NTNU – Trondheim
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The Way Towards a Robust, Cost-Effective, and Future Proof National Mobile Network Infrastructure

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Title: The Way Towards a Robust, Cost-Effective, and Future Proof National Mobile Network Infrastructure

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Problem description:

Our society is becoming increasingly dependent on a stable, reliable electronic communications value chain. A growing number of basic functions in all sectors of society such as electricity supply, water, health care, transport, finance, etc. require that the networks, services and equipment work everywhere – and at all times. Even though it is impossible for a service provider to guarantee a complete and fully robust network, it is still possible to take precautions. Precautions may be to keep upgrading existing networks in terms of robustness and make strategic plans on how to secure electronic communications networks and handle situations that may occur in times of peace, crisis and war.

The demand for faster mobile broadband connections to the customers' premises is constantly increasing as new and more mobile broadband challenging services are being used. This raises the question if it's technical and cost-effective on a national level to build high capacity mobile broadband to everyone. Recent studies look to possibilities of implementing Network Functions Virtualization (NFV) into the next generation mobile network. By manipulating the edge infrastructure, virtualization of network functions may be able to coordinate physical resources and present them as virtual resources to cope with the baseband-up centralization problem.

To cope with the predicted evolution, several questions arise: What will be good enough in the future and who should pay for the investments required? The operators, the state, or a financial mix between the public and private sector? Is it acceptable that critical network functions are executed at computing sites outside Norway? How should we ensure that sufficient operation and maintenance expertise are available when needed? Should the state take more responsibility of building, developing and maintaining critical telecommunications infrastructure, e.g. similar to the case in the power- and road sectors? Is there a need for more regulation in the electronic communications market, or is the best solution to leave it up to the market forces to find the best solutions?

The objectives of the master thesis are:

- To investigate the offered network capacity, quality, and robustness of mobile networks today.
- To evaluate the network capabilities of mobile networks to the future service requirements and demands of users.
- To investigate different strategies for how to best develop the mobile infrastructure in the preferred direction, within a techno-economic and regulatory framework.

Assignment given:	12 January 2015
Responsible professor:	Bjarne E. Helvik, ITEM
Supervisor:	Bjørn Erik Eskedal, Nkom

Abstract

The increased use of mobile devices and the introduction of smartphones have changed the way people communicate. Over the last decade, mobile networks have become a critical infrastructure. Private individuals, governments and businesses rely on mobile networks to provide stable and robust services, both in everyday life and in crisis. There is also an increasing demand for capacity as new and more mobile broadband challenging services are being used. The society will rely on the mobile networks to provide higher capacity, more coverage and increased robustness in the future to come. This provides new challenges for all actors in the mobile industry, in order to meet the increasing demands of the society.

The thesis is written in collaboration with the Norwegian Communication Authority (Nkom) in order to investigate the future development of the mobile network infrastructure with a techno-economical and regulatory point of view. Through literature studies, the thesis has investigated the offered capacity, coverage, and robustness of mobile networks today, as well as the current market structure and current market shares in the Norwegian mobile market. The thesis has also defined and investigated four different strategies for future development of the mobile network infrastructure. Each strategy has been analyzed and evaluated based on nine selected factors, including coverage, capacity, robustness, and regulation. The strategies investigated are:

1. Continue current development
2. Tighter cooperation between Mobile Network Operators (MNOs)
3. Network Functions Virtualization (NFV)
4. A more active government

The thesis presents the results of the strategy analysis in a comparison matrix. The matrix provides an overview of the advantages and disadvantages of each strategy, based on the factors analyzed. In an overall perspective, the thesis found that a tighter cooperation between Mobile Network Operators seems to be the most beneficial strategy of the strategies investigated.

Sammendrag

Økt bruk av mobile enheter og innføringen av smarttelefoner har i stor grad endret måten mennesker kommuniserer på. Gjennom det siste tiåret, har mobilnettet utviklet seg til å bli en kritisk infrastruktur der både privatpersoner, myndigheter og bedrifter avhenger av at mobilnettet gir stabile og robuste tjenester, både i hverdagen og i krisetider. På grunn av at nye og mer bredbåndutfordrende tjenester blir tatt i bruk har vi sett en økende etterspørsel av kapasitet i mobilnettene. Det er forventet at samfunnet vil kreve mer av fremtidige mobilnett med tanke på høyere kapasitet, mer utbredelse av dekning og økt robusthet. Disse forventningene vil føre til nye utfordringer med tanke på videre utvikling av mobilnettene i mobilbransjen.

Oppgaven er skrevet i samarbeid med Norsk Kommunikasjonsmyndighet (Nkom) med mål om å undersøke den fremtidige utviklingen av den mobile nettverksinfrastrukturen med et teknoøkonomisk og regulatorisk synspunkt. Gjennom litteraturstudier, har oppgaven undersøkt den tilbudte kapasiteten, dekningen, og robustheten i mobilnettene i dag, så vel som dagens markedsstruktur og markedsandeler i det norske mobilmarkedet. Oppgaven har også definert og undersøkt fire ulike strategier for fremtidig utvikling av den mobile infrastrukturen. Hver strategi har blitt analysert og evaluert basert på ni utvalgte faktorer, blant annet dekning, kapasitet, robusthet og regulering. Strategiene som er undersøkt er:

1. Fortsett dagens utvikling
2. Strammere samarbeid mellom mobile nettverksoperatører
3. Virtualisering av nettverksfunksjoner (NFV)
4. En mer aktiv stat

Oppgaven presenterer resultatene fra analysen i en sammenligningsmatrise der hver strategi er representert og sammenlignet med sine respektive faktorer. Matrisen gir en oversikt over fordeler og ulemper ved hver strategi. I et overordnet perspektiv har oppgaven funnet at et tettere samarbeid mellom mobiloperatører ser ut til å være den mest gunstige strategien av strategiene analysert.

Preface

This masters' thesis serves as the final work and contribution to our Master of Science degree in Communication Technology at the Norwegian University of Science and Technology (NTNU). Both authors specialize in the field of ICT Economics at the Department of Telematics (ITEM), at the faculty of Information Technology, Mathematics and Electrical Engineering (IME).

First, we would like to thank our supervisor Bjørn Erik Eskedal, Specialist Director at Nkom, for his contribution and for providing valuable input on the subject.

We would also like to thank our responsible professor Bjarne Emil Helvik, at the Department of Telematics (ITEM), for his guidance and valuable feedback throughout the semester.

Morten Eriksen and Petter Bergendal
Trondheim, June 2015

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Chapter 1 Introduction

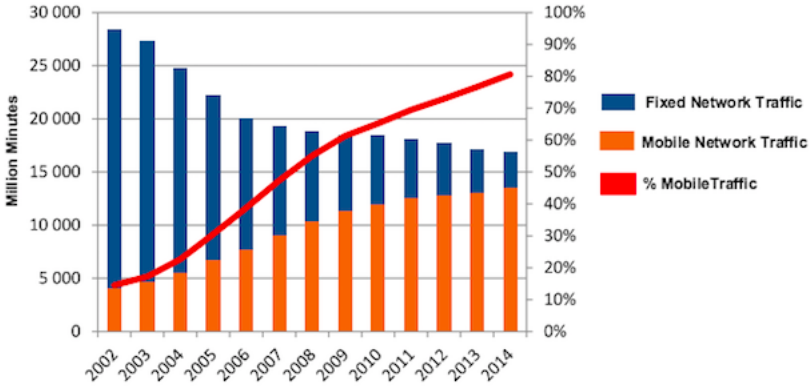
1.1 Motivation

During the last decade, there have been significant changes in the Electronic Communication (ECOM) industry. Mobile devices have replaced traditional fixed telephones as the primary source of communication for end-users. Thus, mobile networks are relied on, now more than ever, to provide a stable and robust service.

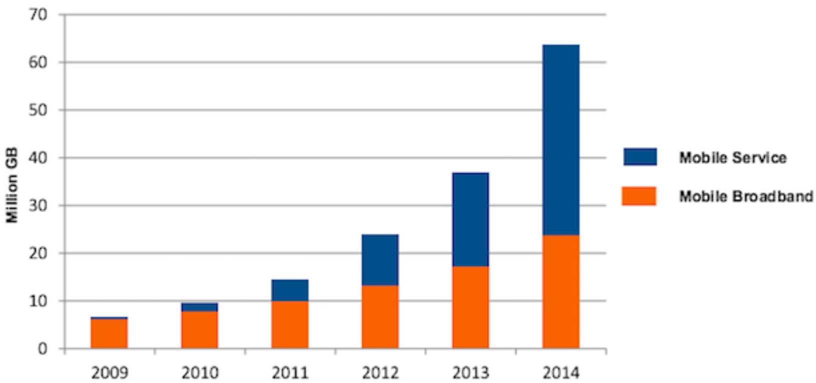
Trends in the Norwegian mobile market indicates a strong increase in mobile voice- and data traffic. Figure 1.1(a) documents a reduction in the generated voice traffic residing in fixed networks and also illustrates the communication change to a mobile future. In 2014, the mobile networks generated approximately 81% of the total voice traffic in the Norwegian ECOM market. Figure 1.1(b) illustrates the significant increase of generated data traffic in the Norwegian mobile networks.
The increase of wireless devices and introduction of smartphones has resulted in a global data explosion which is forecasted to increase to a six-fold over the next four years [1].

To cope with the predicted evolution, future mobile networks will have to provide a robust service offering bandwidth, connection speeds, and quality of service to a large amount of connections simultaneously. Actors in the ECOM industry will continue to investigate new and innovative solutions to further develop the mobile networks to cope with these future challenges.

A growing number of basic functions of the society requires network services and equipment to function everywhere and at all times. As more critical functions are embedded in the mobile networks, society will become even more dependent on reliable mobile communications solutions. Expectations of quality, robustness, and capacity of the mobile infrastructure increases and will continue to do so.



(a) Development of voice traffic in the Norwegian fixed- and mobile networks.



(b) Development of data traffic in Norwegian mobile networks.

Figure 1.1: Development trends in Norwegian mobile networks, [2]

The Norwegian ECOM industry is regulated by the Norwegian Communications Authority (Nkom). Nkom has a societal mission to secure good, reasonably priced and future-oriented ECOM services through efficient use of society's resources, as well as fostering industrial development and innovation. Nkom is responsible to map and audit the national mobile network infrastructure in order to ensure technical development, reliability, and robustness.

This masters' thesis is proposed by Nkom, in order to investigate how to further develop the mobile infrastructure to meet the challenging demands in the future.

1.2 Objectives

The project description proposes three main objectives for the thesis:

- To investigate the offered network capacity, quality, and robustness of mobile networks today.
- To evaluate the network capabilities of mobile networks to the future service requirements and demands of users.
- To investigate different strategies for how to best develop the mobile infrastructure in the preferred direction, within a techno-economic and regulatory framework.

1.3 Scope and Limitations

The problem description for this thesis was written in January 2015 in collaboration with our supervisor and professor. Some slight modifications have been made to the original objectives during the work on the thesis, and these changes will be explained in this section.

During the initial stage it was suggested from our supervisor that coverage was an aspect that should also be highlighted in this thesis. Thus, investigation of the offered coverage of mobile networks today is included in the thesis. It is also a factor considered when investigating strategies for future development of the mobile infrastructure.

It also became clear that for Nkom, the most important objective was the investigation of different strategies for future development of the mobile infrastructure. Therefore, the last objective is the main focus of this masters thesis. The focus on this objective resulted in that the second objective is not explicitly evaluated, it is, however, to some extent evaluated through the investigation of the different strategies.

The third objective states that strategies should be investigated based on a preferred direction of development. The thesis does not define a preferred direction, the strategies are instead investigated based on a set of factors and the impact the strategy has on these factors. This way one can easier relate and compare the strategies to each other.

Investigation of Network Functions Virtualization (NFV) will refer to the concept of Software Defined Network (SDN). The scope of this thesis does not include technical details and further development of SDN, but nearly inform of relation between SDN and NFV and the existence of research on the subject.

1.4 Methodology

The methodology used to achieve the thesis' objectives can be divided into two parts: literature study and strategy investigation, and will be explained briefly in this section.

1.4.1 Literature Study

A literature study has been conducted in order to investigate the topics defined in the problem description, and literature sources have been the main source of information. The research has evaluated the technological, economical and regulatory trends in the current mobile market in order to define and analyze the strategies for future mobile development.

A thorough investigation of the mobile generation development and the Norwegian mobile market has been done in order to better understand where the future challenges originate in the mobile networks.

The thesis provides a study on the concept of NFV and its potential benefits. NFV was introduced and included as a strategy during the first stages of the writing process. Literature study on the concept has been challenging and time-demanding, but through personal correspondence with Telenor and Nokia Networks and research seminars as additional information, a broader perspective was achieved.

The literature study is the foundation on which the strategies emerges from.

1.4.2 Strategy Investigation

The strategy investigation is the main part of the thesis and the the process can be divided into four parts:

- **Strategy definition:** The first part consists of defining the strategies to be investigated. The strategies are defined based on trends found in literature and the general interests of Nkom.
- **Definition of factors:** The second part consists of defining the factors to be analyzed in each strategy. The factors reflect the techno-economic and regulatory approach of the investigation as well as Nkom's interests.

- **Analysis:** The third part consists of analyzing each strategy based on the defined factors. Each factor is analyzed based on sources found in the literature study.
- **Evaluation:** For each strategy, an evaluation is conducted. The evaluation is based on a 5-point scale going from very negative to very positive, where each factor analyzed is given a score on the scale based on how the strategy potentially could affect the given factor. The scores on each factor also lay the foundation of creating a comparison matrix, in order to compare the different strategies.

The procedure of the strategy investigation is further elaborated in Chapter 4.

1.5 Contribution

The main contribution of this thesis is the investigation and evaluation of four possible strategies for future development of mobile network infrastructure. It will hopefully provide value for Nkom in their work of ensuring robust and future-oriented mobile services for end users.

1.6 Related work

The thesis has not been able to find any similar or comparable research during the literature study. However, the thesis has a wide scope and a large amount of research exists within each area.

In recent years researchers, standardizing organizations, vendors, and network operators have studied virtualization of infrastructure components and ways to standardize a common solution, NFV is one of these solutions which are currently under development. In November 2012, The European Telecommunications Standards Institute (ETSI) started the Industry Specification Group (ISG) for NFV, which includes over 230 individual companies, to establish and develop the standards of NFV. So far, the study carried out, by ISG, has resulted in three white papers [3, 4, 5], a paper regarding NFV resilience [6] and a paper describing NFV use cases [7].

Network sharing is another topic covered by the strategies, where operators cooperate and share the mobile infrastructure. Belgian Institute for Postal Services and Telecommunications (BIPT) [8] looks into pros and cons of different network sharing agreements between operators from a regulator's point of view. Frisanco et al. [9] investigate network sharing from an operators point of view, and looks into the technology, regulatory and business landscape, as well as modeling potential cost savings. In [10], Mölleryd et al. investigate the diffusion of network sharing, and looks especially into network sharing in Sweden. Furthermore, an analysis is conducted in order to assess the financial and competitive impacts of network sharing. While Markendahl et al. [11] investigate why and how operators cooperate through a case study of network sharing in Sweden.

Similar for most of the previous work is that only few aspects or one viewpoint is considered. The thesis will use these, and other sources, and put them in a wider context related to the factors investigated for each strategy.

1.7 Outline

The thesis is structured into six chapters, and the outline is as follow:

- Chapter 1, Introduction: includes the motivation and objective for the thesis. The introduction chapter also contains scope and limitations, methodology, contribution and related work.
- Chapter 2, Background: presents the necessary background material for the thesis. A brief summary of the mobile generation development in the mobile networks and their respective technologies is presented. The chapter includes an introduction of the NFV concept before future trends and challenges in development of mobile usage is presented.
- Chapter 3, The Norwegian Mobile Market: evaluates the current market structure in Norway and presents an estimation of the current market shares of mobile services. The chapter also provides a thorough investigation of the offered coverage, capacity, and robustness in the Norwegian mobile market.
- Chapter 4, Strategies: investigates four strategies for future development of the mobile networks based on a set of factors. The strategies are: 1. Continue current development, 2. Tighter cooperation between MNOs, 3. NFV and 4. A more active government.
- Chapter 5, Discussion: summarizes and compares the results of the investigated strategies. A brief discussion on robustness is included in order to highlight some current issues in the ECOM industry today.
- Chapter 6, Concluding remarks: concludes the thesis and proposes further work on the topics.

Chapter 2
Background

This chapter will present relevant theory evaluated in the literature study and describe the necessary background information for the thesis. The background provides a brief introduction of the generation development of mobile networks, and some future technological trends currently under evaluation for future development of mobile networks. Finally trends and challenges of mobile usage are looked at.

2.1 Mobile Telecommunication Systems

A mobile network is defined as a wireless network that provides communication over radio frequencies where Mobile Stations (MSs) can *roam* between *cells* controlled by *base stations* in a network, as illustrated in Figure 2.1. Inside the area coverage of mobile networks, the MSs can use services independent of location as MS and base station keep track of the MS position. These services are receive and initiate calls, send and receive data or other services. What separates the mobile networks from Wireless Local Area Network (WLAN) is the *roaming* ability in the network. *Roaming* refers to the ability for a user to access services while outside of its home network. A single cell is served by a single base station that supports the radio interface towards the MSs and the interface towards the telephone network and the Internet. *handover* between cells avoids disruption of an ongoing call or data session when a user moves from the coverage of one cell to another [12, Chapter 8.1].

The mobile network infrastructure can, in general, be separated into two parts, the Radio Access Network (RAN) and the core network. The RAN is the part of the network that allows end users to connect to the core network. It includes both passive and active elements. The passive elements include sites, mast, and cabinets while active elements are antennas, base station equipment, and circuits to link base stations to the core network[1] [13]. The core network is the central part of the

[1] Usually referred to as backhaul.

network, and it consists of components responsible for switching, service invocation, authentication, billing and connectivity to other networks [12].

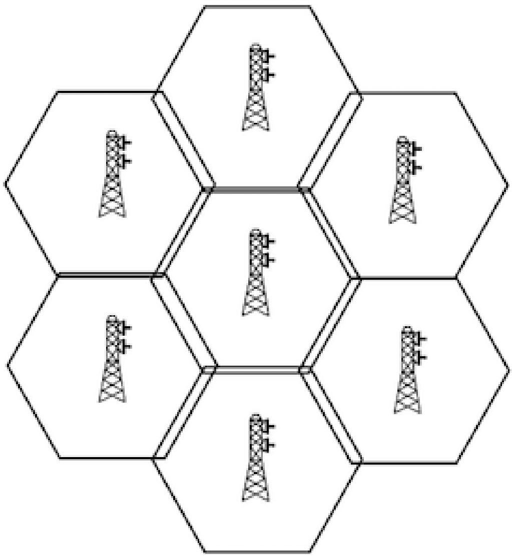


Figure 2.1: A simple illustration of cells and their respective base stations, modified from [12, Chapter 8.1]

2.1.1 The Mobile Generation Evolution

This section will present a brief introduction to the mobile generation evolution and their associated characteristics, to get a better understanding of mobile networks development. Table 2.1 summarizes the technologies and their key characteristics while Figure 2.2 illustrates the key aspects concerning architecture.

1G Since the launch of the first generation analog mobile telephone system in the 1980's, Public Land Mobile Telecommunication (PLMT) has developed continuously. PLMT was the name given by the International Telecommunication Union (ITU) to mobile networks offering mobile services on an international basis, to everyone. The first operational analog mobile network was Nordic Mobile Telephony (NMT). NMT was launched simultaneously in the Nordic countries Denmark, Finland, Sweden and Norway in 1981 and was the first mobile telephone network to provide *international roaming*[2]. The quality of the voice service in 1G was often inconsistent, and a common problem was "cross talk" between users. The analog mobile systems also

[2] *International roaming* is *roaming* across country borders.

supported Plain Old Telephony Systems (POTS) which is voice with some related services like 3-way calling, voicemail, caller ID and speed dialing [14].

2G In 1991, the second generation mobile telephone systems were launched. 2G is based on the Global System for Mobile communication (GSM) standard which is a digital circuit switched system. It allowed for digital encrypted phone conversations, greater penetration levels than 1G and introduced data services on mobile phones through Short Message Service (SMS), e-mail and Multimedia Messaging Service (MMS). With the digital technology, the capacity was enhanced, but using "low-bandwidth" the main focus was to offer a stable voice service with good coverage and not a higher capacity for data traffic. The main standards of 2G are based on Time Division Multiple Access (TDMA) [12, Chapter 5.3] or Code Division Multiple Access (CDMA) [12, Chapter 5.5] multiplexing technologies. GSM combines TDMA with frequency hopping and wideband transmission to minimize common types of interference. 2G has been further developed and evolved into 2.5G and 2.75G, known as General Packet Radio Service (GPRS) and Enhanced GPRS (EDGE) respectively. GPRS was the first step towards the development of 3G and is used for 2G-systems with implemented packet-switched domain opening up for packet data transmission in addition to the ordinary circuit-switched domain. EDGE is an enhancement of 2.5G, which provides increased transmission rates [15].

