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Abstract: This thesis is review on of the trending discussions in the mobile world today, 5G Mobile Networks and how Huawei stands among other competitors and tech companies. Literature and standards reviews, along with interviews of independent experts in the field will provide the base for the research on the topic. The final goal is to provide a detailed and comprehensive analysis with practical implications of 5G and the technology actors participating in it's development. The structure of the research is presented in two main parts. First part will be introduce to the reader the standardisation process; part two will provide a detailed picture of the mobile world and will review the stage of 5G implementation. The second part will rely on mixture of descriptive, explanatory and qualitative methods, for collecting data, followed by analysis. One outcome of the research is that fusion of 5G and it's predecessors will represent the infrastructure, lead by a selection of tech giants in the near future.

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Aalborg University - Copenhagen

Master's Thesis

Analysis of IMT-2020 implementation by Huawei

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A thesis submitted in fulfillment of the requirements for the degree of M.Sc. in Engineering of Innovative Communication Technologies and Entrepreneurship

in the

Center for Communication, Media and Information Technologies
Dept. of Electronic Systems

September 16, 2019

Declaration of Authorship

I, Ivan Gelov, declare that this thesis titled, “Analysis of IMT-2020 implementation by Huawei” and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
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- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date:

"It's often taken for granted that the most dominant tech companies control the world's most important technology and communications platforms. Instead, the truth is that these giants run on top of the world's most important platform: the mobile communications networks."

Börje Ekholm, CEO of Erricsson

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Abstract

Technical Faculty of IT and Design
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M.Sc. in Engineering of Innovative Communication Technologies and Entrepreneurship

Analysis of IMT-2020 implementation by Huawei

by Ivan Gelov

This thesis is review on of the trending discussions in the mobile world today, 5G Mobile Networks and how Huawei stands among other competitors and tech companies. Literature and standards reviews, along with interviews of independent experts in the field will provide the base for the research on the topic. The final goal is to provide a detailed and comprehensive analysis with practical implications of 5G and the technology actors participating in it's development. The structure of the research is presented in two main parts. First part will introduce the reader to the standardisation process; part two will provide a detailed picture of the mobile world and will review the stage of 5G implementation. The second part will rely on mixture of descriptive, explanatory and qualitative methods, for collecting data, followed by analysis. One outcome of the research is that fusion of 5G and it's predecessors will represent the infrastructure, lead by a selection of tech giants in the near future.

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Contents

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List of Abbreviations

1G	**F**ist **G**eneration of communication technologies
2G	**S**econd **G**eneration of communication technologies
3G	**T**hird **G**eneration of communication technologies
4G	**F**ourth **G**eneration of communication technologies
5G	**F**ifth **G**eneration of communication technologies
3GPP	**3**rd **G**eneration **P**artnership **P**roject
5GPPP	**5G I**nfrastructure **P**ublic **P**rivate **P**artnership
ASP	**A**pplication **S**ervice **P**rovider
BS	**B**ase **S**tation
CP	**C**yclic **P**refix
EDGE	**E**nhanced **D**ata rates for **G**SM **E**volution
EPC	**E**volved **P**acket **C**ore
EUTRAN	**E**volved **U**niversal **MTS T**errestrial RAN
FACTS	**F**ramework, **A**alysis, **C**omparison and **T**esting
FBMC	**F**ilter, **B**ank **M**ulti **C**arrier
FTN	**F**aster-than-**N**yquist signaling
GFDM	**G**eneralized **F**requency **D**ivision **M**ultiplexing
GSM	**G**lobal **S**ystem for **M**obile Communication
GSMA	**GSM A**ssociation
GPRS	**G**eneral **P**acket for **R**adio **S**ervices
HSS	**H**ome **S**ubscriber **S**ever
ICT	**I**nformation and **C**ommunications **T**echnologies
IMT	**I**nternational **M**obile **T**elecommunication
IoT	**I**nternet **o**f **T**hings
IP	**I**nternet **P**rotocol

IPR	**I**ntellectual **P**roperty **R**ights
ISDN	**I**ntegrated **S**ervices **D**igital **N**etwork
ITU	**I**nternational **T**elecommunication **U**nion
ITU-R	**ITU R**adiocommunication Sector
ITU-2020	**ITU R**adiocommunication Sector
LAN	**L**ocal **A**rea **N**etwork
LTE	**L**ong-**T**erm **E**volution
M2M	**M**achine to **M**achine communication
MIMO	**M**ultiple-**I**nput and **M**ultiple-**O**utput
MME	**M**obility **M**anagement **E**ntity
METIS	**M**obile **E**nablers for the **T**wenty-twenty **I**nformation **S**ociety
MTS	**M**obile **T**elecommunication **S**ystem
MT	**M**obile **T**erminal
MSC	**M**obile **S**witching **C**entre
NGCN	**N**ext **G**eneration **C**ore **N**etwork
NOMA	**N**on-**o**rthogonal **M**ultiple **A**cess
OFDM	**O**rthogonal **F**riquency-**d**ivision **M**ultiplexing
OFDMA	**O**rthogonal **F**riquency-**d**ivision **M**ultiple **A**ccess
P-GW	**P**acket Data Network **G**ate**W**ay
PAPR	**P**eak-to-**A**verage **P**ower **R**atio
PCRF	**P**olicy **C**hanging **R**ules **F**unction
PDN	**P**acket **D**ata **N**etwork
PSTN	**P**ublic **S**witched **T**elephone **N**etwork
QoS	**Q**uality of **S**service
RAN	**R**adio **A**ccess **N**etwork
S-GW	**S**erving **G**ate**w**ay
SAE	**S**ystem **A**rchitecture **E**volution
SMS	**S**hort **M**essage **S**ystem
SNR	**S**ignal to **N**oise **R**atio
TDMA	**T**ime **D**ivision **M**ultiple **A**ccess

TSG	**T**echnical **S**pecification **G**roups
UFMC	**U**niversal **F**iltered **M**ulti-**c**arrier
VNI	**V**ideo **Network Index**
VoIP	**V**oice over **IP**
WLAN	**W**ireless **L**ocal **A**rea **N**etwork
WRC-19	**W**orld **R**adiocommunication **C**onference 2019
WWW	**W**orld **W**ide **W**eb

Physical Constants

Speed of Light	$c_0 = 2.997\,924\,58 \times 10^8\,\mathrm{m\,s^{-1}}$ (exact)

List of Symbols

a	distance	m
P	power	W ($\mathrm{J\,s^{-1}}$)
ω	angular frequency	rad

Chapter 1

Introduction

This thesis is going to perform a review of the development of mobile telecommunication technologies and in particular will focus on the upcoming 5G technology. The aim of this project is to analyze the strengths and possible weaknesses of the mobile equipment producer Huawei in the mobile network and handset markets. The technological spotlight will be on the development of the 5G standard and the Huawei's involvement with the IMT-2020 [1] standards. The business focus will be on how Huawei operates in network markets running mobile networks for mobile operators and how they approach the handset market.

In this chapter, evolution of mobile communication technologies is going to be introduced along with their classification by International Mobile Telecommunication (IMT) standards and how the world of handsets and mobile devices is moving towards faster, better and more efficient ways of communication – 5G. Motivation for this project will be presented to the reader along with the problem definition itself. Limitations and scope will be discussed and the chapter will end with a conclusion formed on the aforementioned topics.

1.1 Background

The purpose of this subchapter is to provide the bases for understanding of mobile technologies and the different trends that push their development. The terminology of Generation, simply "G" will be explained alongside it to enhance readers understanding.

1.1.1 History and trends in Wireless communications

Ever since the invention of the first mobile in 1973 by Motorola [2], humans have always thrived towards smaller, smarter devices and better services. Initially developed for voice conversations, mobile communication technologies offer much more. In 1981, the first mobile service was

focused on mobile telephony, providing voice communication. It was classified as a 1G Mobile Communication. G terminology or so-called Generation was a classification given by International Telecommunication Union (ITU), in order to distinguish progress in different generations of mobile communication technologies and their related characteristics. It provides easy distinguishable concept that is easy to be understand by the general public and marketed by service providers [3]. Moreover, using the term G proved to be important when describing the services delivered by a certain generation.

Continuing development, future generations made possible of data transfer over the network. Second Generation (2G) enabled roaming communication and even data transfer (SMS), by introducing GSM (Global System for mobile). However, initial data rates were up to 9.6kb/s. Followed by the Internet Boom, Third Generation (3G) focused on a faster data transfers and lower latency (delay) [4]. Smart phones and the adoption of data hungry devices, further accelerated the development of wireless communication technologies. Cisco's Visual Networking Index (VNI) [5] revealed that traffic will triple from 2019 to 2020. Additionally, to the growing usage of such devices, another factor for the increase of data traffic is the different multimedia content that is being transferred across the network such as high quality video, 3D video and other real-time services. Mobile users were also involved social networking, which introduced new consumption behavior with a considerable amount of data traffic. As a result, global voice traffic was overtaken by mobile data traffic in 2009. Table 1.1 shows relative data consumption of smart devices used in our everyday life. As shown, the feature phone is the starting point for data consumption and got lowest rate – 1x. Then data usage rapidly increases to 24 times that of the feature phone – smart phones. Portable gaming devices or the so-called hand-held gaming consoles double the amount of data used to 60 times the data usage of the smartphone. At the end laptops, or the portable computers consume more that 500 times the data of suited for the feature phone. Apart from the exponentially growth of network traffic, additional challenge on the future network is the number of devices connected to the mobile communication infrastructure. Machine to machine (M2M) communications will be common in 2020s. These kinds of communications require very low latency. In addition, mobile devices are not only advancing their computing capabilities, but manufacturers are also moving from lower-generation networks (2G) to higher-generation networks (3G, 4G and now also 5G). That means that in near future almost all devices, if not all, will rely on and consume data.
Next follows a review of the latest and fastest generation of mobile communication – 4G, discussing its reasons for development, advantages and disadvantages.

Device	**Relative Data Usage**
Feature Phone	1x
Smart phone	24x
Hand-held gaming console	60x
Tablet	122x
Laptop	515x

Table 1.1: Data consumption of different devices [4].

1.1.2 Evolution of 4G

But why there was a need for 4G at first place? Initially data transfer over mobile network provided many services that different business take benefit of. People were able to send or receive emails on the go, exchanging different multimedia content. Furthermore, devices became smarter and apps were developed for different purposes. Different business cases appeared that demanded great mobile data transfers. Thus, a better technology, that would provide better speeds at lower cost was needed in order to satisfy the demand. That is how 4G was created.
Nowadays, fourth generation mobile communication technology (4G) is used by more than 35% of the mobile devices globally. This generation of cellular network is mainly associated with Long-term Evolution (LTE) standard, that was considered mobile communication of fourth generation. LTE provided high data speeds and high capacity, enabling users to watch live video. The infrastructure will be analyzed in detail in chapter 3. However, the evolutionary part that 4G brought was that LTE was supporting only packet-switched connectivity. No part of this generation technology is based on circuit switching. The 4G provided secure IP-based network that supports voice, data and multimedia services to mobile users. Speed rates were also increased to up to 100Mbps for mobile users and 1Gbps for statuary ones. However, along with LTE, Worldwide Interoperability for Microwave Access (WiMax) was used in United Stated and also was considered an important 4G technology. Yet, these two rivals were considered as a pre-4G technologies according to the standards developed by ITU for real 4G compliance. Latency was minimized to around 20ms with the implementation of LTE-Advances technology, that eventually was 4G compliant. In summary, 4G was the most noticeable difference from previous generations, shifting operator-centric concept (3G) to a service-centric concept. The need for data and speed increased and 4G showed that mobile internet services have become more important than the voice and messages alone.

But analyzing the trends and the emerging new services, these qualities of 4G will reach their limits, sooner than expected. Therefore something must be done, to prevent mobile network congestion and meet the rising demand.

1.1.3 Why Going 5G?

Considering that 4G satisfies the ordinary user, the question of why we should strive towards a new standard and eventually new generation of cellular network appears? There are a few major reasons to do so, as stated in [3]. When ITU published the classifications of 4G and development of the technology began, main driver was the mobile broadband and its usage. Additional contributing factors also increased the need of new development. 4G was using expensive hardware and infrastructure. In some countries, frequency bands were licensed at a very expensive price. Hence, a more efficient and better mobile communication must be developed. As we are moving towards fifth generation (5G), effort is focused more on latency, reliability, throughput, data volume and mobility [6]. However, the bigger challenge for 5G will be constant need of increased network capacity, as the growth of mobile Internet usage continues to increase over the last two years. According to Rost et al. [6] here are the main reasons for mobile data increase:

- More mobile devices connected to the network.
- More diverse and demanding services, also more bandwidth-hungry.
- Introducing Device-to-device (D2D) type of communication.
- Integration of IoT and Machine to machine (M2M) type of communication.
- User terminals used as a gateway to access other services – cloud, live TV etc.
- Devices that are using the spectrum are more complex and data hungry.

As the focus is on service-based concept, there was immense growth in the mobile broadband since 2006 – 92% [5]. This puts concerns on capacity limits of the existing mobile network infrastructures and with the existing growth, they will soon be reached. Current networks consist of inflexible and expensive equipment that are combined with complex and non-agile control plane [3]. Thus, the overall situation shows that 4G will be not able to handle predicted future loads and improvement of existing networks would be hard. The goal of 5G is to overcome these limitations and provide better performance, bigger capacity following economically sustainable strategy. Following this, the next generation should provide

exceptional user experience over enhanced coverage, while the price is lower compared to other generation. Possible proposal for technical implementation of 5G will be reviewed in chapter 5. This puts 5G as the one of the most efficient mobile networks. Society moves towards full mobile communication integration [7], which aims to achieve the following goals:

- Unconstrained Access to information
- Data transfer will be available for everyone
- Providing real time connection for different devices
- Fully mobile and connected society
- Flexible network that can maintain itself
- Seamless integration with all mobile devices
- Better use of the provided bandwidth

As a result, 5G will be free of the limitations embedded in previous generations, and obtaining World Wide Wireless Web (WWW) [8]. User will be put on top, making next generation of mobile communication user-centric, rather than service-centric orientation followed by 4G. Many of the telecommunication companies have already developed working prototypes and devices. Pre-commercial deployments of 5G have been already done. But as 5G will replace 4G, who is going to be the leader in the global race for 5G and how the world of mobile communication will be shaped. The answers of these questions will be responsible for "painting" the picture of the digital world and especially the mobile part.

1.2 Motivation

The motivation of this master thesis is based on revealing how standards are "born": creating the requirements, classification and implementations. A contribution to the industry and business is another driver for the project, that will allow a better understanding of the standardization process in particular – mobile communications. What the next generation of mobile technology is going to provide is immense improvement of the current 4G services – better speed, lower latency, more devices and additional abilities – Machine to Machine communication, Device to Device communication (D2D), Internet of things infrastructure [9]. The research of how requirements are set by the ITU and then followed by the telecom companies is of a great importance to networking professionals and developers, and will contribute to the better understanding of the evolution of mobile communications and the different standards along it. There are already successful implementations and tests of the 5G technology in

real environment [10]. Telecom operators, together with manufactures of 5G equipment have already proved the improvements providing stable connection that is 14 times better that the current 4G. Smartphone manufacturers are providing 5G ready devices which slowly will increase over the next years. Following the hype for 5G and better speeds, there is a need of comparison between 5G and the previous standards, and different implementations and solutions to the IMT-2020 standard. In addition, there is a shortage in information considering how the big telecom companies participate in development of the standards and how they can affect the progress. Thus a review of the how far each company that is working on 5G has advanced is needed.

1.3 Problem Definition

The objective of that master thesis is to analyze mobile communication technologies, in a specific scope – 5G. A comparison between major telecom companies, like Huawei, Ericsson and Nokia, working on 5th Generation solutions is intended to show the reader the different approaches with their advantages and disadvantages. The analysis is going to highlight firstly the development of the standards, then will reveal the current status of technology development that is compliant with the published 5G requirements and classifications.

Problem Formulation

How Huawei approached and implemented IMT-2020 and how the company operates in network markets running mobile network for mobile operators, including handset market. This will be the major question that this thesis is going to provide an answer to. This will be done by a review of the company's performance and comparison to other 5G competitors.

Sub-questions:

How mobile standards are developed? Who are the main participants in the developments of new standards and technologies? The answer of that question will be provided in chapter 3, reviewing what urges the need of standards and standardization bodies in mobile communication world.

What are the benefits of the 5G? A more detailed picture of the 5G infrastructure and current mass used generation will be presented to the reader, followed by a comparison between the two. In that way, the reader will be informer about the potential of the future generation mobile technologies.

Who are the leading companies introducing 5G to people? After reviewing the theoretical framework and the differences between generations, reader will be introduced to the major companies that contribute to future development of mobile communication and the competition among them.

If we build it, will they come? 5G is predicted to deliver huge profits by exploring a vast market for 5G services and equipment, followed by countless new jobs. However, a realistic assessment of the new generation will be revealed to the reader, trying to propose a future development path.

1.4 Limitations

In this thesis, technologies are going to be reviewed at a higher level. However, knowledge in mobile data communications and management is going to be need. It must be considered that the solutions of 5G, proposed by each tech company are proprietary and so specific details and ways of operations are inaccessible. Consequently, the analysis will introduce 5G and general principles of operation. As the thesis is based on standards and literature, there were no case studies. However, in order to collect as much information about the current situation with 5G, several expert surveys will be conducted. Access to more detailed description of vendor's solution, interviews with experts from the telecommunication or radio sectors would have added a better understanding and contributed for a more comprehensive review of the problem. Case study introduction would have provided further inside knowledge from the business. Adding to the limitations is the framework used. Using multiple analytic frameworks would have produced more detailed research. Finally, it has to be noted that 5G is still in development and is considered as a brand new technology at the moment of writing that project. Therefore, different conclusions can emerge in future reviews.

1.5 Subconclusion

As we can see mobile communications have come a long way since the first mobile call has been achieved. There is now a huge market with vast competition, and mobile telecommunication companies are fighting for every possible piece of influence and profit. Also important part is the innovation to the market. The increasing need of speed and bandwidth, combined with the rapid evolution of network technologies is transforming the mobile communication industry. The goals of this conversion are greater flexibility, automation, sustainability and better services. All of

these have to be achieved at a lower cost. Making that a reality will happen with the help of 5G. Next chapter will present to the reader what will be the approach when obtaining research data and which methods will be applied when analysing the collected information.

Chapter 2

Methodology

2.1 Introduction

This chapter is going to provide detailed description of the methods used to obtain research data necessary perform analysis, in order to provide answer to the problem formulation. When analyzing the 5G technology and the different approaches by the contributing companies, both objective and subjective points of view will be weighted. The thesis will be aligned with pragmatism-based research philosophy and the focus will be on the practical and effective information. Nature of the project requires that no primary data can be used, and this thesis will rely on secondary source data.

