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Impact of regulatory aspects on 5G mobile communication systems

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Summary

The fifth generation of mobile communication networks generally known as 5G is a technology that, if we read anything about it we can arrive to the conclusion that it can be a revolution in many aspects.

Starting with the great change that the telephone introduced, followed by the great improvements that the mobile phones carried along with them and finally internet and broadband access from any part of the world with a pocket device, we arrive to a time where 5G not only will it improve the existing technologies but it will allow the development of new inventions such as Internet of Things (IoT) that up to the date is reduced to various experiments and trials. The fifth generation of mobile communication systems will allow the development of applications, data models, data analysis at very high speeds, sensor measurements, and data transmissions instantly and a very long list of other things that will result in a revolution in one hand for the people's lives and in the other to the markets and the way the companies carry out their business models and their internal and external general management.

People's quality of life will be affected substantially thanks to the establishment of 5G. This will be achieved thanks to the high speeds and the characteristics that 5G includes, and it will allow, for example, that a refrigerator can inform its owner about what products are needed or about what food is about to expire. This simple example is only one of many others that we can find when talking about 5G.

Nonetheless, in order to be able to enjoy these advantages that 5G incorporates, it is necessary to conduct a development and deployment in an agreed upon way between all the different organisms and bearing in mind the regulatory aspects and the legislation valid and that needs to be developed in order to have a correct deployment. To do this, the regulatory organisms, and the commissions of the different countries have to agree between them and investigate what is the best way to provide the best standards, and to ease and speed up the deployments and start-ups of this new technology.

After developing a detail study of the current requirements, objectives and the legislation and standardization, as well as the state of art of the technologies that provide us with the services that we enjoy nowadays, I have studied the barriers and drivers for the deployment of 5G. Finally, and after this previous study, I have analysed the possible deployments for this technology and how will it affect to the economic and social environment the use of these types of mobile communications. At the same time I have arrived to the final conclusions that 5G will be a complete revolution and anything that enables and eases the implementation has to be welcome.

Resumen

La quinta generación de redes de telecomunicaciones móviles comúnmente conocida como 5G es una tecnología de la que, si leemos cualquier información, llegaremos a la conclusión de que puede suponer una revolución en muchos aspectos.

Comenzando por el gran cambio que supuso la invención del teléfono, seguida por la evidente y alta mejora que introdujo el teléfono móvil y finalmente la conexión a internet y el acceso de banda ancha desde cualquier parte del mundo con un dispositivo de bolsillo, llegamos a un momento en el que el 5G no solo mejorará las tecnologías ya existentes sino que permitirá desarrollar ideas tales como el internet de las cosas que, a día de hoy, se reducen a, varios experimentos y pruebas. El 5G permitirá el desarrollo de aplicaciones, modelos de datos, análisis de datos a altas velocidades, lecturas de sensores y transmisión de datos de forma instantánea y una larga lista de mejoras más que resultará en una revolución por una parte de la vida de las personas y por otra de los mercados y de la forma en la que las empresas llevarán a cabo sus modelos de negocio y en general su gestión externa e interna.

La calidad de vida de las personas se verá afectada de forma sustancial gracias a la implantación del 5G. Esto se conseguirá debido a que las altas velocidades y las características que incorpora el 5G permitirán que, por ejemplo, una nevera avise a su dueño de aquello que falte en su interior, o que le informe de aquellos productos que están a punto de caducar. Este simple ejemplo solo es uno de todos los posibles que se pueden encontrar a la hora de hablar del 5G.

Sin embargo, para poder llegar a disfrutar de todas las ventajas que el 5G aporta, es necesario llevar a cabo un desarrollo y un despliegue de forma conjunta entre los diferentes organismos, y teniendo en cuenta la normativa y legislación vigente y que se necesita desarrollar, para que este despliegue sea correcto. Para ello, los organismos regulatorios y las comisiones de diferentes países, deben ponerse de acuerdo e investigar cuál será la mejor forma de proporcionar los mejores estándares y facilitar y acelerar los despliegues y puestas en marcha de esta nueva tecnología.

Después de llevar a cabo un estudio detallado sobre los requisitos, objetivos y la normativa y estandarización actual, así como el estado del arte de las tecnologías que hoy nos proporcionan los servicios de los que disfrutamos, se han estudiado las barreras y los aspectos favorecedores para la implantación del 5G. Finalmente, y tras este previo estudio, se han detallado los posibles despliegues para esta tecnología y se ha estudiado como afectará al entorno económico y social la utilización de este tipo de redes de comunicaciones móviles. A su vez, se han llegado a las conclusiones finales de que el 5G supondrá toda una revolución, y que todo aquello que favorezca su despliegue e implantación, debe ser bienvenido.

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1. Introduction

The fifth generation of mobile communications systems (5G), is born by the need of providing the consumer with a more efficient, low-latency, reliable and less battery consuming way of staying always connected. Given the evolution of our mobile devices and the increasing demand of connectivity, 5G will have to face the high traffic volumes that will be multiplied by 1000 as well as the number of new devices entering the network.

In consequence of the drop in voice telephony revenues and the increase in data content and internet based services, this new technology has been developed to serve not only the needs of the customers but also to improve performance in services such as remote surgery, to provide a more secure and more sustainable technology as well as to test new business models and financial formulas among others. It will also help restructuring the frequency band by closing the gaps caused by an increasing Digital Divide, as new needs arise and new allocation has to be performed, filling up the empty spaces.

In order to be able to analyse how 5G will be developed and how will it affect us in a socio-economic manner, we have to take a close look at the standardization bodies and regulatory organisms involved in the deployment of 5G.

The 3GPP is a group of telecommunications association that work together to develop different generations of mobile communication systems starting with the Third Generation (3G) of mobile phone system specification that came after the Second Generation (2G) known as the Global System for Mobile Communications (GSM). Moreover 3G was developed into the Universal Mobile Telecommunications System (UMTS) and finally to the technology that is in use nowadays Long-Term Evolution (LTE) [1]. This organism plays a very important role in the deployment of the fifth generation as it puts together all the ideas and developments that are being produced worldwide.

Additionally the "ETSI which is the European Telecommunications Standards Institute is in charge of producing standards for Information and Communications Technologies (ICT) including fixed, mobile, radio, converged, broadcast and Internet technologies" [2], and will be in charge of the standardisation needed for 5G in terms of technology, security and so on. The ETSI is part of the 3GPP and in mobile communications, it standardises what the 3GPP proposes.

Moreover we will have to take into consideration the International Telecommunications Union (ITU) that will also play an important role in the standardization and regulation involved in 5G technology. "In the world radiocommunication conferences (WRC), that are held every three or four years a review is done to revise the radio regulations, the international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits. This reviews are made based on the ITU council and it takes into account recommendations made by previous world radiocommunication conferences" [3].

The user cases that can be predicted for this new technology are very well pointed out in the next figure:

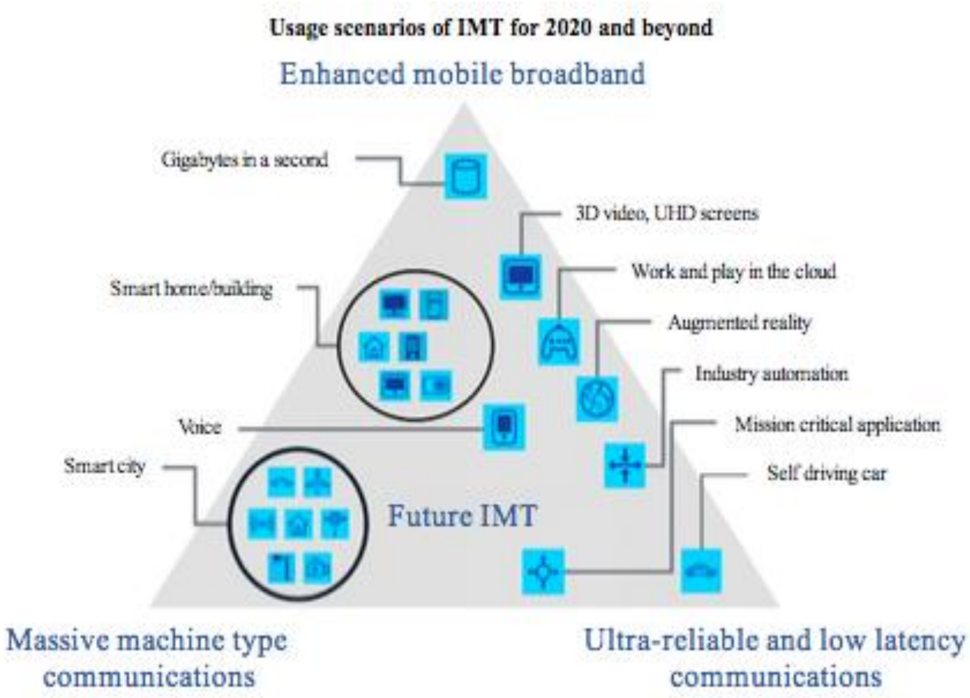

Figure 1. Source: Recommendation ITU-R M2083-0 [4]

First we have the enhanced mobile broadband that is mainly focused on human use cases for access to multimedia services and data. It demands rates of Gigabytes per second and it includes new application areas and requirements to enable a seamless user experience and an improved performance than that of the existing mobile broadband. This scenario has different requirements depending on the specific user case that we are focusing on. For example, for an area of high user density, a high traffic capacity will be needed but for mobility will be low. That is, depending on the specific needs, the requirements may vary. We can include some specific examples that are part of this global user case like for example the interaction between human and Internet of Things (IoT) or multimedia everywhere.

Later on, we can take a close look at the massive machine type communications where we basically have a high number of connected devices at the same time that have a very long battery life and are low cost, but are constantly transmitting a low volume of data to maintain information of a certain type. These can be for example beacons transmitting information about advertisements or devices in a house or a smart city.

Finally there is the ultra-reliable and low latency communications that have strict requirements on latency, throughput and reliability given the importance of the applications they run. We can understand this strictness for the requirements with an example. Take we are performing remote surgery from one country, to a patient in another country. We need our system to work with a near to zero latency because a life is at risk. We also need our application to be available at all times because a blackout in the image or the machinery cannot be accepted. Other examples for this type of user cases are wireless control of industrial manufacturing or transportation safety.

Later on there could be additional user cases that may emerge after the deployment or depending on a certain need or circumstance.

1.1 Motivations

Ever since I started my bachelor degree in Telematics Engineering, I realised I was highly interested on networks. Throughout my academic years, I learned about the importance of network protocols, standards, services and most important about mobile systems.