3G A commonly used name for the third generation network in Europe is Universal Mobile Telecommunication Services (UMTS). The driving force for UMTS was to implement voice and high-speed data services into a single system. UMTS combines the properties of circuit-switched voice network with the properties of packet-switched data network. Because of this, UMTS offers a multitude of new services than its predecessors. As many of the GSM components were reused for the initial UMTS, with modifications, UMTS Terrestrial Radio Access Network (UTRAN) was a new development provided by UMTS. UTRAN introduced a new air interface as a replacement of the time- and frequency multiplexing methods used in GSM, namely Wideband Code Division Multiple Access (WCDMA) [14, Chapter 3.14]. WCDMA is a spread spectrum modulation technique that uses channels with much greater bandwidth than needed for the data to be transferred. Instead of granting just wide enough frequency band to serve maximum data rate, the channels share a larger band. The modulation technique in WCDMA is similar to CDMA. By encoding each channel so a decoder, with knowledge of the code, may select right signal out the other signals using the same band. For more technical details on WCDMA and CDMA, read [16] and [12, Chapter 5.5] respectively. Similar to GSM, there has later been released enhancements of UMTS like High-Speed Downlink Packet Access (HSDPA) and High-Speed Packet Access (HSPA) which improves data rates and capacity [17].

4G The fourth generation network, Long Term Evolution (LTE), is a standard for high-speed radio access based on GSM/EDGE and UMTS/HSPA network technologies [14, Chapter 4]. LTE is the access part of the Evolved Packet System (EPS) as seen in Figure 2.2. The main improvements of LTE are increased downlink and uplink peak data rates, scalable bandwidth, and improved spectral efficiency. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink and Single Carrier - Frequency Division Multiple Access (SF-FDMA) for the uplink and is an all-Internet Protocol (IP) network supporting multiple access [18]. The LTE access network is a network of base stations called evolved NodeB (eNB) which generates a flat architecture as there is no intelligent controller, see Figure 2.2. The intelligence is distributed in the base stations and speeds up the connection set-up and handover time. The effects are improved customer experience in real-time data sessions like online gaming and real-time services like Skype and Facetime.

Long Term Evolution-Advanced (LTE-A) is a backward compatible enhancement of the LTE standard and provides higher bitrates in a cost efficient way. The main new functionalities are Carrier Aggregation (CA), support for Relay Nodes (RN) and enhanced use of multi-antenna techniques like Multiple-Input Multiple-Output (MIMO). More on LTE-A can be studied in [19].

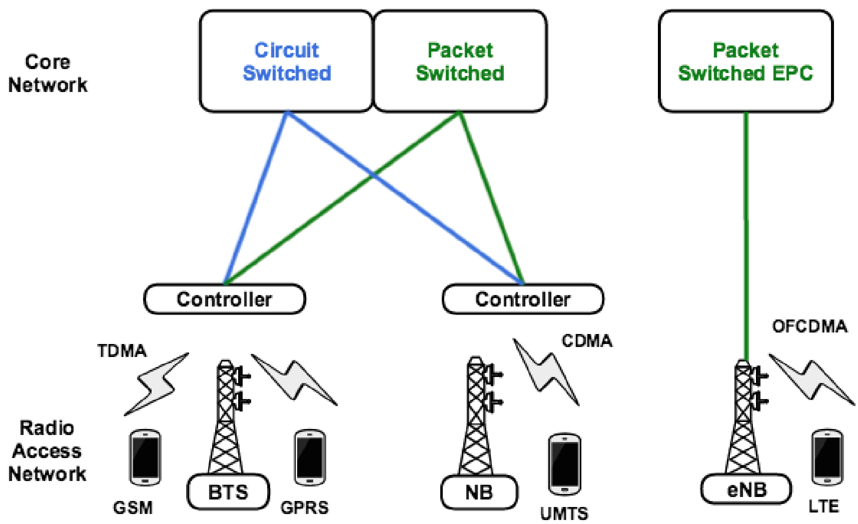


Figure 2.2: Network solutions from GSM to LTE, modified from [18]

	Key Characteristics	Standard	Peak downlink rate	Peak uplink rate
1G	Voice services only	NMT	-	-
2G	Voice service, SMS, data enhancement to GSM, simple multimedia services	GSM	-	-
		GPRS	115 kbps	115 kbps
		EDGE	474 kbps	474 kbps
3G	Data service of UTMS network, enhanced multimedia services (video streaming), new devices	UMTS	2 Mbps	768 kbps
		HSDPA	14,4 Mbps	1,5 Mbps
		HSPA	42 Mbps	11,5 Mbps
4G	Flat IP-based architecture, dedicated applications	LTE	326 Mbps	86 Mbps
		LTE-A	1 Gbps	500 Mbps

Table 2.1: Mobile Generations Comparison, modified from [20, 21]

2.1.2 5G

The fifth generation of mobile technology is expected to address the predicted increasing demands seen in Section 2.3. With enhanced performance, 5G aims to provide greater capacities, lower latency, higher connectivity, and reliability. It is expected that a 5G will operate in a highly heterogeneous environment with multiple access technologies, multilayer networks and multiple devices where the focus on security and trust will be provided. The Next Generation Mobile Networks (NGNM) Alliance works towards delivering 5G solutions by year 2020 in cooperation with operators, standards development organizations and other partners. Some technological benefits presented in the NGNM Alliance white paper on 5G are [22]:

- Improved data rates
- Enhanced spectrum efficiency
- Massive sensor deployments
- Enhanced signaling efficiency

Developers of 5G expect the evolution to go beyond the current capabilities of 4G and its extensions. There will be a need to include new radio interfaces using higher frequencies, support for the *Internet of Things (IoT)* and support for specific capabilities for services to come. 5G will not only look at the radio interfaces, but has the vision to include all aspects of the network, an end-to-end system connecting all access mechanisms. The IoT aspect of 5G is to include massive numbers of devices like sensors, mechanical devices and cameras to the IP network. The use cases of IoT presents a variety of demands and a wide range of new characteristics to be introduced [22]. IoT implementation has already started with e.g. Radio-Frequency Identification (RFID), Quick Response (QR) codes and Near Field Communication (NFC). Potential future application areas of IoT will be to further develop smart cities, smart water, smart environment, logistics, industrial control, eHealth and so on.

In order for 5G to achieve higher data rates than LTE, technologies like ultra-densification, mmWave, and massive MIMO are considered [23]:

- Ultra-densification means to put more nodes per unit area and more nodes per Hz. Making cells smaller is an extreme effective way to increase capacity. The use of smallcells will provide benefits of reuse of spectrum across a geographical area and fewer users per base station.
- The visions of 5G are based on usage of radio spectrum in the range of 30-300 gigahertz called Extremely High Frequency (EHF) or Millimetre Wave (MMW) to achieve high capacities. Use of high frequencies limits the range of base stations and it will be necessary to have a multitude of sites within small areas to provide these high capacities.
- MIMO is a technology where multiple antennas are used as transmitter and receiver. Antennas are combined to minimize errors and optimize speed.

For consumers, 5G will provide enhancements to support new and demanding applications. The 5G innovation will allow for faster development of new services like extreme real time communication and the IoT. For enterprises, 5G will provide capabilities to ensure reliability, security, privacy along with others [22].

2.2 NFV

Network Functions Virtualization (NFV) is a technology that has emerged in the ECOM industry to cope with recent challenges and demands for future development of current infrastructure.

The main principle of NFV is to virtualize parts of the infrastructure by realizing functions in software on generic high-volume servers, storage spaces and switches. NFV may consist of one or more virtual machines, also known as Virtualized Network Function (VNF). VNF runs different software and processes, on top of the generic hardware instead of having custom hardware appliances for each network function. Virtualization may potentially be implemented in all network functions and nodes in a network. The generic hardware may be located in datacenters, network nodes or locally with end users e.g. office buildings or company datacenters. The term that refers to the location in where a network function is implemented is called Network Functions Virtualization Infrastructure (NFVI)-Point of Presence (PoP) [3].

2.2.1 Architecture

The main architectural framework of NFV, as given by ETSI [4] is illustrated in Figure 2.3.

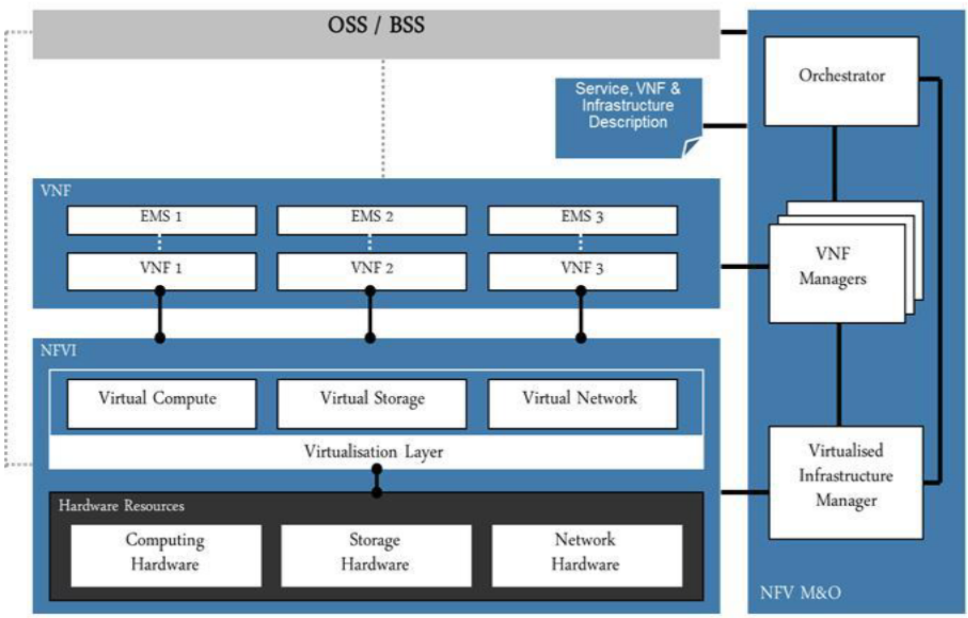


Figure 2.3: Network Function Virtualization Architecture, [4]

VNF

VNF is the software implementation of the network function, free from hardware dependency. VNF is the entity of today's network nodes. VNF is capable of running over NFVI and may be used together with Element Management System (EMS) which manages the individual VNF and its characteristics [4].

Network Functions Virtualization Infrastructure (NFVI)

NFVI provides the virtual resources to support the VNF. NFVI acts as a cloud data center and is used to host and connect virtual functions. Hardware resources, Commercial-Off-The-Shelf (COTS), containing servers, hypervisors[3], network hardware are the underlying layer while the virtual components and the software layer lies above [4].

NFV Management and Orchestration (M&O)

NFV M&O focuses on the management tasks that are specific for the virtualization and are necessary for the NFV framework. M&O is the brain of NFV and covers the orchestration and lifecycle management of software and physical resources that support the infrastructure virtualization. As shown in Figure 2.3, M&O includes three management components that interact with each layer. Interaction with the Operational Support System (OSS)/Business Support System (BSS) landscape allows NFV to be integrated into an already existing network-wide management landscape. The VNF Manager (VNFM) does the lifecycle management of VNF instances while the Virtualized Infrastructure Manager (VIM) does control management of the NFVI resources (compute, storage and networking) [4].

2.2.2 Challenges

Current research on NFV presents a wide range of challenges. The challenges vary in importance, technical difficulty, PoPs in the infrastructure and the time to solve.

In the first white paper on NFV ETSI stated some of the initial challenges that were to be addressed by the ISG committee [3]. In January 2015, ETSI published a resiliency requirements report presenting the current results from ISGs work on these challenges [6]. The report focuses on aspects of resiliency issues, fault management, and service availability in NFV and is a recommended reading for more details on the subject.

[3] A hypervisor/Virtual Machine Monitor (VMM) is a piece of computer software, firmware or hardware that creates and runs virtual machines.

Outage

In the IT industry, virtualization techniques and the use of cloud-based services are already in use and have been for some time. One of the main challenges with virtualization of mobile networks compared to the ICT industry is the high demand for outage management. To provide expected services, up-time in the mobile industry strives to reach the "five nines" (99.999%) to achieve stable and reliable communication. Compared to the mobile industry, outages in the IT industry are negligible [24].

Delay

Implementation of NFV will lead to increased delays as traffic will be transported through an additional layer, namely the virtualization layer. To cope with this challenge, the use of hardware accelerators is suggested[4] to improve efficiency in the processing [26].

Implementation

The implementation of NFV is a step by step process. One of the most challenging parts will be to enable an efficient migration to a fully virtual network infrastructure. The new virtual components need to be compatible with the existing operator systems and physical hardware while being able to function for its ordinary purpose, interacting with other NFV components [26].

A fully integrated NFV platform needs the BSS/OSS to move to a new model as well. It is believed that SDN could be an important addition to the system on this area [3]. The migration process of re-organizing the infrastructure also leads to challenges outside the technical scope. By switching to generic hardware and network functions in software, operators, and service providers are forced to make organizational changes internally [25]. A system running on NFV and SDN technology will be harder to administrate and demands experts with high technical knowledge and skills within the companies. NFV providers will likely experience a different setting compared to the present in the area of service responsibility. Today, service agreements on equipment in the infrastructure is a common solution. The responsibility of handling failures and updates in the different domains are often outsourced to external companies or vendors who already supply the operators. Come the next 10-15 years, delegating responsibility will be more complex, and the discussion on delegating responsibility within the different domains is ongoing [27].

[4] The use of hardware accelerators are mentioned in several research papers: [24, 25, 7].

2.2.3 NFV and SDN

SDN is often mentioned in combination with NFV. The two technologies are both based on the evolution of IT and cloud technology, and SDN appeared around the same time as NFV. The most important function of SDN is the separation of the control plane and the data plane. By separating the forwarding logic from the network control plane, SDN can abstract and control network resources, by programming the forward logic more freely. The idea of SDN is to put controllers in the infrastructure, either centralized or distributed. The controllers map the current state of the network and maintain a global view of the network [28, 3, 5].

2.3 Development of Mobile Usage - Trends and Challenges

Over the last decades, it has been a drastic change in how mobile networks are used, from being primarily used for voice communication to being utilized for a diversity of services by the end users. This has lead to an exponential growth in mobile data traffic. An illustrative example of this is that the global mobile data traffic in 2014 was almost 30 times the amount of the total global Internet traffic in 2000 [1]. There are several reasons for why we have seen this growth:

- The introduction of smart devices and the speed of adoption of these.

- Over-The-Top (OTT) services such as Youtube or Netflix.

- The fact that more and more parts of society utilize and is getting dependent on mobile communications.

It is expected that this development will continue for the next years, as forecasted by the oftenly cited reports from Cisco and Ericsson [1, 29]. *The Data Tsunami* is a term that has been oftenly used to describe these projections [30], referring to the enormous data traffic that is expected. Figure 2.4 shows how the global mobile data traffic is forecasted to increase by the six-fold over the next four years.

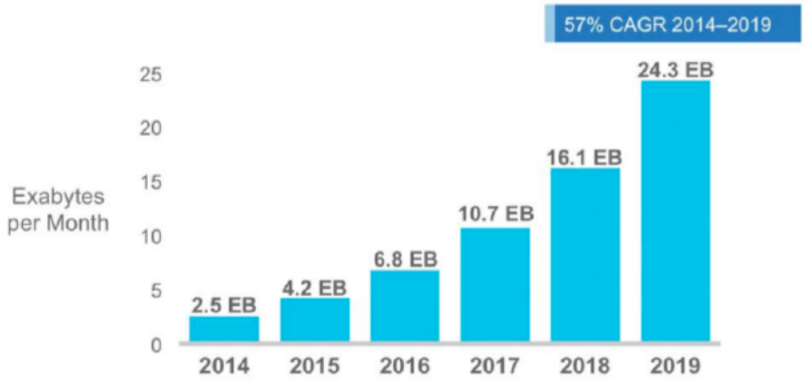


Figure 2.4: Exabytes per Month of Mobile Data Traffic in 2019, [1]

One of the major contributors to the growth of mobile data is, as mentioned, the development and adoption of wireless devices. The increase of wireless devices is expected to continue over the next years and by 2019 reach 11.5 billion devices, as illustrated in Figure 2.5.

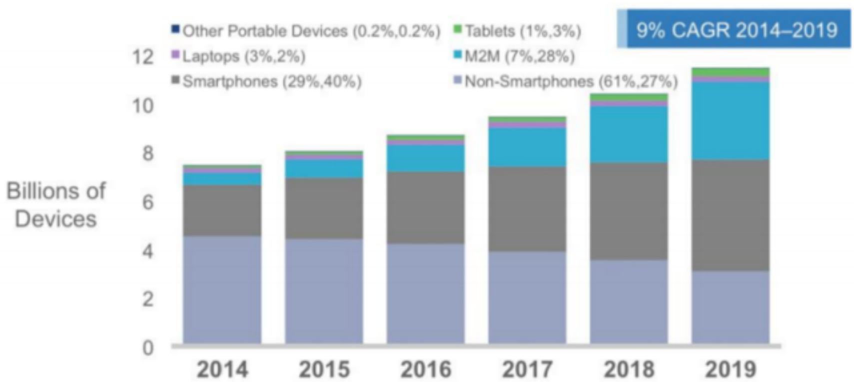


Figure 2.5: Global Mobile Devices and Connections Growth, [1]

We can further observe that the number of smartphones is expected to grow with 11% while non-smartphones is expected to have a severe decline. Another interesting trend is the large expected increase in Machine-to-Machine (M2M)[5] devices. The IoT is a new paradigm within wireless telecommunication which has rapidly been gaining

[5]M2M refers to technologies that allow both wireless and wired systems to communicate with other similar devices, e.g. a sensor capturing and relaying data to a translating software that presents captured information to the meaningful information.

ground, and it has a variety of potential applications. These can be grouped into four domains: *Transportation and Logistics*, *Healthcare*, *Smart environments* and *Personal and social* [31]. Within these domains, we have begun to see the development of applications and services which will be dependent on mobile communication such as smart grids, mobile health, and smart cities to mention a few.

Another suggested contributing factor to the growth experienced, are the OTT services, especially those providing video streaming. Today, mobile video represents more than a half of the mobile data traffic. This is a trend that will continue, and it is expected that the consumption of mobile video will grow with a Compound Annual Growth Rate (CAGR)[6] of 66% between 2014 and 2019 [1].

These trends provide several challenges for the future within the mobile domain, identified in several academic papers [32, 33, 23, 20]:

- **Demand for higher capacity and data rate:** The increasing demand for mobile data leads to that we in the future will need a much higher capacity in mobile networks than what we have today.
- **Spectrum scarcity:** The radio spectrum is a limited resource, and to meet the increasing need for capacity one needs both more spectrum bands and a higher spectral efficiency, making the spectrum scarcity a challenge for the future.
- **Reduction of costs:** It is foreseen that to deal with the increase of capacity usage one need to deploy more network nodes. Thus reduction of costs, such as Capital Expenditure (CAPEX)[7] and Operational Expenditure (OPEX)[8], is important for operators to find it commercially viable to meet the future capacity demands.
- **Robustness:** As the society grows more dependent on mobile networks, this puts further requirements on the robustness of networks. Especially if you also consider IoT applications such as smart grids or mobile health, where a network outage can have severe consequences.

[6]CAGR refers to the year-over-year growth rate of an investment over a specified period.

[7]CAPEX are funds used by a company to acquire or upgrade physical aspects. For mobile infrastructure, the CAPEX would be the investments operators make to deploy or upgrade their mobile networks.

[8]OPEX are expenses that incur a company as a result of performing its normal business operations. In terms of mobile infrastructure, this would be the expenses operators face to operate their mobile networks.

Chapter 3
The Norwegian Mobile Market

In this Chapter, the thesis studies the Norwegian mobile market to investigate the offered network capacity, quality and robustness of mobile networks today. The chapter also establishes a more detailed view of a typical telecom market.

3.1 Market Structure

The thesis studies the value chain in the Norwegian mobile market to describe the market structure. The value chain consists of network operators, mobile operators, distribution channels and end users as shown in Figure 3.1.

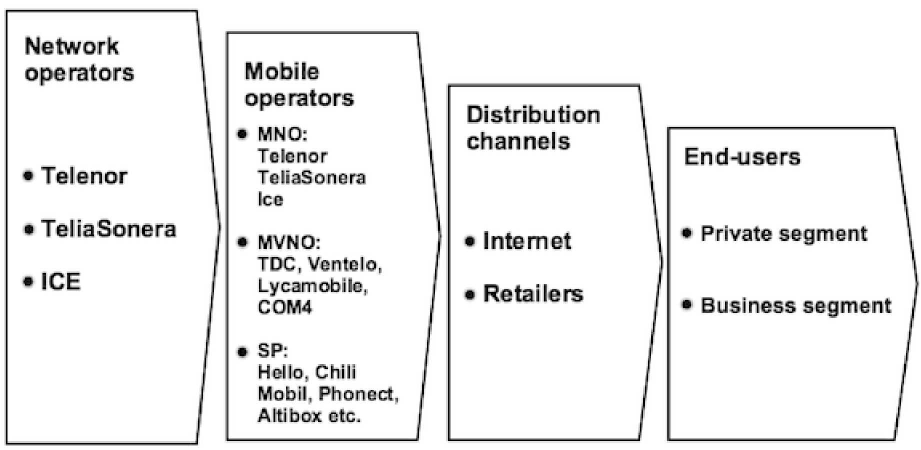


Figure 3.1: Value chain of the Norwegian mobile market, modified from [34]

3.1.1 Actors

Actors in a typical telecom market offer different mobile services. These services may be ordinary mobile services, dedicated Mobile Broadband (MBB) and M2M. Mobile services include what we call regular subscription solutions including voice traffic, SMS and mobile data. MBB includes subscription solutions for mobile broadband services only while M2M includes subscription and services for the machine to machine communication [34].