2.2 Methods applied

Part of the dissertation is the investigation component, which puts focus on both standardization and the technical principles used by companies that follow these standards. The reader will be introduced to the process of standardization and how companies contribute to the development of 5G technology, in addition to how these technologies work. This will form the baseline for the theoretical framework, that is part of this dissertation. Review of literature and standards will be a significant part of Theoretical framework and “State of the Art” chapters. The thesis will benefit from a mix of descriptive, explanatory and qualitative methods, for collecting data. After its collection, the data will be used as a base for the followed analysis. The analysis will not based on certain framework, but instead will follow the approach reviewed in chapter 3. A simple diagram of the whole process is described in figure 2.1

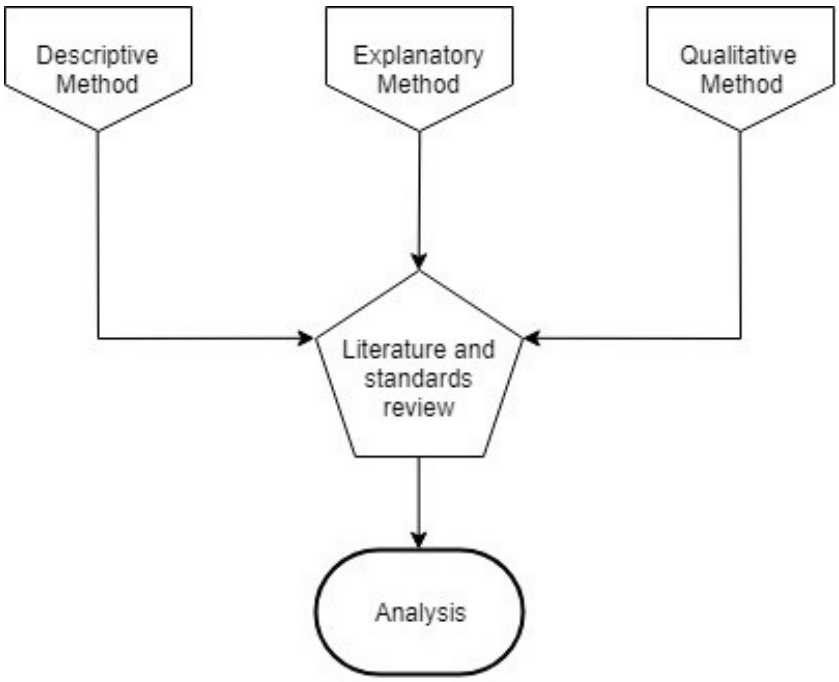

Figure 2.1: *Methodology framework*

Descriptive method

This type of research method is based on fact-finding and interpretation [11]. An example of descriptive research would be mobile market outlook in 2015. It is a description of a satiation [12]. The thesis will benefit from that method and in that way it will provide clear understanding of current mobile technologies and future standards. It will provide the needed comparison between different implementations of 5G. Considering the nature of the dissertation, relying on descriptive research is not enough as it does not provide proper conclusion and analysis. Descriptive research will be used as a step to the next method – Explanatory.

Explanatory method

Explanatory method enhances this thesis by focusing research studies on correlation of different event [13], or in our case – different technologies and implementations. The research consists of reviewing a selected technology, collect the base knowledge for the explanation of its working principles and components. In this dissertation, 4G and 5G will be explained in comprehensive manner. Details regarding infrastructure and mobile network functions will be introduced and analysed. Reader will be provided with sufficient knowledge about the mobile network and different implementations of 5G. Following the explanatory method is the qualitative

Qualitative method

Qualitative data is the core of this research method. It represents non-quantitative data from all types of research. Further in [14], non-quantitative data is type of data that is not measured by numbers. We can take as an examples of qualitative data source interviews and surveys. Following the research method, there are three major principles in it as described in [13]:

- Meaningfulness
- Data classification
- Conceptual analysis

The collected information will be based on meaning (Meaningfulness). In the current dissertation, the data will consist of technology explanations. Then, it will be classified in multiple sections and subsections. The benefit of different types of figures will also be accounted and used, as it provides a more detailed view on the inspected problem. Thus, technology explanation will be presented in comprehensive way. The thesis will benefit of a small portion of quantitative-based data, for the provision of applicable details for the research[14].

Additionally, the qualitative method will use open-ended questions and will be designed based on an inductive approach. The approach defines the structure of the research and helps the research to set objectives and action plan. The research approach for this qualitative study is inductive, which is generally used for the majority of the qualitative researches. The inductive approach collects empirical data [15], which will help the researcher to identify patterns and to form its own hypothesis, which will later on lead to the creation of a new theory.

The aim of this qualitative research is to gain a more in-depth knowledge of 5G network and its general application by interviewing tech professionals who have knowledge and experiences in this field. The participants in this research will share their professional opinion about the development and the implementation of 5G for mass usage. The analyses of their answers would contribute to the better understanding of the 5G topic and will enable the researcher to compare the analyses of this primary research with the findings from the secondary research such as articles, case studies, etc.

The research itself will include 8 open-ended questions, which will be distributed via Google Forms platform. The questions aim to get perceptual and technical insights of the recent 5G development status. The target audience for the research will consist of four working professionals who specialise in 5G technologies and have practical knowledge of the researched problem.

The participants in this project will be purposefully sampled, based on their professional status, knowledge and experience with 5G technologies. All people taking part in this research are experts in telecommunications and are focusing their professional development around mobile networks, particularly the integration of 5G networks or at least they are related to mobile technologies.

All participants in this research will be anonymous, no personal data will be collected [16]. The results of the research will be kept on the Google Forms platform and only the researcher itself will have access to it. When using quotations from the survey for the purpose of this study, the researcher will anonymise this data and will not use your or anybody's name. While the researcher agrees to maintain the confidentiality of the raw data, the researcher may publish analysis and findings from the raw data. All participants are entitled to withdraw from the research at any point. The analyses and the data from the study will be available upon request. All participants will have to read the terms and conditions of this project and voluntarily agree to participate and share their knowledge. The open-ended questions can be seen in Appendix A. Once the data from the research is collected [16], the findings will be organised and divided in categories, based on their similarity. The purpose this is to identify common themes, patterns and relationships between the answers, which will make the findings more logical and easily understandable. The combined results will be presented in consistent manner and will be compared with the results from the secondary research. The following paragraphs will provide comparisons between the primary data and the literature review, and discuss the similarities and differences between them.

2.3 Analysis

Analysis is going to start with a comparison of 4G and 5G technologies. Thereupon data that has been gathered from the research part will be used to provide answer to the problem formulation. Different implementations of the 5G technology and the contribution of major technology companies will be compared. This is going to be executed by reviewing development of 5G in each organization and what influence each has each one caused in the course of the overall development. As mentioned in previous paragraph, this thesis will benefit from an analysis on qualitative open-ended questions.

2.4 Subconclusion

In this chapter, review of the methods for the research and analysis for this dissertation was performed. In addition, the theoretical framework

was also revealed for the accomplishment of the analysis. The purpose of the chapter is to provide an outline of how the research is going to be formed and which methods are going to be applied. In the next chapter, a comprehensive review of the framework will be performed. Explanation of its principles will be provided including its application to the report. Along it, the standartisation process for 5G will be reviewed and discussed.

Chapter 3

Theoretical framework

3.1 Introduction

This chapter is going to describe the approach taken in order to perform literature review, theoretical frameworks and eventually explain why this approach was chosen in order to conduct the necessary analysis for 5G. In this thesis, 4G and 5G mobile standards are going to be reviewed. They are going to be reviewed as different standards, but they share a common thing - they are part of mobile communication technology, only different generations. Considering that, it will be more suitable to review and analyse how these standards are developed, track the road-map of a standard. But why, chose a descriptive type of framework at first place? Explaining other alternatives and comparing them to the chosen approach will answer this question. There are several frameworks that could be consider as alternatives – Standards wars, hype cycle model, the diffusion of innovation theory and FACTS.

Standards Wars

As the name suggests, this framework would put focus on comparing standards [17], but is more market oriented. It would examine the benefits of each standard and will provide a broader view on the market and the rivalry between different solutions. However, it would not fit perfectly for our goal.

Hype cycle model

Hype cycle model is more focused on innovation part of new technology. The framework, developed by Garther [18] tracks the product's expectations and the value over specified period. That part of the framework makes it suitable for this thesis, however there is lack of comparison between standards.

Diffusion of innovation theory

Next is the framework proposed by Everett Rogers [19] - the diffusion of innovation theory. This theory is aimed to analyse the adoption of a certain technology on the market. It performs an examination of the growth of that appliance following the initial stage of its development to the mass spread across people. Diffusion of innovation could be considered a good framework for our project, but it lacks some comparison methodology that is needed for the analysis.

FACTS

Last but not least is the Framework for Analysis, Comparison and Testing of Standards or just FACTS [20]. Again, this is a standards-oriented framework and it would have served as a good basis for the research. However, the goal of FACTS is testing of standards.

As we can see, each of these frameworks are especially good at one thing. The goal of the thesis is to introduce the reader, not only to methods of comparing standards, but to give knowledge of the whole processes from end-to-end perspective. This will mean that a more descriptive framework would be needed in order to explain the processes of initiating, developing and publishing a certain standard. So, for that purpose we are not going to follow a certain framework, but rather follow a descriptive path. A combination of all the previously mentioned frameworks will take place in order to achieve explaining to the general reader several key topics:

- What is standard and why it is needed?
- How a standard is created?
- Who are the main contributors and actors in the standardization process related to mobile networks?

3.2 What is a standard?

Simply said, standards are detailed description of “How thing should be”. It provides an explicit explanation of procedures to perform a certain action or achieve a desired effect. In a paper by Bowker and Star (1998) [21] say “. . . standards are procedures of how to do things.”. The word ‘standard’ also defines a set of things that are mostly done in a same common manner, but no prescriptive qualifications are applied. At some point in time, a detailed record of that ‘standard’ has been created by somebody, group or organization, to determine “how to do things according to standards”. As presented in [22],an example of a standard can be languages. They represent a standard – one certain way to communicate verbally and

express oneself. There is the term “standard behavior” – a certain behavior that is expected by someone in given situation. Also, different measurements are done according to something that is considered as certain – standard. Actually, the first natural standards were those for measuring space and time [23]. Mayan calendar was pretty accurate for time measurement and the length of King Henry I of England’s arm [24][25], also known as ‘ell’, was used as a unit for distance. Compatibility specifications are also considered as standards. Standards can be found in all aspects of life. The definition also applies for technical standards, in the case of this thesis – different generations of mobile technology. Exactly how devices communicate is defined within a standard.

But can we classify or categorize the standards?
In his paper [26], David P. marks three types of standards. According to his classification standards can be reference standards, quality standards, and compatibility standards.

Reference standard – as the name suggests, these standards are usually used for measurement. Distance, width, height, weight and time are core part of the reference standards. For example, *Systeme International* (SI) [27] defines seven fundamental units for seven independent dimensions of measurement. Standard definition of metre is the length of the path that light will cover in a vacuum for a the time of 1/299,792,458 of a second.

Quality standards – this type is used to set the boundaries of acceptance for certain qualities. A quality standard describes a thing or a process compared to an expected set of result in a given situation. For example, steel can have different qualities regarding strength and flexibility, that are required in different use cases. Depending on the case it can be flexible, heat resistant or stainless. Therefore quality standards are introduce dividing steel into grades, that a suitable for specified use cases. On that, steel grade EN 1.4125 [28] is the strong and durable even after heat treatment Usually used for cutlery and ball bearings.

Compatibility standards – following these standards, ensures that different parts of a system can operate and exchange information together. A dramatic example is the fire in Baltimore, USA in 1904 [29]. A vicious fire accident took over 2500 houses and burnt for more than 30 hours. Near cities sent their fire brigades, but they were helpless. It turned out that their fire hoses were not compatible with the local fire hydrants and their efforts were found to be in vain. It proved that compatibility standards need to be followed in order different devices or parts can work together.

In the world of ICT [30], all of the above classifications are used in various of mobile communication standards, However, as noted by the authors in [22], communication standards at their core are compatibility standards. They build upon other standards for quality or reference, but in the communication universe ensuring interoperability is a key goal

in communication between devices and infrastructure elements. That is because they set the methods of transmitting and managing information. Technical standards can be separated by another factor – de jure and de facto standards.

The **de facto standards** are defined by dominant players in different markets. Often called industry standards, a phrase used to describe what is being followed by all manufactures in a specified industry. On the other hand, **de jure** standards are ones that are developed by standardization bodies. The process can be debated not only on regional or national level, but also international.

Standard can be also sponsored or unsponsored. That means that a standard is supported by organizations which involve intellectual property in its development – the sponsorship. Sponsored standards are related to the de facto type of standards. They have the Intellectual Property Rights (IPR) and usually are not opened to the public. Unsponsored one, are these standards that have no IPR and they are aligned with the de jure processes. Open to the public, they are spontaneous and can quickly evolve. However, in the standardization process that follows de jure principle, companies may contribute with their already developed solutions and standards. All of the above factors and terms piece together the standardization processes, making it very complex with different participants from the different markets. Public, also semi- or non-public can also influence the development and sometimes political aspects are also introduced to the technology [31]. This is also part of this project – reviewing all participants including the producers of technical equipment and how they had contributed to the development of 5G.

But are these standards obligatory?
Certainly, standardization bodies are recognized by public institutions, but that does not make standards obligatory. In many cases, standards are voluntary, because at their core standards describe that a specific method and the definite result from using it. It is up to the user or company to decide whether to use a standard or define it in-house. However, public and regulatory organizations, regularly follow them as a base and many companies are keen to use standards as it eases their operation.

But why standards are so important then?
To put it simply, there are two main reasons:

1. It eases everyday life of people.

2. Allows certain actors to be leaders in certain markets.

The first point we have already discussed in chapter 1 by reviewing what 5G will bring in near future. However, the second is one of the key points of this dissertation. From Standards Development Organization's (SDO) [32] perspective , it is always better other companies to follow you. In that way, you can be always ahead of competition and the incomes are

guaranteed. The most basic approach is to patent a technology. A technology that becomes a de facto standard. In this way, a company secures part of the market and everyone follows it and pays for using it's developments. Thus, as described by ETSI [31], influence of special interests on standards rises, and different interest might be involved - from private companies to political organisations. Manufactures then shall pay for using their patented patented chips, interfaces and etc. On the other hand, ordinary people would like to use 5G as its new and offers more to them, but they can be trapped by being enforced to use a single technological solution. To put that in this thesis peripherals means that whoever first developed a technology that can be considered a standard, receives the biggest piece of that particular market. Reinforcing that statement will be further performed in chapter 6 where each of the telecom companies will be analysed.

3.3 How is a standard created?

After discussing what the term "standards" actually means and different types that exist, now comes the question of who defines them? How the standards are created initially? Next section is going to review that process closely aligned with the mobile communication standards and 5G, that follow de jure process. However, it has to be noted that other technical standards follow very similar, if not exactly the same conception in their making and application. The process could be briefly explained with the figure 3.1:

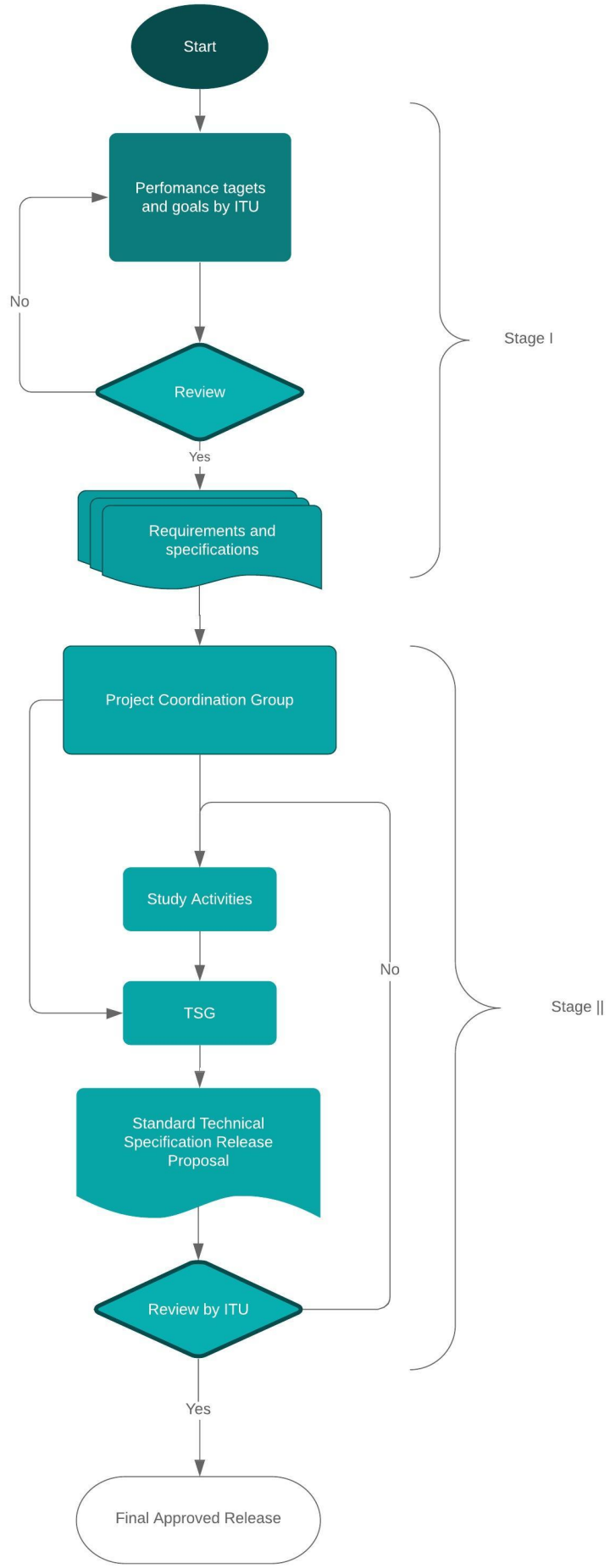

Figure 3.1: *Standardisation workflow (own picture inspired by [31])*

Following the diagram, the standardisation process starts with identifying performance targets – Stage I. The process, technology or the device that needs to be standardised. Considering 5G, the approach will be to look in the future. That could be achieved by reviewing at the trends in mobile communication environment and trying to predict the new use cases that will appear in near future. Since the successful implementation of 4G, technology companies and organizations started discussions about different scenarios where 5G will be the core technology. These will serve as a guidance of what the future definition of 5G standard would look like. In Europe, 5G Infrastructure Public Private Partnership (5GPPP) was formed. It was composed by 31 industry companies, including major research and development centers [33]. Started in 2013, 5GPPP goal is deliver solution, architectures, standards and technologies for the 5G of the next decade. Another one, Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) consortium, also founded in the same year [34], proposed a set of scenarios to challenge the next generation of mobile and wireless communications. On the other side of the globe, in 2014, 4G Americas (now 5G Americas) also provided a summary of 5G initiatives landscapes [35]. ITU [36], also declared its view on the requirements and use cases in 2015, called IMT-2020 [37]. Upon that document, a working party was devoted for that project under the name Working party 5D (WP 5D). WP 5D is bounded with the overall radio system aspects of International Mobile Telecommunications (IMT), covering the IMT-2000, IMT-Advanced and IMT for 2020 and beyond [37]. Supervision was performed with the help of ITU Radiocommunication Sector (ITU-R), which was responsible for ensuring that the radio-spectrum is used rationally, efficiently and economically wisely. Considering that, in this thesis the focus will be put on IMT-2020. After reviewing, the ITU release the IMT-2020 document with the technical specifications and requirements. A summary representation of what to be expected with a triangle infographic was published by ITU, figure 3.2.