Nowadays, mobile communications play a very important role in our lives. From the second we wake up in the morning up to the end of the day, we are constantly making use of at least one type of mobile device. It is for this reason that we have been motivated to develop a fifth generation of mobile communications (5G), that will help cope with the high and increased usage of the network and that will allow us a new way of life.

The regulatory aspects and the standardisation that will be pointed out and analysed in this document will help understand the needs and motivations of the 5G deployment. Moreover, I wanted to investigate about this because I consider it to be a topic of the future. I wanted to be part of something that was not yet developed, but at the same time was about to be done. Something that will be clearly used in a near future and a topic that still needs a lot of investigation.

Regulatory aspects for the fifth generation of mobile communication systems are a key point in the whole deployment, therefore with this investigation and given my current job as an intern in the consulting department for Oracle, I will hope to bring new insights to this technology and continue developing the current information that already exists.

1.2 Objectives

The main objective of my investigation is to be able to know what influence the regulatory environment has, in the deployment of the fifth generation of mobile communications. That is, being able to analyse deeply how the legislation already valid and the future one will affect this approaching technology. For example, it would not be the same to designate a frequency band or another or it would not be the same to deploy 5G this year than in two years.

Moreover, another interesting objective is to check the impact of the standardisation, which also affects the technology involved in the 5G deployment. Standardisation is a process that takes place in a lot of devices, technical instruments, cables, antennas etc. therefore it plays a very important role on the drivers and barriers for the development of 5G, as it affects directly on the time everything will be developed.

All this will also have a significant socio-economic effect as it will determine when and how will society be able to make use of 5G and this will affect scale economies and markets as well as our whole lives as we live them today. 5G brings with it a wide range of new devices and systems and it is therefore important to determine how and when will we be able to experience them.

1.3 Requirements overview

The overall requirements for 5G can be summarised in the next table:

Requirement	Expectation
Connection density	Total number of connected devices per unit area
Mobility	Maximum speed at which a defined QoS and seamless transfer between radio nodes which may belong to different layers or radio access technologies can be achieved
User experience data rate	Achievable data rate that is available across the coverage area to a mobile user/device
Latency	The contribution by the radio network to the time from when the source sends a packet to when the destination receives it
Energy efficiency	On the network side, it refers to the quantity of information bits transmitted to/received from per unit of energy consumption of the radio access network On the device side, it refers to the quantity of information bits per unit of energy consumption of the communication module
Area traffic	Total traffic throughput per unit of spectrum resource and

capacity	per cell
Spectrum efficiency	Average data throughput per unit of spectrum resource and per cell

Table 1. Capabilities of IMT-2020 Source: Recommendation ITU-R M2083-0 [4].

On the next page (Fig. 2) we can take a close look at the differences between what we know as Long-Term-Evolution-Advanced (LTE-Advanced) or equivalent to Fourth Generation of mobile communication systems (4G) and what 5G will be like regarding the capabilities that both technologies have/will have.

These predictions however may change depending on the final development and capabilities that 5G will have.

It is also important to take a look at the type of architecture that will be deployed. It is crucial to know this because the requirements may vary from one architecture to another. For instance if we want a network to be capable of coping with the traditional needs of customers but with a very increased number of them in the network at the same time, we will not need the same requirements as for a network supporting remote services where low latency and high capacities are demanded. 5G will allow us to configure multiple logical networks on the same physical infrastructure so that the different needs can be properly and quickly addressed without having over delays caused by the need of building multiple networks [6].

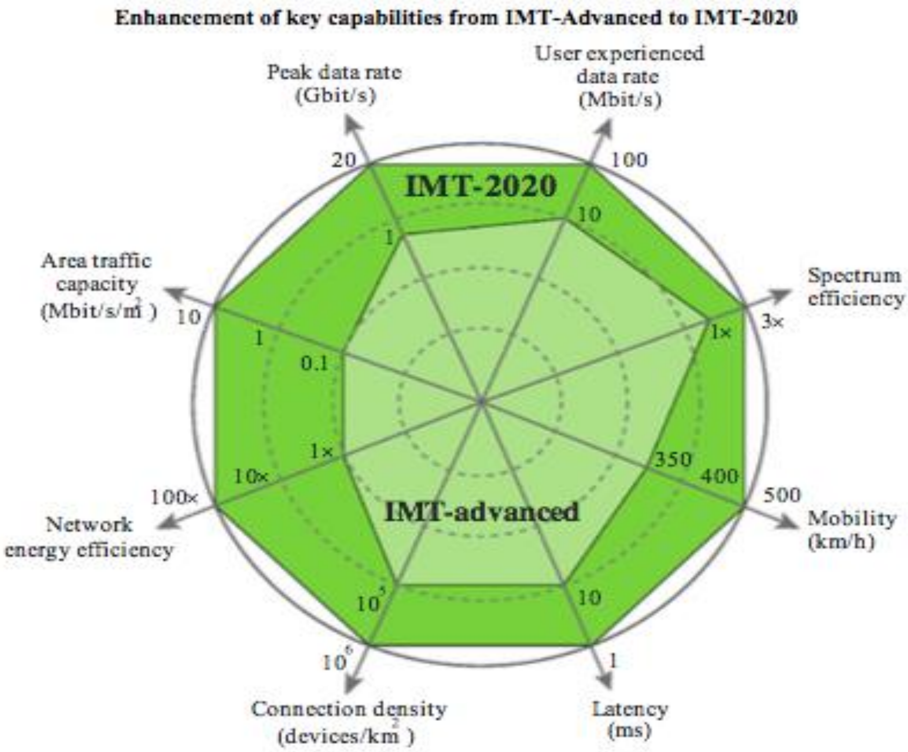

Figure 2. Enhancement of key capabilities from IMT-Advanced to IMT-2020 Source: Recommendation ITU-R M2083-0 [4].

1.4 Regulatory environment

Regarding the regulatory environment for 5G we can clearly point out that there must be a frequency allocation that will be done by the ITU WRC (as mentioned before, the World Radiocommunication Conferences) in the WRC'15 and WRC'19. The next figure shows the "possible scope of WRC'15 and WRC'19 5G spectrum discussions".

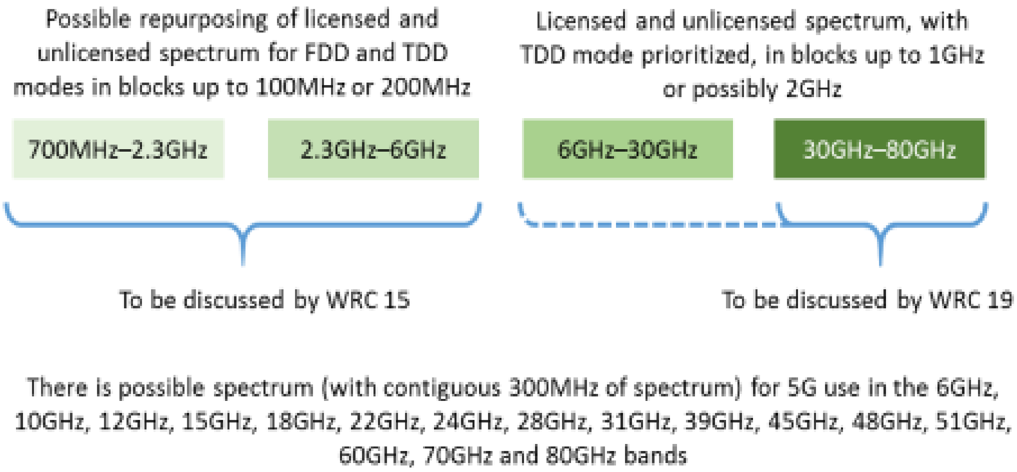

Figure 3. Possible spectrum discussed in WRC 15' and WRC 19' [5].

Moreover, it is important to take a look at how the spectrum allocation is done and by who. To understand how the different commissions work we will take a look at different areas of the world and what organisms perform the spectrum allocation.

For the European Union, the spectrum was reallocated to be able to reassign the band in order to provide a more flexible use of it and introduce an economical growth [6]. This is done by the European Commission and helped by the Radio Spectrum Policy Group (RSPG) that is a high-level advisory group that helps the Commission in the development of the Radio Spectrum Policy. This group ensures a non-discriminatory and proportionate balance of the use of the spectrum made by its users [7]. The EU has gone from a command and control regime to a more flexible way of spectrum use.

For the case of the United States, the Federal Communications Commission (FCC) is in charge of creating the basic rules for the administration of the spectrum in the States. Other bodies have been later created to manage different spectrum allocations and assignments of licenses like for example the Spectrum Policy Task Force (SPTF) that creates specific recommendations in order to create new spectrum policies that are more market oriented. Moreover, FCC has also managed to create initiatives to eliminate the regulatory barriers for the reassignment of the spectrum. All these has been done in order to place the United States as a leader in the use of mechanisms that enable an easier way of exploiting and making a good use of the spectrum [7].

In Asia, the organism that is in charge of spectrum allocations among others, is the Asia-Pacific Telecommunity (APT). The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) and the International Telecommunication Union (ITU) founded this organism.

In general terms, we can outline three possible ways of spectrum allocations:

1. Licensed spectrum where there is an exclusive use by the license holder. This is the foundation of public mobile networks and is critical for satellite, government and military services. There are over forty bands and it is globally for LTE.
   You can be assigned a licensed spectrum by a public auction for the rights of that license, in order to use it to provide a specific service, by public tender where the license is assigned to the best solicitor and by draw, where the grant of the license is done randomly.
2. The licensed spectrum brings the opportunity of having rights of exclusive use of the spectrum and therefore it simplifies the interference management but at the same time can limit the flexibility of the spectrum usage over time. There are moments where the spectrum is not used and therefore there is a waste of resources. Here is when the shared licensed spectrum becomes useful. It enables more flexibility and brings an increase in the usage of the spectrum.
3. We also have the unlicensed bands where there is a collective use of the spectrum by an undetermined independent number of users without a license.

For 5G it would be wise to consider the shared licensed spectrum for many reasons. For example, it would unblock the spectrum that is lightly used by satellite or military, it is also an opportunity to increase spectrum utilization by multiple operators sharing the band and it would attract new providers as well as enable new service models and support new deployment types. Spectrum sharing is also valuable for a wide range of deployments resulting in extreme bandwidths, enhanced local broadband and Internet of things verticals (dedicated IoT networks). The way the spectrum is allocated plays a very important role for the Internet providers and the television broadcasters. When the first Digital Dividend took place, part of the spectrum that was being used by the analog television was reallocated in order to have the 800MHz band free in all Europe and so that it could be used by the Fourth Generation of the mobile communications (4G). This assignment of the band benefits the provider companies, as they are able to deploy their new networks and make revenues with their customers. For television providers this poses more difficulties, as some of their customers have to install new devices in order to be able to receive and see the new television properly. However if we analyse the general economic impact of the Digital Dividend we can estimate a general economic growth that benefits the whole country. It has been estimated that the higher the percentage of penetration of the broadband in a country, the higher is the percentage of increase of the Gross Domestic Product (GDP) [8]. This is shown in figure 4.