Network Operators

Network operators are providers of both wired and wireless network services. Internet Service Provider (ISP) and telephone companies both fall under this category. Telenor and TeliaSonera are the only two actors in Norway that have full population coverage through their mobile networks. For other companies to offer mobile services, access agreements have to be made to access the network operators infrastructure. The policy makers often regulate access prices and mandatory access to open up the networks for smaller companies and encourage competition.

Mobile Operators

A mobile operator may offer services either as a MNO, Mobile Virtual Network Operator (MVNO) or as a Service Provider (SP). The different operator types can be described as follows:

- MNO is a mobile operator that owns its radio-infrastructure and core network, and provides communications services to its customers through this infrastructure. A MNO typically holds its customer service and billing system. MNOs in Norway today is Telenor, TeliaSonera and ICE.

- MVNO is a mobile operator that has technical solutions to cooperate with other network operators, but does not own frequency resources. A MVNO provides services inside the customer segment using its own centres, technical service production and customer service systems. In Norway, MVNO access is granted TDC and Ventelo through Telenor's infrastructure while Lycamobile and Com4 have access agreements through TeliaSonera.

- SP is a mobile operator that offers access to mobile services for their customers by buying services through a MNO or a MVNO. These services are advertised as their own and the SP resell these services, according to their pricing. A SP offers customer service and billing to their clients but leaves the technical production of the product to the MNOs and MVNOs.

Distribution Channels and End Users

Operators distribute their services through channels or third-part retailers. Third-party retailers are typically electronic stores selling mobile devices with the operator subscriptions as a part of the product. Most of the distribution are made from the operators own webpage, allowing the customers to buy and compare the subscriptions to each other in order to find the most suitable product for the customers needs. The operators differentiate private and business subscriptions to the respective end users. A large company may negotiate a tailored contract with the operator instead of the ordinary business subscriptions offered. Web pages often offer a personal account providing a "My Page" option providing customer service, billing information and up-to-date usage overview.

3.1.2 The Mobile Landscape

The mobile landscape in Norway today is dominated by two operators, Telenor and TeliaSonera. For many years Tele2, was one of the big three competitors, providing mobile services through a small, geographically limited, mobile network. The infrastructure of Tele2 consisted of frequency resources in the 900 and 2100 MHz-Band and access infrastructure. For Tele2 to provide acceptable service for its customers, they had to rely on access agreements, national roaming, for access to the transport and core networks. After the frequency auction in December 2013, Tele2 lost their license in the 900 MHz-band forcing them to either sell or restructure the whole company. Tele2 chose to sell and on February the 5th 2015 the Norwegian Competition Authority approved Tele2 being acquired by TeliaSonera.

To secure healthy competition, the Norwegian Competition Authority had to ensure a third MNO to enter the retail market. During Nkom's last frequency auction, ICE won frequency licenses in the 800, 900 and 1800 MHz-Bands making them the natural choice for rising as a MNO challenger. The Norwegian Competition Authority could approve the merger by giving TeliaSonera obligations that would benefit ICE to a significant degree. With the terms listed below, and the recently obtained frequency licenses, ICE would get increased incentives to enter the retail market quickly and challenge the duopoly-like market structure.

The merger was approved on these terms:

- TeliaSonera has to sell infrastructure to ICE.
- ICE is granted roaming and SP access from TeliaSonera.
- TeliaSonera has to sell parts of Network Norway (NN) to ICE. This includes subscribers in the business segment, distribution network and frequencies.

- TeliaSonera has to offer MVNO access for other Norwegian actors.
- TeliaSonera has to offer infrastructure collocation to ICE.
- TeliaSonera has to offer to sell three Tele2-stores to ICE.

3.1.3 Market Shares

As seen in the previous section, the merger between TeliaSonera and Tele2 changed the Norwegian mobile market. In this section, the thesis will illustrate the changes and make an estimation of current market share distributions in the mobile service market. A market summary[1], presented in [2], gives a view of the market shares in the Norwegian mobile service market at the end of 2014, before TeliaSonera's acquisition of Tele2. A total market share includes both mobile service and MBB subscriptions. The estimation focus on mobile services only, hence MBB market shares are not presented in this section. Market shares in mobile services are presented in the number of subscriptions and compares information from 2013 to 2014.

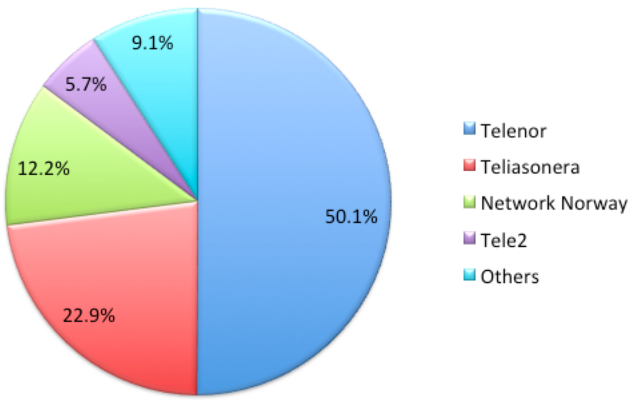


Figure 3.2: Market shares in the mobile service segment divided by actors, modified from [2]

Figure 3.2 illustrates the market shares in the mobile service subscriptions divided by the four dominant actors in 2014. There are few significant changes in the mobile service subscription segment from 2013 to 2014.

[1] Published as recent as May 20th, 2015.

Some small changes can, however, be highlighted:

- The four dominant actors in the segment controls 91% of the total subscriptions.
- Tele2 experienced a decrease of 1.1% from 2013 to 2014.
- NN experienced a increase of 1.0% from 2013 to 2014.

Figure 3.3 illustrates the market shares in the mobile service segment, divided by private and business segment respectively. By the end of 2014, 76.8% of the total shares in the Norwegian mobile market were distributed in the private segment, which is an equal amount compared to 2013.

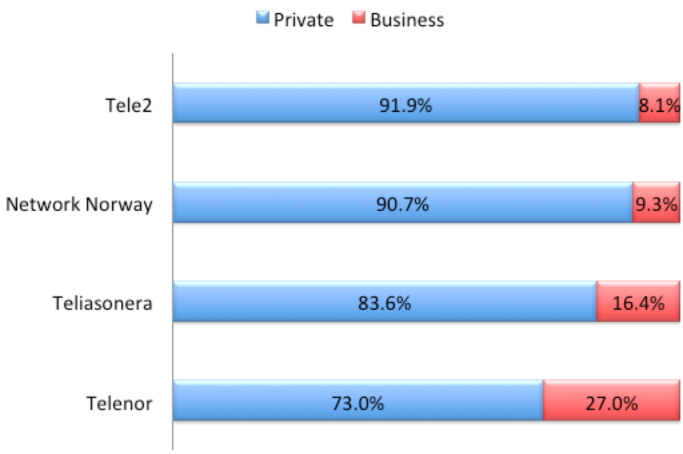


Figure 3.3: Market shares in the mobile service segment divided by private and business segment, modified from [2]

Information obtained from the Nkom summary combined with the information considering the acquisition of Tele2 can be used to create an estimation of the distribution of market shares after the acquisition. Information evaluated are:

- NN's subscriptions were divided between TeliaSonera and ICE:
  - Subscriptions in the private segment, 90.7% from NN's total market share of 12.2%, were assigned to TeliaSonera.
  - Subscriptions in the business segment, 9.3% from NN's total market share of 12.2%, were assigned to ICE.
- Subscriptions from Tele2 were obtained by TeliaSonera, and divided as follows:

- Additional subscriptions in the private segment, 91.9% points from Tele2's total market share of 5.7%.
- Additional subscriptions in the business segment, 8.1.% points from Tele2's total market share of 5.7%.

- Assumption that Telenor and the other actors are left unchanged.

The estimated market shares as of Q2 2015, divided by private and business segment, are presented in Figure 3.4. A comparison of Figure 3.3 and Figure 3.4 illustrates the changes from late 2014 to Q2 2015.

- With the new subscriptions from Tele2 and the obtained private segment subscriptions from NN, TeliaSonera has increased their position in the private and business segment.
  - A total increase of 5.7% mobile service subscriptions in the private segment, with 89.3% compared to 83.6% in 2014.
  - In the business segment, TeliaSonera has experienced a reduction from 16.4% to 10.7% in the company's total subscription distribution. The results are logical as the obtained subscriptions in the private segment is significantly higher than subscriptions obtained in the business segment.
- ICE as a new entrant has obtained subscriptions in the business segment and is a new entrant with 100% of their market shares residing in this segment.

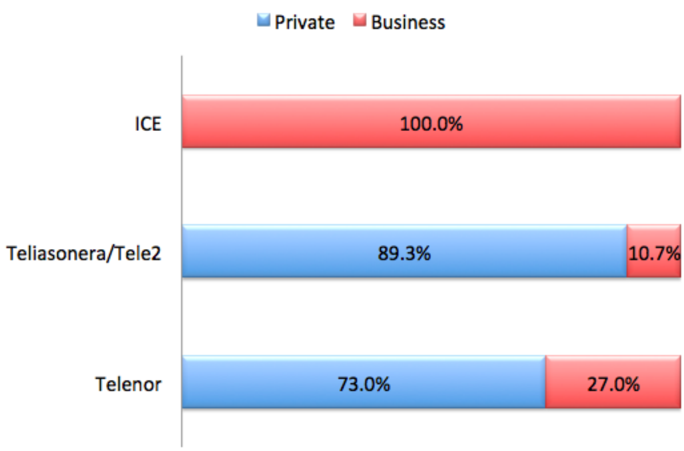


Figure 3.4: Estimated market shares in the mobile service segment divided by private and business segment

Figure 3.5 illustrates the total estimated market shares in the Norwegian mobile service subscription market. After the acquisition, Telenor and TeliaSonera are now controlling approximately 90% of the total mobile service subscribers in the Norwegian mobile market. TeliaSonera has increased their total market share by 16.8%, from 22.9% to 39.7% of the total subscriptions respectively. This shows that TeliaSonera has secured their position as a dominant MNO in reducing the gap to Telenor and increasing the gap to the contenders below.

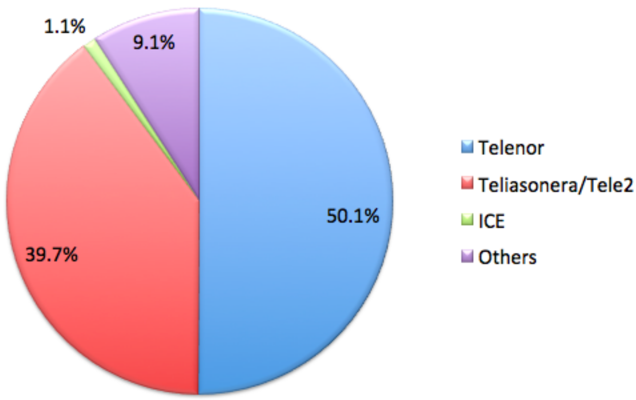


Figure 3.5: Estimated market shares in the mobile service segment divided by actors

3.2 Market Regulation

The Norwegian mobile market is regulated by the Nkom, which is the National Regulatory Agency (NRA). It is an independent agency under the Norwegian Ministry of Transport and Communications. Nkom act under The Electronic Communications Act [35] with the main societal mission to:

> *Secure good, reasonably priced and future-oriented electronic communications services for the users throughout the country through efficient use of society's resources by facilitating sustainable competition, as well as fostering industrial development and innovation.*[2]

Within the mobile domain Nkom's most important tasks are [36]:

- **To contribute and ensure that the end users have access to robust, secure and reliable mobile networks and services.** Nkom maps and continuously audit the infrastructure of national mobile networks, to keep up to date on the technological development and existing levels of robustness and reliability. Also, risk and vulnerability reports for critical infrastructure are conducted to identify concrete measures to improve the robustness and security. An example of such a measure is the minimum requirement for backup power in the mobile networks [37].
- **To contribute to an efficient regulation and facilitate a well functioning mobile market.** In general, the goal is to let the market operate on its own and establish a sustainable competition. However, there is a need for regulation to ensure the same terms of competition for all operators. For instance may operators be assigned several obligations if they are deemed to have a Significant Market Power (SMP). SMP means that individually or jointly with others, operators have a dominant position in the market and may act independently of its competitors [38]. An example is the incumbent operator, Telenor, that due to its SMP is given obligations to allow wholesale access to other operators (such as MVNOs and SPs) on a non-discriminating basis, and at prices that do not put the operators in a margin squeeze[3] [40].
- **To ensure an efficient use of frequency and number resources.** Nkom has the responsibility of managing the national number plan and frequencies for

[2] §1-1 The Electronic Communications Act [35]

[3] The notion refers to the possibility that the combination of retail prices and wholesale prices chosen by a vertically integrated operator makes the margin for other retailers so small that they can not effectively compete [39]

mobile networks. They also hold frequency auctions on behalf of the Norwegian government, to allocate frequency resources in the radio spectrum. The goal of the frequency management is to contribute to as large as possible social welfare over time through an efficient use of a limited and valuable resource. To achieve this few administrative burdens and restrictions with regards to technology and services are given, and with interference from the authority only when necessary [41].

3.3 Coverage

In this section, the thesis will investigate the coverage of the mobile networks in Norway. We will first look at the population coverage, then the area coverage and finally differences in coverage between urban and rural areas.

3.3.1 Population Coverage

First, the population coverage of mobile networks in Norway will be looked at. The population coverage is the amount of people that have outdoor access to a mobile network at their home address [42].

In their report on broadband coverage [42], Nkom looks into the outdoor coverage for 3G and 4G networks in Norway. 2G networks are excluded from the report since it focuses on mobile broadband, but the population coverage is around 99,8% [43]. Based on information on base stations, such as geographical data and technical specifications, gathered from MNOs, the report presents the theoretical coverage of mobile broadband in Norway as of second quarter of 2014. The calculation of coverage takes into account factors such as the distance from the base station and topography of both terrain and buildings. Based on numbers from this report, Figure 3.6 shows population coverage of both 3G and 4G networks. For the coverage of 4G networks, the coverage from the end of 2012 is also provided to illustrate the development of 4G networks over the last couple of years. It is important to notice that the 4G development in Norway is happening fast, and the coverage today is likely to be higher than these numbers from the end of the second quarter of 2014.

If we first look at the 3G coverage, 99% of the Norwegian population had access to a 3G network at the end of the second quarter of 2014. If we compare by county, the coverage varies from 100% in six counties to 93% in Sogn og Fjordane. The six counties with a 100% population coverage, Akershus, Aust-Agder, Oslo, Vest-Agder, Vestfold and Østfold, all share the same demographic characteristics, with a small total area and a high population density.

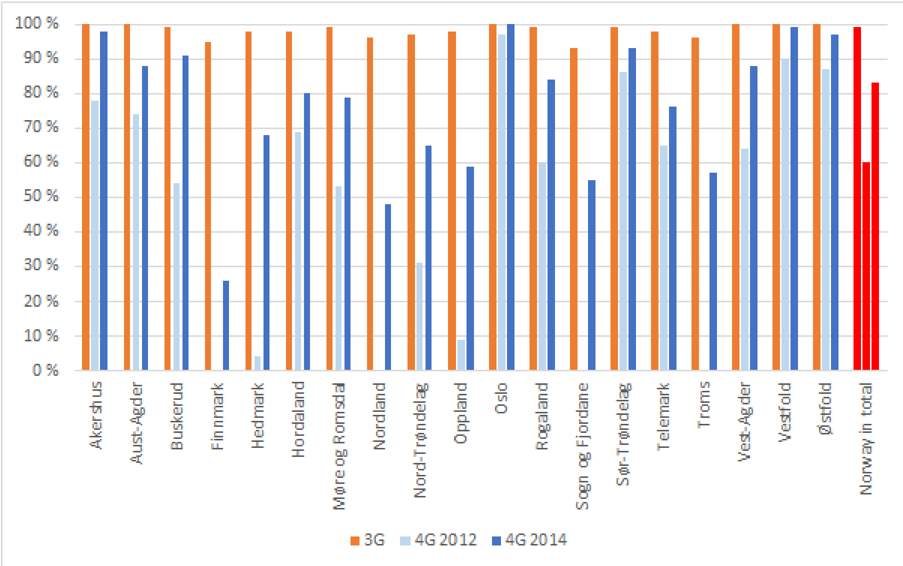


Figure 3.6: Population coverage of mobile networks in Norway by county, modified from [42]

For 4G coverage, 83% of the population had access to a 4G network as of second quarter of 2014. This is an increase of 23% from 2012. As of now, it is only Telenor and TeliaSonera that has a 4G network, and they opened in 2012 and 2009, respectively. The first phase of the rollout focused on larger cities and densely populated areas. This can be seen from the graph, and at the end of 2012, four sparsely populated counties, Finnmark, Nordland, Sogn og Fjordane and Troms, did not have access to any 4G network. As of second quarter of 2014, Oslo has the highest 4G coverage of the Norwegian counties with 100% population coverage. While Finnmark is on the other end of the scale, with only 26% of its population covered.

3.3.2 Area Coverage

As end users are increasingly using their mobile phones, and thus expecting to have coverage wherever they go, makes it interesting to look at the area coverage. Area coverage is the geographical area where an end user has access to a network.

The area coverage of 2G networks is approximately 82% [43]. For 3G and 4G networks, Nkom's report on mobile broadband [42], also presents the theoretical area coverage of 3G and 4G networks in Norway as of second quarter of 2014. Figure 3.7 show the area coverage of 3G and 4G networks, based on numbers from this report. ICE has a CDMA2000 network, which is a different technology from UMTS, used by other operators. It requires specialized equipment to send/receive data on ICE's network. Thus, normal mobile phones can not connect to this network. Also, ICE is using the 450MHz-band, which is a frequency that provides coverage over large areas [42]. Therefore, the area coverage without ICE's network is also included in Figure 3.7.

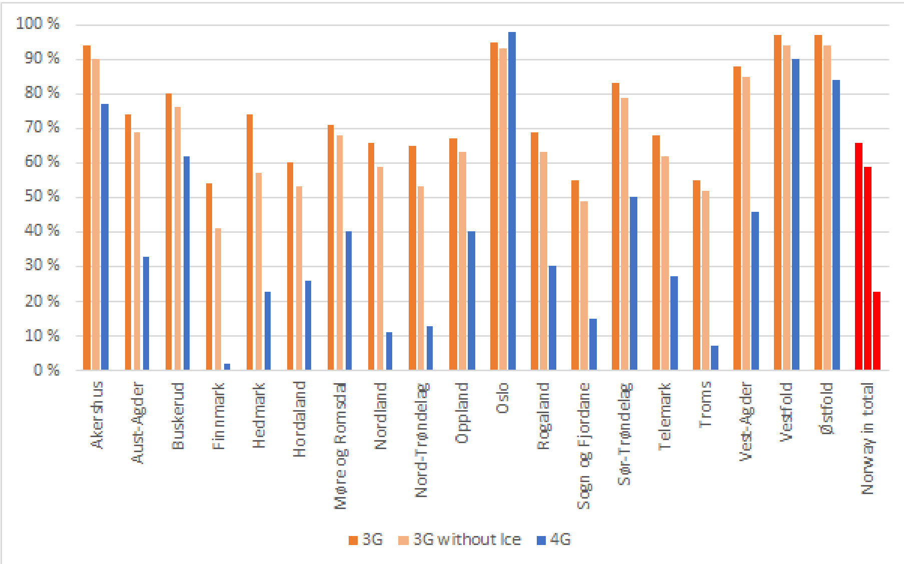


Figure 3.7: Area coverage of mobile networks in Norway by county, modified from [42]

The area coverage of 3G networks, as of second quarter 2014, was 66% on a national scale. Vestfold and Østfold has the highest coverage if you compare counties, with 97% area coverage each. On the other hand, Finnmark has the lowest area coverage with 54% of its area covered. If ICE is excluded, the national area coverage is reduced to 59%. There are big differences between counties on how much reduction in coverage the exclusion of ICE makes. Counties with large areas such as Hedmark, Sogn og Fjordane, and Finnmark see a significant reduction in coverage. While Oslo, which is the smallest county in Norway by area, only see a slight reduction.

From Figure 3.7 we can also see that there are significant variations in 4G coverage between counties. Oslo, Vestfold, and Østfold have the highest coverage, with 98%, 90%, and 84% respectively. An important remark is that these are also the three smallest counties in Norway with a high population per square meter. On the other end of the scale, you have Finnmark, Troms, Nordland with only 2%, 7%, and 11% area coverage respectively. These are counties with large areas and contribute therefore heavily to that the national area coverage of 4G networks is only 23%.

3.3.3 Urban vs Rural

In the two preceding sections we have seen that the coverage of mobile networks, both population and area coverage, may have quite large variations depending on the county. It is especially counties with low population density and a large area that have the lowest amount of coverage. This makes it interesting to also look into the difference in coverage between urban and rural areas. According to Statistics Norway, an urban area is a gathering of houses with a population of at least 200 people and with a maximum distance of 50 meters between houses [44]. This is the definition used in Nexia's broadband coverage report [45], where one of the aspects investigated is the difference in coverage between urban and rural areas for mobile networks in Norway. The calculations of coverage are similar to [42], and provides the theoretical coverage of mobile networks by access technology. The coverage estimates are based on coverage information as of 30. June 2014.