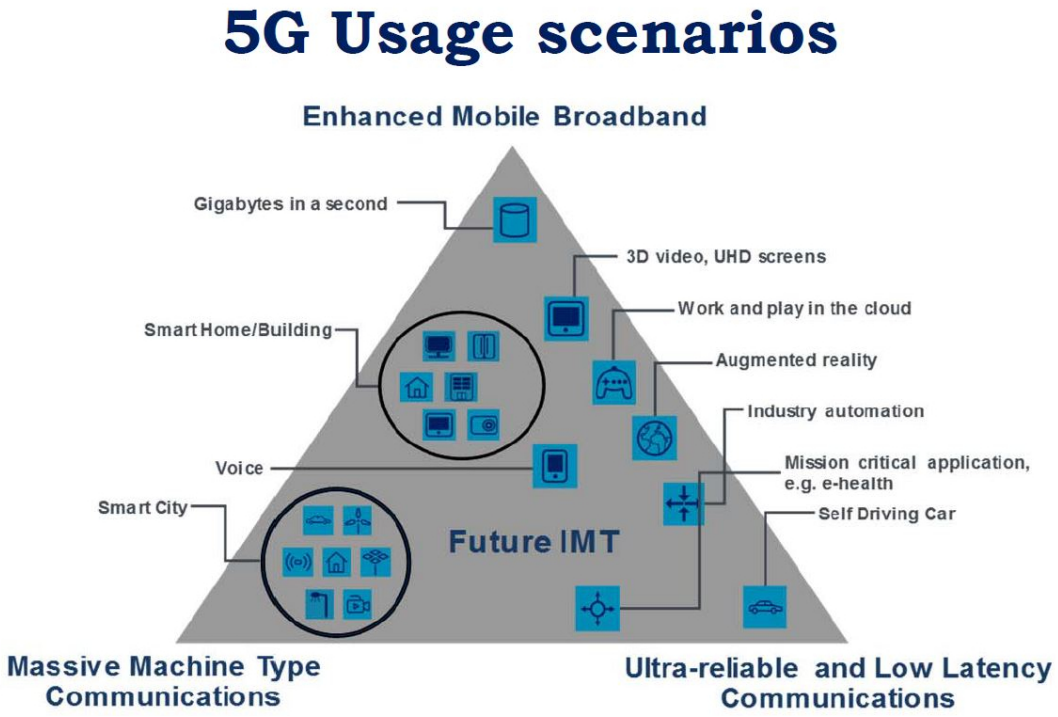

Figure 3.2: *5G Scenarios by ITU [37]*

Upon that initial document, ITU will starts to receive technical proposals and solutions. The next step is technical development. Forming technical specification groups (TSG) in order initiate study activities on the requirements – Stage II. This is lead by Third Generation Partnership Project Agreement - 3GPP [38]. As a dominant technological organization, 3GPP role is to define the architecture, protocols and signal modulations, eventually proposing full technical specification for mobile and radio communications, including 5G. 3GPP is a partnership project between recognized Standardization organizations from Asia, Europe and North America. Their work is to develop harmonized standards for mobile communications, closely related to IMT requirements issued by ITU and its sectors. They form a Project coordination group that leads the study activities and manages the technical specification groups. However, it has to be noted that the work products of 3GPP are different from the one of ITU. While ITU published IMT standards with requirements, 3GPP work on a 'release' based principle. That means that for a certain mobile generations or standards, there could be several releases, as shown in table 3.1.

Phases	1	2	3	4		5
Standards	NMT	GSM, GPRS,EDGE	UMTS, HSPXA	LTE	LTE-Advanced	
3GPP releases			R 99, R4 -7	R8 – R9	R10 - 14	R15 -?
Generations	1	2	3	4		5
IMTs			IMT-2000		IMT-Advanced	IMT-2020

Table 3.1: *Phases, standards, releases, generations and IMTs. [22]*

Here it can be noted before IMTs and the 3GPP releases, different systems were developed (GSM, GPRS, EDGE) that co-existed together. The reason for that is due to the many “standards wars” that took place in different regions around the world, with different standardization bodies and equipment producers [17], persuading slightly different interests. This inconsistency can be seen, when the Generation terminology is introduced to the big picture. Different technologies like EDGE or LTE are not recognized to be compliant with the ITMs set by ITU, though they got the potential. The goal of ITU and 3GPP is to reach globalization by focusing on the development of single standard.

The 3GPP releases are mainly used by engineers as they resemble a more accurate way of illustrating changes. A single release does not represent the big picture in the development. Instead a set of releases is pooled into generations or IMTs. Following the process of standardization, the different 3GPP releases are sent to ITU as technical proposals, where they will be validated against the initial IMT-2020 technical and performance requirements. In a case of successful recognition, the releases will become part of ITU approved standard document. However, there could be other standard bodies, regulators and participants in the creation of a standards. Therefore, building a standard could be a significant effort, requiring agreement of all included parties.

3.4 Main Participants

However, for a certain process, item or technology in our case to become a standard, there must be an agreement between the stakeholder that are participating into it’ creation.

In relation to 5G, many of the actors and related participants have not accomplished an agreement. Different goals and objectives are the main reason that brings delays of even descriptions in the standartisation process, despite many of the issues to be negotiable such as spectrum and modulation [39]. Viewpoints of different alliances also are important. For example, while the rest of the world sees 5G as a next cellular radio replacement, Verizon in the USA and their own 5G alliance sees is as the new fixed-line broadband substitute. All of that makes difficult to predict

the final result or how it will get there and moreover, who will be the winning alliance. Currently the list of actors currently includes [39]:

- European Telecommunications Standards Institute (ETSI) (3GPP – Third Generation Partnership Project);
- International Telecommunication Union Radiocommunication Sector (ITU-R) and the WRC (World Radiocommunication Conference);
- Radio Spectrum Policy Group (RSPG);
- The 5G Infrastructure Public Private Partnership (5G PPP);
- Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society (METIS);
- The Next Generation Mobile Networks Alliance (NGMN);
- Internet Engineering Task Force (IETF);
- The Institute of Electrical and Electronics Engineers (IEEE);
- Telecoms networking equipment and semiconductor manufacturers;
- The Body of European Regulators for Electronic Communications (BEREC) and the NRAs;
- National and regional SDOs; and
- CableLabs;

Here it has to be defined what the term technology company or the so called tech companies will means in the text of this project. In point of 5G, there are many participants 3.4, all of them fighting to get a piece of the new mobile technology under their pattern or get a spectrum license which can be use to generate revenue, as it will be described in chapter 5.

A technology company in this case can be broad conception. In order to be more specific, a tech company will be mention as any participating organisation that is involved in the 5G standartisation and development it regarding the technology itself. Development process can be seen as work on the mobile chips, advancements in mobile equipment for 5G, or infrastructure progress. Thus, companies like mobile device manufactures or mobile equipment manufactures are considered as a technological companies. Additionally, mobile networks operators are also considered technological companies, because of maintaining the mobile infrastructure and connectivity. They are not manufactures, but they implement the already manufactured equipment.

3.5 Subconclusion

In this chapter a detailed explanation of the approach for reviewing standards. The term standard was explained to the reader along with the existing types and classifications. The whole process of creating de jure standardization was described. Different actors in that process were discussed – ITU,ETSI, IEEE and 3GPP, including their main performing parts. The next chapter will focus on the current 4G that is in operation and the development of the technical release that eventually will take over in the near future in 2020 – 5G.

Chapter 4

State of the art

4.1 Introduction

In this chapter a detailed review will be performed on the current fastest mobile network generation 4G. Following that, next generation will be discussed by analyzing IMT-2020 and the latest releases by the contributing organizations like 3GPP. A conclusion will be made about the status of development including future plans and expectations.

4.2 Overview - 4G

Today's fastest network, that is widely spread and true 4G is considered to be LTE-Advanced. Comparing it to the previous generations of mobile networks, it brought not only speed, but change the transmission of information as s whole. Following the standardization process from chapter 3, ITU released an document with requirements of 4G back in 2008, called IMT-Advanced [40]. This was the beginning of change over for the whole world of mobile communication. The IMT document contained the requirements for the next generation of mobile communication. According to it, mobile communication system from 4th Generation should comply with the following requirements:

- Handling of a very high level of multimedia traffic;
- Mobility management at advanced level, which includes location management and hand-overs;
- Different QoS levels and separate uplink and downlink capacity allowing individual transmission speeds - Diversified radio access support.
- Vast diversity of supported applications - structure that facilitates wireless ASPs (Application Service Providers), similar to the environment in wired Internet
- Smooth transition and consistent delivery of data must, achieving seamless network and uninterrupted user experience - Network - seamless, Terminal-seamless and Content-seamless;

In technical view, the 4G is required to offer:

- Peak Data – Download: 1Gdps
- Peak Data – Upload: 500Mdps
- Spectrum Allocation: > 40Mhz
- Latency < 100ms
- Mobility – steady connection for up to 350 km/h and seamless handover.
- High performance.
- Easy global roaming
- Low cost.

But the major introduction was IP. The requirement for mobile IP support change the whole experience, bringing all good benefits of IP internet to the mobile world. The service proved to be so good and reliable that users did not find any difference using their mobile smart phones on Wifi or 4G mobile network. Telecom operators on the other hand, offered the so called 4G cookie device, where a device acted as a WiFi router for a whole family house. But instead of using ethernet cable to transmit data, it relied on 4G network. However, this chapter is focused more on the technological part of the mobile communication. Thus, 4G will be reviewed on that level, starting with a review of the architecture.

4.2.1 Network Architecture

4G is the heir of 3G. As described on table 3.1 in chapter 3. So it still benefits on the same infrastructure level as 3G, however there are some distinct evolutionary changes.

For start, circuit-switching is removed as it is no longer in use. As already mentioned in chapter chapter 1, 4G brings IP connectivity to the mobile world. All voice traffic is handled as packet data at the BS (Base Station). Therefore the MSC (Mobile Switching Centre) used in the previous generations (2G) for voice transmission is deserted. For achieving backwards compatibility, voice data is segmented into packets and routing them through the IP backbone using VoIP (Voice over IP) technology. VoIP Gateway operates to connect voice calls yo PSTN (Public Switched Telephone Network) or ISDN (Integrated Services Digital Network). Next upgrade is done to the Wireless LAN. 4G integrates Wireless LANs into the total mobile network. New air standards, allowed for seamless connection between the 4G IP backbone and the wireless LANs by simply using router with wireless access built-in. On the figure 4.1 all interfaces are air based

and as described there is no need of a control module to be connected to any wired infrastructure. Additional capabilities as ad-hoc networking is also supported via advanced version of the widely existing standard called Bluetooth. The architectural diagram of 4G cellular network is shown below:

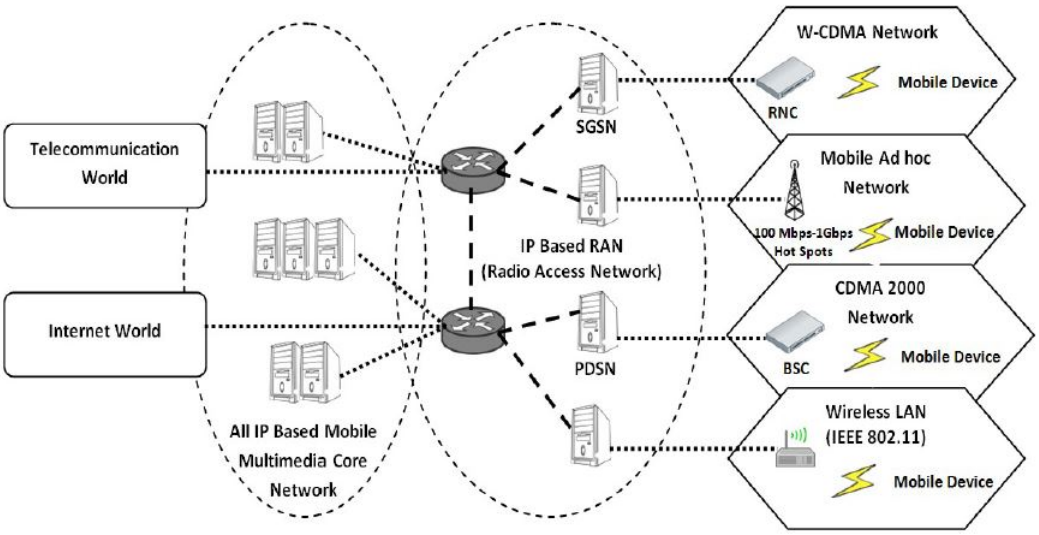

Figure 4.1: *Architecture of 4G Cellular Network [41]*

Show on the diagram is the connection between the ground based IP network and the IP Based Radio Access network (RAN). It demonstrates that the connection can be all wireless and IP based.

Signal Transmission and coverage

Any mobile network relying on radio transmission is going to be affected by the various obstacles. 4G and 5G are no exclusions of that factors. The current 4G network is heavily impacted by buildings or ground level variations. Waves are transmitted in the 2-8Ghz band and therefore the speed and latency vary at different locations. However, big role play cell-sizes. The cell radius, i.e. coverage is generally smaller than one of its previous generations. This is caused by the propagation loss, which is increased not only by urban areas and environment, but additionally by the higher frequencies that 4G is operates at. Higher transmission bit rates leads to a higher threshold of the received signal level than that at lover bit rates, which compensates for noise affect at high bit rates - receiving of an decent SNR (Signal to Noise Ratio). Cell size is determined by the following equations:

$$\begin{aligned} Lp &= 38 \times \log(d) + 21 \times \log(f) + c_0 \\ dLb &= 10 \times \log(\frac{B}{B_0}) \\ R_r &= \frac{1}{10}^{\frac{(21\times\log(\frac{f}{f_0})+10\times\log(\frac{B}{B_0}))}{38}} \end{aligned} \tag{4.1}$$

Where the ***Lp*** = Propagation Loss, ***d*** = Distance, ***f*** = frequency, ***c*** = speed light in a vacuum, ***dLb*** = Increase in noise power, ***B*** = Bit rate, $\mathbf{B_0}$ = Reference bit rate, $\mathbf{R_r}$= Relative Cell Radius, $\mathbf{f_0}$ = Reference frequency.

Following the formula, it is clear that higher frequencies together with greater bit rates will lead to smaller cell size. This is a serious factor, because decreasing cell-size by half will increase the number of Base Stations (BSs) required to cover certain area by 4 times. Laying down the infrastructure in the most efficient way is the highest cost for the providers of mobile services. Another consequence of having small coverage is the time spent within a cell, which is reduced and therefore the frequency of the hand-overs is increased. Nevertheless, fourth generation mobile communication allow Concatenated Location Registration, where a group of mobile terminals (MTs) has similar movement characteristics their locations are concatenated.

4G and WLAN integration

Another big innovation that 4G brought was the integration of mobile network with Wireless WLAN. As illustrated on figure 4.1 Wireless LAN replaces transmission over cables with transmission over air by electromagnetic waves. Here is has to be noted, that by connecting 4G mobile network to WLAN brought several enhancements:

- Reducing cabling
- Increase in installation speed
- Flexibility and simplicity
- Scalability
- Reduced cost of ownership

Additionally, WLANs offer other perks such as ad-hoc connections and roaming access. 4G already is a IP based netwotk and connecting it to the existing WLANs follows the same rules as connecting wired LAN networks to broader Internet. That is done by router, that is responsible for managing IP traffic equipped with a radio transmitter that connects to the cellular network.

4.2.2 LTE Architecture

As mentioned in chapter1, LTE-Advanced is the technology standard that is considered mobile network from Fourth generation. Developed by 3GPP, it provided full IP backbone, fast mobile internet connection. To achieve that, infrastructure was changed from circuit-switching to packet based and access advanced from Time-division multiple access (TDMA) to Orthogonal frequency-division multiple access (OFDMA) and Orthogonal frequency - division multiplexing (OFDM) for Waveform and QPSK,16QAM or

64QAM for Modulation. This new signal encoding transmits data by cutting it to portions or packets. Then these packets are send simultaneously, but to avoid interference different frequencies are assigned for each individual portion of data so that they are “orthogonal”. On the other hand OFDMA is used to restrict one device’s signal conflict with others, by allocating portion of signal spectrum for each individual user [42]. The LTE network architecture can be reviewed as two separate sub networks - access and core networks.

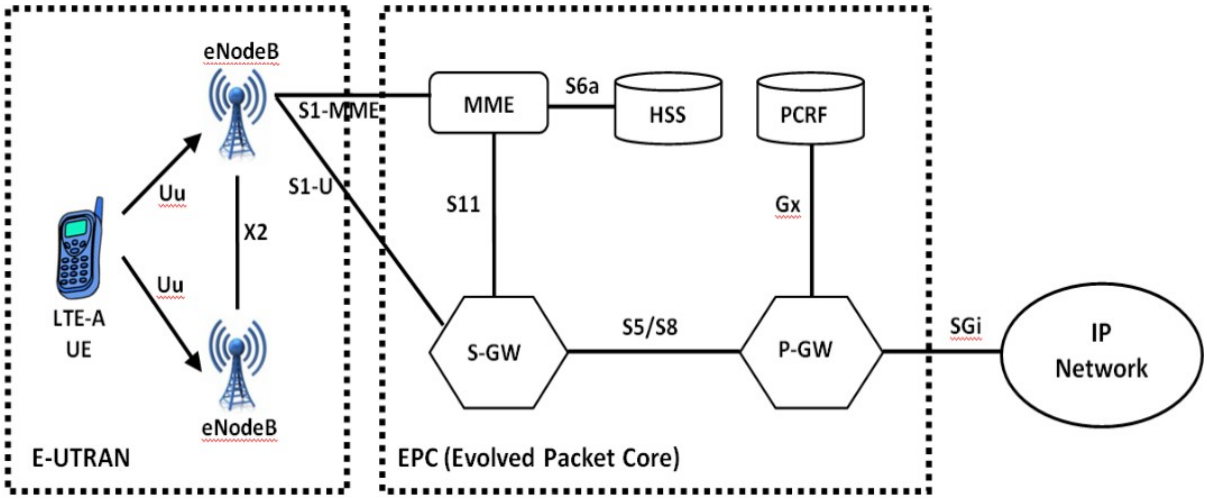

Figure 4.2: *LTE Network Architecture [41]*

Radio Access Network for LTE This sub network of the architecture is radio based and is responsible for communication between the mobile terminals or end users’ mobile phones and operators’ antennas. EUTRAN or Evolved Universal Mobile Telecommunications System Terrestrial Radio Access Network is the full name of the radio network. Some of the mobile operators also directly call it LTE. As described on figure 4.2, several key nodes form EUTRAN:

- **LTE Mobile Terminals**: these are mobile devices that support LTE standard and usually are mobile phones, smartphones, modems and others.
- **eNodeB**: E-UTRAN Node B or eNodeB are the access points to the Core network provided of the mobile operator.
- **Radio Interface**: As this sub network is accounts for the radio communication, thefore this node resembles radio interface used for wireless connection between LTE mobile terminals and eNodeB.