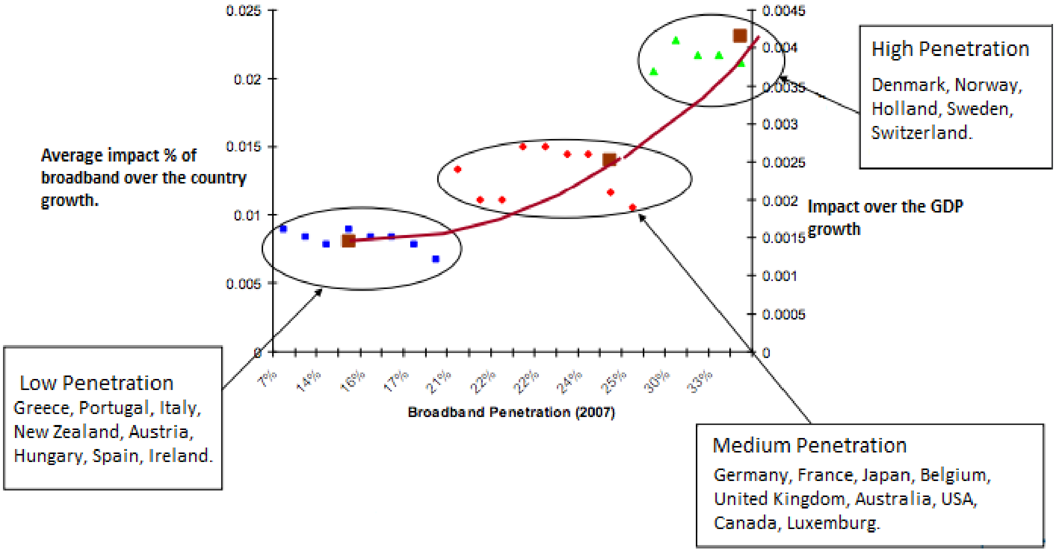

Figure 4. Impact of the GDP due to the growth of the broadband penetration [9].

1.5 Standardisation

Given the fifth generation for mobile communication systems has not been deployed yet, the standardisation is a continuous process that involves different types of organisations and will be done for different technologies. If we take a look at the different use cases that arise when we think of 5G, we can instantly have an idea of many of the standards that will have to be developed.

An example of this is tactile internet. Tactile internet consists on applications that have “an extremely low latency in combination with high availability, reliability and security” [10]. These types of services have a huge impact on businesses and society and enables the emergence of new technology markets and other ways of delivery of public services (e.g. remote surgery). The machinery and equipment that these types of services make use of, result in the need of multiple standards to define the norms and requirements for the technical systems.

Moreover, we can also see that the need of standards arises when a Quality of

Service (QoS) or Quality of Experience (QoE) wants to be delivered to the users of a network. 5G aims to achieve high levels of these two characteristics with its network, therefore the standardization process will be an important aspect when developing and deploying 5G. In the line of QoS and QoE we also have the standards created for telecommunication protocols. These protocols are in charge of handling the communications between devices among others so they are also an important aspect to consider.

To end with, other examples where standards need to be defined and thought about are Internet of Things (IoT), Smart Cities, Big Data activities, Cloud services... It is evident how standards and the definition of norms are an aspect that influences the deployment of 5G. Depending on the speed of the creation of these standards, the agreements between the different bodies involved and the cooperation between all of the parties, 5G deployment will be quicker or slower.

1.6 Document structure

The structure of this document is as follows:
In the introduction I would like to explain briefly what will be covered in the whole document. There will be an outline of the most important aspects that will be discussed further on in the document. It will include as we can see in the index, the basic ideas regarding the requirements, the regulatory environment and the standardisation involved. Further on I will deepen into these aspects of the topic.

Moreover, for the part that involves the state of art after a brief introduction, the current mobile networks will be analysed in a global environment scope. In these parts, I will point out how the current network was developed inheriting the characteristics and part of the architecture of the previous generations of mobile systems (1G, 2G and 3G). Furthermore, I will explain the technologies involved in this new technology and at this point and, given we have already developed many mobile communications solutions, I will only go through structure of the current technology existing today which is Long Term Evolution LTE also known as Fouth Generation or 4G.

To end with the state of art, the structure of the fifth generation for mobile communications systems will be clarified and explained. I will go through the different possible structures, and the solutions already existing.

Furthermore, a possible deployment will be analysed with a suggestion for the socio-economic impact that it will have. To be able to predict this impact I will investigate on the road map, the barriers and the drivers that arise when thinking about 5G deployment and settlement.

Regarding the possible impact that 5G technology will have, I will analyse the different possible uses of 5G in Oracle. As a trainee in the consultancy department in Oracle Ibérica, I have an insight of all the products that the company uses to meet our clients' expectations. Nowadays, many of these products make use of Cloud computing and require networks that are quick, efficient and the least energy consuming possible. Further on in this document I will analyse the impact of 5G in Oracle and in the companies that are our clients.

For the last part of this document, there will be a project planning to examine the different phases involved in the project as well as to determine the critical tasks implicated in it. To have a clear view of the whole planning I will make use of a Gantt diagram, and I will include a budget for the project.

Finally a possible future work will be examined and the general conclusions that I will arrive to will be explained.

2. State of art

2.1 Introduction

After the success of the Wireless Local Access Networks (WLAN), and given the cellular network was present worldwide, the need of Internet connection everywhere began to arise. It was for this reason that cellular networks were extended to support not only voice telephony but also wireless Internet access everywhere at considerable rates and with a seamless mobility. The idea was for the user to be able to maintain a TCP (Transport Control Protocol) session in a bus or in the street. It was intended for the connection to support videoconferences and streaming sessions.

Before this happened, the First Generation of digital cellular telephony systems (1G) was born, providing users with a mobile telephony communication system that made possible a telephone conversation without wires. This technology was based on analog FDMA (Frequency Division Multiple Access) systems that were designed for voice-only communications.

After this considerable advance in communication systems, Second Generation digital systems (2G) shown in figure 4, replaced 1G, but were designed mainly for voice purposes and short message services. 2G are also known as Global System for Mobile Communications or GSM for short (originally came from Groupe Spécial Mobile). Therefore were later on extended by 2.5G systems that included data as well as voice services. 2.5G systems are still known as evolved GSM nowadays. 2G's architecture started to define what we have today and the next generations are based on it.

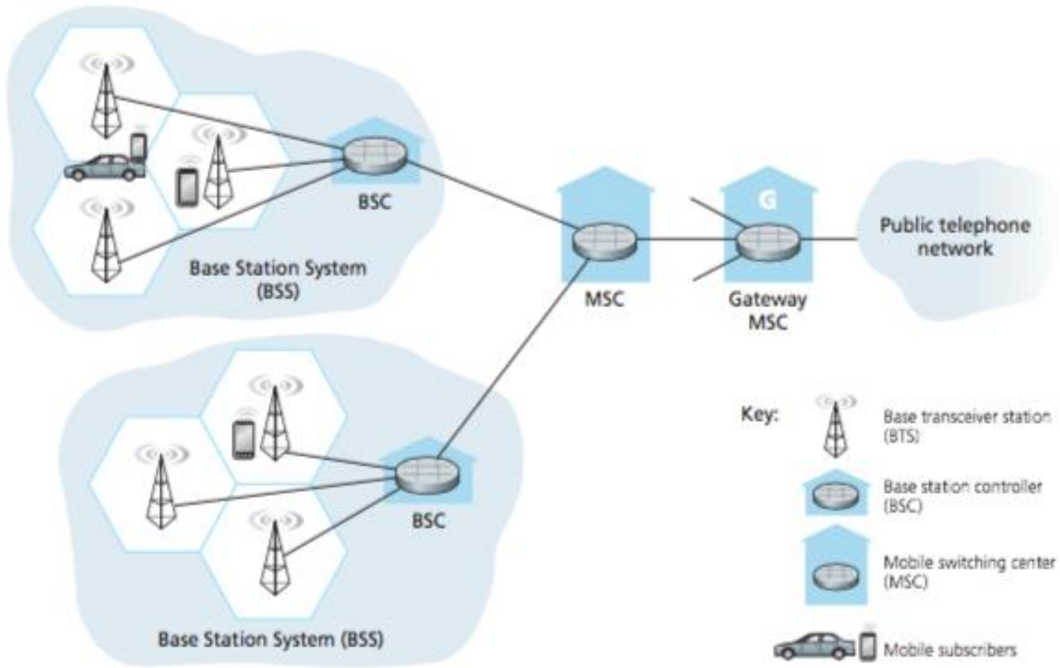

Figure 5. GSM 2G cellular network architecture [11].

Following 2G, the third generation of mobile communication systems (3G) was developed and, as well as supporting data and voice services, the idea was to increase data capabilities and include higher-speed radio access links. As 2G included already a great amount of services and a well-developed architecture, the approach taken by the 3G designers was clear “leave the existing core GSM cellular voice network untouched, adding additional cellular data functionality in parallel to the existing cellular voice network” [11]. If not, inserting new data services to the already deployed core network would have resulted in a challenge to integrate both services. The result of working on the already existing core network is shown in figure 6.