Figure 3.8 and Figure 3.9 show the urban and rural population coverage of mobile networks in Norway. The charts are generated based on raw data obtained from the appendices of the Nexia report [45]. The figures separate on three different access technologies, 3G(UMTS/HSPA), CDMA2000 and LTE. The argument to separate between 3G and CDMA2000 is the same as in Section 3.3.2.

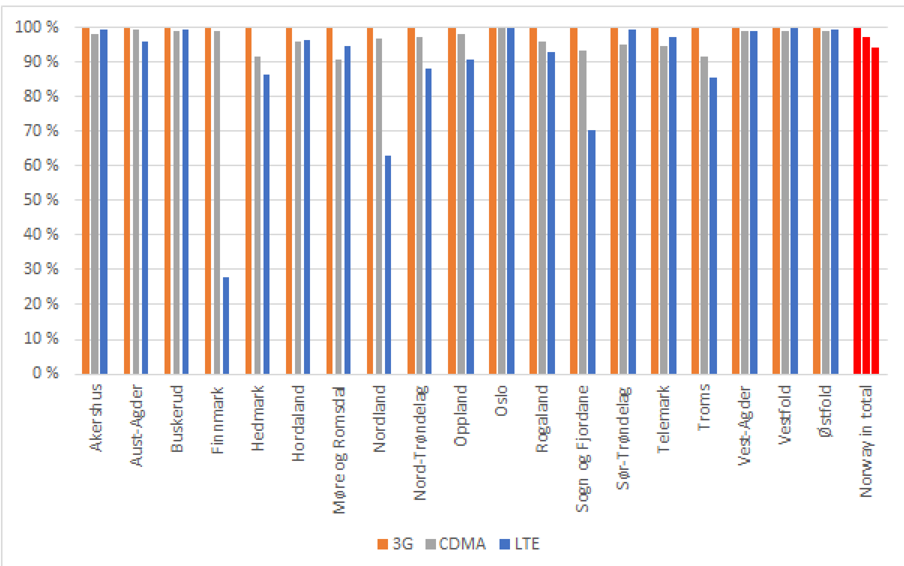


Figure 3.8: Population coverage of urban areas in Norway by county

The population coverage of urban areas is quite high on a national scale if we look at Figure 3.8. 100% of the population has access to a 3G network while 97% and 93% has access to a CDMA and LTE network respectively. There are some variations in coverage especially for LTE networks if one compare the counties. Finnmark and Nordland have the lowest coverage of urban areas, with 28% and 63% respectively.

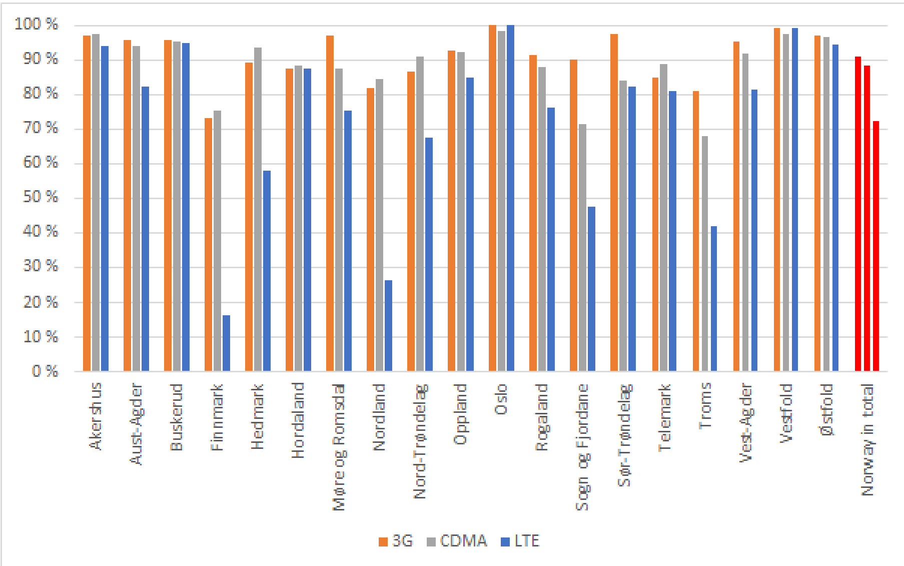


Figure 3.9: Population coverage of rural areas in Norway by county

Figure 3.9 shows the population coverage of rural areas in Norway. These include the population that live in areas not defined as an urban area. As we can observe, the rural population coverage is lower than the urban coverage presented in Figure 3.8. For 3G and CDMA networks, the coverage in rural areas is 9% lower than in urban areas. The number is over twice as low for 4G networks, with a 22% lower population coverage in rural areas compared with urban areas. It is especially the rural areas in counties with a large area and low population density, such as Finnmark, Nordland, Sogn og Fjordane and Troms, which has a low population coverage. This is especially evident for the 4G coverage, where Finnmark has as little as 16% of its rural population covered by a 4G network.

3.3.4 Summary

Through the last sections, the thesis has investigated the coverage of mobile networks in Norway. In general the population coverage is high, and almost the whole population has access to a 3G network. The 4G coverage has seen significant improvements over the last years, and it covers a large share of the population. The area coverage is significantly lower than the population coverage, which is natural for a country with Norway's topography. There has also been identified that there exists significant coverage differences between urban and rural areas. These differences are especially evident for 4G networks, where rural areas in large and sparsely populated counties experience low coverage.

3.4 Capacity

In this section, the thesis will investigate the offered capacity of mobile networks in Norway today, and the focus will be on the capacity offered to end users. The provided capacity for an end user relies on several factors. First of all, the access technology used sets restriction of what capacity a user can achieve, as seen in Table 2.1 different generations offer different peak data rates. The peak data rates are however theoretical capacities, and the experienced capacity is often much less due to other factors. These other factors that affect capacity are the distance to the base station, interference and the number of connected users [46]. Some of these factors may vary over time. Thus getting a deep perception of the offered capacity of mobile networks in Norway would require large-scale measurements of the networks, which falls out of the scope of this thesis. In this section we will, however, try to give a picture of the offered capacity today based on literature sources.

In [42], Nkom has gathered data from their online capacity testing tool, nettfart.no[4], where users can test their available capacity. Figure 3.10 shows the average capacity for mobile networks over the last three years based on measurements from nettfart.no. As can be observed, the average capacity for both downlink and uplink has seen a growth over the last years. For the downlink, the average capacity of the last period was 12,0 Megabits per Second (Mbps), an increase from 6,4 Mbps of the first period. On the uplink, the average capacity of the last period was 4,6 Mbps, which is an increase from 2,6 Mbps of the first period. It is reasonable to assume that the increased rollout of 4G networks during the period of measurements has played a big part in the capacity increase. But there has also been several upgrades in the 3G network in this period, which may have played a role in the increase of measured capacities. An important thing to note is that mobile operators in Norway often put a capacity limit on their subscriptions. For instance, both Telenor and

[4]http://nettfart.no/

Teliasonera have a capacity limit of 10 Mbps on their cheapest mobile subscriptions[5]. To get access to higher capacities, end users has to buy more expensive subscription. This is a factor that can have affected the measurements.

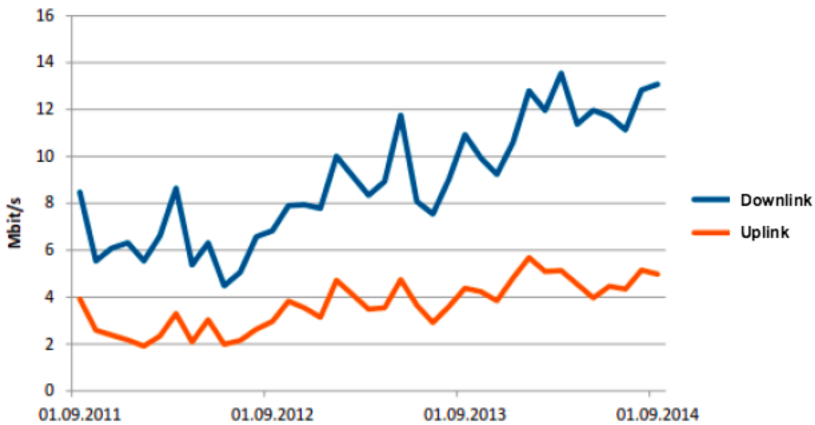
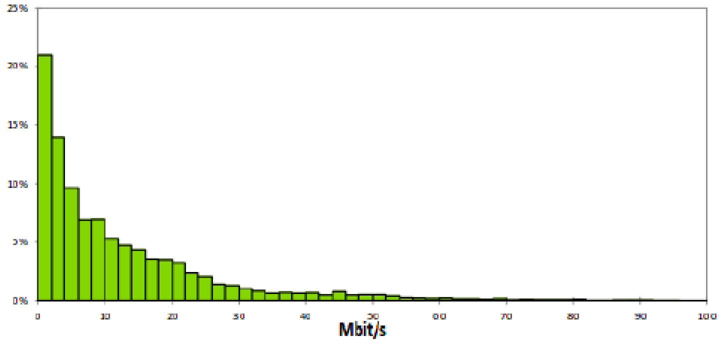


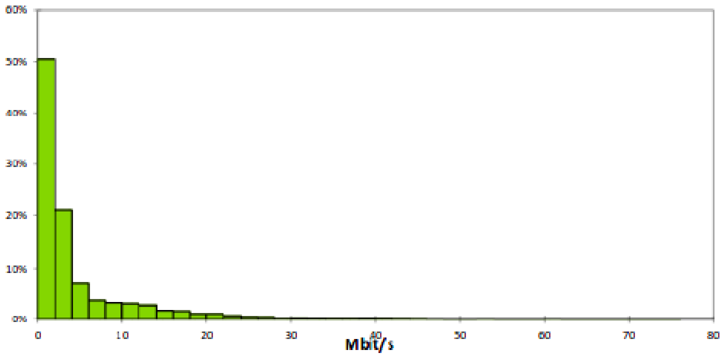
Figure 3.10: Average offered capacity from 2011-2014, based on measurements from nettfart.no [42]

Looking at the average offered capacity may, however, be a bit misleading. Figure 3.11 shows the distribution of measurements from nettfart.no from January to September of 2014. We can observe that there are only a few measurements which experience a high offered capacity, and thus drags the average upwards. On the downlink, a significant part of the measurements experience offered capacity between 0 and 10 Mbps. A similar skewness in the distribution can be seen for the uplink, where over 50% of the measurements experience a capacity between 0 and 2 Mbps. It could, therefore, be more clarifying to look at the median values instead. For the downlink the median value is 7,5 Mbps, and for the uplink it is 1,9 Mbps [42].

[5]http://www.telenor.no/privat/mobil/mobilabonnement/velg.jsp
https://netcom.no/privat/mobilabonnement/smart



(a) Downlink



(b) Uplink

Figure 3.11: Distribution of capacity measurements, [42]

3.5 Robustness

In this section, the thesis gives a brief introduction to the robustness aspect and presents observations considering robustness in the Norwegian mobile market.

Robustness is the ability to resist sudden changes and outages that might affect a system's functionality, and to tolerate these consequences should they occur. In mobile networks, robustness is a complex term including parameters like connection stability, changes in coverage proportions, maintenance and inspections of equipment, failures, and packet-loss [47]. The complexity of robustness makes it hard to measure as there is no clear or accepted method to quantify robustness in mobile networks. Often actors speak of the magnitude of the robustness in a network [47].

Society depends on ECOM services to provide a stable and robust service. The vulnerability in the networks increases as more critical infrastructure are embedded in the ECOM networks. In cases of emergency situations such as power outages and natural disasters, the society must be able to function, hence focus on robustness is a major factor for the society.

Recent studies show improvements on several areas in terms of robustness and quality of service. In April 2015, Centre for Resilient Networks and Applications (CRNA)[6] published the most recent robustness report from the Norwegian mobile market [48]. The main observation presented was an overall increased user-experience in 2014 compared to 2013. The main findings of the report are highlighted below:

Higher stability in connections:

- Reduced interruptions in total and smaller differences between operators.
- Higher connectivity between test-nodes[7] and the mobile networks.

Higher stability in the data-plane:

- Reduced packet-loss in 2014 compared to 2013.
- Reduced critical outages in 2014 compared to 2013.

Higher stability in capacity:

- Failures in download attempts have been reduced significantly. Few connections exceed 3% in failure-rate.
- Higher stability in bandwidth where 80% of all connections reaches a download speed of minimum 1 Mbps, 95% of the time.

Through recent years, the Norwegian ECOM industry has experienced situations where outages in mobile networks have affected millions of people caused by extreme weather [37]. This has led to increased concern for the mobile network security and robustness among policy makers and government. Nkom states in [49], that the current incentives for MNOs concerning offered service quality, coverage and capacity for end users and ability to handle the high load in the infrastructure are throughout good. The report states on the other hand that improvements in robustness are necessary for the areas in terms of ensuring security and to cope with the potential outages in the Norwegian infrastructure. There is increased concern for robustness

[6] CRNA analyzes the current state of robustness in the Norwegian mobile networks and publishes yearly reports.

[7] Measure-nodes implemented in selected areas in Norwegian networks by CRNA to capture relevant data for analyzes.

differences between urban and rural areas. Følstad and Helvik [50], presents the distribution of access network failures divided by area groups. The study detects a higher service failures in rural areas compared to urban areas, especially in power failures and failures in leased services in access infrastructure. The paper states that dependencies between MNOs might be significant in rural areas as there are limited infrastructure available and less economical incitements in infrastructure investment.

In a vulnerability report [51], Nexia recommends these actions for increased robustness in the Norwegian ECOM industry:

- Regular risk and vulnerability reports from actors on their systems.
- General demands for actors in terms of securing a more robust network and to achieve a higher quality of service.
- Establish/maintain documentation of current infrastructure.
- Create/maintain documentation and procedures for new equipment and planned maintenance.
- Regular inspections of critical equipment.
- Agreements should be established for actors to get access to new updates, expertise and spare parts from third party vendors if an error should occur.

Chapter 4
Strategies

In this chapter, the thesis will present and analyze four different strategies for future development of mobile networks in Norway.

The strategies have been defined through an iterative process where several potential strategies were identified through trends evaluated in the literature study. The final strategies were selected through discussions with Nkom, and based on their viewpoints, the following four strategies were defined to be investigated:

1. Continue current development
2. Tighter cooperation between MNOs
3. NFV
4. A more active government

In the following sections, the chapter will describe and analyze each strategy based on a set of factors. The factors reflect the techno-economic and regulatory viewpoint of the thesis. The factors were defined in an iterative process in the same way as the strategies.

To work systematically and to be able to give a comparison of the different strategies, several questions are raised for each factor. For each strategy, the thesis will try to answer these questions. The factors and questions is presented in Table 4.1.

Factor	**Questions**
Technical Aspects	What technical changes will the development lead to? What are the implications of these changes?
Coverage, Capacity, and Robustness	How may the development affect the coverage of mobile networks? How may the development affect the offered capacity? How may the development affect the robustness of the mobile networks? How may the development affect differences between rural and urban areas?
Economic Aspects	Will the development entail any large-scale investments? Who should pay for these investments?
Market	How may the development affect competition? How may it affect the barriers to enter the market?
Regulation	What regulatory measures is needed to ensure this development? Will the development lead to new regulatory challenges that need to be considered?

Table 4.1: Defined factors and accociated questions

At the end of each section, a summary and an evaluation of the strategy is presented. The evaluation is based on a 5-point scale ranging from -2 to 2 as depicted in Figure 4.1. Each factor is given a score based on how the strategy affects the factor. In order to provide accurate and insightful scores, some factors are separated into smaller parts. The Coverage, Capacity, and Robustness factor is separated and given a score for coverage, capacity, robustness, and urban vs rural respectively. The market factor is also separated giving one score for competition and one for entry barriers.

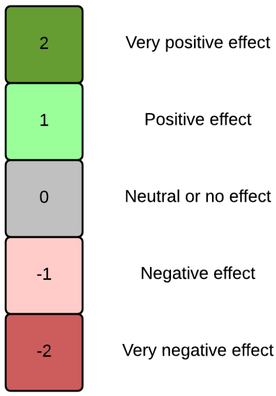


Figure 4.1: The 5-point scale

4.1 Strategy 1: Continue Current Development

4.1.1 Definition

The first strategy assumes the future development of the Norwegian mobile industry to follow the current trends seen today.

From the end users point of view, the strategy assumes increased demands concerning capacity, coverage and robustness from the future mobile networks. Actors in the mobile industry will continue to maintain their strategic models to capture market shares and deliver high-quality services while focusing on factors such as coverage, capacity, quality, and prices.

Trends show that Average Revenue per User (ARPU) is decreasing, even so, reduced equipment- and transmission costs expect to maintain the network operator's incentives for investments in their infrastructure. It is expected focus on continued innovation with deployment and efficiency improvements of the LTE networks and further research and future implementation of a potential next generation network, 5G.

The strategy assumes policymakers to continue to monitor and regulate the necessary areas in the market to ensure healthy competition and a development pattern that benefits society as a whole.

4.1.2 Technical Aspects

The technical development in the Norwegian mobile networks has a strong focus on the implementation of LTE. Recent analyses have shown that together with development of fiber, development of LTE has the strongest growth out of all the broadband technologies in the Norwegian ECOM industry [45]. In 2014, more than 30% of the Norwegian households had access to broadband services through fiber while 83% of the population had LTE access [42].

The strategy assumes the technical development to continue with implementation of these two technologies in order to provide more capacity and coverage for higher quality of service. Operators will continue to modernize their current infrastructure independent of each other. In other words, operators will continue upgrading networks based on the respective frequency licenses acquired and individual vendor agreements. A different angle of this development will be investigated in Section 4.2 where the thesis evaluates cooperation between operators as a future development strategy.

In addition to the continued deployment of LTE, operators will improve capacity, speed and general quality in the mobile networks. There are incentives to introduce new methods to increase speeds of Very-high-bitrate Digital Subscriber Line (VDSL) copper transmissions in the "last mile connection"[1]. Investments in infrastructure by upgrading base stations and the transport network with new technology are motivated by the operator's commercial incentives [42].

As seen in Section 2.3 the increased amount of wireless devices and mobile data traffic worldwide are expected to reach 11.5 billion devices and 24.3 exabytes per month respectively, by 2019. In order to cope with the predicted increase of data traffic, the strategy assumes the future implementation of 5G as the next technological step. See Section 2.1.2 for more details on 5G.

The technical benefits of 5G are predicted to be [22]:

- Improve data rates significantly:
  - Within a small area (e.g. an office floor) 5G is expected to offer capacity up to 1 Gbps.
  - In crowded areas it is expected that 5G will provide several tens of Mbps to tens of thousands users simultaneously.
- Significant enhanced spectrum efficiency.
- Be able to serve hundreds of thousand active connections simultaneously within a square kilometre with massive sensor deployments.
- Minimized energy consumption and radio resources with enhanced signaling efficiency.

4.1.3 Coverage, Capacity, and Robustness

Coverage

Section 3.3 presents the current state and trends concerning coverage. With the deployment trends seen in Northern Norway, it is likely that the Norwegian infrastructure will be more redundant as a result of achieving two nationwide LTE networks [52]. Also, ICE as a new entry to the smartphone market, will continue to develop a separate LTE network with a coverage target of 75%-80% [53].

Current active agreements in the Norwegian mobile industry will ensure completion of a 98% *population coverage* of LTE in the next 3-4 years. The main drivers for coverage development are mainly competition among MNOs and obligations from policy makers. A nationwide *area coverage* is uncertain without strong regulation set by policy makers. Economic incentives for operators to invest in low-density areas will remain small.

[1] http://en.wikipedia.org/wiki/Last_mile

The possible deployment of 5G, in terms of coverage, will most likely be concentrated in the urban areas. This is because of the short coverage range from each node and the ratio between the number of sites needed and the costs of each site [54]. The visions of 5G are based on usage of radio spectrum in the range of 30-300 gigahertz to achieve high capacities. Use of high frequencies limits the range of base stations to 100-200m, and it will be necessary to have multiple sites within small areas to provide these high capacities.

Capacity

Trends show that MNOs are continually improving the offered capacity to fulfill the upcoming service demands from end users. With the allocated frequencies of three individual networks in one area, which is the intended goal for the mobile industry, it will be possible to ensure good capacity in general. If however an area has coverage from only one operator, capacity will be limited by the frequencies allocated to the given operator.

The current strategy assumes network operators to meet end users demands concerning capacity in the years to come by fulfilling these continuing trends [55]:

- Substantial investments in infrastructure.
- Deployment of fiber in the transport networks.
- Reduce failures in transmissions.
- Increased use of small cells and mechanisms to secure seamless transitions between mobile networks and WiFi.
- Introduction of 5G technology.

To deliver high capacity for the future mobile networks, investments have to be made in the transmission networks and access networks in addition to technical improvements in spectral efficiency. With the introduction of LTE, MNOs can reach capacities in the 100 Mbps to 1 Gbps range[2]. Section 3.4 shows the current state concerning capacity in the Norwegian mobile market. Future deployment of 5G could also provide possibilities to enhance capacity in LTE networks with increased use of small cells, higher frequency bands and MIMO technology.

