be an appreciated value, as the longer fiber have higher market value than the shorter while the shorter have less latency, and thus have the preferred low latency.

Meter pricing is not based on project cost, rather the investment focus and gearing of the cable owner and investor.

It has been searched for other comparative factors.

An unrepeated cable based on G24 or G96, having 24 or 96 fiber strands, will in principle be the same cable in physics and production, except from the number of fiber in the central tube. Project cost difference is only singular percent. Project cost divided per fiber is significantly different. This shows that a universal meter price base should be challenged

The shortest route gives the highest value by means of lowest latency. Latency sets the border for application delivery and both human and machine to machine interaction (e.g. response time, disk mirroring). By investing in new routes having lower latency, the market for service delivery expands, and the value of the investment becomes larger. This should set the latency as the most important price factor.

Uptime and stability is directly impacting the fiber customers' service production, and thus the resulting customer value. Investing in a safe route and expensive cable burial or other protection will directly reduce risk for cable damage and thus increase uptime and stability. A protected route represents less outage and should represent a higher customer value.

Much the same arguments go for maintenance both proactive and reactive. Where in sum preparations and cost spending for reducing outage time and cost lead to less outage and shorter repair time and thus higher customer value.

Investing in fiber quality reduces attenuation and provides better performance. Positive performance increases customer value, as the market increases by reach, latency, capacity and capability.

In high quality open fiber systems, the partner or customer might use his own transmission or DWDM system, independent from the fiber systems special line termination equipment (SLTE). This gives the customer full flexibility as capacity can be increased directly by the customer. Thus, fiber quality and system openness is an appreciated customer value.

Uniqueness will always give a better customer value as long as the uniqueness matches the customer's needs. Best examples are the matching of endpoints with customer needs or the providing of the best latency between customer locations.

The conclusion of the discussion is that these factors should be evaluated more carefully in pricing of long haul submarine dark fiber systems, traditional meter pricing is not a sustainable pricing factor. Other factors might represent higher investment and larger customer effect and should therefore represent a higher direct impact on pricing. From the interviews the cable representatives clearly pointed that there are other important price parameters than length. As an example, Tampnet explained that price per meter would be a metrix, but quality parameters must represent a more important factor setting the total price.

Making these factors more available as pricing parameters, the market will stimulate the infrastructure developers and fiber operators to invest in projects having the appreciated performance and quality, and smartness in designing safe and efficient routes between the new important traffic hubs for internet and cloud traffic.

7.2 Future Work

For future work it would be interesting to study how this can be modelled and applied for concrete pricing. The challenge will be to gather the data to calculate this because developers and operators are keeping the numbers to themselves. Future studies will need pricing examples of both CAPEX and OPEX from developers and operators and their sales prices to be able to create these models.

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Appendix A: Cable Laying Vessels

From the industry of subsea contactors, this list is compiled the following list of Dedicated cable lay vessels (CLVs) that can be available for subsea projects in the nordics:

- NKT Victoria
  - Newbuild vessel designed primarily for high voltage cables. Delivered to Danish cable manufacturer NKT after they bought the business from ABB. Ship managed by Remøy
- Lewek Connector
  - Originally built for EMAS and outfitted for cable installation services for ABB. Owned by Ocean Yield, part of the Aker group. Bareboat charter terminated when EMAS went bust, but now charted short term to install cables at the Hornsea wind farm.
- Nexans Skagerrak
  - An older cable layer mainly used by Nexans to install their own products.
- Nexus
  - Built for dutch Van Oord for use on their renewables EPCI projects
- Ndeavor and Ndurance
  - Two similar CLVs buit for Boskalis in direct competition to Van Oord
- Maersk Connector / Deep Endeavour / Volantis
  - Part of a fleet of offshore construction vessels operated by Deepocean out of Haugesund. In addition to these three CLVs, they have a variety of cables ploughs & jet trenchers available.
- Cable Innovator / CS Sovereign / CS Recorder / etc
  - Part of the fleet of specialist CLVs operated by Global Marine
- Simon Stevin / Joseph Plateau / Willem de Vlamingh / Isaac Newton
  - Part of the fleet of offshore vessels operated by a Belgium civil engineering contractor

Pipelay vessels (PLVs)

- There are also a number of large vessels outfitted for rigid & flexible pipeline installation, featuring vertical reels and tensioning equipment. These are mostly controlled by large offshore EPCI contractors, but might have some availability for cable lay in a winter installation window. Most are not ideally outfitted for cable lay.