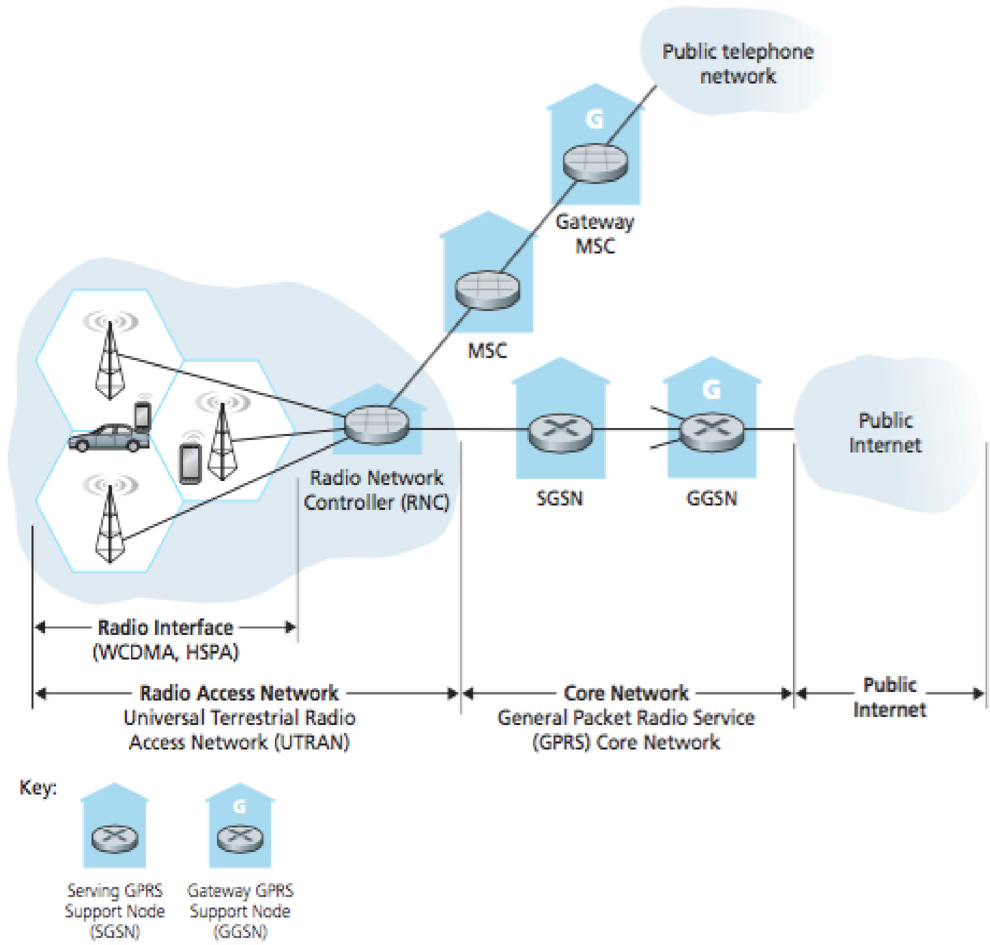

Figure 6. 3G system architecture [11].

New types of nodes had to be implemented in order to be able to integrate both technologies and to make a solid architecture. If we compare the previous architecture to the one we have in figure 5 we can see how 3G includes what is called by the name Serving GPRS Support Node. This node is used to make both technologies compatible and serves as a support in the new generation for the previous ones.

The next generation of mobile communication systems is what we use every day and is known as 4G or Long Term Evolution (LTE). By 2014 the deployment of 4G was as shown in figure 7, where the lighter blue means 4G is already deployed and in use in the country and dark blue means 4G is being negotiated. Later on in this chapter we will go through the most important aspects of LTE technology.

Figure 7. LTE deployment worldwide [12].

2.2 Current mobile networks

As introduced previously in this document, the technology that we currently use is the result of the evolution of older architectures with advancements and improvements to obtain higher and faster performance. Figure 8 is a timeline of the different generations of mobile communication systems.

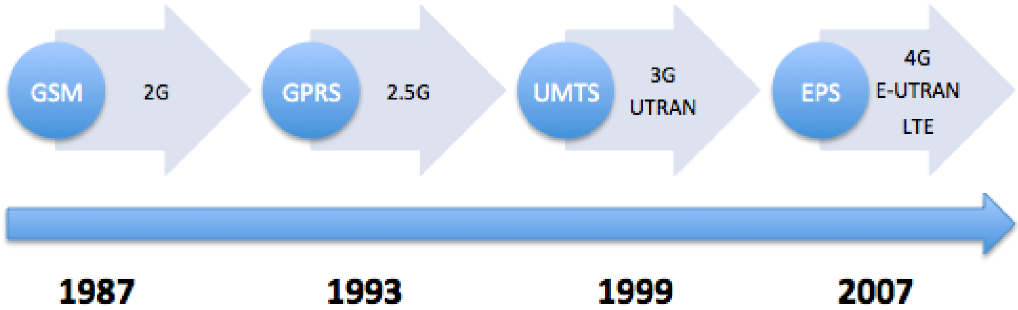

Figure 8. Mobile communication systems evolution timeline.

For this section, we will focus on the current generation that, as briefly mentioned in the previous section, is 4G LTE or Long Term Evolution. However it is not LTE as we have seen before but is already being developed as LTE-Advanced. This means it is constantly changing and new innovations and standards are being created to improve aspects such as latency, throughput, number of users in the network and so on. In this section I will go through LTE architecture and explain each aspect of it. It is important to point out how this generation is deployed because it will be the starting point for 5G technology.

Two main innovations that 4G includes and 3G does not are the Evolved Packet Core (EPC) and LTE Radio Access Network.

EPC is “an all-IP core network that unifies the separate circuit-switched cellular voice network and the packet-switched cellular data network” [11]. When a network is all-IP it means IP datagrams will be carrying both data and voice services.

An all-IP network provides a basic QoS (Quality of Service) to its users. Once the UE (User Equipment) is registered connected, it establishes a default carrier to maintain an IP connection constantly. This basic QoS has certain parameters that must be negotiated and maintained to be able to ensure the QoS to the client. Some of this required parameters are for example:

1. Allocation and retention priority where you give a carrier a certain priority over the rest of the carriers. This is a priority in terms of allocation of a service/bearer. For example if the node is highly loaded and the UE wants to set up a VoIP (Voice over IP) communication and another type of service at the same time, the node would typically set only VoIP session because it usually has the highest priority and in order to not get overloaded. If it is already overloaded the node could “kick off” other bearers to lower their priorities.
2. QoS Identifier identifies the values of priority, packet loss and packet delay. This mechanism is used in LTE networks to ensure bearer traffic is allocated appropriate Quality of Service. The different types of bearers are classified into different classes where each class has an appropriate QoS parameter for the traffic type. Examples of these QoS parameters include Guaranteed Bit Rate (GBR), non-Guaranteed Bit Rate (non-GBR), Priority Handling, Packet Delay Budget and Packet Error Loss rate. In general, this mechanism is called QCI (QoS Class Identifier). These parameters handle things such as maximum bit rates, or having a bit rate guaranteed for a service. It also includes parameters like Aggregated Maximum Bit Rate (AMBR) that consists on associating various IP flows to one same carrier [13].

Another interesting aspect of EPC is that it is compatible with 2G and 3G radio access networks therefore it is easier to integrate all technologies at the time of the change from one generation to another. However the fundamental task of this core network is to manage the resources in a way that it provides a high quality service. This is achieved by including mobility support features (like handoffs) implemented in the control plane and by separating the data plane from the control plane.

Another new feature that 4G has is LTE Radio Access Network which uses a combination of Time Division Multiplexing (TDM) and Frequency Division Multiplexing (FDM). This is used in the downstream channel and is called Orthogonal Frequency Division Multiplexing (OFDM). The allocation of the time slots in one or more channel frequencies enables mobile nodes to be able to obtain higher transmission rates and the slot reallocations in the mobile nodes can be done every millisecond. This results in much higher transmission rates. An advantage of LTE is that the scheduling algorithms determine the allocation of the time slots to the mobile nodes. If there is a matching between the physical layer protocols and the channel conditions, and a correct decision as to which receiver to send the packets, the radio network controller will make optimal use of the wireless medium. LTE can use priorities to provide scheduling for downstream packet transmissions. LTE-Advanced provides downstream bandwidths of hundreds of Mbps. Finally, another significant innovation for LTE is the use of Multiple Input Multiple Output (MIMO) antennas that provide a maximum data rate for a user of 100Mbps in the downstream direction and 50Mbps in the upstream direction and a 20MHz wireless spectrum.

It is clear how the constant need of communication and the advancements in both technology and lifestyles have led to the mobile communication networks that we have nowadays. This adaptation of the technologies is the result of years of evolution and investigation. 5G systems is therefore the next step towards the future way of communication and connection to the Internet and data services but also of linking all devices with one another and of introducing IoT among other services, to our day to day lives.

2.3 Technologies involved in 5G

2.3.1 LTE structure

The LTE architecture is very similar to the one we have for 3G. However it incorporates new nodes and functionalities that are used to, once again, improve the previous generation 3G networks and are key aspects to obtain high throughputs with QoS among other improvements. This architecture and its structure is shown in figure 9 and 10. After the figures we can also see a brief explanation of the most important elements in the architecture and their uses. To sum up, at the end of this section there is brief explanation as to how all these elements interact together.

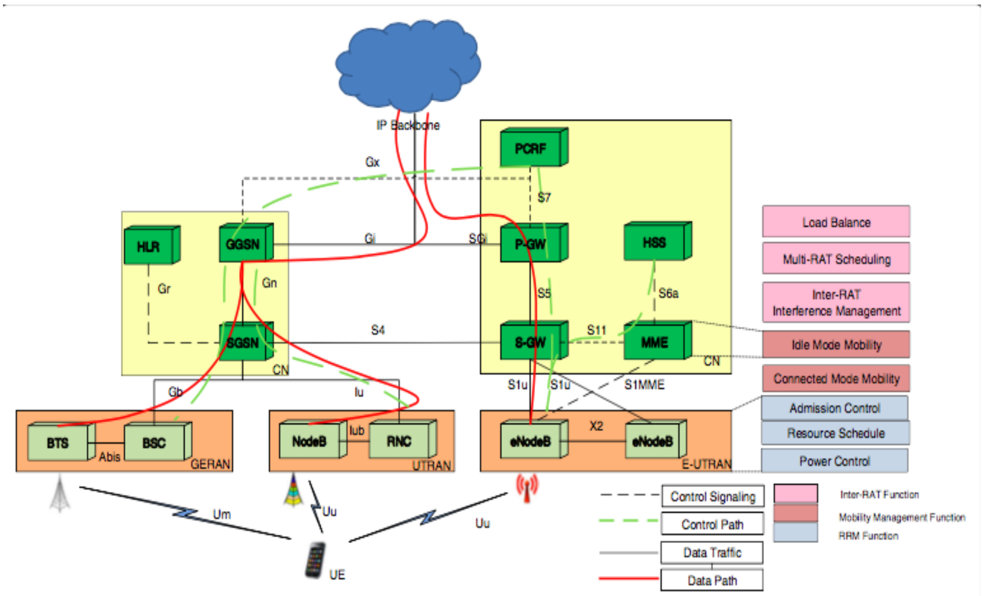

Figure 9. Current mobile network architecture (LTE) defined by the 3GPP [14].