Core network

This sub network is the actual brain of the LTE system. Telephony switches are used to facilitate all of the previously mentioned services. The connection is bi-directional, which means that devices from the core

network connect the mobile devices from the mobile network with internet and fixed telephony and vise versa. The sub networks also manages calls between mobile terminals. There are 5 nodes that combined form the core network as described of figure 4.2:

- **MME** - this node is Mobility Management Entity and is the central control node. Mobobility and security signalling, as well as tracking and paging of mobile terminals is done by MME.
- **S-GW** - Serving Gateway or S-GW is managing the transportation of user traffic between MTs and the external networks, but connecting to P-GW. Also serves as a connection between the E-Tran and the LTE core.
- **P-GW** - This is a gateway that connects the core network to the external IP based ones. It is called Packet Data Network Gateway and routes traffic to packed based networks.
- **HSS** - That node containes the database of all mobile users, including all subscriber data. In addition the Home Subscriber Server (HSS) managers authentication, call and session setup.
- **PCRF** - Policy and Charging Rules Function relates to the different policy rules and charging. In this node the mobile performs these two processes.

The core network is called Evolved Packet Core (EPC) or System Architecture Evolution (SAE). Having reviewed LTE architecture, the next subsection is going to list all main players, that pushed 4G development.

4.2.3 Main Players

The main players are those technology companies who have contributed the most to the R&D development of 4G - LTE. There is a brief list with them:

- Alcatel-Lucent
- Ericsson
- Huawei
- NEC
- Nokia
- Samsung
- ZTE

- Intel
- Qualcomm
- Motorola

All of the above had contributed to the 4G mobile communication. As this thesis is focused on 5G, these the list will be used for comparison when evaluating 5G companies in the next chapters.

4.2.4 Status of LTE

4G network has been long present in our everyday live. It LTE and its variations is one of the most popular and fastest mobile network that end user can connect and experience, reaching more that 80% of the world population, as GSMA stated [43]. It is used by over 734 operators over 219 countries. In a report by Opensignal [44] from 2018 the true state of the world's mobile network was presented. According to the document, LTE resources are near exhaustion as the limit of what current technology, spectral bandwidth and mobile economics can support. The speeds have come to a halt at around 45 Mbps. Regarding coverage, however, mobile operators are constantly working on improvements for spreading the signal.
"Throughout the world, it's much easier to find an LTE signal now than it ever has before." was stated in the report.
Additionally, work on improving the 4G, proved that speeds can be increased. Gigabit LTE was deployed along with other upgrades designated to accelerate present LTE [45]. Download speeds of 70 Mbps were the average for Toronto. Yet, 4G cannot carry out raising demands or support future services like Vehicle-to-Vehicle communication (V2V). For these and more reasons 5G is being developed, which is going to be reviewed in next subchapter - 4.3.

4.3 Overview - 5G

The next generation - 5G, is promised to be a tremendous upgrade over the current set of speeds, services and capabilities. Looking for the next successor of 4G had began in the 2014 with the two-part feature topic on 5G released by IEEE in February and May [46]. From a marketing perspective, mobile operators and technology providers have described it as:

1. "Amazingly fast"
2. "Great Service in a crowd"
3. "Best experience follows you"

4. "Super-real time and reliable connections"

In technical terms 5G should be support these 5G critical services [7] - Extreme Mobile Broadband (eMBB); Massive Machine-Type Communications (mMTC); Ultra-reliable Machine-Type Communications (uMTC)-. Indeed, as we already mentioned in chapter 1, all of that and more is listed in the ITM-2020 standard published by ITU [37]. However at is very core, 5G is a mobile communication technology. And as a mobile communication technology, it needs to answer on some of the initial, but very critical for its existence, questions in that field:

- **How to transfer data quicker?**
- **How to provide better network coverage?**
- **How to use the allocated spectrum more efficiently?**
- **How to deliver low latency connection?**
  and most of important question of all
- **Will it be exceptional different from previous generations?**

To answer the above questions or at least try to provide explanation, the next few subsections are going to present a detailed picture of the current state of 5G and its integration; what has been developed; architecture and transmission.

4.3.1 5G Spectrum specifications

Current allocated spectrum is not sufficient to cover the need of the future 5G NR network. Compared to LTE, in order to achieve speeds of above 1Gbps, frequencies above 6Ghz need to be put into use [47]. This is shown on figure 4.3

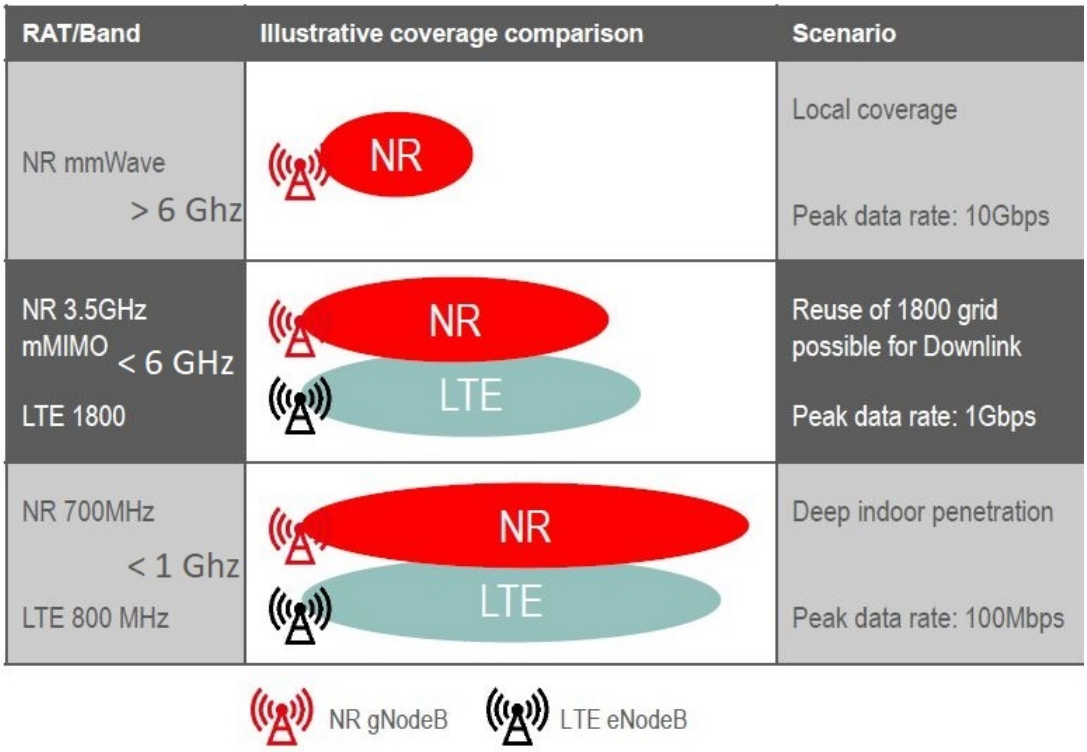

Figure 4.3: *Mobile technologies that will impact 5G [47]*

This provides reasonable answer to the question about speed of data transfer. However, the illustrated comparison shows that using high frequencies tends to retract the coverage of a radio communication network. The propagation loss starts can be noticed at waves above 3.5 Ghz in frequency. This undesirable effect is going to be compensated by introduction of Massive MIMO and Beamforming. Two techniques that 5G NR will benefit from, in order to provide better coverage and answer the second question. Moreover to be compliant with the set by ITU requirements, 5G has to make use of several bands and take a significant part of the harmonised radio spectre. Thus fragmenting and cleaning the radio prime bands is one of the main tasks that needs to be completed. Millimeter wave (mmW) spectrum has been allocated to the new generation. However, several bands would be reserved according to the technology using it.

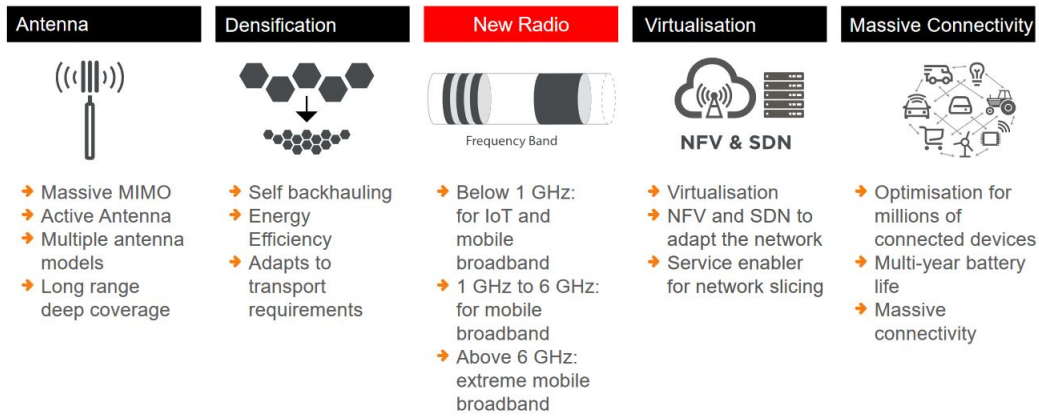

Figure 4.4: *Frequency coverage comparison in 4G and 5G [47]*

As presented on figure 4.4 by GSMA, frequencies below 1GHz will be allocated for IoT devised, between 1 GHz and 6GHz will be assigned for the mobile broadband and all above 6GHz will provide the necessary so called extreme broadband to meet the ultra-high speeds and capabilities of 5G. Regulators also aim to provide 80-100 MHz spectrum per operator in the mid-bands (3.5GHz) and 1 GHz per operator in the millimetre wave bands (26/28GHz). At the ITU World Radiocommunication Conference 2019 (WRC-19), occurring every three to four years, one of the main tasks will be to facilitate an international agreement of the usage of hi-speed bands above 24GHz for 5G networks.

Modulation and Wafeforms

To deliver a low latency and use the provided spectrum in the most efficient way, 5G will have to rely on a new modulation scheme and waveform. Reviewing waveforms and signal modulation, several factors need to be addressed:

- list bandwidth efficiency
- scalability
- interoperability
- implementation complexity
- robustness

Looking to accomplish these challenges in 5G, OFDM used in 4G will be avoided. Although it has several advantages as Fourier transform (FFT), Inverse FFT (IFFT), MIMO communication, lox-complexity in implementation, OFDM is very strict regarding signal synchronisation. Additionally Cyclic prefix (CP) and null guard at the spectrum edges,that is used for signaling are also necessary, which contributes for inefficient use of the

allocated spectrum. Finally, the structure of the signal frames along with the different protocols (e.g.scheduling and retransmission) in the LTE systems builds up to a latency of more than 10ms, which compared to the initial requirement for 5G network is not acceptable. In fact, for the next generation of mobile communication, delay on the physical layer is specified in the borders of 100μs. This is described on figure 4.5:

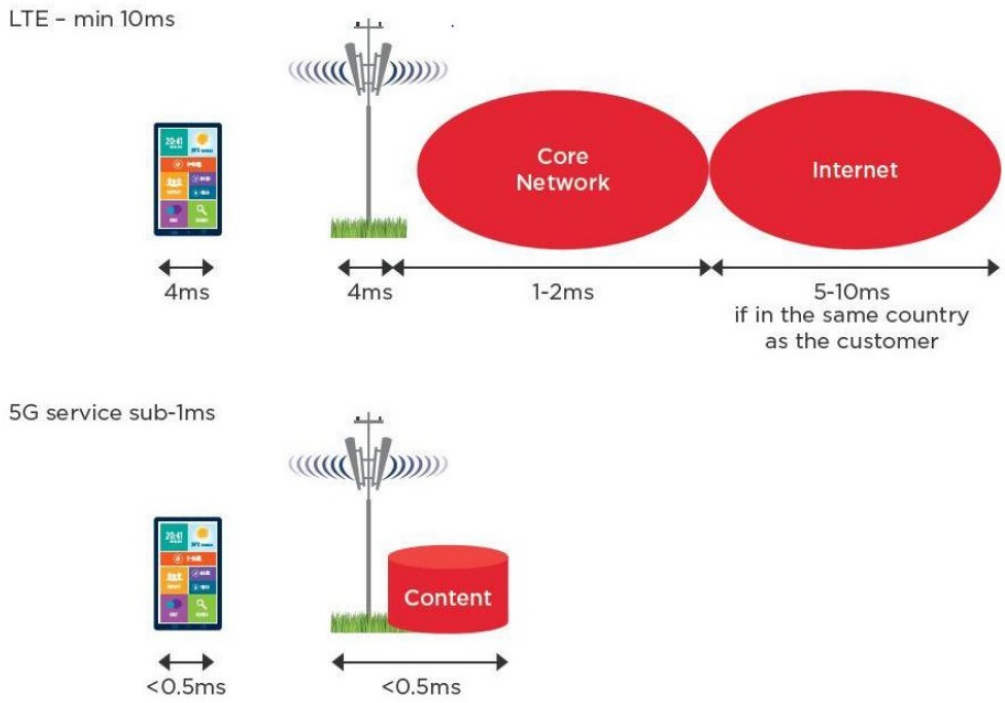

Figure 4.5: *Latency in content representation (Source: GSMA Intelligence)*

The current latency in LTE based mobile networks is already bringing 4ms delay upon communication with the Base Station (BS), compared to a less than 0.5ms using the 5G communication. This latency ruins chances for machine to machine communication (M2M) on LTE as the requirements are aggressive regarding latency and capacity. In order to accomplish that blazing data transmission, future mobile communication technology has to rely on a better signal modulation. There have been several offers for new 5G waveforms [48].
One of them was the faster-than-Nyquist (FTN) signaling. FTN can be beneficial, by compressing more data in the time or frequency slots, or even in both. By employment of FTN in both slots, larger spectrum efficiency is achieved than only using FTN in time of frequency separate. Although, this waveform has several benefits and sound really promising, more research and development work need to be focused on the practical implementation phase [49].

Another type of waveform, that 5G could be based on is Filter bank multi-carrier (**FBMC**). This waveform performs filtering is performed per sub-carrier. That way the sidelobes are supressed and the FFT/IFFT blocks can follow processing similar to that of OFDM [50]. FBMC is surpasses OFDM with several factors:

- Utilizing white spaces in cognitive radio networks
- Robustness in frequency misalignments and synchronization issues
- Suitable for random access traffic

However, FBMC has flaw and that is realizing the extensive MIMO that is predicted for 5G. Recent activies on the physical operation resulted in efficient implementation of MIMO-FBMC and it is even matching the current MIMO-OFDM technique [51, 52].

Universal filtered multi-carrier or **UFMC**, is another waveform that is modified version of FBMC. This approach relies on filtering in the sub-band, rather per subcarrier implemented in FBMC. Therefore, UFMC benefits the advantages of FBMC [53], in addition with substantially shorter filter length than the FBMC one by the different approach on filtering. On the other hand, UFMC is more unstable to time misalignments, because of not requiring CP, compared to CP-based OFDM.

Next comes **GFDM** or Generalized Frequency Division Multiplexing. With this waveform, modulation is performed for independent blocks. Individually, blocks are comprise a number of subcarri- ers and subsymbols. GFDM enforces filtration for each subcarrier and the filters are circularly shifted in frequency and time. The design of GFDM allows flexibility in different configurations, thus this waveform meets several 5G requirements and many of the OFDM algorithms for synchronisation can be utilized by GFDM. As confirmed in paper [54], combination of GFDM waveform and space time coding can be used in he multi-antenna wireless system, while remaining flexible for resource sharing among users by applying wireless scheduling.

Another variant to be considered is **NOMA** - Non-orthogonal Multiple Access. This framework exploits power-domain superposition multiplexing. It could provide same benefits as OFDM, while users are overlapped on the same spectrum [55]. Thus NOMA is less energy hungry than the previous methods for signal encoding.

At the time of writing this paper - July 2019, there are already several implementations of 5G. Mobile tech companies provided solutions that follow 3GPP Release 15 documents for early development[56]. This means that, current 5G connections are "Non-Stand Alone" Architecture, that rely on the already established 4G LTE signal transmission - OFDM. Although OFDM has it’s advantages, it comes with high peak-to-average power ratio (PAPR), making it less energy efficient compared to NOMA or other encoding schemes. This will be undesirable when applications that

require high multiple user access, such as clusters of Internet-of-Things (IoT) devices. Usage of individual spectrum for each device could impact the network characteristics negatively, Yifei Yuan, ZTE Corp.'s chief engineer of wireless standards reported in an interview for IEEE Spectrum. [57] However, with the completion of Release 16 Scheduled for December 2019, crucial findings will be published regarding OFDM replacement and its successor [58, 59]. For now, 5G will be used mostly by smartphone users and future applications (e.g M2M) will not come at least a year after Release 16.

4.3.2 Network architecture

Continuing the review of 5G, on a joint RAN/SA meeting in June 2016, Deutsche Telekom AG presented their research paper outlining possible architectures of 5G networks[60]. The network architecture was segmented in the same manner as the LTE, specifying two distinct elements - radio access network (RAN) and core network. Only by utilising both segments, subcriber can take advantige of the Data Network (DN) resources that include operatior services, Internet access and other over-the-top (OTT) services. On that discussion, two possible radio technologies were identified to be suitable for future mobile communications:

- LTE, particular part enhanced LTE (eLTE)
- Next Generation radio - NR

The core network was also reviewed and discussed. Again, two concepts were specified:

- EPC (Evolved Packet Core) used in 4G.
- Next Generation Core Network (NGCN) - the next core network for 5G (5GC).

Another major review was done regarding User Plane (UP) and Control Plane (CP)[61]. ITU described UP as a set of resources across the network that ensure transfer of traffic. CP on the other hand is explained by [61] as the set of functions that perform the control over network functionality, like instructions to devices. Additionally CP is responsible for several backstage processes like performance, fault and configuration managements. Different scenarios for 5G architectures using the specified solutions for radio and core networks were presented by Deutsche Telecom. In total 12 potential options for migration to 5G were documented. First are the separate 4G based and the new 5G solutions.

Figure 4.6: *5G scenarios in 3GPP NR and NGCN - variants 1 and 2 [60]*

As shown on figure 4.6, the control plane and user plane are assigned only on it's corresponding architecture. This separates two distinguishable network - Standalone LTE, EPC connected - legacy and Standalone NR, NGCN connected. A standalone network is a network, were both the radio network and the core network belong to the same technology generation and does not rely on other standards to exists. Next was proposed a variation of between the two networks, described with the next figures.

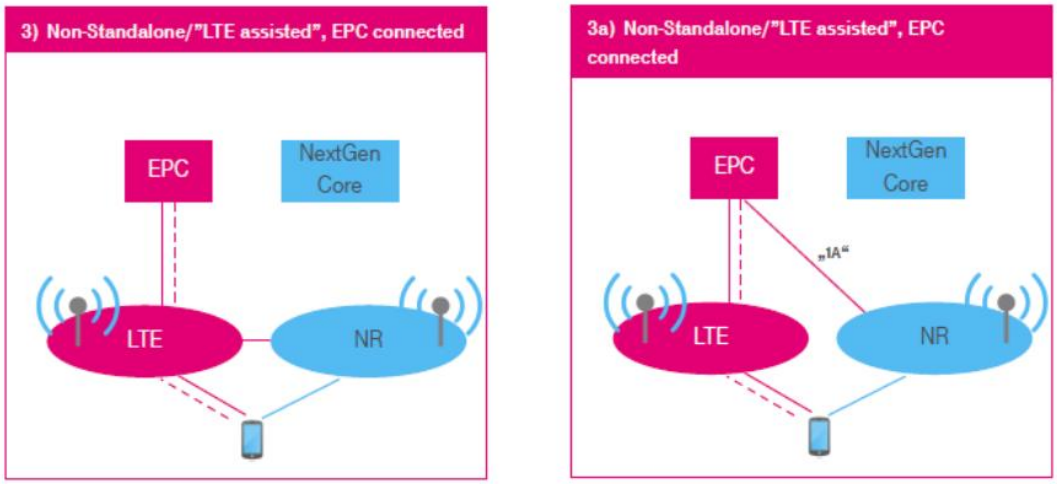

Figure 4.7: *5G scenarios in 3GPP NR and NGCN - variants 3 and 3a [60]*

Figure 4.7, describes 5G NR deployment with using EPC as a backbone core network. Users will able to connect to both NR and LTE. However, NR will ralays traffic to EPC using the LTE network and the control plane will be primarily established as LTE connection. This is Non-standalone architecture (NSA) where the mobile network is composed of mixed architectures. Users benefit from 5G radio connection, but still can access only

4G features. Variant 3 and 3a show LTE assisted architectures and EPC connected.