Offshore construction vessels (OCSVs)

- There are many subsea construction vessels that can be temporarily outfitted with carousels, cable lay and trenching equipment. This equipment is either controlled by the installation contractor, or can be rented from several sources.

In addition to the cable lay spread, there are vessels for:

1. pre-lay survey
2. route clearance
3. crossing preparation
4. shore approaches
5. ploughing
6. backfilling
7. crossing protection
8. post-lay survey
9. remedial burial

Some of these activities could be combined into campaigns, so require fewer vessels. A lot depends on your execution strategy, i.e. would you award all installation activities to the cable manufacturer in a single EPCI contract, separate the transport & installation scope, or select and award each phase of the offshore scope individually. There is a significant amount of engineering, planning & project management to be done in any scenario.

Appendix B: Fiber Tech

Figure 19 shows the building components of the typical subsea double armored optical cable. Much effort is put into safe guarding the fiber strands and protect from mechanical stress, water and oxygen, elements that damages or degrades the cable properties.

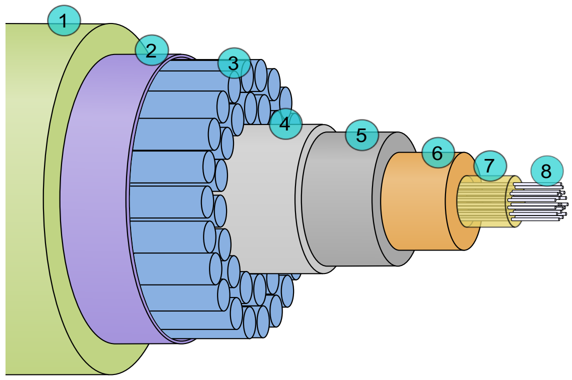

Figure 19: Illustration of an example of cable layers: 1. Polyethylene, 2. "Mylar" tape, 3. Stranded metal (steel) wires, 4. Aluminum water barrier, 5. Polycarbonate, 6. Copper or aluminum tube, 7. Petroleum jelly, 8. Optical

B.1 Dispersion

The light wave sent through the fiber are a subject to a phenomenon called dispersion. Chromatic Dispersion is a phenomenon caused by light at different frequencies traverses the cable with different speeds. Thus, the signal will be smeared out and this normally affects the signal detection precision. This have normally been one of the mayor limitation to data capacity in long-haul communication.
The length of the fiber affects the resulting effect of dispersion, the longer the cable is the more will the dispersion affect the signal. If the cable is too long the dispersion will result in a distorted signal which is unreadable by the receiving equipment.

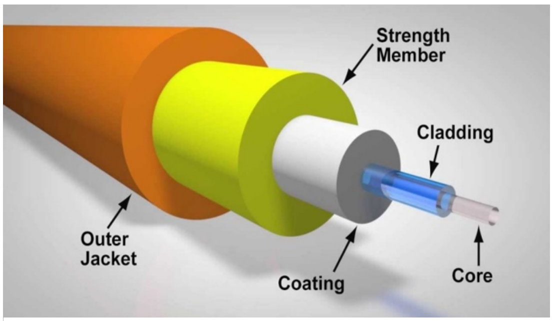

Figure 20: Illustration of cladding [66].

Due to refractive index and the light entry angle, and the consecutive angle with the fiber border, light might be reflected and kept in the glass guide of the fiber, the core or first medium. The rest of the light, not being immediately reflected will end up in the second medium, the cladding part of the fiber, thus giving the fiber different capabilities.

Figure 21 shows how the light having angle Beta, will be reflected and refracted and that the reflected part of the light will bounce or be dampened in the Medium 2 (cladding part, Figure 20, of the fiber).