This architecture is an adaptation of the previous one with the important difference that in this case, control plane and data plane are completely separated and handled by different nodes. Some important entities and their functions are:

1. UE: User Equipment is the mobile device, the Subscriber Identity Module (SIM)… it is what the client would use to establish a communication with another UE.
2. BTS: Base Transceiver Station that has the transceivers for a given geographical area.
3. BSC: Base Station Controller serves as a support node for the mobile switching centre (MSC), and controls the number of BTS present in the network.
4. MSC: Mobile Switching Centre controls the number of BSS covering a big area. This element is also present in previous architectures (2G and 3G). It does not appear in figure 9 but it is used in LTE.
5. HLR: Home Location Register is the main database for permanent subscriber information. Even though it is not shown in figure 9, there is also a VLR that corresponds to the Visitor Location Register and holds information for the users that are currently (note that they are not permanently in the network) in the location area.
6. GGSN: Gateway GPRS Support Node is an interface with external networks. It uses tunnelling to route external traffic to the appropriate network when the user is roaming.
7. SGSN: Serving GPRS Support node performs routing and tunnelling

as well as mobility management.

8. Node B: is the radio transmission and reception to/from the User Equipment (UE) in one or more cells. Note that later on when we see eNodeB it stands for evolved Node B and is used for the evolved architectures.
9. RNC: Radio Network Controller controls a set of Node B's and manages radio resources.

Next figure shows how in this architecture, the control plane and the data plane is already separated to perform different functionalities. The dotted line represents the control plane whereas the thick one represents the data plane.

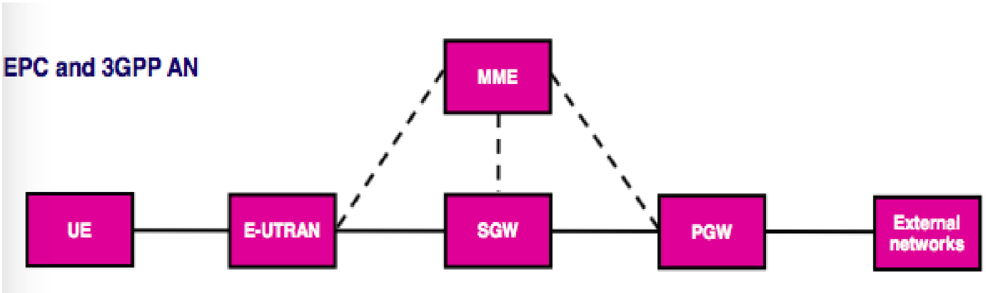

Figure 10. 4G architecture division of control plane and data plane [15] [16].

If we take a look at this division we can find specialised nodes for the different functionalities. Some of this nodes also appear in figure 9 as they are part of the LTE architecture. These are:

10. MME: Mobility Management Entity that is the main control-plane node in this architecture. It has the same control functions as the SGSN. A UE is always attached to a specific MME and the MME authenticates and authorises the UE.
11. S-GW: Serving Gateway is the user-plane gateway from the Access Network (AN) and the Core Network (CN) and is controlled by the MME. The UE is always associated to a specific S-GW.
12. P-GW: Packet Gateway is the data-plane gateway and is equivalent to the GGSN in the earlier architectures. It assigns an IP address to the UE and has an important role in mobility control.
13. HSS: Home Subscriber Server is a database that contains user and subscriber information. It helps in the mobility management and the setup and authentication among others.

For LTE networks, all these elements play an important role and interact together to obtain a quicker and more efficient technology. The packets that go from the UE to an eNodeB are data packets that are transferred through the Serving Gateway (S-GW). A tunnel is then established between the S-GW and the P-GW. It is thanks to the P-GW that the QoS policies are followed, as it is the one that enforces them. It also carries out the traffic monitoring to perform the policing. The P-GW is also in charge of connecting to the Internet and other cellular networks [14].

The Mobility Management Entity (MME) is in charge of the control plane functions and of handling functions such as session setup, reconfiguration and mobility managements. It does this with the help of the eNodeN, the S-GW and the P-GW [14].

Later on for the 5th generation of mobile communications' architecture, all this components will be somehow used and improved to support new functionalities and improve the already existing ones.

2.3.2 Basic structure in the fifth generation of mobile communication systems

Already on the Fourth Generation of mobile communication systems, the main organisms, engineers and developers of the future technologies saw how separating the data and control planes could result in a more efficient way of handling the resources and therefore offering higher efficiency services as a result. It was for this reason that the Fifth Generation is being designed bearing in mind that this two planes have to be separate. However this time, 5G will do this differently than in 4G. Here is where Software-Designed Networking (SDN) appears. SDN is basically considered as an alternative to the distributed approaches based on highly specialised hardware. SDN provides a way of configuring the data and control planes with software in a centralised way with the programming of interfaces and virtualisation technologies or what is known as Network Function Virtualisation (NFV). This future technology aims to have both the Radio Access Network RAN and Core Network CN enhanced with programmability. Nevertheless, there are still various lines of investigation still open as to how to implement 5G. A few of them are as follows.

One possible architecture that could be taken into consideration when deploying 5G is an architecture of SDN-based wireless access network or SDNRAN for short. This architecture aims to separate as much as it is possible the control plane from the data plane. This architecture is driven by the specific requirements as well as the evolution of air interface technologies that are arising near the deployment of the 5G technology. Figure 11 is an illustration of this possible architecture.

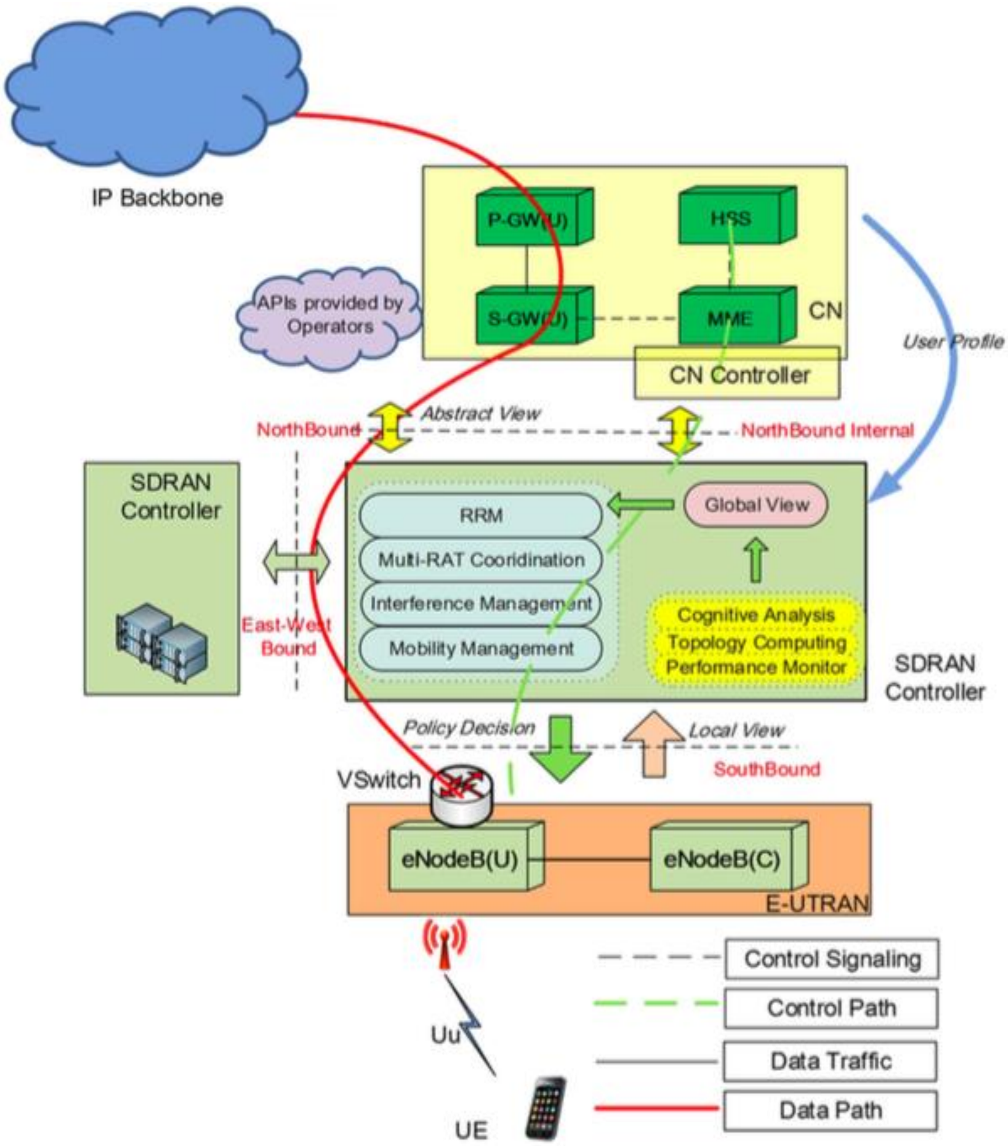

Figure 11 SDRAN architectures and the modules, interfaces [14].

We can identify a few significant aspects of this architecture [14]:

1. Separation of the control plane and the data plane (red full line and green dashed line correspondently) into the RAN side and the CN side. This separation is useful for the deployment and update of a new service, or to facilitate the realization of centralized controller but it can bring some issues that have to be taken into account. For example, scalability, reliability, security and consistency.
2. We also have two differentiated nodes, eNodeB(U) and eNodeB(C). eNodeB(U) implements radio transmissions with the configurations interpreted by eNode(C) taking into consideration the delivered

policy. eNode(C) reports things such as network status, network load and interference, back to the central controller.

3. The gateways are also identified as P-GW(U) and S-GW(U) and managed by the CN controller, and are also virtualised.
4. Centralized regional controller in RAN. The controllers in this architecture are also divided into RAN controller and CN controller as we can see in the image. The SDRAN controller gets the local view from the eNode(C) and with the collected local view and the subscriber profiles it creates a global resource and the network topology.
5. From the SDRAN, you can access three interfaces. An interface to external API (to dynamically change and share resources and policy). Another internal interface to the CN controller (information is exchanged between them to enable the cooperation and coordination of RAN and CN functions). Moreover there is also an interface to RAN entity (eNodeB) (it is used by the SDRAN controller to enforce, according to the requests from the virtual operators, the policies as well as for realising an effective virtualization of the access network and resource, among others). Finally there is also an interface to another SDRAN controller (it is used to provide policies exchange to adjacent SDRAN's).
6. Flow-like policy control that is achieved thanks to SDN is used to communicate across multiples technologies. The different flows can have different granularities of policies in order to have effective traffic isolation and QoS management.
7. As we can also see in the figure, this architecture has a VSwitch (Virtual Switch) that not only does it forward data packets, but it can intelligently direct communication on the network by inspecting packets before passing them on.

It is true that this architecture is similar to the ones in the previous generations, but it has various technologies that are more software oriented. It separates the data from the control plane and uses SDN to achieve this.