Following that, Deutsche Telecom AG suggested a NSA configuration to be NR assisted and NGCN connected. This means that the backbone infrastructure will be NGCN, and the users will be connected to LTE or 5G NR. Control plane will be provided on 5G NR. In this variant, shown on figure 4.8, users will be granted will all goodies of 5G. LTE will be the supportive radio network and will be in place to make sure users connectivity is supported.

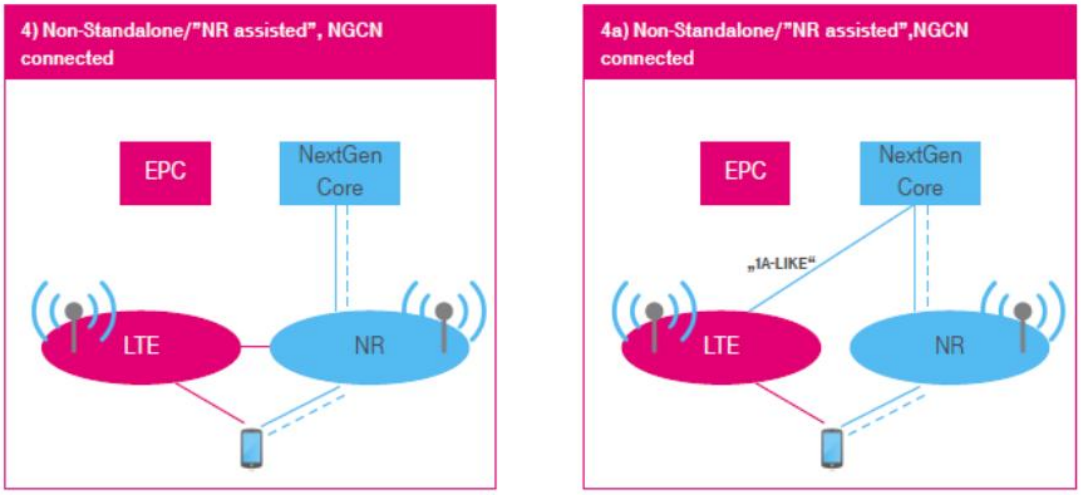

Figure 4.8: *5G scenarios in 3GPP NR and NGCN - variants 4 and 4a [60]*

Variants 5 on figure 4.9 proposes an approach were the radio network is LTE - Standalone LTE, but the backbone is upgraded to 5G Core network - NGCN connected. There is no switching between networks and mobile devices do not need to be upgraded in order to connect to the mobile network. However, this approach may impact the future targets of 5G - latency, volume of users, speed. The other way around it is to use 5G NR as mobile network and rely on the EPC as a backbone illustrated on figure 4.9 as variant 6. Speed and latency will be improved dramatically, yet number of devices is probably going to cause an issues at some point in the future. These two variants are described as Standalone Architectures, but they cannot be considered as a real 5G network.

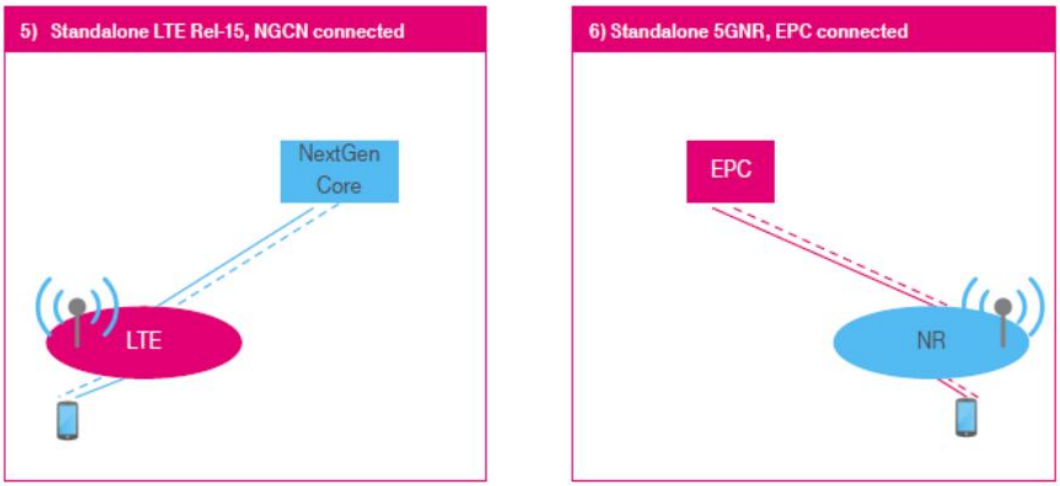

Figure 4.9: *5G scenarios in 3GPP NR and NGCN - variants 5 and 6 [60]*

Suggestion was also to implement NSA network, which is LTE assisted and NGCN connected. Here the core network will be NGCN and the radio will be either NR or LTE depending on the conditions. 5G NR can even relays to LTE networks in some configurations as shown on figure 4.9, variant 7.

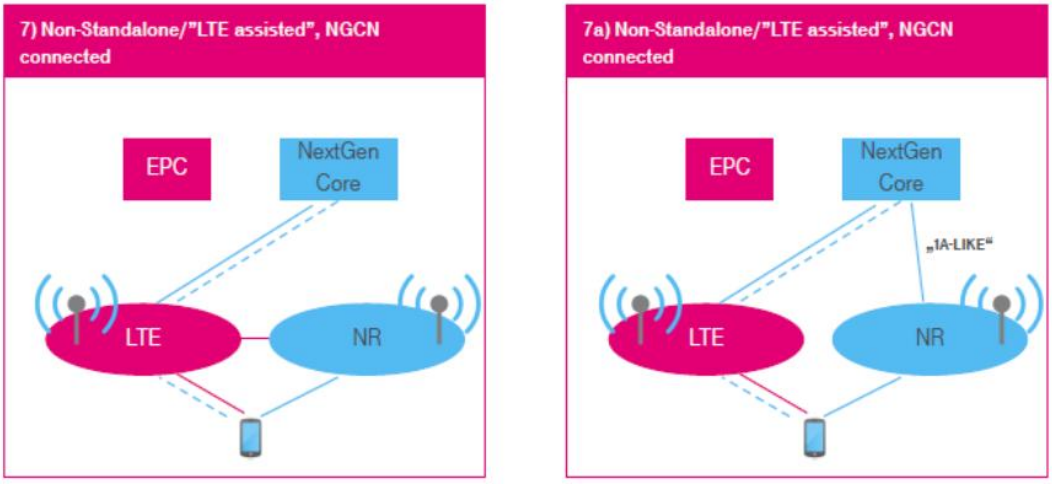

Figure 4.10: *5G scenarios in 3GPP NR and NGCN - variants 7 and 7a [60]*

Last alternative was the NR assisted concept, resembling NSA architecture which is EPC connected and relies on 5G NG to provide mobile connectivity - figure 4.11

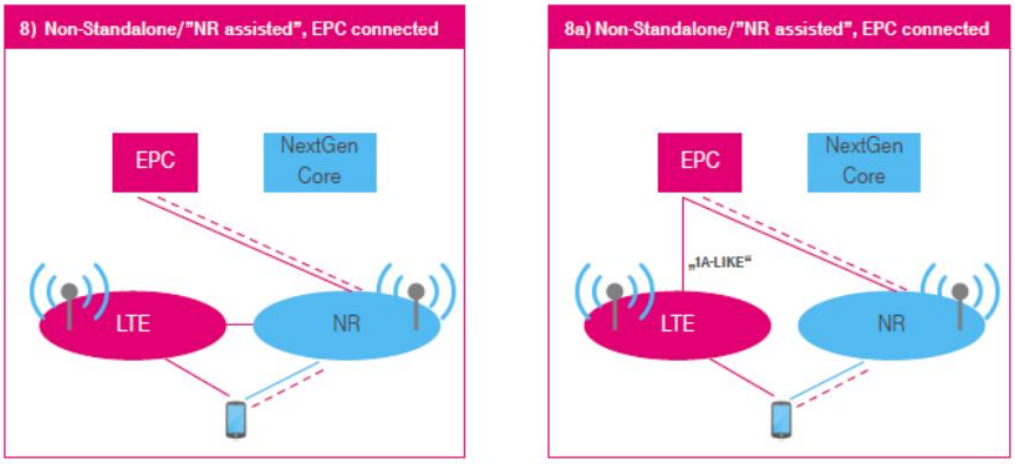

Figure 4.11: *5G scenarios in 3GPP NR and NGCN - variants 8 and 8a [60]*

Scenario 1 is the current 4G LTE network and is consithered to be legacy, thus removed from the options. All of the above suggested path to 5G networks are trying to answer one question to the mobile operators:

Which is the most cost efficient and smooth way of delivering 5G networks to the users? In order to provide sufficient answer to that question, several factors need to be considered like avoiding fragmentation, support of legacy architectures, phasing possibilities, cost efficiency.

Fragmentation

This undesirable effect will be achieved if there is a strict separation between networks. That means that, if variant 2 is strictly followed, users will have to chose between using 4G or 5G network, which combined with the current coverage of 5G will fragment usage. Smooth transition will not be possible and the installation of 5G network at once will come at high cost.

Support of legacy architectures

Other factor to be considered is the backwards compatibility. That property defines whether the next generation of mobile communications will be a totally independent from it's legacy architectures. That have to be considered, because it can also support for the fragmentation of the network. Not only that, but separation in devices by their ability to support downward compatibility to previous generations.

Phasing

Possibility to divide the installment of 5G network on stages or phases is described as phasing. This is very important moment when it comes to

carrying a newly developed system/standard out into live environment. By phasing a certain implementation, mobile operators and users will benefit from a smooth transition from LTE to 5G NR. Additionally, mobile operator can predict future issues and more tests can be carried out while delivering 5G connectivity, making it as efficiently as possible and avoiding fragmenting own network.

Cost efficiency

Scope of cost efficiency is not only about mobile operator equipment. Choosing the wrong path for 5G implementation is going to impact all that rely on mobile technologies. Manufactures would have to make more expensive devises that can operate in both standards or make individual releases. On the other hand, installing 5G only equipment will be very expensive transition for a single operator, not to forger the fragmentation of the network that will be added. Deutsche Telekom AG put the focus on the architectures that need to be supported and continued in development by 3GPP and shed light on most promising variants. Upon that in Technical Release 21.915 [56], only two options for deployment of 5G NR were documented as feasible. Release 15 by 3GPP specifies a "Non-Stand Alone" (NSA) architecture and "Stand-Alone" (SA) architecture. Option 3 - LTE Assisted NSA will provide 5G functionality by integrating 5G Radio Access Network (AN), also referred as New Radio (NR), with the present LTE and EPC infrastructure Core Network (respectively 4G Radio and 4G Core). This is option 3. In that way, users will benefit from 5G speeds without replacement of mobile operator’s equipment. NSA architecture is also goes under the name E-UTRA-NR Dual Connectivity (EN-DC), as it still follows E-UTRA from LTE Architecture described in 4.2.2

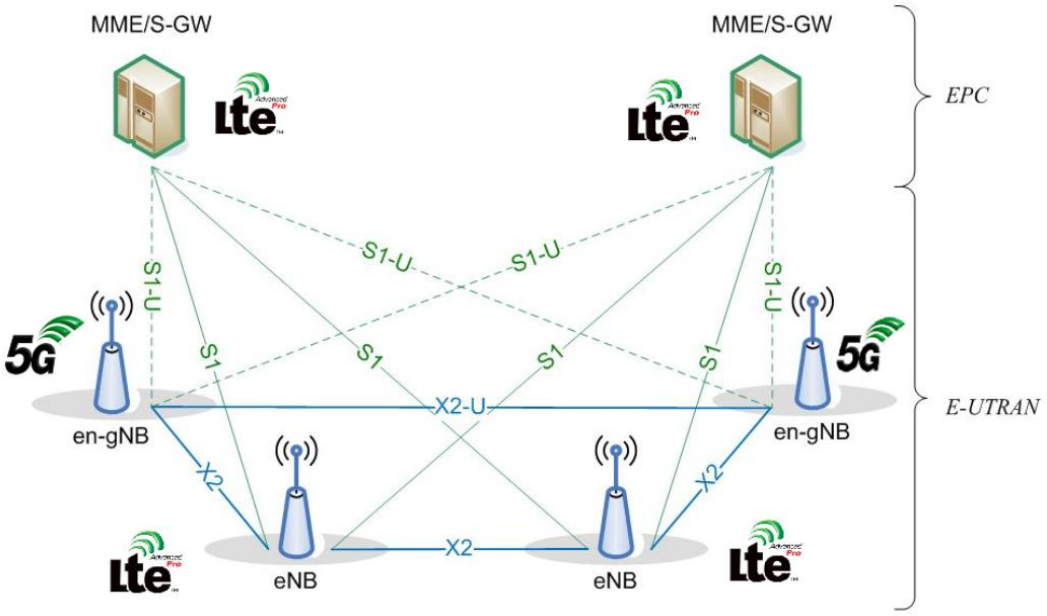

Figure 4.12: *The NSA Architecture [56]*

As shown on figure 4.12, the 5G NR base station (logical node "en-gNB") is connected to 4G LTE base station (node eNB) via X2 interface. X2 interface has been used before for connection between 4G nodes. In the case of NSA 5G, X2 will be also used to support connection between en-gNB and eNB nodes. The E-UTRAN will be connected employing S1 interface. In this configuration, eNB is set to be the master node, while en-gNB is secondary node. Such dual connectivity is called EN-DC. Following that approach will reduce significantly the risk of fragmentation, while ensuring steady process of 5G implementation at reasonable cost. However, this type of configuration is considered as temporary step towards full implementation of 5G network. List of accessible services will still be the same as the backbone of the initial 5G configurations is still the well known 4G. Users will be connected to 5G Radio network, which comes with perks like low latency and faster speeds, but features like massive MIMO for M2M communications will still not perform as required. Stand Alone architecture is promising more. Illustrated on fig 4.13, SA architecture will be entirely composed of next generation components. The base stations (logical node "gNB") connect between themselves using Xn interference. This is the specified NG-RAN part of the architecture. It will connect to the core network (5GC) via NG interface.

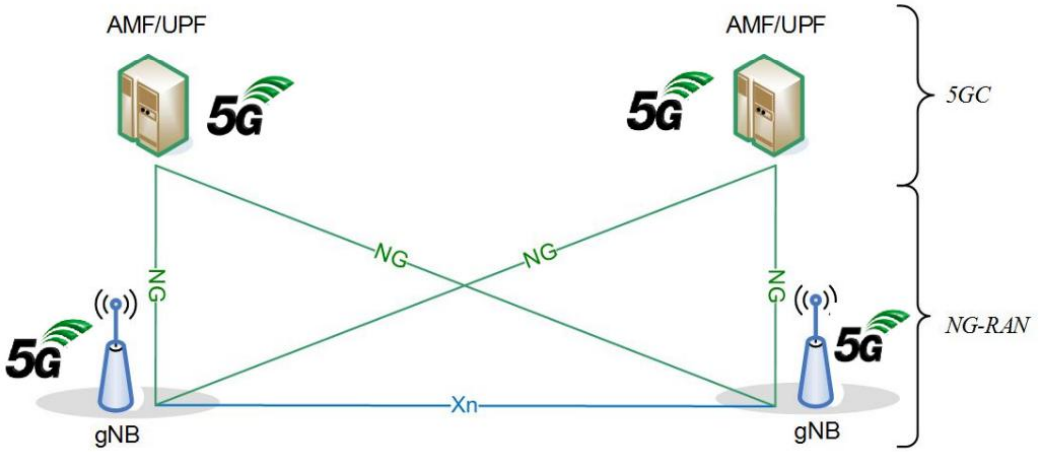

Figure 4.13: *The SA Architecture [56]*

A closer look on the 5G System Architecture reveals that this generations relies on a so-called "Service-Based Architecture" (SBA) framework [56]. In that manner, architectural elements are specified in terms of "Network Functions" (NFs), not by traditional "Network entities". This allows any NF can provide it services using interfaces of a common framework to the other authorised participants on the network - NFs and users that are granted to use these available services. By following the SBA approach, such architecture can benefit of modularity and reusability. On figure 4.14, 5G system architecture is illustrated:

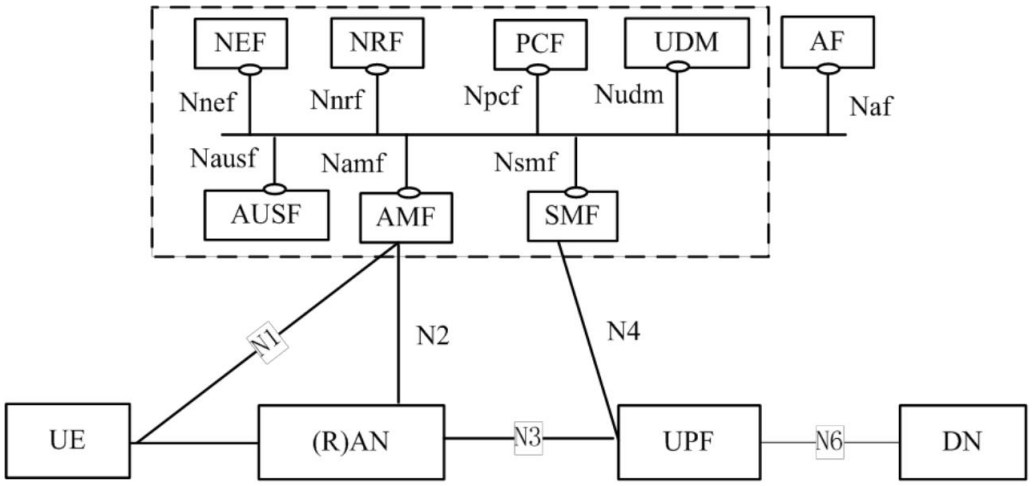

Figure 4.14: *3GPP 5G network architecture [62]*

User equipment (UE) represents any terminal that is connected to the mobile network. UE and RAN form the NR part of 5G, while the core network (5GC) is composed by the remainder of network components. Starting point is UP connectivity. This is ensured by the Protocol Data Unit (PDU) session protocol, connecting UE, through RAN and User Plane Function (UPF) to Data Network (DN). PDU Session User Plane Protocol

protocol, described by by 3GPP's specifications [63], includes in it's procedures a QoS (Quality of Service) service, set by QoS Flow Identifier (QFI) field. Through that field different QoS profiles enable administration of the transferred packets. Simply said, each PDU session could have many QFI channels and each of them transfers data with diverse QoS instructions. Also of major importance is the UPF element, because of it's direct engagement in the PDU Session operations. According to [64] document, UP connectivity will follow a certain path - from the gNB towers (essentially RAN) to the UPF - the core network. Thus UPF is seen as a key pivot point for RAN, especially as it is fixed at the UP channel, making it ideal to execute a certain QoS policy. Following the review of the scheme, the upper layer of figure 4.14 reveals block related for management of subscribers data and session is presented, constructing the control plane. Firstly engaged is the Access and Mobility Management Function (AMF). This block of the system has administrative function regarding subscribers mobility like tracing area and potential cell attachment. 3GPP stated in a technical specification [65], that AMF also operates in registration and security management, assessing whether the subscriber has the right to utilize the network resources upon authentication. Next is Session Management Function (SMF), which is controls the establishment and the discontinuation of PDU Sessions, along with their modification. Therefore, SMF plays role in the policy control function - evaluating whether or not a certain data session can be organised. After the SMF comes the Unified Data Management (UDM) element. It represents a cental repository containing the subscriber information, used in access authorisation. This data consist of security keys and the profile of each subscriber, thus UDM is also in charge for registration and mobility management, as it tracks where the user is attached. Policy Control Function is the next element of the architecture, responsible for dynamically administer control policies over the network. The conditions are determined by the dynamically changing network environment at any point in time. For example, if a users attempts to set up a PDU Session, SMF will analyse whether the network conditions are suitable for connecting the terminal to DN. On the other side, PCF reviews the data based on a criteria (subscriber geolocation, credit, bandwidth) and allows or forbid session establishment. Authentication request are handled by Authentication Server Function (AUSF). These type of request can be for both 3GPP or non-3GPP networks [66].
Here we can note that the previous standard (4G) was established as an upgrade to his ancestors. 5G architectures is oriented as a more flexible one. This applies the requirement to 5G to be able to support and deliver cloud-based services like [62]:

- Software Defined Network (SDN);
- Network function virtualization NFV;
- Multi-access edge computing (MEC); and

- Network Slicing;

The evolutionary change was further recommended by the authors of [67]. Rather a typical upgrade in speed and latency, 5G is seen as a technology that is more permanent and evolutionary, that offers wide array of services in diverse use case and is flexible enough to meet the established requirements and accommodate future needs.