[2] 1Gbps is referred to as the theoretical maximum speed achievable, not the experienced capacity from a users perspective.

Robustness

The strategy assumes increased focus in terms of robustness in the Norwegian mobile industry as the society become more dependent of the mobile infrastructure. Society functions like power, water, transport, health and finance embedded in the ECOM infrastructure demands a high level of robustness to handle unexpected events. It is important to notice that a 100% robust network is impossible to achieve, but there will always be areas to improve.

In an internal report, Nkom states that there is a gap between what society demands and what network operators deem commercially profitable in terms of robustness [55]. To further improve robustness in the Norwegian infrastructure, government contributions and more obligations from policy makers have to be made as network operators have low investment incentives concerning robustness. The strategy assumes the gap between what society demands and what network operators deem commercially profitable will increase in the future in terms of robustness without a more active government or stronger regulation.

Even if it is highly unlikable, a current strategy *may* lead to a possible scenario where the focus on robustness will increase from the operators perspective. MNOs might prioritize developing robust infrastructure to provide the best service and to differentiate from other competitors. Robustness could, in time, be a competition and market factor on the same level as capacity, coverage, price and service quality are today.

Urban vs Rural

Changes in differences between urban and rural areas in the current strategy can be identified with aspects that may affect coverage, capacity and robustness.

- **Robustness:** More focus on infrastructure development in rural areas will be necessary to secure a more robust mobile network in the long run. To secure increased robustness in rural areas, increased regulation from policy makers may be required as there are low incentives for robustness investments from operators in areas with low population density. The strategy does not introduce new economic incentives for developing infrastructure in rural areas from the MNOs point of view.
- **Coverage:** For MNOs, continued investments in coverage is an absolute necessity to meet end users increased service expectations in the years to come. MNOs have high economic incentives for coverage investments in populated areas as it is one of the most important service factors, together with capacity and speed. The strategy does not introduce new incentives for coverage

deployment in the most rural areas. It is, however, possible that the LTE area coverage could improve with the current deployment of LTE. Because of the wide range of signals in the 800 MHz-Bands, new LTE base stations are expected to cover more ground. Areas with no 2G/3G coverage may benefit from this, getting access to the mobile broadband services provided by LTE [42, 52].

- **Capacity:** The introduction of LTE will offer higher capacities for end users in rural areas. A future deployment of 5G will most likely be concentrated in the urban, high-density areas, as seen in Section 2.1.2. However, it is possible that some efficiency improvements of 5G will be implemented in the existing LTE infrastructure at a later stage.

4.1.4 Economic Aspects

The strategy assumes the economic development to remain stable and follow the economic trends seen today. This assumption is based on the economic patterns seen in recent years and the fact that the strategy does not assume any significant technological changes that could move the mobile industry in a new economical direction. As seen in Figure 4.2, the revenue streams from mobile services shows a stable increase in recent years, with exception of 2013 revenues. Table 4.2 show the total revenue for mobile services and MBB. In the end of 2014, total revenue was approximately 17.3 billion Norwegian Kroner (NOK) which is an increase of 3.6%, ~600 MNOK, compared to 2013.

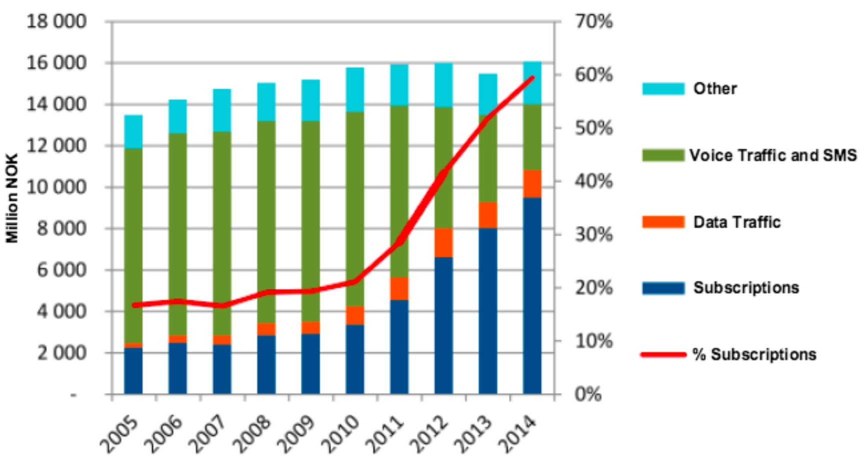


Figure 4.2: Revenue streams from mobile services, Nkom [2]

	2009	**2010**	**2011**	**2012**	**2013**	**2014**
Mobile Services (MNOK)	15 146	15 781	15 897	15 940	15 482	16 010
MBB (MNOK)	801	897	1 017	1 160	1 188	1 257
Total (MNOK)	15 947	16 678	16 915	17 099	16 670	17 267

Table 4.2: Total revenue of mobile services, modified from [2]

The strategy assumes the mobile industry to follow the current cost trends seen today. Cost reduction measures taken by operators in the recent years are [56]:

- Greater use of Online sales channels.
- Online billing.
- Increased "self-service" for end users.
- Outsourcing of field operations to equipment vendors.
- Site sharing in access networks.

The strategy assumes that the current duopoly will give incentives for more coordination between Telenor and TeliaSonera and lead to a more transparent market:

- Coordination of market behaviour between actors.
- Market transparency.
- end users will experience stable prices and possibly higher service quality.
- Deviation from the normal could lead to punishment with lost profit in a transparent market as the competitor can respond with strategic actions against the deviation. An example would be for an MNO to decrease/increase prices or to offer better terms in access agreements with MVNOs.
- Incentives in deviation from the normal will be profitable if profit surpasses loss related to the deviation.

Investments

The strategy expects increased investments in mobile infrastructure to secure a fully deployed LTE population coverage. Numbers from recent years show that investment incentives in the Norwegian mobile industry are throughout good. In 2014, Norwegian operators invested 1.4 Billion NOK in LTE technology. This is an increase of 809 MNOK compared to the 625 MNOK invested in 2013 [2]. The total investments in mobile infrastructure were 2.5 Billion NOK in 2014 and ~2.6 Billion NOK in 2013. Also the MNOs invested in frequency resources which were close to 1.8 Billion NOK at the 2013 auction.

The strategy assumes continued investments in fiber deployment and the fixed networks which includes investments in the core/transport networks and robustness. Total investments in fixed networks have increased with approximately 5-10% the last couple of years. Investments in fiber had a ~28% increase from 2012 to 2013, ~2 Billion NOK to ~2.6 Billion NOK respectively. Investments in fiber deployment in 2014 was ~2.5 Billion NOK [2].

4.1.5 Market

As presented in Section 3.1.2, the future Norwegian mobile market will be dominated by the two largest MNOs, Telenor and TeliaSonera. A comparison of top 3 MNOs in the Norwegian mobile market from [57] is presented in Table 4.3. Per now, the Norwegian mobile market structure can be considered as a duopoly which is a special case of oligopoly. Section 3.1.3 presents an analysis of the current Norwegian mobile market. In time, a few existing firms will have some power to set prices in the Norwegian mobile market. This is based on assumption that ICE will have the incentives to grow into a competitor in the retail market and change duopolistic market trends back into the former oligopoly structure.

Company	**Telenor**	**TeliaSonera**	**ICE**
Technologies	2G/3G/4G	2G/3G/4G	4G
Subscribers	3.2M[3]	2.6M[3]	~204k
# Base stations	~ 8000	~ 5000	~ 1100-1800
Available LTE capacity	~60MHz	~ 40MHz	~ 40MHz

Table 4.3: Comparison of top 3 MNOs in Norway, modified from [57]

[3]These are public numbers given on operator's websites.

The concentration of the end-user segment after the merger, measured with Herfindahl-Hirschman Index (HHI)[4], show an increase of 600 points, from 3 460 to 4 060. An increase of 600 points indicates that the merger has resulted in a more concentrated market [34]. In other words, a reduction of competition in the market. A higher concentrated mobile market will not affect end users in a negative way as seen in 4.1.4.

ICE

ICE aims to reach a moderate 9% market share in the mobile market by 2019. Taking into consideration the incentives and advantages ICE possess, this might be a conservative goal [58]. The strategy assumes that it is highly likely for ICE to reach the targeted market share based on their future investment incentives. ICE states that the roaming agreement with TeliaSonera gives them time to design and optimize their 4G network before moving 2G/3G end users over to the ICE network. This way, ICE claims to secure a high-quality product for their future end users in the mobile market. After remedies agreed upon between ICE and TeliaSonera, ICE now has an option to acquire 1500 sites for 133MNOK. A general rule of thumb estimates the cost of one site in the mobile networks to 1MNOK [53]. After simple calculations, this shows that ICE are left with an investment cost of 8.87% of the total estimated costs for regular operators.

ICE development goals for expanding in the Norwegian market are [57]:

- Capture 9% of the market[5] within 2019.
- Focus in 2015: Continue upgrading base stations to LTE technology.
- Focus from 2016 and beyond: Keep expanding by building new sites, especially in urban areas, and increase overall capacity.
- Goal to achieve a population coverage of 75%-80%, similar to Tele2's previous area coverage.
- A 6-year roaming agreement with TeliaSonera secures a 100% population coverage through 2G/3G technologies.
- After acquiring NN from TeliaSonera, ICE obtained 90 000 new subscribers within the mobile service business segment, in addition to support systems and technical platforms previously owned by NN.

[4] HHI is a measure of market concentration and is used for evaluation of mergers. The Norwegian Competition Authority operates with these values: HHI < 1000 indicates low concentration, thus high competition in the market. $1000 <$ HHI < 2000 indicates a moderate market. HHI > 1000 indicates a high concentrated market, thus low competition.

[5] Mobile service market: mobile-voice, SMS and mobile-data services

Entry barriers

The strategy assumes the current high entry barriers for new entrants to maintain:

- A new MNO entrant will need to obtain frequency licenses and substantial investments in infrastructure to provide a significant population coverage and obtain a decent customer base.
- With the low amount of MNOs, opportunities for access agreements will also be reduced for MVNOs.
- A significant increase in customer base (e.g. the case of TeliaSonera) will make an operator less dependent on access agreements, hence lead to a higher barrier for new entrants.
- High HHI indicates a concentrated market. This, however, do not implicate high entry barriers itself as a concentrated market may have low barriers of entry.
- As agreed upon in the merger between TeliaSonera and Tele2, TeliaSonera has to offer fair wholesales access agreements to their networks for new and existing MVNOs [34]. This obligation expires at the end of 2016, but it is reasonable to assume that policy makers will continue to regulate ease of access for MVNOs when necessary in the future.

4.1.6 Regulation

As seen in the market analysis, the current state for the Norwegian mobile market is a well-known scenario. The merger between TeliaSonera and Tele2 may lead to a more uncomplicated market in terms of future regulation. Reduced number of dominant actors may simplify the topology and improve the regulators ability to monitor the market, vulnerabilities and services in the mobile industry.

The strategy would expect regulators to play a continuing role in securing development for critical infrastructure in the future, maintaining the dialogue with operators and government instances to secure a social beneficial ECOM infrastructure. It is likely that the mobile industry will experience increased regulation concerning robustness and security, especially in the rural areas, to limit the increasing gap between the social demands.

4.1.7 Summary

The strategy investigates the continuing trends in the mobile industry and assumes development to follow the ordinary development as of today, through the next decade. The strategy will be summarized based on the subjective opinion of the authors of the given factors. The summary is seen in Table 4.4.

- The technical aspects are given a positive score. This is based on the expected investments and deployment of LTE in the mobile networks and fiber in the transmission and core networks. The introduction of 5G technology will be the next technological step for future development of access networks in urban areas and is expected to increase efficiency and capacity.
- Coverage and capacity are given a positive score. It is expected increased focus on the development of capacity to meet the demands of society. It is also predicted a more efficient use of the current infrastructure.
- In terms of robustness, more focus from policymakers in reaching a more robust and secure infrastructure may be anticipated. In the last years, user experience in terms of robustness is increased. Robustness is given a neutral score.
- The strategy expects the development regarding robustness and coverage in urban and rural areas to follow the current trends. The strategy assumes mobile operators to maintain low incentives for investments in rural areas but increased incentives for policymakers to improve robustness in terms of regulation and coverage. Urban vs. rural is given a neutral score.
- Economic Aspects are given a neutral score as trends in the mobile industry shows incentives in cost reduction and the introduction of new services to generate profit. The industry continues to invest in improvements in infrastructure and new technologies. The revenues in the Norwegian mobile industry has been stable in recent years. The strategy does not expect innovation on a scale that will increase economical benefits to a great extent.
- Competition is given a negative score as a transparent market with two dominant operators, and a coordinated market leads to low competition incentives.
- Entry Barriers are given a negative score. Entry barriers are currently high for MNOs and are not expected to change due to the high concentrated market. Ease of access for MVNOs rely on regulation from policymakers. It is expected high barriers for entry for MVNOs as the number of MNOs are scarce.
- Regulation is given a positive score. It is expected that policymakers will continue to regulate in areas that will improve the ECOM industry in a beneficial social direction.

	Technical aspects	Coverage	Capacity	Robustness	Urban vs Rural	Economic aspects	Competition	Entry barriers	Regulation
Strategy 1	1	1	1	0	0	0	-1	-1	1

Table 4.4: Summary of strategy 1

4.2 Strategy 2: Tighter Cooperation Between MNOs

4.2.1 Definition

In this strategy the MNOs go into a tighter cooperation with each other by utilizing different types of network sharing. Network sharing can typically be divided into three types: passive, active and roaming based sharing. The differences of these types of sharing are explained in Table 4.5. Passive sharing agreements are already applied in Norway, Telenor is obliged to provide collocation on reasonable terms due to its SMP and now also TeliaSonera is obliged to offer ICE collocation after the acquisition of Tele2. Roaming based sharing has also been adapted, oftenly used to allow a new entrant to get national coverage while rolling out its network. ICE's roaming agreement with TeliaSonera is an example of this. This strategy will, therefore, focus on:

- Active network sharing
- Roaming based sharing in case of outages

The active sharing can take place if operators decide to share a complete network together, or just in specific geographical areas. It is also assumed that even though sharing takes place, the sharing operators will still compete on both the retail and wholesale market. Sweden is a good example of active sharing in practice, as sharing of complete networks has been utilized since early 2000. Today there are three shared networks in Sweden, each owned by joint ventures between two MNOs, two 3G networks, and one 2G/4G network [59]. Roaming based sharing in this strategy will take place if an operator suffers from an outage, and its customers can then roam to another network.

4.2.2 Technical Aspects

To actively share a network, or parts of a network, it has to support the joint utilization of the RAN from the sharing operators. This would naturally lead to some technical changes in how the network is constructed, as network components have to be shared. Figure 4.3 shows a high-level technical overview of the difference between two independent LTE networks and an LTE network with shared RAN. As briefly seen in Table 4.5, there are several ways how this could be done, for instance MORAN and MOCN. Solutions for both these sharing approaches exists today. MOCN was standardized by Third Generation Partnership Project (3GPP) in Rel 6 for 3G networks and in Rel 8 for LTE networks [62], and all major network equipment vendors provide solutions for both MOCN and MORAN. These technical solutions are also used in commercial deployments, where, for instance, MOCN is

Type	Description
Passive sharing	Involves sharing of passive network elements such as collocation and sharing of base station sites and masts between two or more operators. Base stations and antennas are separately deployed, but costs of construction and rental can be shared.
Active sharing	Involves sharing of active network components, typically in the RAN, between operators. For active RAN sharing one can separate between Multi-Operator RAN (MORAN) and Multi-Operator Core Network (MOCN). In MORAN frequencies are dedicated and operators have independent control of traffic quality and capacity, while in MOCN frequencies are pooled and operators, to a large extent, do not have independent control of traffic quality and capacity.
Roaming based sharing	When one operator depends on coverage and capacity from another operator on a permanent basis.

Table 4.5: Types of network sharing, [60, 61]

used by sharing operators in Sweden and MORAN is used by sharing operators in the UK [8].

In the case of roaming based sharing in case of outages, it would not require any technical changes as existing roaming infrastructure could be utilized. Some specific configurations, as opposed to regular roaming agreements, would be needed. These will not be elaborated here, but interested reader is referred to ENISA [63] where the specific technical setup is described.

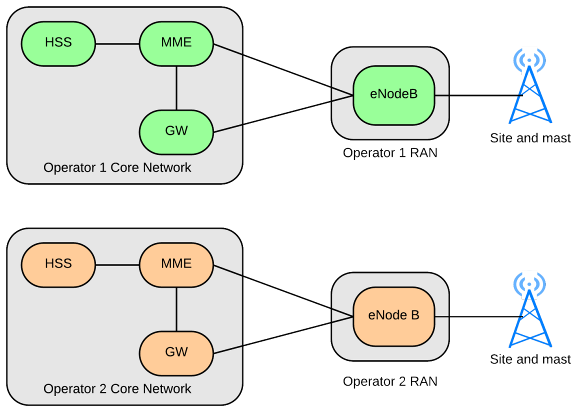
Implications

If operators agree to actively share a network, the technical aspects provides some implications that will be shortly explained in this section.

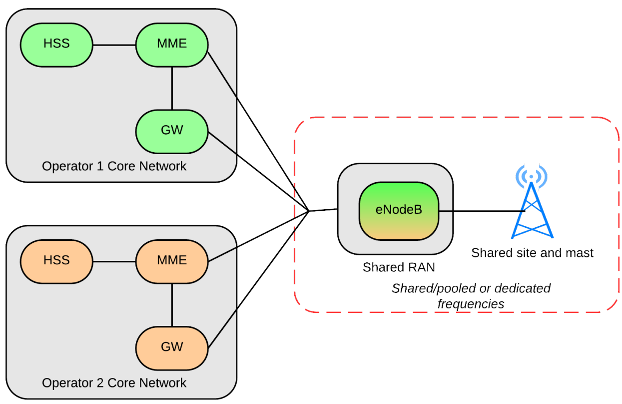
- **Potential for cost savings**: As the network will be shared, there are potential for CAPEX savings because the operators can share the costs of network components, site acquisition, and civil works. There is also potential OPEX savings, as costs can be shared on for instance site rental, maintenance, and power supplies.
- **Less independence between sharing operators:** Since the network components of the RAN will be shared, the operators have to coordinate the

network strategy for the shared network. This implies that there will be less independence between the operators in terms of network strategies.

- **Environmental impacts:** By sharing the network infrastructure, there could be several environmental benefits. One benefit could be that it might lead to a reduction of masts and towers which would reduce the visual impact of mobile networks [8]. Another solution would be a reduction in energy consumption as power supplies can be shared.



(a) Two operators with no sharing.



(b) Two operators who actively share RAN.

Figure 4.3: Difference between two independent LTE networks and a LTE network with shared RAN, modified from [8]

4.2.3 Coverage, Capacity, and Robustness

Coverage

A tighter cooperation between operators in terms of network sharing could help achieve better coverage of mobile networks, especially for rural areas and in terms of *area coverage*. As seen in Section 3.3, the coverage of mobile networks today in urban areas is good while it is significantly lower for the rural areas. This is especially evident for the 4G networks. With an active sharing agreement between two operators, one could more cost-effectively build out a 4G network in rural areas because investments and OPEX can be shared. The cost savings could lower the risk and barriers for operators to build networks in areas with limited commercial potential as less revenue is needed to justify serving an area with limited demand. A good example of active sharing in order to improve coverage is the joint venture between the Finnish operators Sonera and DNA. The operators have an agreement to roll out a shared 4G network in the sparsely populated eastern and northern parts of Finland to improve the coverage in these areas [64].

According to Mölleryd et al. [10] network sharing could also facilitate a faster rollout of new technology, because a sharing agreement between two operators could include pooling of existing base station sites and resources which reduces the need to acquire new sites and increases resources to meet the demands of a rollout program [10]. Thus network sharing agreements between operators could ensure a faster coverage of new technologies for end users, for instance when the time comes to the rollout of 5G networks.

Capacity

The thesis will now look into how a tighter cooperation between operators may affect the offered capacity. Active sharing of networks may not in itself affect the offered capacity, but it may provide incentives or lower the barriers for MNOs to invest in network equipment. By doing so, MNOs can offer more capacity due to the aforementioned potential savings in both CAPEX and OPEX.

If the sharing agreements also include pooling of frequencies, where the sharing operators combine their allocated frequencies, it may give the operators an opportunity to more efficiently use the spectrum. Hence, it will give them the opportunity to provide networks with a higher capacity.

Robustness

In terms of robustness, a tighter cooperation between MNOs could affect it in a positive manner. If national roaming agreements are made between operators in case of network outages the overall robustness of mobile networks could be improved, as users will be able roam to another operators network in the event of an outage in their home network.