The next table shows different limitations that we currently have with 4G technology and how this specific architecture for 5G could help palliate them.

4G problem	5G SDNRAN solution
High Capital Expenditure (CAPEX)/Operating Expense (OPEX). The use of dedicated hardware to support different	There is a reduction of CAPEX/OPEX because there is an SDN based architecture that reduces the need of common network hardware and simplifies the technology needed and its

Radio Access Technologies (RAT) increase the capital needed for replacements, updates and support of the network hardware.	maintenance.
Low resource utilization efficiency. There is an inefficient resource allocation because the resource for each RAT cannot be integrated and virtualized. The performance in a distributed resource management is not optimal.	Simpler internetworking and interoperation by network virtualization, slice and isolation. In this case the physical network resources can be turned into virtual network resources to ease the low resource inefficiency. A centralized controller facilitates the coordination and cooperation of various RAT's. Virtual network isolation would alleviate the possible security risk.
Complex interworking and interoperation. If the network equipment has vendor specific configuration interfaces, being able to understand the functionalities and implementations of the interfaces is difficult. Interoperation between RAT's is inefficient and complicated.	Optimized resource utilization efficiency by global view and centralized control. An SDN-enabled centralized controller will have a global view of the resource allocation, interference distribution and resource usage. An SDN controller can make more efficient management of radio resources.

Table 2. Limitations of 4G and 5G solutions [14].

This architecture clearly has strong advantages and brings numerable improvements to the architecture we have nowadays. It is true the synchronization times for the RAN's has to be optimised, but in general it will allow us to manage resources in a more efficient way and revolutionise the mobile communications as we know them nowadays.

Another possibility would be to use NFV that is linked to SDN. NFV refers to the implementation of network functions but done by running them on software in general purpose computing platforms. In opposition to the traditional technologies that implement network functions in hardware, NFV wants to effectively reduce the innovation cycles or replacements that have to take place with hardware and substitute them with software updates. When combined SDN and NFV, SDN has control and configuration of the devices and network functions whereas NFV is in charge of the lifecycle of those functions. Advantages of this configuration includes less update costs form the operator's perspective and more support to the virtual operators. With the cooperation of NFV and SDRAN, Virtual Network Operators

(VNP) can lease virtual networks from Mobile Network Operators (MNO), resulting in more subscribers and revenues for the MNO's. For MNO's given the network can be isolated into slices the update or maintenance of a slide will not affect the rest of the slices. For Service Providers (SP), this solution allows them more flexibility control of the infrastructure without having to invest vastly and therefore provide better services to their customers [14].

2.4 State of the standardisation

The current situation regarding our mobile communication systems is directly related to LTE-Advanced (Long Term Evolution Advanced) that is the evolution of what used to be our 4G telecommunications system. But, what is LTE-Advanced and what does it include?

LTE-Advanced is an evolution of the already existing LTE technology. It is however focused on achieving higher capacity in a cost efficient way as well as supporting more users connected to the network at the same time. According to the 3GPP specifications, "the main new functionalities introduced in LTE-Advanced are Carrier Aggregation (CA), enhanced use of multi-antenna techniques and support for Relay Nodes (RN)" [17]. It is also important to take into consideration other requirements that LTE-Advanced has to include, for example spectrum flexibility which looks for support for flexible deployment scenarios depending on a region/country or the compatibility of LTE-Advanced with LTE Release 8 (previous LTE generation). Therefore if we take a look at this three main innovations that LTE-Advanced incorporates we can understand the need of a fifth generation technology of mobile communication systems.

In order to be able to increase the capacity (carrier aggregation) the most straightforward way would be adding more bandwidth. However, it is important to remember that Release 10 (LTE-Advanced) has to be compatible with Release 8 (LTE) and therefore the increase in bandwidth is provided through aggregation of R8/R9 carriers which are used for both FDD (Frequency Division Duplex, that uses two channels, one for transmitting and the other for receiving) and TDD (Time Division Duplex, that uses one frequency but allocates different time slots for transmission and reception), which are schemes used in radio communication systems, to be able to communicate in both directions.

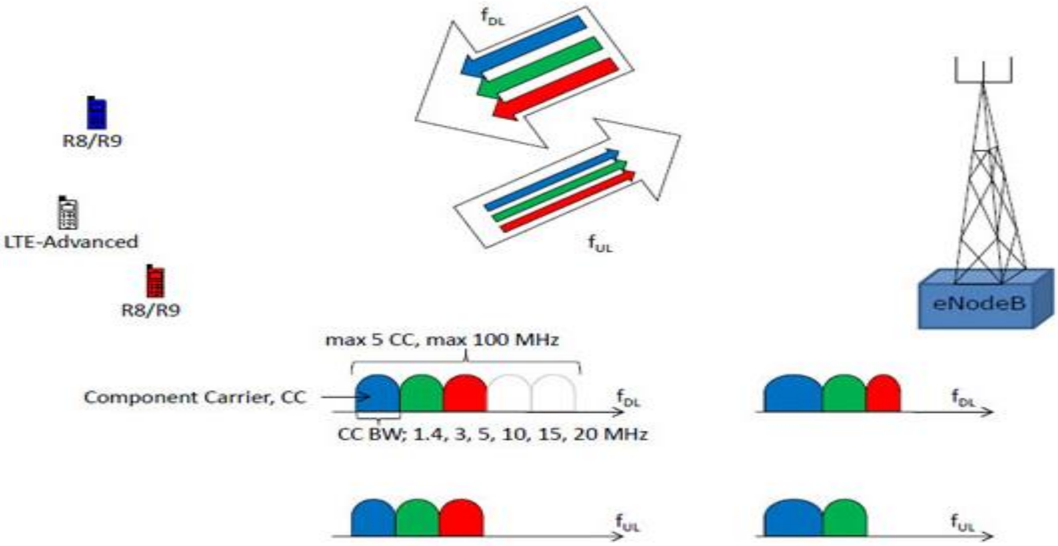

Figure 12. Carrier aggregation for LTE-Advanced [17].

Figure 12 is a **carrier aggregation** schema. There is a device that supports both R8 and R9 as well as a device specifically created for LTE-Advanced. A component carrier can have a determined bandwidth as shown in the figure, and a maximum of five component carriers can be aggregated, having therefore a maximum bandwidth of 100MHz. There is a differentiation between uplink (UL) and downlink (DL) as we can notice in the figure. The next releases include different carrier aggregation configurations that have been developed for practical reasons and are explained on each release document.

The idea here is to arrange aggregation using contiguous carriers within the same operating frequency band (intra-band contiguous) however due to frequency allocation scenarios, this aggregation cannot always be performed. The alternatives are having non-contiguous aggregation or non-contiguous and mixing different frequency bands.

The key point of carrier aggregation is that there are a number of serving cells one for each component carrier. There is a primary serving cell that is in charge of the connection. The other component carriers are secondary component carriers and serve the secondary serving cells. With this idea, you can include more users in a network at the same time and therefore support more connections.

Furthermore the use of **multiple input multiple output** (MIMO) or spatial multiplexing enhances an increase in the overall bitrate through the transmission of two or more different data streams with the use of two or more different antennas but using the same resources in frequency and time. LTE-Advanced makes use of

8x8 MIMO antennas in the downlink and 4x4 MIMO antennas in the uplink.

With multi-antenna techniques, there is a pre-coding used to map the modulation symbols onto the different antennas. This is done in order to achieve the best possible data reception at the receiver and therefore to achieve higher capacities. In different releases, new functionalities have been included to improve things such as regeneration of the information sent, or the coding used.

Relay Nodes are low power base stations that provide coverage and capacity in the edge cells. They are also used to connect remote areas without fiber connection and as a hot-spot area. A relay node (RN) is connected to the donor eNodeB (DeNB radio access node), and the resources are shared between the User Equipment (UE) and are directly provided by the DeNB and the RN. These relay nodes relax the network and provide access to more users.

3. Deployment

As we can see in the previous section, the current technology already leads us to 5G as new requirements rise. LTE-Advanced and its new incorporations are a key point for the further development of the next generation of mobile communication systems that will be deployed in 2020. Further on in this chapter we will analyse the main ideas of the most important service providers of the world and see what will be their future and current job regarding the deployment of 5G. Moreover, we will go through the various drivers/barriers that come along with the development of 5G.

3.1 Road map to 5G

But what do all the advancements in the previous chapter have to do with 5G? Well, as we have seen on previous technologies, each future generation is based on the previous one. Therefore it is easy to predict that 5G mobile communication systems will include these functionalities and will continue to develop new ones. LTE-Advanced is part of the roadmap for 5G as it is already deployed.

Next figure shows a detailed timeline for the IMT-2020 in ITU-R. In it we can see what functionalities and specifications are already existing and what are the future plans for the development of 5G.

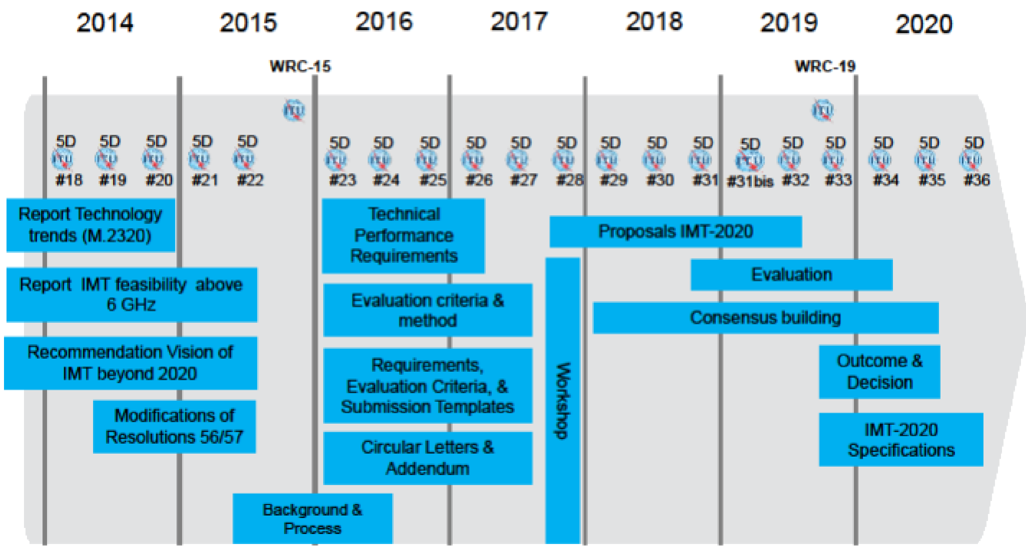

Figure 13. Timeline for IMT-2020 in ITU-R [18].