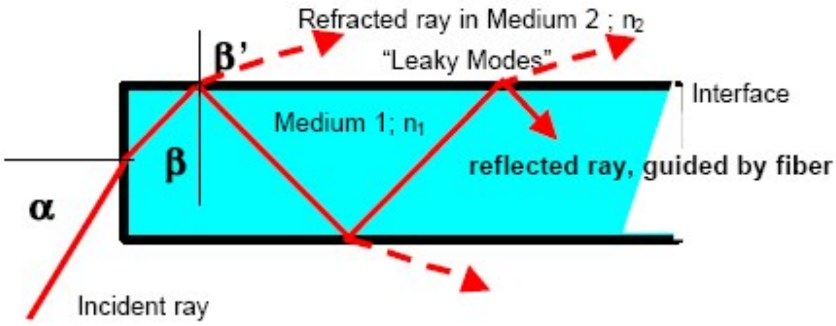

Figure 21: Illustration of reflection and refraction [67].

B.2 Single Mode vs Multimode Fiber

In a single mode fiber there is only one path for the light beam, while in multimode fiber the core is wider, and thus the light might be reflected and be able to traverse

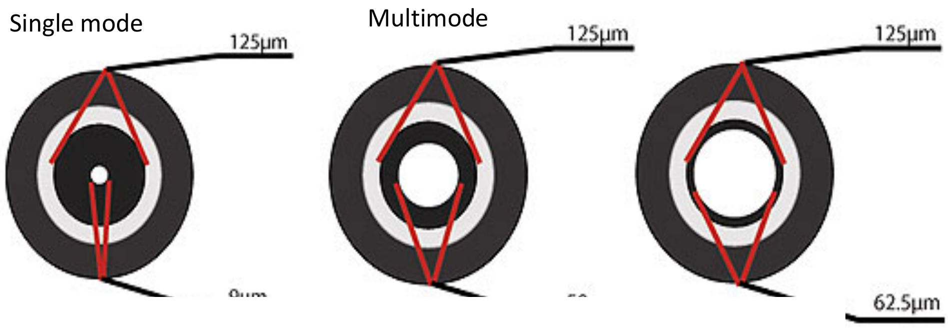

Figure 23:

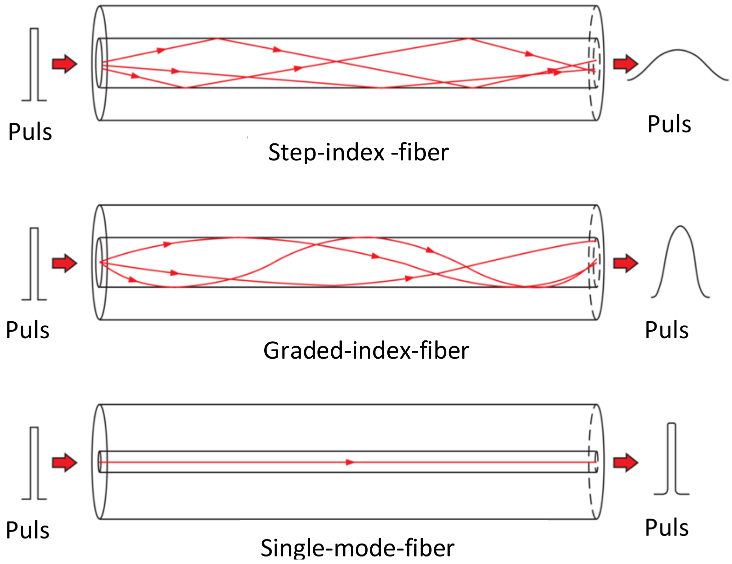

Figure 22: Illustration of the passage of light through different types of fiber [13].

various paths in the same fiber, which will represent different lengths. A light signal running a short path will be detected before the signal having run a longer part, thus signal will be smeared out. In single mode fiber, less (none) reflection will interfere with the light signal, and thus disturbances are avoided. The consequences of this is ability of better signal definition, and this leads to better capacity [54].