In [48] it is shown that the correlation between network downtimes in Norwegian networks is low, and that the availability from an end users point of view could be significantly improved if one combined connections from two MNOs. This raises a question if it would be an even better solution, from a robustness perspective, to let end users roam freely between operators network, and not just in case of outages. This may, however, work against its purpose, as MNOs will have little incentives to invest in robust networks since they could use other operators networks as a fallback solution in case of an outage. Markendahl [65] analyzed the feasibility of MNOs to implement such a dynamic roaming scheme, and found that there were no incentives for operators to do so as it would result in lower degree of control of end users and network traffic that could lower incentives to provide quality services and networks. This could be an attractive solution for some special cases such as rural areas where providing good coverage can be complicated, but on a national scale it is not a feasible solution,

Although roaming in the event of an outage may provide more robust networks for the end users, there are also some limitations and potential drawbacks that need to be considered [63]:

- **Outages affecting shared infrastructure:** If outages affect areas where networks are shared, and there is not another overlapping network, for instance in a rural setting, roaming would not provide any extra form of robustness.
- **Outages caused by overloads:** If outages are caused by overloads in the network, due to a large amount of people utilizing mobile services within a geographical area, roaming would have little affect on robustness as there is a high probability that all network will be saturated.
- **Outages that affect all networks:** If an outage affects all networks, roaming will not affect the robustness as there would be no network to roam to. Examples of outages that could affect several networks are power cuts and natural disasters.
- **Overload in the visiting network:** In case of an outage, the roaming end users could cause an overload in the visiting network or reduce the quality of service for the original end users of the network. This can be limited to some

extent by for instance only allowing voice services for the visiting users or by prioritizing the original end users of the home network to guarantee a certain level of quality.

In summary, one can say that roaming based sharing can only improve the robustness to some extent in case of outages, as the limiting factors set several restraints of when it would be beneficial.

Urban vs Rural

If we now consider how this development may affect the differences between urban and rural areas, there can be identified aspects that may affect coverage, capacity, and robustness differences between them.

- **Better coverage and higher capacity:** As mentioned earlier in this section, network sharing could help achieve better coverage of mobile networks for rural areas. This also implies that network sharing could lead to that rural residents get access to networks or network technologies that offers higher capacity, which could help bridge the gap between rural and urban areas.
- **Faster rollout of new technology:** Network sharing could facilitate a more rapid rollout of new technologies, which could lead to that rural areas get access to the technology faster. In Section 3.3 we saw that the rollout of 4G networks initially focused on larger urban areas, and that there are clear differences between urban and rural areas. The rollout of a new technology, such as 5G, would probably also focus on urban areas initially, as seen in Section 4.1.3. However, with network sharing one could potentially reduce the time frame between when urban users get access to the technology and when rural users get access to it.
- **Difference in robustness:** In terms of robustness, a tighter cooperation between operators could lead to larger differences between urban and rural areas. If a shared network is the only available network for end users in a rural area, then the solution of roaming in case of an outage is not applicable because there are not any other networks to potentially roam to. Thus the end users in urban areas, where several mobile networks may coexist, have access to a more robust network.

4.2.4 Economic Aspects

The development will most probably lead to further investments in infrastructure by MNOs, as described in Section 4.1.2. The difference in this strategy is that operators, through active sharing, have the potential to save both CAPEX and OPEX. The savings rely on several factors, such as the type of sharing agreement and organizational issues, so the exact savings could only be estimated on a case-by-case basis. Some sources, however, indicate that actively sharing RAN could lead to [9, 66]:

- Network CAPEX savings between 25-40%
- Network OPEX savings between 20-30%

These savings could, as mentioned earlier, lower barriers for MNOs to further invest in infrastructure, especially in less dense areas.

4.2.5 Market

Competition

A tighter cooperation between operators in terms of active sharing could have both positive and negative effects on competition. OECD [59] highlights that there are some competition concerns on active sharing of networks, like unilateral effects and information sharing.

- Unilateral effects: With network sharing one could arrive at a situation where the market might have a dominant groups of network sharers. This could lead to a cost disadvantage towards a smaller operator or a new entrant facing the dominant group of networks sharers. This could lead to less competition in the long run or hinder entry of a new operator to the market.
- Information sharing: When operators have a sharing agreement there has to be an exchange of information, for instance in terms of network strategy, to align on strategies for the shared network. There is a risk that this information sharing, if not adequately restricted, could have collusive outcomes as the sharing operators also may align their commercial strategies based on information they otherwise would not get access to.

On the other hand, active sharing could also have positive effects on competition. A smaller player, like ICE, could use an active sharing agreement with another operator to facilitate a more cost-effective rollout of its network, for instance in rural areas, and thus increase its competitive position. The barriers for a new entrant could also be lowered, as will be discussed in the next section, which could lead to a more competitive market.

Another aspect is that by actively sharing networks, the sharing operators have less independence towards each other in terms of coverage and capacity. These are aspects that are currently being used by operators to differentiate themselves from each other. Network sharing could therefore lead to more focus on innovation and innovative services, as the operators would need to find other ways to differentiate themselves. This type of competition could benefit end users, by being offered new and improved services.

As mentioned earlier, active sharing could lead to economic benefits throrough reduction of network costs for operators which could facilitate further network rollouts and improved coverage and capacity. Another aspect is pointed out by Mölleryd et al. [10], which is that competition in the market could lead to that these cost savings are being passed on to end users, not only through improved capacity and coverage, but also through lower prices of mobile services.

Entry barriers

If we now consider how a tighter cooperation between the operators may affect barriers to enter the mobile market, there are some aspects that should be highlighted. First of all, it may lower the barriers by making investment in network infrastructure more cost-efficient with operators sharing the costs. As Markendahl [65] underscores, network sharing has a significant impact on greenfield investments which could lead to positive effects for potential new entrants.

Secondly, network sharing gives operators without spectrum the opportunity to enter the market if a network could be jointly built with an operator which holds enough licensed spectrum. There is of course strategic consideration MNOs has to take before agreeing on network sharing, and it is not likely that Telenor and TeliaSonera would be interested to share networks with a new entrant without any licensed spectrum due to their large market shares. For ICE, this could be a possible option in order to achieve cost-effective rollout of their 4G network. An example of this is from Sweden, where Telia was able to enter the 3G market without any licensed spectrum by building a joint network with Tele2 [59].

On the other hand, as briefly mentioned earlier, network sharing could also increase the barriers to entering the market. If sharing agreements are in place between existing operators, a potential new entrant would not be able to achieve the same amount of cost savings without a sharing agreement. Since operators already have agreements in place, it may be hard for the new entrant to find a sharing partner and it thus increase the barrier for entry.

To summarize, there exist aspects of active sharing that could lead to a reduction in competition in the market and an increase in the barriers to entering the market. However, if these aspects are dealt with, active sharing could have positive effects on both competition and entry barriers which in the end could benefit the end users.

4.2.6 Regulation

If we first consider roaming-based sharing in case of outages, it is probably necessary for Nkom to stimulate the operators to participate in such a scheme as operators probably will have few incentives to conclude such deals on a commercial basis. Another aspect is that there should also be defined a threshold for when such a service should be activated. This could be in terms of users affected and after a certain limit of time [63]. A challenge could be that operators would use such a scheme as a fallback solution, instead of further investments in order make the infrastructure more robust. This could be solved by defining the roaming costs for the operator that has suffered an outage, and thus has to bear an extra cost. It could also serve as an incentive to provide a more robust network, as no outages would lead to no additional roaming costs.

In terms of active network sharing, examples from other countries indicate that the regulators coverage demands and frequency strategy has been underlying reasons for active sharing between operators. Markendahl et al. [11] interviewed Swedish operators in order to understand why they went into active sharing agreements. One of the main factors for network sharing was the only feasible solution to ensure a cost efficient rollout in order to meet coverage requirements in the frequency licenses. Thus, high coverage demands on frequency licenses is one regulatory measure that could facilitate active sharing between operators.

Another regulatory action could be to promote active sharing by developing a particular policy framework or best practices in terms of active sharing which defines conditions that need to be met. These conditions could include the scope of sharing, for instance if sharing is allowed on a national basis or just in rural areas and also if spectrum is allowed to be shared. Another condition could be how the sharing should be governed, and that a clear definition of roles between the sharing operators should be defined. This would provide operators with more predictability towards potential sharing agreements, which could make it easier for them to conclude such agreements.

Active sharing of networks could also provide some regulatory challenges. First of all, sharing agreements complicates the ownership picture of a network as there are not just one MNO but two or more that owns it. This could provide a challenge for Nkom in terms of responsibility for the network in case of incidents or in case of fines due to violations. However, this could be mitigated by defining clear conditions on how sharing agreements should be formed as mentioned in the previous section.

Another challenge is to make sure that sharing agreements do not have a negative impact on the competition in such a way that it will harm the end users. This could be solved by evaluating each sharing agreement to make sure that it does not invoke any of the potential competition concerns highlighted in Section 4.2.5, and if it does one should refuse the agreement.

4.2.7 Summary

In this section, the strategy will be summarized based on the subjective opinion of the authors of the given factors. The summary is seen in Table 4.6.

- The technical aspects are given a positive score due to the fact that the technical solutions exists today and are also deployed in commercial networks, which imply that there should be few challenges regarding the technical aspects.
- The coverage factor is given a very positive score due to the benefits provided through sharing. For the impact on capacity, it is given a positive score since network sharing can both lower incentives for further investments to offer more capacity and give operators the opportunity to utilize the spectrum more efficiently.
- In terms of robustness, it is given a neutral score as a tighter cooperation between MNOs will have limited impact in the offered robustness.
- The differences between urban and rural areas are given a positive score due to positive effects the strategy can have on both coverage and offered capacity for rural areas. This outweighs the potential larger differences in robustness as they are seen as much less probable than the effects on coverage and capacity.
- The economic aspects are given a very positive score, as active sharing could offer MNOs substantial cost savings, which again can benefit the end users through better coverage and capacity.
- Both competition and entry barriers are given a positive score. Even though active sharing presents some concerns about competition and entry barriers, these concerns can be dealt with through regulatory policies and it is reasonable to assume that the positive effects thus outweigh the potential negative effects.

- The regulatory factor is given a negative score. This is because of the needed regulatory facilitation to ensure this development. Also, the regulatory facilitation might not be enough to for instance guarantee active sharing, as these are agreements that are done between operators. Further on, this strategy may provide some regulatory challenges, like governance of the network and limited competition. However, these could be minimized, if not mitigated, by clear regulatory policies.

	Technical aspects	Coverage	Capacity	Robustness	Urban vs Rural	Economic aspects	Competition	Entry barriers	Regulation
Strategy 2	1	2	1	0	1	2	1	1	-1

Table 4.6: Summary of strategy 2

4.3 Strategy 3: NFV

4.3.1 Definition

The NFV strategy investigates the implementation of NFV technology as a possible future strategy for mobile network development. As presented in Section 2.2, the main principle of NFV will be to virtualize parts of the infrastructure in software running on the generic hardware as illustrated in Figure 4.4.

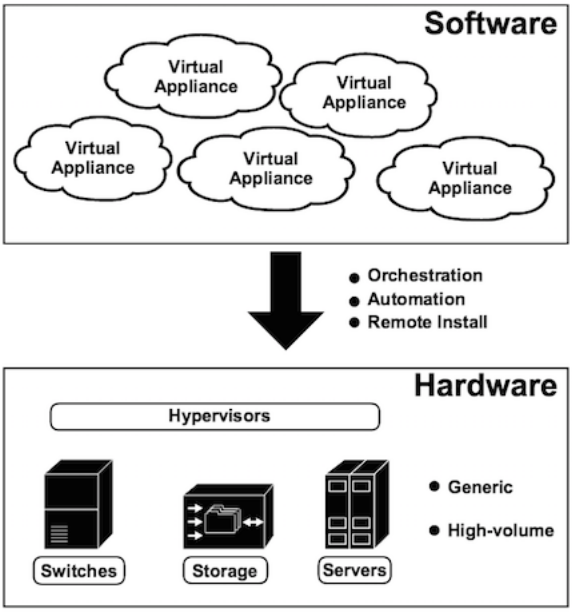


Figure 4.4: The general idea of NFV, modified from [4]

There are large incentives from researchers, standardization organizations and large mobile operators to develop and standardize NFV. Expected benefits and the drivers for development of this new technology are:

- Faster time-to-market
- Increased speed and agility in the networks
- Higher innovation
- Reduced costs and new revenues
- Lower entry barriers for MVNOs

In addition to the literature study on NFV, personal correspondence with Pål Grønsund (Telenor) and Abul Kaosher (Nokia Networks) have been made in order to obtain different points of view on NFV. Telenor and Nokia Networks are currently doing research on NFV and are representing two different sides of the ECOM market as a mobile operator and a vendor respectively.

4.3.2 Technical Aspects

The development of NFV aims to reduce the complexity in systems and improve operational issues. By consolidating to standard generic high-volume hardware, virtualizing custom appliances (routers, firewalls, controllers, radio access network nodes and other network devices), operators will be able to [7]:

- Run tailored virtual appliances on generic high-volume hardware.
- Deploy new network functions remotely.
- Improve orchestration.
- Run automated recovery.
- Reduce the cost of site upgrades as appliances have similar power, space and cooling requirements.

Assumed technical benefits of NFV are as follows:

- Reduced vendor dependency by using industry standardized equipment.
- Improved network operation efficiency through IT orchestration mechanisms:
  - Temporary repair of failures by using automated reconfiguration.
  - Allocating resources where it is needed by moving traffic onto spare spaces with free capacity.
- Reduced power consumption by using power management in servers and storage. It will also be possible to use virtualization techniques to manage the workload during peak and off-peak hours. By managing the workload, servers that are not needed (e.g. during the night) will be put into power saving mode.
- More efficient testing and integration of new services by running production, test and reference facilities on the same infrastructure.

Timeline

Figure 4.5 illustrates four phases of NFV development and future deployment. Per now, NFV development and some use cases are in the first two phases: developing a standardized NFV platform and the test phase. After deployment of the NFV platform, operators will deploy use cases with low risk and high-value results. The main idea is for NFV to be a hybrid solution to migrate each function separately from the current infrastructure to the NFV platform as seen in Section 2.2.2.

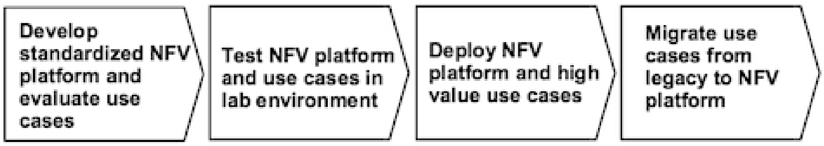


Figure 4.5: High-level map of possible deployment of NFV, modified from [25]

A possible implementation scenario of NFV is currently evaluated by separating network functions into use cases. In a subjective evaluation[6], Telenor assumes Evolved Packet Core (EPC)[7] and IP Multimedia Subsystem (IMS), located in the core network, to be the first network functions to be virtualized. The evaluation shows that these areas are more or less NFV-ready and offer fewer challenges than e.g. virtualization in the edge network with virtual base stations [25]. Figure 4.6 illustrates Telenor's expected maturity of the NFV use cases. After implementation in the core networks, both Pål Grønsund (Telenor) and Abul Kaosher (Nokia Networks) expect the virtualization scenario of NFV to be continued in the regional network before finally virtualizing functions in the base stations at the edge of the network [26, 69]. It is important to notice that an unexpected innovation in more efficient software implementations may change the implementation view [25]. For impact assessment of use cases in Figure 4.6 see [25].

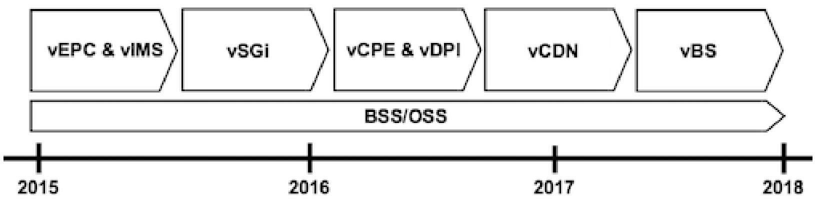


Figure 4.6: Maturity of NFV use cases, modified from [25]

[6]This is a subjective analysis, hence the use case assessment does not include any detailed modeling [26].

[7]Studies and recommended readings on virtualization of EPC are: [67, 68].

NFV and SDN

NFV are highly complementary to SDN[8] as seen in Section 2.2.3. The two technologies do not depend on each other, but it is predicted that combining both technologies, see Figure 4.7, will increase benefits, operational efficiency and lead to higher innovation, among others [25]. More on relationship between NFV and SDN can be read in ETSIs third white paper on NFV [5].

Implementation of SDN is predicted as a possible next step for further development of the ECOM infrastructure after the early stages of NFV is implemented. There is still ongoing research on both technologies and many challenges to be solved before a full implementation is possible. In 10-15 years, a fully developed infrastructure with the combined NFV and SDN technology could potentially provide faster delivery service, more operational efficiency, higher flexibility and automation in the mobile network infrastructure.

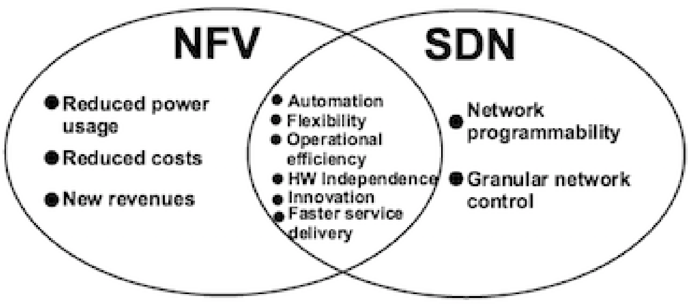


Figure 4.7: SDN relationship with NFV, modified from [25]

4.3.3 Coverage, Capacity, and Robustness

Coverage

If we first consider coverage, the implementation of NFV in the operators network will not have any direct effect on the coverage of the networks as NFV is only a platform for separating network functions from underlying hardware. However, the nature of NFV, where one goes from dedicated hardware appliances to cheaper COTS hardware may indirectly affect the coverage of the networks. Virtualization of base station functionality, which are highly hardware dominant, may reduce both CAPEX and OPEX for operators. The cost reductions may increase incentives for further

[8]The scope of this thesis does not include technical details and further development of SDN, but nearly inform of relation between SDN and NFV and the existence of research on the subject.

rollout of base stations, as less revenue would be needed to serve areas with lower commercial potential. Which again would result in better coverage for the end users.

Capacity

If we now consider capacity, the implementation of NFV in the operators network does not directly affect the offered capacity for end users. However, it will provide the operators with a flexible network platform that may be used to offer better capacity.

It seems like one could get the biggest impact on capacity improvements if functions in the edge of the network are virtualized. The concept of a virtualized base stations may provide several opportunities for the operators to improve offered capacity as the baseband processing function from several base stations within a defined area are centralized and virtualized in a data center [70], it may provide several opportunities for the operators to improve the offered capacity. A virtualized base station environment will make it easier to apply techniques to improve the spectral efficiency, such as Coordinated Multi-Point (CoMP) technology, which can improve the offered capacity for end users significantly [71]. Furthermore, it could also make it easier for the operators to, for instance, deploy small cells in dense areas where the demand for capacity is high. As most of the processing functionality is centralized in a data center, deployment of new cells only require to connect additional radio equipment to the virtualized base station instead of deploying a complete base station [72]. A virtualized base station with centralized baseband processing would, however, need high speed and capacity transmission links between the radio equipment and centralized baseband processing, and fiber seems like the most probable solution [72]. This may put restrictions on where to possible deploy such solutions as will be discussed when we look at differences between rural and urban areas.

A virtualized infrastructure may also allow operators flexibility to scale their networks towards user demands. The capacity dedicated to a VNF may be dynamically modified to the actual load of the network since the functionality of a network function is separated from the underlying hardware. If traffic increases in the network one can either increase capacity of network functions from the underlying hardware pool or deploy a new network function on demand. This can help avoid bottlenecks in the networks and thus improve the offered capacity.

In summary, NFV provides operators with a flexible platform where resources dynamically can be scaled towards user demands which could improve the offered capacity. As more advanced techniques for spectral efficiency in the edge network functions, such as baseband processing at the base station, could be virtualized and centralized, one would achieve a big impact on capacity improvements which would improve the offered capacity for end users.

Robustness

With a virtualized network architecture new challenges in terms of robustness occur. ETSI has, as a part of their work on standardizing NFV, published a document which addresses many of the new challenges of a virtualized infrastructure compared to a non-virtualized infrastructure such as failures of VNF, failures of underlying hardware and software infrastructure [6]. The document outlines requirements for robustness that need to be met by the VNFs. Where the top-level requirements are:

- Service continuity and failure containment
- Automated recovery of failure
- Prevent a single point of failure in the underlying architecture
- Support a multi-vendor environment
- Support a hybrid infrastructure

An aspect that might affect robustness is the centralization of VNFs in data centers, for instance where a natural disaster could knock out the entire data center and thus all the VNFs in it. This could potentially have big consequences, but can be mitigated by geographical redundancy in other data centers.

Another aspect that might affect the robustness is the fact that the change to virtualized networks requires both organizational changes within the operators and new competence and skills related to operation and processes as mentioned in Section 2.2.2. If these changes are not implemented well or the competence and skill level is not adequate, they can impact the robustness of the networks in a negative way.

Even though there are some robustness concerns to be aware of regarding a NFV deployment, it also brings some potential improvements. The scalability of NFV may provide a higher degree of robustness in case high traffic demands, for instance in the case of disasters. Resources can then be pooled or dynamically re-allocated to the relevant VNFs to meet those demands. Japanese operator Docomo stated, after a proof-of-concept of a virtualized EPC in October 2014, that: "NFV is expected to offer key advantages, such as operational sustainability with improved connectivity for dense data traffic and during natural disasters, as well as in the event of hardware failures." [73]. One can question if the statement might be exaggerated, as it is from an official press release. It shows however that operators believe NFV could potentially improve the robustness of their networks.