But what do all the provider companies have to say about 5G?
In Spain, leading company Telefónica has clear expectations for 5G systems. As pointed out in 2016 [19], Telefónica's point of view focuses on three main objectives that are spectral efficiency, support of billions of devices and the reduction of the latency throughout the incorporation to LTE of new technologies

and developments that support these objectives. It also points out the need of the use of high frequency bands but they are conscious of the big technical challenge that this represents. After various studies, they concluded that there should be support of the requirements that come from different 5G use cases and a support of network slicing to introduce new services. It seems clear that 5G will also incorporate NFV and SDN to meet the requirements posed. In terms of regulation, Telefónica states that an adequate regulation is mandatory in order to foster investment; the candidate bands that have been proposed for discussion at WRC-19 have to be sufficient to meet the broad range of requirements for 5G use cases and scenarios. The general idea of Telefónica is that the standards and the regulation developed for 5G should not be rushed as the functionalities that 5G includes are a huge opportunity for telecommunications worldwide. Committees and provider companies as well as the 3GPP and ITU should consider wisely the best ways of developing this technology instead of searching for a quick deployment and commercialisation.

Another big company involved in the deployment of 5G is Vodafone. Currently, Vodafone is working with Ericsson and Qualcomm Technologies to test 5G with a "over-the-air trial based on 5G New Radio specifications of the 3GPP". With this trial, the idea is to validate 5G NR technologies to enable operators to test 3GPP standards created for 5G and the infrastructure and devices. This trial is taking place in the United Kingdom and plans to test the technologies that use wide bandwidths in order to increase network capacity and achieve multi-gigabit per second data rates. The executive vice president and chief technology officer Matt Grob of Qualcomm Technologies Inc. says "The work between Qualcomm, Ericsson and Vodafone is just another example of how collaboration on impactful 5G NR trials between global industry leaders is pertinent to not only drive the technology forward, but to ensure timely commercial deployments of 5G technologies based on the 3GPP specification" [20]. With this we can understand the importance of teamwork and agreements between the companies, designers, providers and other parties in order to accelerate the deployment and manage to create an efficient technology. On the other hand, Matt Beal the director of technology, architecture and strategy of Vodafone says, "The demonstration of the 5G standard in sub-6GHz bands is an important step forward in the development of 5G. Standardization of this technology will help deliver high performing reliable 5G mobile networks with global coverage. A common standard also promises to deliver the economies of scale, which will help drive adoption of the technology in consumer devices and Internet of Things" [20].

On the other hand, in the United States, different provider companies are trying to lead the deployment of 5G in order to win over their competitors. Companies such as T-Mobile are looking for a quick deployment in all the States and aspects of 5G such as less consuming networks or lower congestion in the network, whereas Verizon or AT&T are focusing on providing coverage in congested areas to ensure high transmission and reception rates, rather than a medium rate in all the possible areas of US [21].

Further updates from AT&T show that for the past year this company has tested 5G technologies at 4GHz, 15GHz and 28GHz in their labs in the United States. As many other companies worldwide, their main tests are being done focusing on fixed wireless that is providing over the air broadband Internet service between two stationary points. The company has already used high-frequency millimetre waves to provide super-fast Internet services. The next step is to expand the fixed wireless trials to serve pilot customers [22].

And what about Asia? Back in South Korea, leading company SK Telecom will start testing this new technology in the second half of 2017 and will work with the 3GPP 5G NR (New Radio) specification in order to be part of the Release 15 (release for 5G). 5G New Radio (NR) is the wireless standard that will become the base for the fifth generation of mobile communication networks. It is expected to rely on millimetre-wave spectrum bands as well as those below 6GHz. The idea of SK Telecom is to help accelerate the development of devices and infrastructure with their tests, and speedup the emerging 5G NR standard. However, even though SK Telecom is the leading company in South Korea, KT Corporation is right behind and has said it will launch 5G services for the upcoming winter Olympics that will be celebrated in South Korea, and has been named the official telecom sponsor of the games [23].

It is clear how 5G is a subject constantly discussed these days not only by engineers and developers of these technologies but also by companies of all sorts all over the globe. The 3GPP works on new releases each day in order to improve and include new functionalities to the current network. Figure 14 shows a timeline for the releases for 5G in the next three years. It is planned that by 2020 5G will be available and working in the entire world.

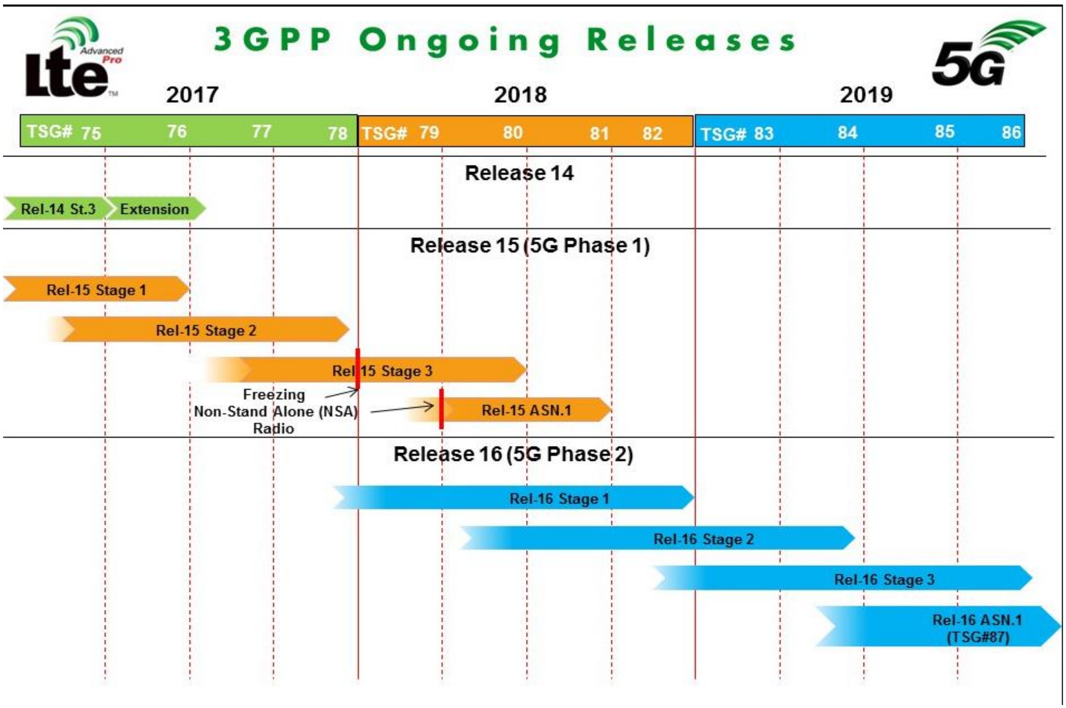

Figure 14. 3GPP timeline for releases [23].

3.2 Barriers

The fifth generation of mobile communication systems seems like a desirable network to develop given de requirements and needs of the current users. The world is evolving and it demands its networks to evolve with it. It is for this reason that at first, it may seem we can only find drivers for the deployment of 5G. However, what we ask of the fifth generation of telecommunication systems is not easy to achieve and it involves a great amount of work, requirements, companies, and an overall coordination and cooperation of every member involved in anything that has to do with a piece of this bug puzzle.

It is for this reason that we can find many barriers to this deployment, some of them include:

1. The difficulties to create a network that meets the demands of every specific customer. That is, to create a network at the service of each subscriber and to know what type of experience the subscriber demands and it's getting and what services they have available. This network has to be prepared for any possible fault and be able to react and fix it. In order to create something like this there has to be a lot of time involved and a large group of engineers to develop it [24].
2. In the current networks, EPC's (Evolved Packet Cores) are a bottleneck as they have to process a lot of information and perform multiple tasks such as mobility management, detection of security threats, determine subscriber policies etc. 5G has the challenge of changing this by having the network

nodes, base stations and air interfaces talking directly to each other without going via the EPC. This will be done by creating a mesh with full connectivity and will lead to the network decentralisation that will result in better services and performance. However, the barrier here is the difficulty to change form the existing architecture that has EPC as a pillar to the idea for 5G [24].

3. If we consider what 5G plans to do with the LTE-Advanced current architecture, we can see that the idea is to go from a hardware based architecture to a software based one. This, as mentioned in previous sections, will be done through SDN (Software Designed Networking) and NFV (Network Function Virtualisation). The full deployment of SDN and NFV already has its own barriers and is yet too young. In order to be able to have a consistent 5G technology, every solution involved in it has to be fully developed and tested [25].
4. Some of the user cases for 5G involve critical applications and remote services. For instance, driverless cars cannot allow themselves to be connected to a network with latency issues. This also happens with remote surgery. It is for this reason, that 5G networks that will provide connectivity to these type of services, need to ensure visibility form gateway to cell tower to be able to rapidly detect and pinpoint issues to their origin. This is increasingly complex to manage and optimize with 5G and even though it has been predicted it will be feasible, there is still a long way to go before it is achieved and poses some problems in the moment of the deployment [24].
5. As mentioned before, in the current existing network, the traffic is routed via EPC. This is important because routing the traffic this way enables the operators to interconnect efficiently with other operators and obtain control over content and services provided. Throughout the EPC, operators can check if subscribers operate within the established policies, the security threats are minimised and QoE (Quality of Experience) is maximised. Therefore even though routing the traffic through the EPC brings its benefits, for now on it is implemented on hardware and it cannot be distributed through the network. Then the challenge will be achieving considerable QoS (Quality of Service) and QoE in a virtualised mobile network like the one 5G is predicted will be, without inducing security, network performance and latency issues [24].
6. Another barrier for the deployment of this new generation is the security issues that arise when virtualising a network. It is important to maintain the strong safe network and at the same time to be able to turn it into a software based one but without inducing new security problems.
7. This new generation of mobile communications will make use of higher and more frequencies in the frequency band. In terms of regulation, it is challenging to restructure the band and allocate each service to a specific frequency. There has to be a consensus between the regulatory bodies and

the companies and providers.

8. When making use of higher bands, and to facilitate 5G deployment, the need of more cells will increase and specifically for higher frequencies. It is for this reason that all these cells have to be connected to one another and therefore the need of more backhaul to connect everything arises. In some given areas, the supply of these backhauls is still limited and therefore it will lead to higher costs for the wireless networks, higher prices for consumers and difficulties in the whole deployment of 5G [26].
9. Another challenging aspect when thinking about the deployment of 5G is the specifications that have to be agreed upon in order to efficiently coordinate the different bodies and commissions that work on these aspects. It is important to have coordination because if companies, providers, commissions and other parties do not agree, the deployment could be delayed, resulting in more costs as the personnel involved in the deployment has to continue working.