B.3 Cable Types

ITU (International Telecommunication Union) have defined standards for cable type and families, with different capabilities, like zero dispersion, dispersion shifted, cut of shifted etc. This refers to how the single fiber is designed with respect to the fiber-core and the so-called cladding, the rest of the material forming the singular fiber strand. These are referred to with number series as for example ITU G.652.D

Different single mode optical fibers defined by ITU-T include G.652, G.653, G.654, G.655, G.656 and G.657 [55]. Each single mode fiber type has its own area of application. The evolution of these optical fiber specifications reflects the evolution of transmission system technology. Choosing the correct can be vital in terms of performance, cost, reliability and safety.

B.4 Refractive Index and Latency

Optical Fiber Type	Wavelength	Refractive Index	Distance*
Brand A (G.652)	1310 nm	1.4677	204.260 m/μs
	1550 nm	1.4682	204.191 m/μs
Brand A (G.655)	1550 nm	1.468	204.218 m/μs
	1625 nm	1.469	204.079 m/μs
Brand B (G.652)	1310 nm	1.467	204.357 m/μs
	1550 nm	1.468	204.220 m/μs
Brand B (G.655)	1550 nm	1.470	203.940 m/μs
	1625 nm	1.470	203.940 m/μs

Table 7: Refractive index [56].

Table 7 shows the refractive index and the signal propagation speed in different cable types and at different wavelengths. The various cable types have different properties, which affects the refractive index of the special glass substrate used in the fiber [56].

B.5 Coherent Optics Detection

Since 2010 coherent optics have been deployed for fiberoptic long-haul systems and provides solutions to old problems like degrades signals due to chromatic dispersion, described in Section B1. Below is a cutout from manufacturer Ciena, and their insight articles [57], describing the coherent optics in a few lines.

"Coherent optics solves the capacity problems network providers are facing. It takes the typical ones and zeroes in a digital signal—the blinking on and off of the light in the fiber—and uses sophisticated technology to modulate the amplitude and phase of that light and send the signal across each of two polarizations. This, in turn, imparts considerably more information onto the light speeding through a fiber optic cable.

Coherent optical technology forms the foundation of the industry's drive to achieve transport speeds of 100G and beyond, delivering Terabits of information across a single fiber pair. Digital signal processors electronically compensate for Chromatic and Polarization Mode Dispersion (CD and PMD) to enable robust performance over old and new fibers alike and eliminate the need for dispersion-sloped compensating modules from the photonic line. Coherent optics enables greater network flexibility and programmability by supporting different baud rates and modulation formats. This results in greater flexibility in line rates, with scalability from 100G to 400G and beyond per single signal carrier, delivering increased data throughput at a lower cost per bit.

Advanced coherent optical technology has a number of key attributes, including:

High-gain soft-decision Forward Error Correction (FEC), which enables signals to traverse longer distances while requiring fewer regenerator points. It provides more margin, allowing higher bit-rate signals to traverse farther distances. This results in simpler photonic lines, less equipment, and lower costs—while, of course, increasing bandwidth significantly.

***Spectral shaping**, which provides greater capacity across cascaded Reconfigurable Optical Add-Drop Multiplexers (ROADMs), resulting in increased spectral efficiency for super channels. Spectral shaping is critical in flexible grid systems because it allows carriers to be squeezed closer together to maximize capacity.*

***Programmabilit**y, which means the technology can be tailored for a wide variety of networks and applications and the same card can support multiple modulation formats and/or different baud rates, enabling operators to choose from a variety of line rates. Fully programmable coherent transceivers provide a wide range of tunability options with fine granularity between incremental capacities, enabling network operators to make use of all available capacity and convert excess margin into revenue-generating services.*

***Strong mitigation to dispersion**, which offers better optical performance at higher bit-rates. Coherent processors must account for dispersion effects after the signal has been transmitted across the fiber, including compensating for CD and PMD. The advanced digital signal processors in coherent optics take away the headaches of planning dispersion maps and budgeting for PMD by mitigating these effects. Additionally, coherent processors improve tolerances for Polarization-Dependent Loss (PDL) and must rapidly track the State of Polarization (SOP) to avoid bit-errors due to cycle slips that would otherwise affect optical performance. As a result, operators can deploy line rates up to 400G per carrier across longer distances than ever; high bit-rate signals can even be deployed on old fiber that previously couldn't support 10G."* [57]