Urban vs Rural

Its hard to say how an implementation of NFV would affect the differences between urban and rural areas. On one hand you have the potential savings in CAPEX and OPEX for the operators that may lower the barriers to rollout and network improvements in rural areas. This may lead to that rural areas may get access to networks which offer a higher capacity and thus help bridge the gap between urban and rural areas.

On the other hand, some of the potential benefits of NFV might not be suitable for rural environments. For instance the virtualized base station with centralized baseband processing, as discussed earlier in this section, has strict latency and high bandwidth[9] demands on the link between the centralized processing and the radio equipment and one probably needs fiber to achieve this [72, 70]. Compared to urban areas, availability of fiber in rural areas is limited and operators might not find it commercially viable to deploy fiber. Thus, some potential benefits of NFV might just favor urban end users.

4.3.4 Economic Aspects

The possibility of cost reduction is one of the main drivers behind future development of NFV. Reduction in both CAPEX and OPEX can be achieved by centralizing and automate the management of routing functions in software. This could lead to a reduction of manufacturing cost and time reduction in configuration and deployment of new services [74]. The first assessment of use cases from Telenor predicts that operational efficiency will benefit highly in cost reduction for all use cases implemented with NFV [25]. Variables like automation, elasticity, portability/relocation and service delivery are expected some- to high-benefit in cost reduction.

As mentioned in the Section 4.3.2, implementation of NFV will most likely start with virtualization of the EPC use case. A report made by PA Consulting Group, for the Intel Corporation, studies the transition from traditional EPC to a virtual/cloud EPC [68]. The report includes a Total Cost of Ownership (TCO)[10] model which investigates the cost drivers behind the core network to quantify the cost differences achievable in deployment and operation of a virtual EPC. Results from this analysis show that in a ten year period, total savings for the model could be up to 29%.

[9] In terms of Gbps

[10] TCO is defined as combined costs of an asset, the purchase price and the costs of operating the asset. TCO is the long-term price.

The main cost drivers for the EPC are network functionality, software releases and staff. The forecast states that 80% of the savings are related to reduced costs of network functionality and OSS/Network Management System (NMS) software releases over time. Figure 4.8 shows the model's comparison of total cumulative cost in the traditional EPC and the vEPC.

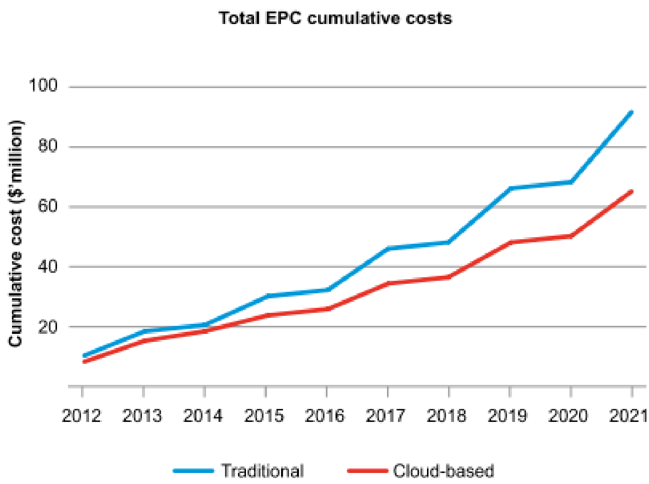


Figure 4.8: Total EPC cumulative costs, [68]

A possible deployment of NFV networks will entail large-scale investments. Investments in network functions and virtualization technologies will be required for data centers, hardware, software development and licenses. For operators who already owns infrastructure, there will be gradually migration costs for a technological shift from the proprietary hardware appliances to the NFV infrastructure and restructuring of the organization.

The question of who should pay for the investments of implementing a possible NFV infrastructure is maybe not as open as the initial expectation on the matter. After conversations with Pål Grønsund and Abul Kaosher, it seems quite clear that the industry is aware of the necessity for future investments and is willing to spend in order to provide innovative new solutions and the best quality of services for their customers [26, 69].

4.3.5 Market

Competition

The deployment of NFV may certainly have an impact on competition. For instance can virtualization of base stations provide a more cost-effective rollout as base stations are hardware dominant, and operators may benefit from the reduction of CAPEX by going from proprietary to commodity hardware. There are also potential OPEX savings with for instance efficient workload management as discussed in Section 4.3.2. With a more cost-effective rollout of base stations, an operator such as ICE could deploy more base stations and improve its competitive position towards Telenor and TeliaSonera, which again could improve the overall competition in the market.

NFV may also provide operators with the possibility of faster time-to-market for new services by reducing the typical operator cycle of innovation [3]. This can ensure a higher degree of innovation as operators will try to come up with new innovative services to differentiate themselves from the others. Which again can enhance the competition on the service level which will ultimately benefit the end users.

Entry Barriers

A virtualized network could also lower the entry barriers for MVNOs to enter the market. By implementing network functions in software over COTS hardware instead of more expensive proprietary hardware appliances, they can more cost-effectively deploy their own functionality in the mobile networks. It is also possible that the network operators will offer this as a service by either providing the virtualization infrastructure, NFVI-as-a-Service (NFVIaaS), or the network function, VNF-as-a-Service (VNFaaS), as a way to generate new revenue streams. This can open up for new actors, without much experience of mobile service operations, to enter the market. Potential new actors could be big OTT providers, which enter the market in order to further enhance and promote their other products and services. Recently we have seen Google enter the mobile market in the USA as a MVNO, with an innovative offering based on WiFi and agreements with two MNOs [75].

To conclude, NFV may impact the market in several ways. Competition wise it could lead to improved competition in the market with a larger focus on service innovation. It could also lower entry barriers for MVNOs, and make it easier for them to deploy own functionality in the mobile networks. NFV could also open up for new business models, where virtualization infrastructure or VNFs could be offered by the MNOs. This would open up the possibility of new players, such as OTT providers, to enter the market.

4.3.6 Regulation

The thesis has not been able to identify any specific regulatory obstacles that may hinder or affect the deployment of NFV; this has also been supported through our conversations with Telenor and Nokia Networks. Thus is it hard to define or see specific regulatory measures that could ensure this development. The development will, to a larger extent, be dependent on the industry's ability to meet the current challenges as presented in Section 2.2.2.

However, the deployment of NFV may provide some new regulatory challenges that need to be considered.

Network functions outside national borders: NFV will allow operators to a larger extent centralize many of their network components by utilizing COTS hardware and placing these in data centers. From the operators point of view, this could be very beneficial by centralizing for instance core network components to exploit the economies of scale. The benefits would be even larger if an operator with operations in several countries could use a centralized core network for all or some of its operations across borders. Both Telenor and TeliaSonera have operations in several countries, and already today we have seen some of the core network functionality being centralized outside Norway's borders [76]. NFV can make it even easier for the operators to move central network functions to data centers abroad. From a regulatory point of view this can provide challenges in terms of auditing operator's placement and security of critical network components, as Nkom only has jurisdiction within Norwegian territory. Placement of central network functions outside Norway would also challenge the Electronic Communications Act demand of confidentiality as the data processing would take part outside Norwegian jurisdiction.

Non-traditional market actors: NFV may open for non-traditional actors to enter the market. This could be OTT providers, but also other companies that, for instance, want to cover local geographical areas. This could challenge current regulations, as only providers defined as ECOM providers are obliged to follow the Electronic Communication Act, so if new actors start providing mobile services, this would need to be included. Another aspect is that new actors may not have the same level of expertise or knowledge as the established providers, which could provide challenges to ensure that end users have access to secure and reliable services.

Complex ecosystem of providers: NFV encourage an open ecosystem, where different software and hardware can be mixed and matched independently of the vendor. This could evolve into a complex ecosystem where there are a large potential amount of various providers of products/infrastructure to the MNOs. From a regulatory point of view, this could make it harder to keep an overview and secure national interests.

4.3.7 Summary

In this section, the strategy will be summarized based on the information presented in the analysis the subjective opinion of the authors of the given factors. The summary is seen in Table 4.7.

- The technical aspects are given a very negative score due to many uncertainties regarding NFV. There are many potential benefits of NFV, but as seen in Section 2.2.2 there are still many challenges to be dealt with, which provides uncertainties in how many of the benefits that can be reaped for mobile networks.

- The coverage factor is given a positive score, as the potential cost savings for the MNOs may indirectly affect the coverage, as less revenue will be needed to build out the networks in areas with limited demand.

- The capacity factor is also given a positive score due to the flexibility NFV provides for the operators to dynamically scale resources towards user demands. Also, if edge network functions are virtualized, there is a significant potential for offering higher capacities through advanced techniques for spectral efficiency.

- There are several challenges in terms of robustness in a possible implementation of NFV, but they are often of the technical sort, and we consider the negative score of the technical aspects to cover many of these. On the other hand the scalability and flexibility NFV offers can have positive effects on the robustness. Thus, robustness is given a positive score. Due to the scalability and flexibility NFV potentially may offer.

- The differences between urban and rural areas are given a neutral score. An implementation of NFV may lead to rural areas getting access to networks with higher capacity. But there are also potential capacity benefits regarding NFV, such as virtualized base stations with centralized baseband processing, that seems only economically feasible in urban areas.

- The economic aspects are given a very positive score due to the potential cost savings NFV could provide, which again could be passed to the end users.

- Both the competition and the entry barriers factor are given a positive score. As NFV may provide competition more focused on service innovation which could benefit the end users. Also, it may lower entry barriers for MVNOs and new market players.

- The regulatory factor is given a negative score due to the potential regulatory challenges regarding a deployment of NFV. These challenges may make it harder for Nkom to do their job in terms of keeping an overview and auditing of critical network functions.

	Technical aspects	Coverage	Capacity	Robustness	Urban vs Rural	Economic aspects	Competition	Entry barriers	Regulation
Strategy 3	-2	1	1	1	0	2	1	1	-1

Table 4.7: Summary of strategy 3

4.4 Strategy 4: A More Active Government

4.4.1 Definition

In this strategy, the government takes a more active role in the development of the mobile network infrastructure, primarily by subsidizing mobile infrastructure development. We further define two types of subsidies:

- Subsidies for mobile infrastructure development in areas were MNOs do not find it commercially viable to expand their networks.
- Subsidies for robustness improvements in the existing mobile network infrastructure.

The subsidies for development in areas where operators have no commercial interest in network development can be organized through an open tender process. Development in particular areas are put out on tender, and MNOs put in offers for the development. It would only be relevant to subsidize the development of one network within a precise area. Therefore will an important aspect be that the MNO who builds out the network is obliged to provide access to other operators[11].

The subsidies for robustness improvements in existing mobile network infrastructure can be organized by identifying areas where measures to improve the robustness of the networks can be taken. Then either through an application process or an open tender process the subsidies can be distributed.

4.4.2 Technical Aspects

The technical development in this strategy will be quite similar to what is described in Section 4.1.2. The only difference is that further development projects of mobile network infrastructure may be concluded due to the state aid.

4.4.3 Coverage, Capacity, and Robustness

Coverage

With this strategy, we will probably see a similar development as described in Section 4.1.3, where each MNOs builds out their networks to provide coverage. A difference in this strategy would be that through financial support from the government, one could achieve better coverage in areas where operators not originally

[11] For instance access to sites on a fair and non-discriminatory basis, so other operators can install their base station equipment and provide coverage in the same area, or national roaming within the specific area.

have the commercial interest to provide coverage. This would both impact the *population coverage* and *area coverage* in a positive manner.

Operators do not find it commercially viable to expand their networks in rural areas where the population density, and thus the demand, are low. Another potential area for subsidies is along the railway. A recent report from Nexia [77] revealed that mobile coverage along the railway lacks in many areas and that under half of national rail network is covered by a 3G or 4G network. The report also recommends state subsidies to be a suitable strategy to provide coverage along parts of the rail network.

Capacity

In general one would see a similar development in offered capacity as seen in Section 4.1.3. However, a difference may be that through financial aid from the government, areas with low commercial interest for operators may get coverage of new technology, such as 4G, which would significantly increase the offered capacity in these areas.

Robustness

With the government taking a more active role through subsidizing mobile network development the overall robustness of mobile networks may be improved significantly. In the definition, a subsidy with the aim of improving the robustness of existing mobile network infrastructure was defined. As mentioned this could be distributed by either an application process or an open tender process, and both could naturally affect the robustness in a positive manner. The different processes can serve different purposes:

- **Application process:** Nkom can make resolutions to improve the overall robustness of mobile networks where MNOs may apply for financial support in order to execute them. These resolutions will typically be decisions MNOs would not take on a commercial basis.
- **Open tender process:** By identifying areas in the mobile infrastructure where improvements in robustness are needed, the development can be put out on a tender. This could be if more redundancy is needed in a specific area to ensure a stable provision of mobile services for the end users.

Subsidies for robustness improvements could also have synergies towards nonpublic mobile networks as well. Norway has today built out a national emergency network[12] based on the TETRA standard, which is a more robust and secure mobile network available for the emergency services. However, it is reliant on renting transport capacity from commercial providers and it has been pointed out that the rented capacity is a major vulnerability to the emergency network [78, 79]. Thus, if subsidies were to support robustness improvements in commercial infrastructure, it could also have very positive effects on non-commercial networks.

Urban vs Rural

In this strategy there is a focus on development in rural areas through a larger degree of financial support for mobile network development. As seen in the sections on coverage and capacity it may have positive effects on both. They can be summarized as the following:

- **Coverage:** By subsidizing infrastructure development in rural areas the coverage in these areas may be increased.
- **Capacity:** With increased coverage in rural areas, residents may get access to mobile networks that provide higher capacities. An example would be if 4G coverage were rolled out in an area where only 2G previously was available, this would result in significant capacity improvements for the residents.

Together these aspects may decrease differences between urban and rural areas, as rural residents may get access to technology that already are provided in urban areas.

4.4.4 Economic Aspects

This strategy would involve further investments in mobile network infrastructure incentivised by state subsidies. To estimate the amount of public funds to be distributed is out of the scope for this thesis. However, it is likely that it would require a considerable amount of state subsidies to achieve the highest positive effects in both coverage and robustness.

EU's best practices for state aid to broadband development [80] highlights that the amount of funding should be reduced to the minimum necessary for development in a particular area. This can be achieved through the open tender process where the amount of public funding needed should be one of the selection criteria. This would result in that the investments would be a mix of private and public funding.

[12] Nødnett in Norwegian

4.4.5 Market

Competition

With this strategy, the competition in the market will probably be quite similar to what described in Section 4.1.5. In the areas where subsidies are granted for mobile development, the MNO that wins the tender process could potentially gain a competitive advantage as it would be the only operator providing coverage in the area. This would create a local monopoly where end users in the area would only be able to access services from this operator. Providing operators with a competitive advantage through the use of state aid is not an optimal solution, and through the obligation of providing access to other operators on a fair and non-discriminatory basis this can be mitigated.

Entry barriers

This strategy will not affect the barriers to entering the market, and the barriers will be similar to what is described in Section 4.1.5

4.4.6 Regulation

As is this strategy is based on the state taking a more active role, the development in this strategy is more reliant on political decisions rather than the regulatory measure. Nkom should, however, play a vital role in this strategy. As they are the competent authority, it is natural that Nkom would facilitate and audit the distribution of subsidies. To ensure an efficient and socially useful development within this strategy, the possible tasks Nkom should facilitate are:

- **Identify areas for development/improvements:** For the subsidies to affect the areas with highest needs there should be a process where the potential areas for development or improvements are identified. This could be done by Nkom itself or put down on a municipal level, where Nkom supervises the process.

- **Handle the tender/application process:** Nkom, as the NRA, should have the competence and overview to decide where the subsidies are needed and should, therefore, play an important role in the tender/application process.

- **Monitor the use of subsidies:** There should be a monitoring of the distributed subsidies to ensure that they are used for their intended purpose.

4.4.7 Summary

In this section, the strategy will be summarized based on the information presented in the analysis and the subjective opinion of the authors of the given factors. The summary is seen in Table 4.8.

- The technical aspects are given a positive score based on the same arguments as given in Section 4.1.7.

- Due to the fact that this strategy could improve the coverage significantly, especially in underserved areas, the coverage factor is given a very positive score.

- The capacity factor is given a positive score based on the same arguments as given in Section 4.1.7 and the fact that it could improve capacity in areas with low commercial interest.

- The robustness factor is given a very positive score as a more active government through subsidies can have a significant effect on the robustness of mobile networks.

- This strategy can have a very positive impact on both coverage and capacity in areas with low commercial potential, which again will help reduce the differences between rural and urban areas. Therefore, the differences between rural and urban areas are given a very positive score.

- The economic aspects are given a negative score due to the effects of the strategy will rely on the state subsidies, even though the investments would be a mix of private and public funds.

- In general the competition in the market will be similar to what is described in Section 4.1.5, and the competition factor is therefore given a negative score.

- For the same reason as in Section 4.1.7 the barriers to entering the market are given a negative score.

- This strategy would not entail any large regulatory challenges, but the competence and monitoring from Nkom would be needed to ensure an efficient and socially optimal development within the strategy. The regulatory factor is thus given a neutral score.

	Technical aspects	Coverage	Capacity	Robustness	Urban vs Rural	Economic aspects	Competition	Entry barriers	Regulation
Strategy 4	1	2	1	2	2	-1	-1	-1	0

Table 4.8: Summary of strategy 4

Chapter 5

Discussion

5.1 Strategy Comparison

In Chapter 4, the thesis investigated four potential strategies for future development of the mobile infrastructure. Each strategy was summarized and subjectively evaluated based on the factors investigated. Table 5.1 shows a comparison matrix of the subjective evaluation of the investigated strategies. From Table 5.1 we can observe that the different strategies offer different advantages. In the following sections, the thesis will compare and discuss the different advantages and aspects of the strategies.

	Technical aspects	Coverage	Capacity	Robustness	Urban vs Rural	Economic aspects	Competition	Entry barriers	Regulation
Strategy 1 (S1)	1	1	1	0	0	0	-1	-1	1
Strategy 2 (S2)	1	2	1	0	1	2	1	1	-1
Strategy 3 (S3)	-2	1	1	1	0	2	1	1	-1
Strategy 4 (S4)	1	2	1	2	2	-1	-1	-1	0

Table 5.1: Comparison matrix of the investigated strategies

If we first consider the technical aspects, it is assumed continuing efforts to introduce new solutions for further technological improvements in all strategies. It is expected that S1 will continue to encourage investments in the deployment of LTE in the mobile networks. The current research and possible future implementation of the 5G technology are the primary cause for a positive technological score in S1. It is expected that 5G deployment in urban areas and the general improvements 5G potentially could bring to the LTE networks will be sufficient to cope with the society's increased demand for future networks. S3 aims to virtualize parts of the infrastructure, realizing network functions in software running on generic high-volume hardware. A technical challenge with S3 is that NFV is still in a research phase. Implementation of NFV is given a very negative score in the matter of technological aspects. This is based on the high uncertainties and challenges left to solve before implementation is even possible, especially uncertainties in aspects of virtualization in the edge network. However if development of the NFV technology succeeds in the future, it is believed to have the potential to redefine the network industry seen today concerning infrastructure functions, but also redefine the industry on a organizational level.

In terms of coverage and capacity, all suggested strategies are expected to have positive effects. It is however S2 and S4 that stand out as the most beneficial strategies in considering these aspects. They are on the other hand quite different in their approach. Network sharing could help to increase coverage and faster roll-out of new technologies through reduced costs from actively sharing a network. In S4 the positive effects on coverage is mainly caused by incentives for development through financial support from the government. Another strong side of S4 is its impact on differences between urban and rural areas. It could have a very positive impact as areas with limited commercial potential could get access to new technology. S2 also shows a positive effect for rural areas, as active sharing agreements could reduce the costs for operators and hence enlarge the areas to where it is commercially viable to roll out a network. The 4G roll-out between the Finnish operators Sonera and DNA to improve coverage in low-density areas is a good example of this.

If we consider robustness, there is one strategy that stands out, namely S4. With state subsidies, one could identify areas in the existing infrastructure were robustness improvements are needed, and then subsidize projects to improve them. S3 could also have a positive effect on the robustness through the flexibility and scalability a platform like NFV offers, but these positive impacts would rely on that the technical challenges associated with NFV are solved.

A key factor for future development is the economic aspects. In this aspect, both S2 and S3 stand out. Both strategies may have a very positive impact on the economic aspects as they introduce potential savings for operators both in terms of CAPEX and OPEX. These savings could again incentivize further investments in mobile infrastructure, which ultimately would benefit the end users in terms of better services and networks. In the three first strategies, the further investments depends only on the operators own financial capabilities. S4 on the other hand, is largely reliant on public funding to have optimal effects and is the only strategy given a negative score on this factor.

When we look at the market factors, competition, and entry barriers, it is S2 and S3 that points out. They could both have positive effects on competition and entry barriers. Both could lead to a market where competition is more focused on mobile services and service innovation. Considering the entry barriers, S2 could make it easier for a new MNO to enter the market through a sharing agreement. S3 could have a positive impact of entry barriers for MVNOs and non-traditional market actors. On the other tip of the scale, S1 and S4 are given a negative score due to the current situation in the Norwegian market with two very dominant actors.