4.3.3 The hype about 5G

However, not everything runs that smooth and is as brilliant as presented.

5G suffers from multiple issues [39]. In this article by Simon Forge and Colin Blackman, 5G is compared not only as a technology, but also as industry hype that everyone is talking about. The telecommunication industry sees 5G as the generation that will bring new services - the next global market. And with new services comes new streams of revenue.

Nowadays, telecom operators revenue is slowly coming to a stall. Along it, the equipment manufactures in telecom industry are also starting to struggle. This is primarily caused by two reason.

First, the developments in network industry, especially those related to SDN are showing result. Less equipment is required on the field. The units previously distributed across the network, now are replaced by centralised data centers that use software to replace and enhance the required network functionalities. This is also known as network virtualisation. Implementing these new technologies by vendors is actually making Mobile network Operators (MNO) more efficient and reliable. Yet by doing that, vendors cannibalise their own profit. On the other hand, revenues will come from different fees, licences or Service Level agreements (SLAs), stretched over long period of time. With that MNOs will replace the massive infrastructure that require huge investments in hardware when upgrading to a new mobile network infrastructure.

Second reason is sourced by the MNOs' expectations about payoff from latest investments i.e 4G - LTE and it's upgrades. In his article, Purdy concludes that LTE has not delivered the expected sufficient revenue [68]. As a consequence, MNOs tend to lower their spending on mobile broadband. Consumers also backed that conclusion as they prefer offloading traffic to fixed Wi-Fi and using over-the-top (OTT) services at much lower cost and higher quality. All of these a push the focus from the delivering a service to the end user to ways of establishing and maintaining revenue.

More facts throw scepticism over the hype about 5G. MNOs and fixed line operators are looking for a new stream of revenue by a number of industry convergences. First and primary direction is union with the media companies [43]. Many MNOs are also willing to become media operators themselves. Second possible stream of new revenue is the IoT world. However, IoT network infrastructure is presumably going to use narrowband instead of the offered rented broadband. This is because many IoT

developers have already been working on different networking technologies and prefer to own the network rather than hiring it from a third party like MNO. Third business model is cooperation of the MNOs with the bank sector, by many mobile financial services delivering banking to the end user [69]. Yet that approach could greatly be dependent on the country it is being introduced to. There are questions of how usable it will be for intelligent transport systems that as a concept are more about autonomous driving rather than a vehicles, relying on a network to orchestrate their movements. So, stepping back from the hype for 5G, the reader must know that there is still yet work on a solid business case that can justify the fifth generation development. However, in the next section we will review the mobile network of today and the current status of 5G.

4.3.4 Current state of mobile networks

So far, we have discussed about the current LTE technology and the fresh implemented for commercial use 5G [70]. Logical approach will be review of the two mobile generations in terms of real life performance. The scope in this thesis is going focus on three main domains - Speed, Availability and Quality of Experience (QoE) [44][71]

4G LTE Performance

LTE-Advanced, the real fourth generation mobile technology has been in operation for more than 5 years after it's first day of operation [72]. There were numerous performance test in different areas. Many companies focused to deliver accurate analysis of the LTE performance. This gives us the ability to compile a good enough perception about 4G in global scale. Organisations like OpenSignal [44], 4GMark [73] or the GSM Association (GMSA) have performed numerous measurements and analysis in different countries and different field.

Speed

In their of 2018, OpenSignal describes the state of LTE speed as a plateau. One of the dominant countries in mobile world has been stuck reaching speeds close to 50Mbps. 4GMark also confirm that with their two reports. The first one, released in 2017 shows the overall KPIs for 2016. There we can see that the top speed reached is the moderate 28,5 Mbps in Netherlands [74]. Then for the next year, mobile development boosted these results to 33,1 Mbps for a download link. Opensignal noted that for it's sample period between October 1st and December 29th, the highest speed recorded is by Singapore at 44,31 Mbps as shown on figure 4.15.

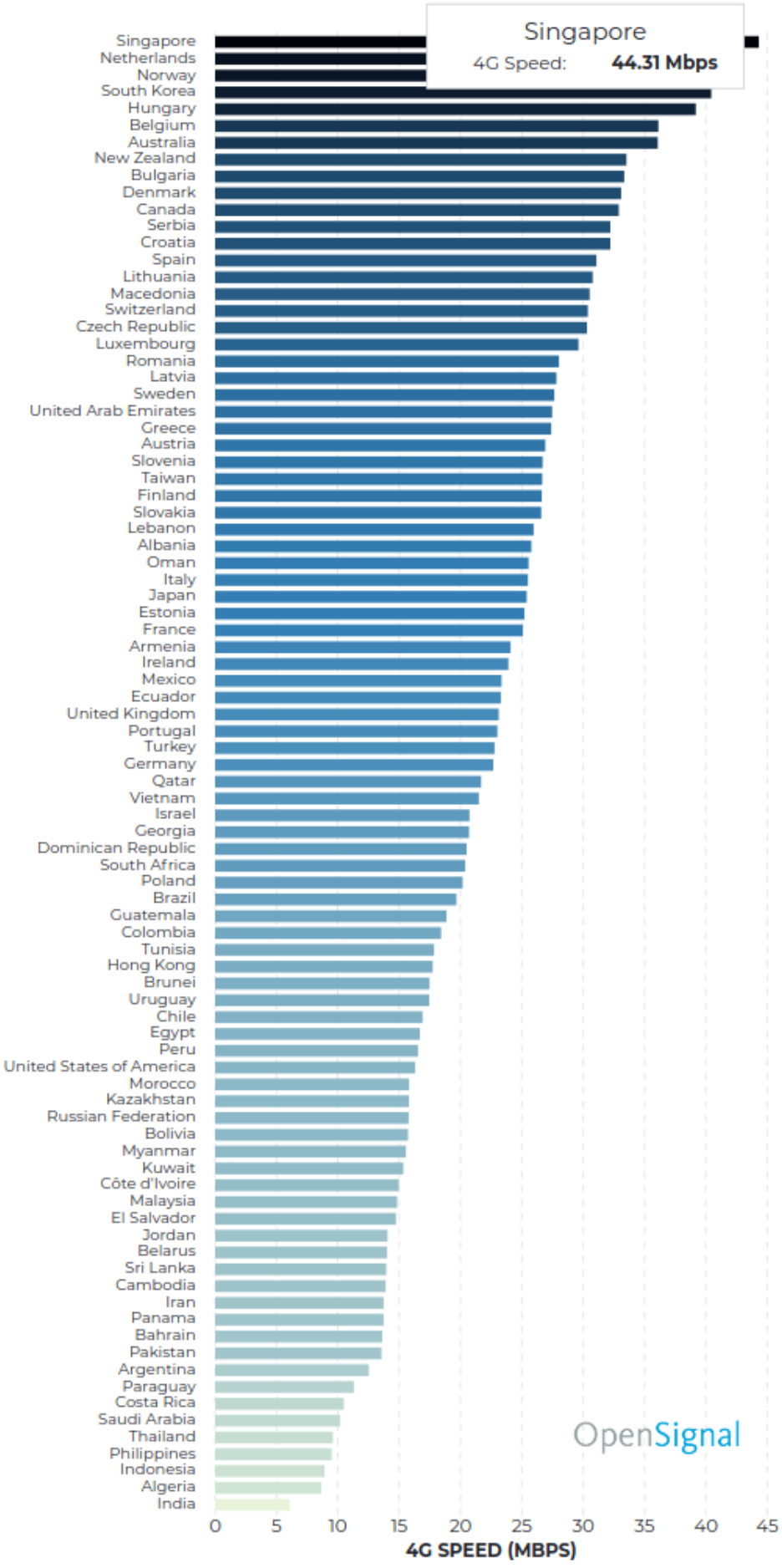

Figure 4.15: *4G Speed comparison [44]*

Over the course of 3 year, 4G reached the a status of stagnation in relation to speed. However it has to be noted that more and more countries are reaching to that 50 Mbps speed. In comparison, in year 2016 [75] only 13 countries were able do deliver average speed of 30 Mbps. Now [44], this number increased to 18 countries, in a addition to 5% growth of countries with average of 20Mbps or above. This also facilitated by 4GMark. From their tests in 2016 [74] and 2017 [71], same acceleration in speed was monitored.

Availability

Here under the term availability will be described not the coverage in geographical measures, but rather the proportion of times user have been connected to a specific network.

While speeds have been in a halt, industry has been outperforming itself in the 4G availability. From previous reports [75] there is a dramatic increase in the availability. In the end of 2017, only three country could provide 4G access to their customers, 90% of the time[75]. The later report by Opensignal [44], show by the analysis of over 50 billion tests, that that number has increased to five countries - South Korea, Japan, Norway, Hong Kong and United States of America. The total numbers of countries that have LTE networks availability of more that 80%, has also been increased to a total of 30, from the previously mere 20. All data results show a substantial expansion in coverage and availability of the LTE service.

Quality of Experience

The third domain is a combination of the other two, in addition with web and online video experience. Presented and analysed by 4GMark [73] it provides KPI on the basis of customer experience.

Therefore, comparing their two world benchmarks from 2016 and 2017, a very distinctive gradient of increased QoE is noticed. More and more countries provided better LTE services satisfying the commercial needs. However, a different trend can be acknowledged. Countries that were among the first to implement LTE, tend to not to improve the server in the following years. For example Denmark has been in first place in 2016, now it falls back to third. United Kingdom has the same fate - from 19 place to 21 in just one year.

This show that the mobile market is vast and fast developing.

5G Performance

The latest generation of mobile network stated deployments back in 2018 with the first pre-commercial release for the Olympic Winter games in South Korea [70]. And yet, commercial released have been announced not till the beginning of April 2019 by South Korea’s big three operators

[76] and Verizon at US. Therefore, as a new technology there are no very detailed analysis of it's performance in real live environment. This is one of the limitations mentioned in chapter 3.

Speed

The theoretical speed that the ITU [9] required for 5G is 10Gbps. However, in the research made by Opensignal [77], Peter Boyland described 5G early performance as no way near the one specified by IMT-2020 [1]. From the total of 87 countries that were examined, on one provided speeds over 50Mbps - South Korea. Users in other countries showed results in the range of 10-20 Mbps and the lowest score being less than 2Mbps.

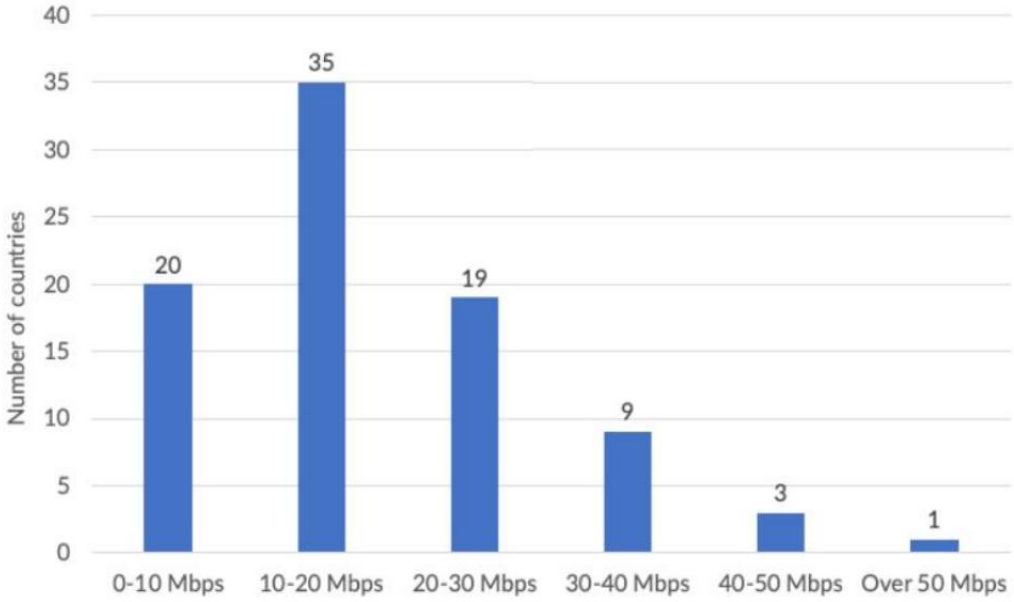

Figure 4.16: *Number of countries by Download Speed Experience range [77]*

From the above figure 4.16, it quickly becomes clear that speeds from these early deployments are scattered all below 50 Mbps, with one over that speed. However, it has to be noted that these are very early stages of commercial 5G. With the allocation of more bandwidth, especially in 20GHz, speed will improve dramatically.

Availability

Availability of the new generation of mobile communication at this stage could be hard to measure as the coverage itself is pretty unstable. As we discussed in 4.3.1, depending on the frequency used 5G signal can be lost even if we stand behind a tree. Furthermore, only handful of companies has managed to introduce 5G Standalone Network. Ericsson and Telstra in Australia, complete the first call over 5G SA in end of July 2019 [78], around the same time when T-mobile announced it's first data transfer

over 5G SA network[79] in North America. Using 5GSA will dramatically improve numbers in future. Therefore at the time of writing this master thesis, the is hardly any valuable test and measurements to assess 5G in relation to availability.

Quality of Experience

Although there are some early reviews of the 5G network, it is hard to say the overall experience in long term usage. Additionally, handsets that support 5G are not that many and not that spread among the people. Currently, there are seven main smartphones that users can make some 5G benefits, according to internet article by 5G.co.uk [80]. However, there were some tests performed in real live environment. The Verge media [81], performed a test on the Verizon 5G network. The test was done with two of the initially compatible 5G phones - Samsung Galaxy S10 5G and Motorola Z3 with MotoMod. The results were the following:

- Good 5G coverage is really hard to find.
- Speeds can vary from device to device.
- Upload is limited to speed compared to LTE.

Adding to that, Opensignal [77]confirmed that latency tests for the early deployed 5G network, where in the also not showing great results. Only one country was close to the 30ms with 30.7ms result. The rest of the countries were with longer latency, up to 157ms.

5G eventually will develop and mobile network operators will be able to deliver better speed and services. The first network are in operation and with the expected expansion for new 5G handsets it is expected to see the new mobile generation outmatching the current existing mobile experience.

4.3.5 Subconclusion

The mobile world is working at a high pace. This chapter presented the current state of the mobile world by reviewing the newest and vastly distributed 4G. On top of that, 5G was reviewed with it's different variants of implementation and the results of it's operation. Though,5G offers different solutions for the cities of the future, it is greatly over-hyped and the focus is moved from the end client to a new and sometimes unnecessary business scenarios which are believed to bring more revenue to the stakeholders. The follow-up chapter 5, will introduce to the reader the main stakeholders in the case of technological companies. Huawei will be analysed and compared against the competitions.

Chapter 5

Analysis of secondary resources

5.1 Introduction

In this chapter, the main contributors and actors that have effect on the development will be reviewed as part of analysis of secondary resources. Focus will be on the big technical companies and race for being the first provider of 5G equipment. As it is the main spotlight of this project, Huawei will be compared to other companies in both communication infrastructure development and headset markets. Additionally, the qualitative research will be analysed, accompanied by several other independent researches. The goal of the chapter is to provide conclusion or at least a prediction about who is the leader and who will have the chance to lead in the world of mobile communication for the next decade.

5.2 Main Tech Companies

While the standardisation bodies has been reviewed, it worth now to take a look on the actual technological companies that has participated into the development of the devices that will be part of the 5G infrastructure. In chapter 4, we have described what is to be considered a technological company. However, in this scope of the analysis will only be included companies participating in manufacturing of network equipment and handsets, as well as some MNOs that have left a mark in the development in 5G [82]. The list includes the following participants:

- Huawei Technologies Co. Ltd. (China)
- ZTE Corporation (China)
- Nokia Networks (Finland)
- NEC Corporation (Japan)
- Ericsson (Sweden)
- Qualcomm (US)
- Intel Corp. (US)

- Samsung Electronics (South Korea)
- Verizon (US)
- Orange (France)
- Mobile TeleSystems (Russia)
- AT&T (US)

It must be acknowledged, that in there might be more companies that have contributed to 5G, but for the purpose of this thesis the scope will be limited to the major players. Following that, Huawei will be introduced with its history, culture and progress on 5G. Then each of the other companies will be compared to Huawei performance.

5.2.1 Huawei Technologies Co. Ltd. (China)

History Background

Huawei has been founded by Ren Zhengfei, a former People's Liberation Army officer, in 1987 as a telecommunication company. Since then it has become a major player, not only in it's own country but on a worldwide level.