To conclude, based on the investigated factors it is S2 that looks like the most beneficial strategy in an overall perspective. However, if the focus is on robustness and conditions for rural residents, S4 would be the most attractive strategy. It is also worth to mention that if the technical challenges of NFV are dealt with, S3 would be a strategy that could have a very positive impact based on the factors investigated. S1 is on the other a strategy that scores quite average on the investigated factors and compared to the others, is the strategy with least to offer.

5.2 A More Robust Future?

The subject to be discussed is to what extent the government and policy makers should interfere with the ECOM market to secure a more robust future. The topic is highly relevant to the current situation in the Norwegian ECOM market. This section highlights two questions in order to structure the discussion and considers a few of the many relevant aspects considering the topic.

Through recent years, the Norwegian ECOM industry has experienced situations where outages in mobile networks have affected millions of people caused by system or human errors and extreme weather. This has led to increased concern for the mobile network security and robustness among policy makers and government. The increased focus has resulted in thorough evaluations and analyzes of the current mobile infrastructure, and some obligations have already been put in motion. Some examples of recent events and changes are:

- A server error, on the 10 of June 2011, caused an 18-hour downtime in the Telenor network. The outage affected approximately 3M subscribers and was one of the main reasons for the government assigning Nkom the task of analyzing the Norwegian mobile infrastructure in a complete vulnerability report [51].

- The storm "Dagmar" led to power outages affecting 728 base stations in the access networks in December 2011. The analysis shows that lack of power and transmission were the direct cause for approximately 70% of the outages in the base stations [81]. This led to increased focus on robustness in terms of backup power in the MNOs access networks. The demands in service time (backup power) for base stations have now been redefined, in cases of power outages, and are presented in [37].

- A robustness analysis [47] from CRNA presented in 2013 measured data proving that Telenor's connections experienced a higher rate of short outages and a higher rate of packet loss than its competitors. A recent analysis[1] [48] presents that configuration changes in Telenor's software carried out in June 2014, see Figure 5.1, has improved the connection quality and reduced the packet loss markedly.

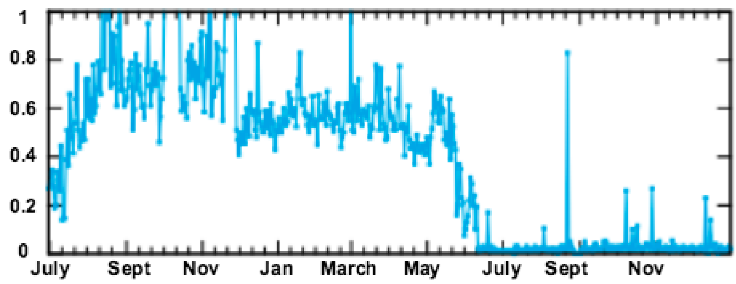


Figure 5.1: Reduction of median packet loss, Telenor 2013-2014, modified from [48]

1. Will subsidizing network development be the right medicine for the Norwegian market?

If we consider yet again the possible scenario with a more active government in the mobile market as seen in Section 4.4.

The primary goals for a more active government involvement will be to ensure a more robust and secure infrastructure to provide a service quality that satisfies end users demands in the future. From Section 4.4, we can see many positive effects of potential governmental involvement in the ECOM industry. Governmental subsidies is an attractive solution for mobile infrastructure development in areas where MNOs do not find it commercially viable to expand. As thoroughly discussed in S4, governmental subsidies on tender is an attractive solution for robustness improvements in the existing mobile network infrastructure. Governmental subsidies may increase incentives for coverage and capacity improvements in areas with reduced commercial interest, as well as robustness enhancement. The thesis has previously mentioned that even if it is impossible to achieve a complete, robust infrastructure there will always be improvements to be made. The above mentioned examples presents some of the positive and effective interferences government can take to

[1]Published April 13th 2015.

secure a more robust network for the society. However, it is important to be aware of to which degree the government interferes with the Norwegian ECOM market.

With governmental funding, it may be difficult to find the balance in the matter of the amount of funds to provide. The subsidies provided by the government may potentially have a negative impact as increased governmental cost may lead to increased taxation or other revenue solutions on another area of the industry. Finding the balance between the amount of funds to subsidize and the value provided from a new development project might be a challenging task. With government subsidies, one might experience reduced incentives for MNOs to invest and take actions to secure a robust infrastructure as MNOs may rely more on subsidies than focus on own investments in other areas.

2. Will there be a need for more regulation in the ECOM market, or will the solution be to leave it up to the market forces to find the best solutions for the future?

The thesis has previously presented that the general focus on robustness from policy makers has increased during the recent years and several reports claims that the current state of the Norwegian infrastructure potentially has many areas to improve. Section 3.5 presents several vulnerabilities, uncovered by Nexia, in the Norwegian infrastructure that may indicate a stronger need for regulation in the ECOM market.

General concerns for leaving future development entirely up to the market forces is that focus on disaster prevention and robustness may be less prioritized compared to focus on operational, competitive and technological research areas. The fact that lack of actions listed in Section 3.5 have not been prioritized by MNOs gives the concerns credibility and that there is a lack of development focus in areas that are not beneficial for MNOs. Regulatory authorities could play a significant role in identifying and establishing solutions in areas where actors have low incentives for action to increase robustness in the ECOM industry. We might experience stronger regulation concerning robustness measures and development.

Chapter 6
Concluding Remarks and Further Work

The future development of the mobile network infrastructure is a wide and complicated topic. New technologies and services are constantly pushed to the market leaving the industry as a whole in constant change. This thesis has studied different strategies for future development of the mobile network infrastructure with a techno-economic and regulatory point of view.

The offered coverage, capacity and robustness of mobile networks today has been investigated, as well as the current market structure of the Norwegian mobile market. Furthermore, four different strategies for future development of the mobile network infrastructure has been proposed. The strategies are:

1. Continue current development
2. Tighter cooperation between MNOs
3. NFV
4. A more active government

The strategies have been analyzed and evaluated based on a set of factors. The evaluation of each strategy was presented in a comparison matrix, which provides an overview of the different advantages and disadvantages of each strategy. Based on the analysis of the given factors, strategy 2 looks like the most beneficial strategy in an overall perspective. However, the strategies have different strengths and weaknesses, so if some factors are more important than others a different strategy may be more beneficial. For instance if focus on robustness and conditions for rural residents are the most important, strategy 4 is the most attractive strategy. If the technical challenges of NFV are met, strategy 3 could be a very beneficial strategy for future development. While strategy 1 is the strategy with least positive effects to offer compared to the other strategies.

Further Work

There can be identified several areas suitable for further work:

- **A more detailed analysis:** The analysis done of the different strategies is based on factors that have a large range. Since the thesis covers a wide range of topics, the detail level of the analysis of each factor can be considered high-level. A potential topic for further work could thus be to go even deeper in the analysis of the different factors for the different strategies.
- **Add more factors:** Another potential topic for further work could be to extend the amount of factors analyzed. This would provide an even deeper insight into the potential advantages and disadvantages the different strategies provide.
- **Investigate other strategies:** The framework used to analyze the different strategies in this thesis could also be used to analyze other potential strategies for future development of the mobile network infrastructure.

References

[1] Cisco. Cisco Visual Networking Index : Global Mobile Data Traffic Forecast Update , 2014 – 2019. *Growth Lakeland*, 2015.

[2] Nkom. Det norske markedet for elektroniske kommunikasjonstjenester 2014. 2015.

[3] ETSI. Network Functions Virtualisation. *Introductory White Paper*, pages 1–16, 2012.

[4] ETSI. Network Function Virtualisation Updated White Paper. *Terminology for Main Concepts in NFV*, pages 1–16, 2013.

[5] ETSI. Network Functions Virtualisation (NFV). *White Paper #3, Architectural Framework*, 1:1–21, 2013.

[6] ETSI. Network Functions Virtualisation (NFV); Resiliency Requirements. *GS NFV-REL 001 - V1.1.1*, 1:1–82, 2015.

[7] ETSI. Network Functions Virtualisation (NFV); Use Cases. *GS NFV 001 - V1.1.1*, 1:1–50, 2013.

[8] Belgian Institute for Postal Services and Telecommunications (BIPT). Communication of the BIPT of 17 January 2012 Containing Guidelines for Infrastructure Sharing. 2012.

[9] Thomas Frisanco, Paul Tafertshofer, Pierre Lurin, and Rachel Ang. Infrastructure sharing and shared operations for mobile network operators from a deployment and operations view. In *Network Operations and Management Symposium, 2008. NOMS 2008. IEEE*, pages 129–136. IEEE, 2008.

[10] Bengt G. Mölleryd, Jan Markendahl, and Mårten Sundquist. Is network sharing changing the role of mobile network operators? 25th European Regional Conference of the International Telecommunications Society (ITS), Brussels, Belgium, 22-25 June 2014, Brussels, 2014. International Telecommunications Society (ITS). URL http://hdl.handle.net/10419/101392.

[11] Jan Markendahl, Amirhossein Ghanbari, and Bengt G Mölleryd. Network cooperation between mobile operators-why and how competitors cooperate? In *Proc. 29th Annual IMP Conference, IEEE, Atlanta, USA*, 2013.

[12] Jan Arild Audestad. *Technologies and Systems for Access and Transport Networks.* Artech House Publishers, 2007.

[13] Ofcom. Mobile evolution, ofcom's mobile sector assessment. 2009.

[14] Martin Sauter. *From GSM to LTE-advanced: An Introduction to Mobile Networks and Mobile Broadband.* John Wiley & Sons, 2014.

[15] M Eriksson, A Furuskar, M Johansson, S Mazur, J Molmo, C Tidestav, A Vedrine, and K Balachandran. The gsm/edge radio access network-geran; system overview and performance evaluation. In *Vehicular Technology Conference Proceedings, 2000. VTC 2000-Spring Tokyo. 2000 IEEE 51st*, volume 3, pages 2305–2309. IEEE, 2000.

[16] Erik Dahlman, Per Beming, Jens Knutsson, Fredrik Ovesjo, Magnus Persson, and Christiaan Roobol. Wcdma-the radio interface for future mobile multimedia communications. *Vehicular Technology, IEEE Transactions on*, 47(4):1105–1118, 1998.

[17] Syed Ismail Shah. Umts: High speed packet access (hspa) technology. In *Networking and Communications Conference, 2008. INCC 2008. IEEE International*, pages 2–2. IEEE, 2008.

[18] 3GPP. LTE. 2011.
http://www.3gpp.org/technologies/keywords-acronyms/98-lte
Accessed: 28.05.2015.

[19] 3GPP. LTE-A. 2011.
http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced
Accessed: 28.05.2015.

[20] Anna Zakrzewska, Sarah Ruepp, and Michael S Berger. Towards converged 5g mobile networks-challenges and current trends. In *ITU Kaleidoscope Academic Conference: Living in a converged world-Impossible without standards?, Proceedings of the 2014*, pages 39–45. IEEE, 2014.

[21] Robert DiFazio, Philip J Pietraski, et al. The bandwidth crunch: Can wireless technology meet the skyrocketing demand for mobile data? In *Systems, Applications and Technology Conference (LISAT), 2011 IEEE Long Island*, pages 1–6. IEEE, 2011.

[22] NGMN Alliance. 5G White Paper. 2015.

[23] Jeffrey G. Andrews, Stefano Buzzi, Wan Choi, Stephen V. Hanly, Angel Lozano, Anthony C K Soong, and Jianzhong Charlie Zhang. What will 5G be? *IEEE Journal on Selected Areas in Communications*, 32(6):1065–1082, 2014. ISSN 07338716.

[24] Laxmana Rao Battula. Network Security Function Virtualization (NSFV) towards Cloud computing with NFV Over Openflow infrastructure: Challenges and novel approaches. *2014 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, pages 1622–1628, 2014.

[25] Pål Grønsund and Telenor. Opportunities and Challenges with NFV / SDN from a Mobile Operator's Perspective, 2015.

[26] Pål Grønsund . Personal Correspondence, Telenor, Date: 24.04.2015.

[27] Pål Grønsund, Andres Gonzalez, and Telenor. NFV–Main Concepts, Business Perspectives and Dependability Modeling Use Case Assessment of NFV use cases Dependability modeling and assessment. (March), 2015.

[28] Bram Naudts, Mario Kind, Fritz Joachim Westphal, Sofie Verbrugge, Didier Colle, and Mario Pickavet. Techno-economic analysis of software defined networking as architecture for the virtualization of a mobile network. *Proceedings - European Workshop on Software Defined Networks, EWSDN 2012*, pages 67–72, 2012.

[29] Ericsson. Ericsson mobility report. Update Feb 2014. 2014.

[30] Jens Zander and P Mahonen. Riding the data tsunami in the cloud: myths and challenges in future wireless access. *Communications Magazine, IEEE*, 51(3): 145–151, 2013.

[31] Luigi Atzori, Antonio Iera, and Giacomo Morabito. The internet of things: A survey. *Computer networks*, 54(15):2787–2805, 2010.

[32] Shanzhi Chen and Jian Zhao. The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication. *IEEE Communications Magazine*, 52 (May):36–43, 2014. ISSN 01636804. doi: 10.1109/MCOM.2014.6815891.

[33] Shanzhi Chen, Yingmin Wang, Fei Qin, Zukang Shen, and Shaohui Sun. LTE-HI: A new solution to future wireless mobile broadband challenges and requirements. *IEEE Wireless Communications*, 21(June):70–78, 2014.

[34] The Norwegian Competition Authority. Vedtak V2015-1 – TeliaSonera AB (publ) - Tele2 Norge AS/Network Norway AS – konkurranseloven § 16 jf. § 20 – inngrep mot foretakssammenslutning (1). 2015.

[35] Lov om elektronisk kommunikasjon (ekomloven). https://lovdata.no/dokument/NL/lov/2003-07-04-83269, Accesed 09.04.2015.

[36] Samferdselsdepartementet. Statsbudsjettet 2015 - tildelingsbrev til Nasjonal kommunikasjonsmyndighet, 2015.

[37] Post og teletilsynet. Minstekrav til reservestrømkapasitet i landmobile nett 6. 2014.

[38] Council of European Union. Directive 2002/21/ec, article 26, 2002.

[39] Bruno Jullien, Rey Patrick, and Claudia Saavedra. The economics of margin squeeze. 2014.

[40] Post- og Teletilsynet. Varsel om vedtak om utpeking av tilbyder med sterk markedsstilling og pålegg om særskilte forpliktelser i markedet for tilgang til og samtaleoriginering i offentlige mobilkommunikasjonsnett. 2014.

[41] Nkom. Frekvensstrategi for Nasjonal kommunikasjonsmyndighet, 2015–2016. 2015.

[42] Norwegian Post and Telecommunication Authority. Bredbånd i Norge 2014. 2014.

[43] Berit Svendsen, Telenor. Robusthet i telenettet – trender, utvikling og krav. 2014.

[44] SSB. Tettsted.
http://www.ssb.no/a/metadata/conceptvariable/vardok/141/nb
Accessed 03.04.2015.

[45] Nexia. Bredbåndsdekning 2014. 2014.

[46] Nexia. Bredt nok? Kapasitetsbehov og utviklingstrender innen bredbåndskommunikasjon. 2011.

[47] CRNA. Robusthet i norske mobilnett. 2013.

[48] CRNA. Robusthet i norske mobilnett, tilstandsrapport 2014. 2015.

[49] Post og teletilsynet. Sårbarhetsanalyse av mobilnettene i Norge. 2012.

[50] Eirik Larsen Følstad and Bjarne E Helvik. Failures and changes in cellular access networks; a study of field data. In *Design of Reliable Communication Networks (DRCN), 2011 8th International Workshop on the*, pages 132–139. IEEE, 2011.

[51] Nexia. Kost nyttevurdering av tiltak for styrking av norsk sambands og ip infrastruktur. 2012.

[52] Ida Oftebro. Bygger raskere enn noen gang. *InsideTelecom*, 2015.
http://www.insidetelecom.no/artikler/bygger-raskere-enn-noen-gang/189531
Accessed: 16.05.2015.

[53] AINMT. Investor Presentation. 2015.
http://www.paretosec.com/upload/files/AINMT%20-%20Investor%20presentation%20-%2027%20March%202015.pdf, Accessed 13.05.2015.

[54] Håvard Fossen. Neppe 5G-fart på bygda. *InsideTelecom*, 2015.
http://www.insidetelecom.no/artikler/neppe-5g-fart-pa-bygda/168252
Accessed: 19.05.2015.

[55] Nkom. Ekomtjenester, -nett og -utstyr Utvikling og betydning for PT. 2014.

[56] A.T. Kearney. A Future Policy Framework for Growth. 2013.

[57] Ida Oftebro. Slik skal Ice angripe det norske markedet. *InsideTelecom*, 2015. http://www.insidetelecom.no/artikler/slik-skal-ice-angripe-det-norske-markedet/185842
Accessed: 10.05.2015.

[58] Arne Joramo. ICE bør bli mer aggressiv. *Computerworld*, 2015. http://www.cw.no/artikkel/telekom/ice-bor-bli-mer-aggressiv
Accessed: 13.05.2015.

[59] OECD. Wireless market structures and network sharing. 2014.

[60] T. Frisanco, P. Tafertshofer, P. Lurin, and R. Ang. Infrastructure sharing and shared operations for mobile network operators from a deployment and operations view. In *Network Operations and Management Symposium, 2008. NOMS 2008. IEEE*, pages 129–136, April 2008.

[61] A. Khan, W. Kellerer, K. Kozu, and M. Yabusaki. Network sharing in the next mobile network: Tco reduction, management flexibility, and operational independence. *Communications Magazine, IEEE*, 49(10):134–142, Oct 2011.

[62] 3GPP. Network sharing; Architecture and functional description. 2014. http://www.3gpp.org/DynaReport/23251.htm
Accessed: 08.05.2015.

[63] ENISA. National Roaming for Resilience. 2013.

[64] Ole-Harald Nafstad. Deler nettverk i Finland. *InsideTelecom*, 2015. http://www.insidetelecom.no/artikler/deler-nettverk-i-finland/162696
Accessed: 07.05.2015.

[65] Jan Markendahl. Mobile network operators and cooperation: A tele-economic study of infrastructure sharing and mobile payment services. *PHD Thesis.*

[66] Coleago Consulting. Mobile network infrastructure sharing. 2015.

[67] Faqir Zarrar Yousaf, Johannes Lessmann, Paulo Loureiro, and Stefan Schmid. SoftEPC - Dynamic instantiation of mobile core network entities for efficient resource utilization. *IEEE International Conference on Communications*, pages 3602–3606, 2013. doi: 10.1109/ICC.2013.6655111.

[68] PA Consulting Group and Intel Corporation. Evolved Packet Core and Intel's vision for the Telco Cloud. 2012.

[69] Abul Kaosher. Personal Correspondence, Nokia Networks, Date: 23.04.2015.

[70] M. Hadzialic, B. Dosenovic, M. Dzaferagic, and J. Musovic. Cloud-ran: Innovative radio access network architecture. In *ELMAR, 2013 55th International Symposium*, pages 115–120, Sept 2013.

[71] Bobo Cheng, Xiang Mi, Xibin Xu, Zhan Xu, Xiangxiang Xu, and Ming Zhao. A real-time implementation of comp transmission based on cloud-ran infrastructure. In *Wireless Communications and Mobile Computing Conference (IWCMC), 2014 International*, pages 1033–1038. IEEE, 2014.

[72] A. Checko, H.L. Christiansen, Ying Yan, L. Scolari, G. Kardaras, M.S. Berger, and L. Dittmann. Cloud ran for mobile networks 2014; a technology overview. *Communications Surveys Tutorials, IEEE*, 17(1):405–426, Firstquarter 2015.

[73] NTT DOCOMO. DOCOMO Successfully Trials NFV Using Multi-vendors' Virtualization Systems, 2015.
https://www.nttdocomo.co.jp/english/info/media_center/pr/2014/1014_00.html
Accessed: 07.04.2015.

[74] Josep Batallé, Jordi Ferrer Riera, Eduard Escalona, and Joan a. García-Espín. On the implementation of NFV over an OpenFlow infrastructure: Routing function virtualization. *SDN4FNS 2013 - 2013 Workshop on Software Defined Networks for Future Networks and Services*, 2013.

[75] Kurt Lekanger. Google blir mobiloperatør. *InsideTelecom*, 2015.
http://www.insidetelecom.no/artikler/google-blir-mobiloperator/186033
Accessed: 24.04.2015.

[76] Nard Schreurs. Norske politikere kan overvåkes. *Computerworld*, 2012.
www.cw.no/artikkel/sikkerhet/norske-politikere-kan-overvakes
Accessed: 24.04.2015.

[77] Nexia. Bedre mobiltjenester på tog. 2015.

[78] Oslo Economics. Beredskap for nødkommunikasjon ved lengre strømbrudd. 2014.

[79] DNK. Robusthet i transmisjon. 2014.

[80] Filomena Chirico and Norbert Gaál. State aid to broadband: primer and best practices. *Competition Policy Newsletter*, 2011.

[81] Post og teletilsynet. Foreløpige erfaringer og forslag til tiltak etter ekstremværet Dagmar. (2), 2012.