Through the years, Huawei strove in performance. In 1993, it produced it's first program controlled telephone switch. The next year, the Chinese government signed contract with Huawei to be the first nationwide telecom operator. It was awarded "national champion" by the China's central government. In practise, that would mean that this will be the only telecom company in China, favoured by it's government. Main business of the organisation was selling telecom equipment to rural markets in China. However, the drastic expansion to Huawei came after the year 2000 with the reach of foreign markets. The company landed on the handset market with their first phone, C300 in year 2003.After that the company continued it's acceleration. By 2014 Chinese champion got some serious achievements, recognised across the world:

- First 3G phone by Huawei - June 2005
- First Vodafone- branded 3G headset by Huawei - 2006
- At Mobile World Congress (MVC) 2009 Huawei presented their first Android smartphone
- In 2012 at Consumer Electronics Show (CES) range of smartphones was unveiled under the name Ascend
- Huawei launched the Ascend D1 at MWC 2012

- In September 2012, the company stepped on the 4G podium with the Ascend P1 LTE
- The world's first LTE Cat4 smartphone at MWC 2013 was delivered by Huawei - Ascend P2
- Huawei Ascend P2 was brought to the revealed in June 2013
- The independent brand Honor was launched as a subsidiary in December 2013 in China.
- CES 2014 - the smartphone Ascend Mate2 4G was
- In the year 2014, Huawei introduced two products - MediaPad X1 tablet and Ascend G6 4G smartphone
- Ascend P7 Sapphire Edition as China's first 4G smartphone with a sapphire screen. 2014

Revenue also increased gradually and in 2018 it surpassed 100 billion dollars. Each year the sales were increasing by around 10%. However, the moment Huawei went overseas, this was when the sales and revenue soar towards new limits, as show on figure 5.1.

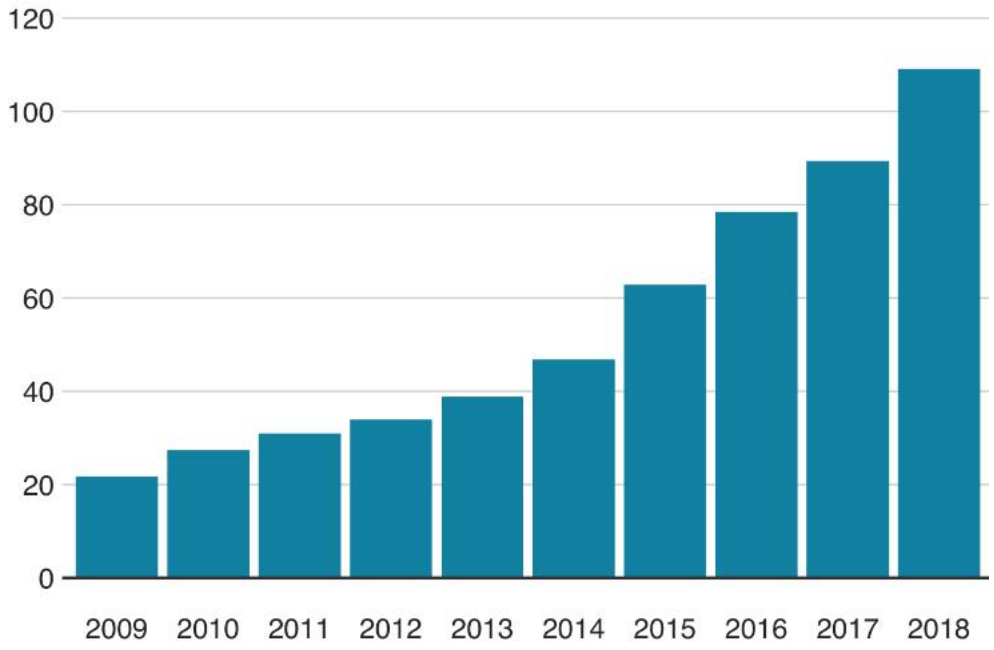

Figure 5.1: *Huawei revenue in billions in dollars*

It allowed to perform a steady build up over just a 10 years time. This put the company among the biggest sellers of telecommunication equipment not only in China, but in the world.

Following that, consumers recognised Huawei's hands held devices. Hard work on smartphones showed it results. Apple was even outstripped

in the smartphone market, where for the first time the Chinese champion was selling more smartphones than the American competitor. In a market research by International Data Corporation (IDC), Huawei proofed to be considered in top 5 smartphone companies. But why Huawei has such success? Partly is due to it's working culture.

Culture

Huawei has developed a set of key values, beliefs and attributes among it's members referred as 'wolf-culture'. This defined three distinctive characters. The first was the ruthless of the wolf. It's employees were highly sensitive to market information and could be flexible to change, responding quickly to any occurred. Second wolf character is coldness survival. Every member of Huawei in focused on making progress, no matter how far the goal is or how difficult is to achieve it. Last character is the wolf pack. Taking action in teams is a something that the Chinese people are notorious of. Same applies to Huawei atmosphere of team cooperation that pushes people to develop and share between themselves. This allowed to the company to work with clear vision between it's employees and to focus workforce in the most efficient way.

Another factor is that Huawei invest a lot in research and development. Each year investments are set to be 10% of the annual revenue for the R&D. The 2018 EU Industrial R&D Investment Scoreboard [83] put Huawei on fifth place globally with total share in R&D of over $10Bn. However, remember why standards are important in chapter 3? Huawei is not an exception to that explanation either. In an analysis by Jefferies [84], by early 2017, almost 10% of 1,450 patents that were the 5G-essential were owned by Huawei and ZTE. This secures it's position among the other participants.

5G Progress

Through their research Huawei has not been outmatched in the financing of R&D, especially in new technologies. The have been heavily investing on patenting key technologies, also. For example, in 2017 $12bn were spent on R&D. Compared to Ericsson for the same year it was 3 times more, which was $4.1bn. For the next year, Huawei allocated $800 million [85], just to be sure that they are going to be the leaders in next generation of mobile technology. Some of the ambitions it had was to hit the marker with full range of Huawei commercial equipment, including domestic network devices - access point, switches and routers. In February 2018, the world's fist call on a 5G network was made by Huawei and Vodafone. It was performed on a non-standalone 3GPP 5G-NR network in the sub 6GHz spectrum. Together, the two companies built 5G NR end-to-end test network and used spectrum in 3.7GHz for the trial. In 2018 at Mobile

World Congress, the Chinese giant showcased its 5G customer-premises equipment (CPE). It was the world's first commercial terminal device that was 5G compliant according 3GPP standards and supported it. Innovation was not stopped there, because Huawei used the chipset Balong 5G01 [86] - world's fist commercial chipset supporting 3GPP specification for 5G, that was developed in-house by the company. It performed astonishing with speeds up to 2.3 Gbps.Huawei officially started manufacturing 5G products.

At the start of 2019[87], Huawei finished successfully the 5G NR test at lower frequency of 2.6GHz, organised by IMT-2020 promotion group. In the same period, TianGang chip was introduced [88]. Designed for base stations, it was capable to provide all network standards with addition of all 5G band and the C-band that were used in commercial satellite communication. This Huawei chip is also developed to support the integration of active power amplifiers along with passive antenna arrays into very small antennas. This is one of the key requirements for 5G base stations. Thailand joined to the Huawei's venture in February 2019. In the handheld world, Huawei also were keep pushing in development and at MWC 2019 [89], the company introduced the fist 5G enabled foldable smartphone - Mate X. The same phone, was announced too carry Huawei's 5G modem - Balong 5000, developed inhouse and only integrated in Huawei handsets. On that same event Huawei introduced the public to HUAWEI 5G CPE Pro. Part of the 5G customer-premises equipment, it was defined as an all in one home network device, allowing speed in the ultra-high broadband and smart Dual-link features. It was also benefiting from company's HiLink protocol - connection with a smart home offering interconnection to all types of smart devices.

But Huawei was not alone in that race.
The company collaborated with many organisation, building relationships that would boost it's 5G lead across the world. Some of the unions were with:

- Carleton University - in the end 2017, Huawei cooperated with Canadian university and Huawei's Canada research centre on an extended research partnership program for 5G communication research [90].
- Qualcomm - together the companies worked on 5G NR, based on 3GPP standards[91]. They successfully finished Interoperability and Development Testing (IODT) testing.
- French and Netherland telecom companies - Bouygues Telecom and Altice [92], respectfully, have joined Huawei venture, by inviting the Chinise company to 5G trial in February 2018.
- Migu - Migu, China Mobile's entertainment content subsidiary [93], joined Huawei and Shanghai Mobile delivering world's first real 4K UHD video broadcasting using 5G network slicing features.

- World's first remote surgery [94] - Huawei and China Unicom teamed up to perform the first remote surgery on animals over 5G. The distance between the operator and the animals was 50 km, but the connection delivered HD video and low latency. That allowed real-time control and fiber-optic experience for the surgeon, resulting in successful surgery.

- Maxis, Malaysian MNO - a memorandum of understanding (MoU) was signed between Maxis an Huawei at MWC 2019, ensuring accelerated deployment of 5G networks in Malaysia. [95]

- VIVA Bahrain and Nova Iceland - Huawei and VIVA anounced that Bahrain VIVA network will be upgraded to non-standalone 5G Core adn 4/5G dual-mode radio delivering 5G services by June 2019. Contract between Nova and Huawei was signed for 5G trials in Ireland. [96]

- LG Uplus collaboration - the telecom network maker and the mobile carrier in South Korea delivered Gbps 5G network [97]. Together they have deployed 5G on over 10000 sites. The two companies showcased ultra-HD, Virtual Reality (VR) services over 5G enabling new commercial appliance.

- Vehicle-to-x technology - on that same MWC 2017, Barcelona, Huawei cooperated with Vodafone to demonstrate a Cellular V2X (C-V2X) technology[98]. Performing a cellular connection between a car and another car or roadside infrastructure allowed rapid exchange of information over 5G network.

All of these and other collaboration launched Huawei ahead of competition. The company was seen as a valuable ally and one that can be prepared and capable to deliver 5G infrastructure.

Huawei modem

5.2.2 The other competitors

Giving the 5G is will be the next mobile generation that whole world will follow, Huawei is not the only company racing to deliver this technology and conquer new markets. As the report by Analysis Manson revealed [99], there will be more than 80 MNOs in 40 countries across the world. by year 2020.

ZTE Corporation (China)

Competitor for 5G supremacy is ZTE. The Chinese company, founded just 10 years after Huawei, proved to be leader in 4G LTE[100] . It provided end-to-end LTE solution to differed markets. It's research on 5G started back in 2015, with the alliance with Deutsche Telekom. ZTE also invested

heavily on R&D of 5G, reaching $295 million in 2017. The company collaborated with Qualcomm and China mobile to showcase the first end-to-end 5G NR connection based on 3GPP R15 standard. 5G smartphone by ZTE was also produced in 2019. Same year, ZTE was included in global top 3 ranking by ETSI, with over 1400 5G Standard-Essential Patents(SEP) and patent application. At Selular Awards 2019 [101], the Huawei's rival won award for best 5G Solution, recognised for the efforts of early introduction to the global markers and development of 5G.

Nokia Networks (Finland)
Famous for it's sturdy old phones, Nokia also joined the hype around next generation of mobile technologies. The Finland telecom joint it's R&D with Hamburg Port Authority and Deutsche telecom for their 5G MoNAArch. Their approach was to collect real life knowledge about industrial uses of 5G networks - traffic light management, data processing from mobile sensors, and VR applications. Again, collaboration was inevitable and Nokia allied with Qualcomm, China Mobile institute, Sandvik and many others. However, the company is lacking on the mobile phone arena, announcing that their phone will be revealed in 2020.

NEC Corporation (Japan)
This 5G contestant came with a different concept - "5G. A Future Beyond Imagination" [102]. Toshimitsu Shimuzu, the Senior Vice President (SVP) of NEC, stated the company aim is to create new business models and services by taking advantage of advanced ICT 5G technologies with combination of NEC's proprietary AI, IoT, and other digital technologies. In that way different industries and related companies will interconnect. NEC have done many achievements in 5G development like:

- Successful massive beamforming transmission from a single antenna using 28GHz band for 5G;
- Successful remote control of construction machinery over 5G network.
- Provision of a facial recognition demo system utilizing Multi-access Edge Computing (MEC);
- Development of Radio Units (RU) for 5G base stations;
- Developing an enhanced Traffic Management Solution (TMS). System that improves 5G data transfer in rates more that 5Gbps.
- Releasing it's white paper - "Making 5G a Reality" [103]. bringing overview of 5G and it's standartisation perspective in relation to 3GPP.

However, although the company participated in the development of 5G, it did not came up with any handset that can be rival of Huawei's ones. This put the company in a very niche in the mobile world.

Ericsson (Sweden)
The Swedish multinational networking and telecommunications company, claims to be have the fist 5G network on 4 continents. Ericsson's prototypes were the first to enable MNOs to perform live 5G test in their networks, collecting understanding of how the new mobile technology would perform [104]. The company was recognised for it's expertise in mobile communication from fifth generation and other technology organisation have establish collaboration. In 2017, Ericsson had 8% of the 5G-essential patents. Latest achievements of the tech company include:

- Deal with Ooredoo Qatar to make it's internet fully 5G, by bringing Ericsson Radio System, 5G NR solution 10Gbps microwave solutions to upgrade and make Ooredoo's network futuristic and introduce 5G across the country.

- Saudi Telecom Company (STC) and Ericsson collaborated together to introduce a mid-band 5G network in Saudi Arabia.

Ericsson was also chosen by Etisalat, as main company for the deployment of 5G in United Arab Emirates (UAE) and put UAE on the world map of 5G. The Swedish company was also selected by U.S. Cellular for their deployment of 5G. The role was to support U.S. Cellular, by providing it with 3GPP standards-based 5G New Radio (NR), in both hardware and software. This was primarily caused the by the fully developed 5G platform. It allowed MNOs to quickly integrate 5G into their networks and provide upgraded services to their clients [105].

Ericsson also secured it's research through the use of Intellectual Property (IP). It filed a landmark patent application with World Intellectual Property Organization (WIPO) and United States Patent and Trademark Office (USPTO) in order to secure development on 5G. The application itself the largest in terms of number of inventors that is present in the world of cellular communication. The total number of inventors is 130. That demonstrated that Ericsson approached 5G and the standartisation not by focusing on individual small inventions, but rather combining them to build a complete 5G network.

Qualcomm (US)
This company was actually focused more on delivery of an actual technology, rather that a commercial product [106]. The company introduced the world's first 5G modem -Snapdragon X50 5G [107] in 2018, declaring with several other MNO leaders that in their test devices will be the Qualcomm modem. Following that the company announced additional achievements like first commercial 5G PC Platform, helping PC manufacturers benefit from 5G networks or it's first CPE equipment designed for the sub-6 GHz and millimeter wave (mmWave) 5G fixed wireless broadband (FWB) products. But for their royalties, Qualcomm announced that every 5G handheld that is going to benefit from their technology would be up to $16.24

in price [108]. Ericsson on the other hand is going to charge $5 per 5G phone.

Intel Corp. (US)
Intel was involvel in the 5G development after the acquisition of Infineon's modem business. The company introduced the XMM 8160 modem, capable of both sub-6GHz and mmWave operations in both types of 5G - SA and NSA [109]. However due to troubles with finding a client for it's chips, Intel decided to reevaluate the R&D cost on 5G and will no longer be working on 5G smartphone modem. All of this happened after Apple, currently the only Intel client for modems, decided to move on with Qualcomm [110].

Samsung Electronics (South Korea))
Samsung has long history in handset making that dates back to 1988 with the SH-100. For the 5G, Samsung started the R&D process back in the 2011. [70] The company is well familiar with phone modems and has significant network infrastructure business, so it is their interest to be involved with 5G. Like Huawei, they also Samsung's modems are built-in in-house and only implemented in the company's handsets. Their chip - Exynos Modem 5100, was also capable of sub-6GHz and mmWave work and is compatible with both 4G and 5G. However, not all phones come with that chip. For some of the markets, the South Korean phones are equipped with Qualcomm modems.

Mobile Network Operators
Here Verizon (US), Orange (France), Mobile TeleSystems (Russia) and AT&T (US) are companies that deliver 5G directly to the end user, through their already established networks. Each of these companies have been involved in the 5G and it's development, either being a test bed or actually building 5G NR networks. This means that at some point these MNOs, actually worked together with network equipment manufacturers like Qualcomm, Nokia, Huawei to build the 5G Standard. And the list does not end with these companies. Danish telecom group has been involved in 5G development with Ericsson. Therefore, MNOs can be seen as secondary companies, that implement the development of the primary companies. For that reason, this thesis would not focus on analysing performance or development of each of the companies. However, all of the MNOs work and invest on R&D the same way network equipment manufacturers do, because of these major interests:

- Being most innovative MNO on the market
- Have the best network performance on the market
- Deliver innovative services in the most effective way
- Keep the growth in customers rising.

Therefore, it will be hard to evaluate each of the MNO performance, because of the innovative technology that is yet to develop and because of the many alliances and contracts between the companies.

As a whole, each of the reviewed companies has contributed to the 5G. However, those who re really wining it are the company that invest heavily in research and development in end-to-end solutions like Huawei or Ericsson. For 5G, we can definitely note that Huawei is the leader in the new technology with it's investments of over $10bn just for 5G. Nevertheless, the real winner in the market would be eventually sorted out after the 5G SA becomes widely spread across the world. The next subsection is going to present other researches.

5.3 Other researches

Big consulting companies have also investigated the greatly hyped 5G technology and how it is going to impact society and business. Among them Deloitte performed many different analyses on 5G [111]. Through their analysis, the company has concluded that the new generation of mobile communications will bring to a country a significant addition of to it's GDP. For Australia that was in the focus it was $50 billion in additional GDP after a decade of performance. The business was also interviewed with more than 550 business larders and the main concern was to have faster and more reliable telecommunications. However, many customers were focused on the price of the new services and were not wiling to pay more for 5G. However, Deloitte put focus on that 15% of the businesses in Australia are not really sure if they actually need to implement an emerging technology [111].

PwC on the other hand focused more on the end customers, rather that the business [112]. In their analysis of a 1000 Americans between 18 to 64 years old , they discovered that despite the hype, people are actually not in a great need for 5G. More that two third (74%) of the participants would wait to ensure themselves that the innovative technology is really what it actually is. The research also revealed that the end user is willing to pay more for 5G, if it reasonably priced.

Other analysis done by EY, has been focused on China and it's leadership in the race to 5G [113]. In their paper, they predicted 576 million connection over 5G by 2025, which will be representing 40% of the global traffic. Also noted was Chinese companies also take lead in the race for 5G supremacy, because of the country's strive for becoming a digital leader.

Another research by Jefferies [84], showed how China aggressively pushes the research and development of 5G, in order to follow government's goal of leader in communication services. This pushed US carries away from Chinese manufacturers of mobile equipment like Huawei and ZTE, to their competitors - Nokia, Cisco, Ericsson. However, China

was recognised as the owner of 10% of the essential Intellectual Property Rights (IPRs) for 5G.

5.4 Subconclusion

This chapter have presented the main players that have influenced the development of the fifth generation mobile communications. Huawei was analysed and compared against other companies racing for 5G. Additionally other researches were reviewed that facilitated the understanding of the 5G arena. All together they compiled that China is in lead of 5G with Huawei and ZTE and though the next generation will offer both improved and new services, people will be not willing to pay extra for it and many businesses are trying to understand how can 5G would bring them benefits. The following chapter will perform an analysis on a primary research in an attempt to collect a professional opinion of 5G and Huawei.

Chapter 6

Analysis of primary research

6.1 Introduction

In addition to the secondary research, this thesis will provide an analysis of a primary research, conducted via open-ended questions on Google Forms. The participants in this qualitative primary research were asked to complete a questionnaire of 8 open-ended questions and to provide their professional opinions on the development and implementation of 5G technologies. All five participants are experts in the following fields: IP networking, 5G telecoms, IT and telecommunications. The below paragraph aims to show and explain the question from the primary research and to analyse the results from it.

6.1.1 Open-ended questions – Results and Analysis

The first question: 'As an expert in your field, what are the benefits of utilising 5G technology for commercial and business purposes? (Speed, higher quality of content, better user experience, etc.)' was designed to explore the positive outcomes of 5G for mass and organisational purposes. Even though all participants are experts in similar fields, the answers varied, everyone of the explained a different benefit of 5G. Some suggested that the 5G network will provide 'HQ content', ability to manage multiple devices', 'Enabling IoT & M2M communications', others supported the theory that in the nearest future all homes and businesses will go completely wireless because of the 5G developments. From the results, it can be concluded that there are multiple positives of utilising and developing 5G. All experts were able to suggest different features, which will make 5G a successful network in the future.

The second question: '*In your opinion, how would 5G influence the network connectivity and the digitalisation of the consumers?*' aimed to give participants more freedom to answer and to get more in-depth information of the application of 5G. The results were controversial, one participant suggested that the 5G capabilities will also stretch the storage demands, the consumers will need faster data applications and real-time analytics. According to another participant, the current LTE is too congested and customers must move towards 5G in order to transmit data.

Other responses focused on another theory that most consumers will not see the difference between the current 4G and the future 5G technology. The speed will be faster, but not significantly, therefore the common user will probably have similar experience as nowadays. However, 5G will be most beneficial for the big enterprises and the automobile industries, where the faster speed can make a difference.

Another viral question that circulates around the media is: '*Do you think that the modern 5G network will be more cost-effective, considering all the equipment necessary for its implementation and support?*'. The results from this question were also mixed, 50% of the participants did not think that 5G will be very cost-effective, because it will not require special equipment from a customer point of view. The other half of the respondents said that 5G will be 'roughly 5 times more efficient in the core in terms of capacity' and its speed will be '1000 times faster', which is why it will be very cost-effective. The results from this question distinguished a clear pattern in expert's opinions, half of them believe in the efficiency of the 5G whether the other half do not.

The fourth question: '*Would the better quality of data serviced lead to more expensive consumers' data plans?*' aimed to understand whether customers will pay more for a faster and more efficient service or the prices will remain as they are today. This question again triggered different reactions. Some guesses were that telecoms will increase the prices for data packages, especially during the initial trial of 5G networks. However, other argued that the data plans must go cheaper, because mobility reports suggest that 'the traffic is growing and the prices are going lower'. The overall summary of the answers showed that initially prices can be a bit higher, but after some time they will be as equal as the current 4G ones or even cheaper.

The findings from the next question: '*How would 5G be implemented globally for commercial and business purposes?*' suggested that there will be a big change in the telecom markets. All participants agreed that the new 5G networks will require new equipment and more modern digital devices. Some argued that the consumers will need new mobile devices as well as new equipment sensors. Other guessed that companies will have to utilise new software technologies and new antennas, as well as video cameras and even smart lights. The implementation of 5G will require more advanced technologies in order for it to be distributed globally.

Question number six: '*In the growing conversation about the sustainability of 5G, for example, the building of multiple cells network, do you think this will have an impact on the local community and businesses?*' was designed to explore the impact of 5G on community and markets. The responses were similar, all suggesting that the fifth-generation cellular technology will be beneficial for both local community and businesses. The technology itself will 'open-up a range of new business applications', it will be more reliable and cost-effective. The 5G network will use 'less

energy' and will offer 'useful new features such as different networks over the same cellular signal'. All experts seemed to have the same opinion that 5G will have and impact on the masses and it will be a positive one. Another questions that bothers the current 4G users is the safety of the technology, which is why the next question: '*In the rising concerns about health and safety in terms of radio waves, do you think that 5G will present any risks?*' aimed to discover the opinions of the telecom professional on health and safety. The majority of the respondents, 75% of them, believed that 5G will not be harmful, it will 'present no more a risk than any other technology'. The new network will 'use waves with higher frequency, however, the waves only penetrate a few millimetres of the body, therefore industries suggest that there is no risk for the consumers.' The rest 25% of the respondents believed that 5G could have an impact on the health of the people and it should not be neglected.

The last question of this qualitative research was: '*In your opinion, which technology company is the market leader in the development of 5G? (Huawei, Nokia, Intel, Samsung, Ericsson or other, and why?)*'. The result of this question was rather curious. Four of the expert believed believed that Huawei is the market leader in the development of 5G technologies. The reason behind their answer was that Huawei has the biggest budget: 'They spend £2b a year on R&D which vastly outweighs the entire R&D budget of its competitors'. Exception made one of the five participants. The provided answer not for Huawei, but for Nokia. The explanation was that according to the participant's believes, all of these technological giants invest sufficient resources.

6.1.2 Conclusion

The results from the qualitative research showed that the experts in 5G, IT and Telecommunications have various points of views and support different theories. However, they all believe that the 5G network will be beneficial in terms of speed and efficiency. It will have a positive impact on the local community and on the other business owners. And the thing that they are most certain of is the fact that Huawei invests the most in research and development of 5G, and up to date it is the leader in the market.

Chapter 7

Discussion and Conclusion

7.1 Discussion

This thesis performed an detailed review of the standartisation process, particularly in mobile communication technologies. Followed by that, the current (4G) and the futuristic 5G networks were compared in regards of capabilities. Hype of 5G and race for that technology proved how valuable are mobile networks. Huawei was compared to it's rivals based on their prevalence in the IMT-2020. The concept of these reviews and analysis was to provide understanding of how the mobile standards are formed, how an invitation of a new beliefs for the future alter the the mobile industry. Firstly a discussion will be established around what have been found throughout this report, then we are going to sum up the answer to the problem formulation. The approach will be to start with the sub-questions and later answer the main question of that thesis.

Findings of the researches

Most of the finding from the primary research correlated with the ones from the literature review and other similar researches on 5G. However, other papers did not support the views of the participants in the primary research, which are discussed below.

As discussed in chapter 4, Simon Forge and Colin Blackman (2017) [39] suggested that the majority of the telecommunication companies see 5G as a possibility to offer different and more advanced services on the global market. The 5G network will require less field equipment, will provide better coverage and much faster and secured connection. The findings from the primary research showed a correlation between the literature of Simon Forge and Colin Blackman, and the opinion provided by the telecommunication specialists. According to the participants in the research, the new technology will be beneficial in terms of speed and efficiency. It will affect positively the local community and also the major corporations.

On the other hand, researchers like Gerry Purdy (2016) [68] argued that the 5G will not be as beneficial as everyone suggests, it will not deliver enough revenue, which will result in higher costs for the general consumers. This theory, however, was not supported by the specialists from

the primary research, they concluded that initially 5G data packages can be a little bit more expensive than the current 4G ones, but in a long-term perspective, the 5G deals will become much cheaper and more efficient.

Furthermore, a recent research, completed by Deloitte [111], suggested that 15 million users in the UK are ready to switch to 5G data plans and feel the demand for a faster and more optimal network. Dan Adams, head of telecommunications at Deloitte, argued that once 5G technology is fully functional and the initial skepticism is overcome, the consumer will start to see the benefits of the technology and will begin to use it. The same thoughts were shared among the experts in the primary research, all of them believed that there are many areas of 5G that have to be tested ,but once the technology is fully developed, the users will switch to it, because of its advanced characteristics.

How mobile standards are developed?

Standartisation process discussed in chapter 3 is the topic of the first question that we are going to revise. After performing a full review of that process in chapter 3, in summary these are the most essential aspects. Standards can be classified differently according to their use and implementation. The creation of a standards, firstly begin with developing an agreement between the participating sided on the requirements and aspects of the new standards. Then upon that technology prototypes are being developed to achieve the initial requirements. All of this is being monitored by a standartisation organisation for proper establishment of a standard.

What are the benefits of the 5G?

Second sub-question in that master thesis's problem formulation is related to the advantages of 5G technology, discussed in chapter 1. The advantages of 5G, compared to the current 4G - LTE were examined in chapter 4, so here were are going to put shed on the three main ones, considered to be the most important ones. The first to be listed is Extreme Mobile Broadband (eMBB). This advantages is needed in relation to the vastly growing world of mobile devices. Second is Massive Machine-Type Communications (mMTC), that is required to have as in future there is expected the presence of a lot of smart houses, building or even cities that require many devices using machine-to-machine communication. Last, but not least, is the Ultra-reliable Machine-Type Communications (uMTC), needed for delivering always on connection with less than a 1ms time latency.

Who are the leading companies introducing 5G to people?

Third of the sub-questions was aimed to provide a detailed picture of the 5G companies that work on delivering this upgrade to the people. We began by clarifying who are the actors in 5G in chapter 3. Based on the research documented in chapter 5, we have identified six leading tech companies that are considered drivers for 5G: Huawei, ZTE, Ericsson, Nokia, Qualcomm, Samsung Electronics. Along these, there were the MNOs, that through their network were delivering 5G to their customers.

How Huawei compares to it's rivals in the 5G race?

The main question of this thesis is focused on the reveling who is the leader in 5G race, both in the mobile communication and in the handsets markets. That has been examined in chapters 5 and 6. In the world of mobile communication Huawei was identified as a winning players in the the race to 5G, for company massive investments in R&D for 5G and their culture. Through the year the company has become a major rival to the European and American relatives, but the futuristic thinking and endless effort have protruded it among the others. Additionally, analysis of the literature on this topic found that major research companies support the idea that Huawei is the company, which invests the most in the development of 5G and is the market leader at the moment. The same theory was also discovered in the primary research in chapter 6. The majority of the participants supported the idea that Huawei is company number one, in terms of 5G development. Some of the specialists said that: 'Huawei spends over £2b a year on research & development, which vastly outweighs the entire research and development budget of its competitors'. However, we should be alerted when a sigle company is trying to conquer 5G markers, for reasons that might not always be beneficial for the end user.

7.2 Conclusion

As part of this thesis, future trends in mobile communication world along with the terminology were introduced in chapter 1. The standardisation process in telecommunications was introduced to the reader in chapter 3, along with the different related organisations and participants. Followed by that, chapter 4 presented the current 4G (LTE) technology in place and the status of the futuristic 5G. Qualitative research was performed on both primary and secondary data, respectfully in chapters 6 and 5. Thus delivering a comprehensive picture of the mobile arena for 5G. The applied approach of reviewing and analysing data was discussed in 2. The beginning of this chapter introduced the results from the analysis.

As a result of this thesis, it can be concluded that there are various opinions about 5G, its development, implementation and application. Some support the idea that 5G will be more efficient and will be able to offer more to the end users. Other are skeptical and does not see a bright future for this technology. However, the data from both primary and secondary researches showed that Huawei is the market leader and the company invest the most in the development of 5G.

Intentions of this thesis are to provide better picture of the standartisation process and the current generations of mobile telecommunication technologies. The analysis on standardisation was designed to clearly define how the new generation of mobile networks are born. That way, it helped understanding what is behind the G terminology by presenting 4G and 5G in an understandable manner for the reader. This way, a broader audience is targeted, even though some knowledge of telecommunication field is required to understand the analysed technologies. This project aims, also on providing practical information on the subject, that can be used by specialist as a reference for their own analysis.

Based on the results and analysis described in this report, the statement that there will be always a race for mobile network leadership, As it was reviewed, mobile communication world is vast and the revenue hungry companies are always looking into a new niche to develop new services for new revenue and market share. Even now, telecom giants are putting 5G aside and focus on the next generation and next 10 years of development - 6G [114, 115].

7.3 Future research recommendations

There are many gaps in the literature about 5G, since it’s a modern technology, which is not yet finalized and not yet introduced for a mass usage. There is a need of further and more in-depth research. Such future researches can be made after certain period, evaluating 5G and whether the technology investments have been justified. Other research project can be conducted about relevant question regarding 5G Business cases. Nevertheless, the primary research for this thesis provided a decent insight and investigated the opinions of telecommunication experts who work on the 5G development field. The results from this research can be used as a foundation for a more extended future study around the topic of 5G and its application.

Appendix A

Questionnaire

0. What is your current field of expertise?

1. IT & Telecommunications
2. IP networking
3. Telecom / 5G
4. IT & Telecommunications
5. Networking and network programming, SDN/NFV

1. As an expert in your field, what are the benefits of utilising 5G technology for commercial and business purposes? (Speed, higher quality of content, better user experience, etc.)

1. Higher quality of content, speed, Ability to manage multiple devices.
2. Enabling IoT and M2M communications.
3. Hard to say. We need to be critical towards these improvments. Speed comes at the cost of realiability. Depending on the use-case really. If you want to have eMBB + ULL use cases you need to buy more spectrum - and this is cost. Depending on the business really.
4. Lower latency allowing for wider consumer and enterprise application of real time technologies across automotive & health industries. NW capacity allowing more to do more with less. Ability to go completely wireless in the home and primarily business in the near future (5-10 yrs).

5. Network design flexibility, vendor independent service deployments, on-demand network functionality addition - instead of purchasing dedicated devices, the network engineers in the 5G world will be able to deliver both software and hardware solutions without depending on a few world-wide well-known vendors; As a result, that will lead to serious innovation boost.

2. In your opinion, how would 5G influence the network connectivity and the digitalization of the consumers?)

1. The nature of services and capabilities enabled by 5G networks is also going to stretch the storage demands for a much wider range of smart, connected devices. There will be a need to support Fast Data applications with real-time analytics. Fast data means getting more insights for faster action.

2. It will probably improve these two.

3. "Again not yes and no answer. The problem is now that LTE is simply too congested. We must move towards 5G's spectrum to transmit data. Thats the first use case. Will it influence cars? I don't think so. See this: "We have been speaking with Volvo and Bosch and there is no chance that 5G will be able to handle that. Most of those autonomous case is being done in car. This vehicle-to-vehicle communication. I went to the government's 5G plan presentation and again you hear politicians talking about the need for the low latency because of the autonomous cars. Two week later, I went to Malmo to see Volvo's presentation and I heard that they say we do not need 2 ms of latency. They had already today they have the cellular service that two Volvos car coming down the road, one of is starting to block the breaks, the signal is going up to the cloud, which is distributed to the other cars in the area. All the other Volvos car are receiving the message ''Hey we are experiencing you know sliding

tires". So why 2 ms? I mean 20 milliseconds is fine, 50 ms even is fine. I have not seen, I am yet to see, a car manufacturer claiming that the 5G networks will handle the autonomous ride. Because that is not what they believe it why I've been talking to Scania as well there are some use cases on the truck side which has to do with this platooning. There are certain applications where you would need a cellular network either as a fallback or as providing guidance as to the on-road/ off-road movement of special vehicles. But the minute you are there, and you are driving you would not be dependent on the circuit of 5G networks not anytime soon. However, that does not mean that the cellular network is not providing valuable data. I would encourage anyone to go to Qualcomm page and look at what they believe actually the 5G network can do for the cars information systems. That is amazing what they work on. Come in here and call come is it I mean this is it you have basically what they can do is that they can provide you with and ."

4. Not sure I understand. But general consumer customers won't really feel the benefits of 5G directly. Yes faster speeds etc but 4G is already fast enough for most consumer applications (internet, streaming) when you have a good signal. Low latency gives online mobile gaming a huge boost esp for real time gaming (fortnite type games where cursor speed and shooting needs to be real time rather than laggy). Major applications are in the enterprise market where automotive and health applications are huge opportunities. Consumers will benefit indirectly from these.

5. Greater network throughput and multi-path connectivity will make the services faster and more reliable.

3. Do you think that the modern 5G network will be more cost-effective, considering all the equipment necessary for its implementation and support?)

1. Download speeds will be 1000 times faster, meaning that a movie that currently takes 20 minutes to download will only take a couple of seconds.Latency — the time it takes to retrieve data — will fall from 50 milliseconds to under 1 millisecond.

2. No.

3. 5G does not require equipment. It requires software - NFV + SDN features so no, I don't think so. Maybe for 3-D beamforming and massive MIMO you need a different antenna model. Also...to use C-RAN network you need strong fibre optics.

4. Yes. it is roughly 5 times more efficient in the core in terms of capacity.

5. Yes, definitely. Nowadays we have examples like Netcope, NXP LS2xxx series, smart NICs from Netronome. All of these vendors deliver flexible hardware chips that can be programmed for specific network application. All-software projects like DPDK turn a $2 NIC into a fast-forwarding smart device. Those technologies come without any license fees. The NXP LS2xxx chips also come with reference hardware design. This is an indisputable fact that 5G would completely break the ice (and the standard ways of building network equipment).

4. Would the better quality of data serviced lead to more expensive consumers' data plans?

1. Initially, 5G subscriptions might cost more than 4G, so that the telecom operators can differentiate the different services. My guess is that with time the operators will push the monthly cost for a 5G subscription to the same range as today's subscriptions, since most people don't want to pay more than they are already doing. Hence you will get a much better service for your money.

2. Probably yes.

3. I don’t think so. The price of data must go lower. See Ericsson mobility report. The traffic is growing and prices are going lower.
4. Depends on how companies position it. Some will price as a premium and others will not.
5. I doubt.

5. How would 5G be implemented globally for commercial and business purposes?

1. The world is going mobile and we’re consuming more data every year, particularly as the popularity of video and music streaming increases. Existing spectrum bands are becoming congested, leading to breakdowns in service, particularly when lots of people in the same area are trying to access online mobile services at the same time. 5G is much better at handling thousands of devices simultaneously, from mobiles to equipment sensors, video cameras to smart street lights.
2. That can only be achieved after all countries and their local telecom operators migrate to 5G.
3. hm its mostly "softwarised" and new antennas.
4. Not sure I understand this question.
5. Mostly by optics and radio. Optical link between radio (pico)cells.

6. In the growing conversation about the sustainability of 5G, for example, the building of multiple cells network, do you think this will have an impact on the local community and businesses?

1. Fifth generation cellular technology is not only fast and efficient enough to replace fixed wireless, which in itself will open up a range of new business applications. It also

is more reliable, costs less, enables massive device connectivity (think Internet of Things applications), uses less energy, and offers useful new features such as different networks over the same cellular signal.

2. Yes.
3. Start-up will have better network to use if that's what you mean.
4. 5G works with 4G cabinets so I don't see it being a huge impact.
5. It depends. Health factor should be the main focus upon building the high frequency 5G networks.

7. In the rising concerns about health and safety in terms of radiowaves, do you think that 5G will present any risks?

1. High-frequency waves only penetrate a few millimetres into the body and this is being used as a 'no worries' card by industries — but our skin is the biggest organ in the body and is linked to numerous things including immune response
2. No.
3. at some point yes. I wouldn't neglect that.
4. No this is scaremongering and there's no evidence to support this. TV masts have a much much vastly higher output and we are not concerned about those being dotted around the country. 5G presents no more a risk than any other technology.
5. I would answer with a question - can someone present me an official report that states that there are no risks for the living organisms that will be exposed to 5G-frequency radiation?

8. In your opinion, which technology company is the market leader in the development of 5G? (Huawei, Nokia, Intel, Samsungs, Ericsson or other, and why?)

1. Huawei
2. Huawei, since their R&D budget is the biggest.
3. Huawei.
4. Huawei. They spend £2b a year on R&D which vastly outweighs the entire R&D budget of it's competitors.
5. All of them invest enough effort. Personally, I believe in Nokia.

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