Being able to identify these barriers and many others is a key point in order to successfully analyse the needs, the requirements, the specifications and overall the equipment needed for the deployment of 5G. It is for this reason that analysing barriers before deploying is fundamental in order to avoid making mistakes that could lead to higher costs and less efficient networks.

3.3 Drivers

Many are the drivers that have led us to the design and the decision of implementing and deploying a new and more efficient network. These drivers are in fact a key point for the evolution of the networks and make the difference in many of the decisions taken at the moment of creating new technologies. These drivers are, among others:

1. 5G will enable users with a continuous connectivity experience regardless of the situation. Currently, users are always connected independent of the challenging environment where they may be. For example, users nowadays demand a connexion that can be maintained in a moving train or bus, or for instance want to share videos or live sessions of a football match. What happens in these kinds of environments is that it is difficult to ensure seamless mobility with 4G networks. Also, highly condensed environments congest the network and it cannot cope with the number of users in it using high consuming apps. 5G networks will solve these types of problems and given that if we take a close look at the future trends, they will continue to grow. It is for this reason that the demanding needs of customers are a key driver to the deployment of this new technology [27].
2. Moreover, every day the concept of Internet of Things (IoT) comes to everyone’s mind. IoT is becoming part of a near future and we can already see this in things like wearables, home devices, sensors, automobiles and so

on. The need for electric devices connected to one another in order to make human's life easier is growing at an alarming rate. Nonetheless the urge of staying always connected to social media and messaging services is higher every day. 5G will provide a platform that will connect a massive number of sensors that will make these IoT predictions possible. Not only will it connect devices to devices, but it will do so in an efficient, less battery consuming way and with security and QoS/QoE incorporated [27].

3. Another driver for the development of this technology includes the remote, mission critical services that require very high reliability, low latency and global coverage. Specific networks are currently handling these types of services that include for example remote surgery, driverless cars or automated factories. The idea with 5G is to become the native infrastructure that will provide connectivity among other functionalities (e.g. security, QoS…), to these services [27].
4. 5G's idea is to integrate networking by creating a unified programmable infrastructure composed by computing and storage resources. By creating this unified infrastructure, there will be a more optimized dynamic and efficient usage of the resources that will be now distributed. Also, the fixed, mobile and broadcast services will converge and there will be an easier management of them. All these things will result in better use of the resources, saving on energy and overall on money which results in better revenues [27].
5. In addition, 5G will boost the markets as it is based on cloud computing. It will push forward the digital market creating new ways of developing business innovations and services. The creation of start-ups in the telecommunications sector will increase, as more support for the maintenance of cloud services will be needed it will also have an effect on the number of available jobs that will increase, generating an overall increase of quality of life.
6. Moreover, nowadays we need to be using networks that ensure saving energy on our devices. This is quite a difficult task to perform and 5G will help doing it. The idea is to be active only when and where needed in order to save energy as much as possible. It also looks for transmitting only when needed and to minimise the transmissions in order to save up energy. The ideas of turning off base stations when there is less congestion is also in the air but it proves to be a difficult decision given the need of "always connected" high number of customers in a network [28].
7. Finally, another important driver of the development of 5G is the spectrum reorganization. It is a good way of organizing the spectrum in order to provide the new technologies with a frequency band and optimize their services. It is good to reorganize the band if we take into consideration possible technologies to be developed.

Even though we may find some barriers for the deployment of 5G, it seems clear the need of a new evolution of the current technology. There are many reasons to continue investigating on new ways of granting users the needs on connectivity, low latency, less energy consuming devices and so on that are constantly arising.

3.4 Proposal to accelerate drivers and slow down barriers

The next two tables indicate the drivers and barriers and a proposal to accelerate or slow down correspondingly each of them.

Driver	Proposal
Demanding needs of customers	Continue to study the customers' needs in order to be able to give the best services possible at the moment of the deployment. A good analysis of the requirements will help future work. Also, an analysis of the frequency band is important in order to be able to assign the frequencies effectively to maximize its use.
IoT	Investigate what is needed for IoT in terms of equipment and networks and purchase the tools needed to accelerate the incorporation of IoT in the near future. When there is a need of so many tools and new technologies, it is also important to study the need of the new specifications to create and put together all these technologies and tools.
Mission critical services	As with IoT it will be essential to describe the equipment needed (plus the standards and the specifications) for these types of services so that when the deployment is done the performance of these services is optimal.
Integration of networks	Start with the deployments as well as create new standards and specifications to deploy the new networks.
Market advancements	Develop new applications that will help boost the markets and that will make the need of 5G grow.
Energy saving	Come up with new less consuming devices and applications that run efficiently and that will be used in 5G.

Table 3. Drivers and proposals.

In general, a good way of accelerating the drivers is to clearly know what is needed of each driver in order to be prepared for the deployment and have a quick integration and development of the services.

Barrier	Proposal
Specific network for every customer	Even though each customer has different needs, it is possible to group up the similar users and create dedicated networks for each type of group or what's known in 5G as slices. With specific groups specialised on every aspect of 5G (in this case slicing), this process can be done more easily.
Difficulty of changing the current network	It is important to start changing different things of the current network already. More than a drastic and instant change it is important to make the change gradually to avoid errors and to have a better service. This can be done by creating new standardization groups specifically dedicated to 5G that focuses on network slicing, in order to adapt the current network performances.
Difficulties in deployment of SDN and NFV	Even though the deployment of these two technologies may seem challenging it is true that a big deal of investigation and development has already been done and there are many standards and regulation that has already been created. The different parties and companies have to work together to evolve together.
Good visibility form gateway to cell tower	A way of making this barrier easier to be reduced would be to analyse how the network has to be built and to take into consideration the current regulation about these technologies in order achieve this requirement.
QoS and QoE	Analyse the services and the quality that has to be granted to the clients in order to implement the QoS and QoE

	demanded. It is true that there are already many protocols created for QoS and EoS so to slow down this barrier, developers could take a look at what has been already created and adapt it to what has to be done.
Security issues	Security is always a difficult aspect to control. It is important to analyse how the new technology brings up more security issues in order to palliate them and to continue with the 5G deployment.
Band restructuring	A lot of work has already been done with the restructuring of the band and so therefore even though there is still a lot to go this barrier can be controlled like it has been done before. Already it has been talked of a new Digital Dividend to restructure again the band. It would help to analyse the frequency needs for 5G thoroughly and look for a new reorganization if needed.
Limitations of backhauls	In order to be able to build more backhaul it is important to have an economic boost with investments to facilitate these deployments. With more income destined to this, it would be moderately easier to face this barrier.

Table 4. Barriers and proposals.

3.5 Possible deployments

We can identify various possible 5G deployment options and the basic characteristics of the technologies used for them.

Given the way the networks evolve, it would be obvious to think that our next generation of mobile communication systems will be an evolution of the already improved LTE network, or what we know as LTE-Advanced. LTE-Advanced is today's option for providing mobile broadband for macro and small cells. However, in order to meet the 5G requirements for capacity and data rates, new and more advanced 5G systems are needed. For its deployment, 5G will use the full spectrum range, from below 1GHz to 100GHz and by using it, it will be able to provide coverage and high capacity in dense areas. Spectrum bands below 6GHz are already being used but there will be an increasing need to unlock the spectrum bands from 6 to 100GHz for mobile use. Based on the different radio propagations and possible carrier bandwidth, we can split the spectrum range from 6 to 100GHz into two parts, the centimetre wave (cmWave), and the millimetre wave (mmWave).

For the cmWave, we would be talking of bandwidths of 500MHz and massive MIMO antennas. cmWave uses a large number of parallel transmit streams with Single User MIMO antennas (SU-MIMO) and Multi User MIMO antennas (MU-MIMO). It is deployed at 10 and 28GHz and has a bandwidth of 500MHz. A disadvantage of the deployment at different frequency ranges is the penetration loss. In frequencies lower than 6GHz, the main penetration loss is outdoor-to-indoor propagation loss but in higher frequencies like cmWave, the user's own body can cause strong shadowing for the signal and completely block the communication link. This is an important aspect to consider in the deployment of 5G and various experiments have to be conducted in order to analyse the possible uses of cmWave. Further on in this document I will analyse the deployment requirements for 5G and take a close look at the wave propagation, reflection, diffraction and scattering for each individual ray.

On the other hand, the mmWave has a bandwidth of 2GHz and uses a large number of antennas both SU-MIMO and MU-MIMO to create narrow beams and in order to mitigate the path loss caused when interfering with objects and users. It is deployed at 28, 39 and 73GHz frequency band. However, mmWave has the same problem than cmWave. It has difficulties penetrating objects and users and even though there is a solution to this problem, it is important to take it into consideration when using it as a candidate for deploying 5G.

The next table shows a brief summary of the basic features of each technology that have to be taken into consideration when using them for the deployment of the next generation of mobile communication systems.

Parameter	**LTE-Advanced**	**cmWave**	**mmWave**
Frequency band	<= 6GHz	6-30 GHz	30-100 GHz
Carrier bandwidth	100 & 200 MHz	500MHz	2GHz
Modulation order	64 QAM	256 QAM	64 QAM
MIMO combination	8x8	8x8	2x2
SU-MIMO rank	8	8	2
MU-MIMO rank	2	2	2

Table 5. Assumptions used for three different systems for 5G deployment [29].

As we can see this three systems vary considerably in the frequency bands they use and the carrier bandwidth that they have. Their modulation uses QAM (Quadrature

Amplitude Modulation) that is both an analog and digital modulation scheme and is used in these types of systems because high spectral efficiencies can be achieved with them. All these systems use MIMO antennas as we have been predicting all along.
If we take a look at the analysis for the possible deployments done by Nokia [29], we can outline three different scenarios in order to determine the importance of the propagation and absorption of the rays for each system mentioned previously.

1. An indoor deployment case study like an office or a shopping mall.
2. A simple case study performed in an urban outdoor environment like for example a small subset or a city centre.
3. An urban realistic case study performed outside like for example in a city like Tokyo. It has an LTE-Advanced macro layer representing an aggregated spectrum of 100MHz at 2GHz and below, a small cell layer of cmWave deployed at 10GHz with 500MHz bandwidth and a co-located small cell layer of mmWave at 73GHz with 2GHz bandwidth.

For the first scenario, and after having conducted the experiments for the two next scenarios, the conclusions were that the outdoor cells couldn't provide the needed capacity indoors. The conclusion was that a dedicated indoor deployment was required with the integration of WiFi and cellular technologies or with technologies like LTE-U in the unlicensed spectrum. LTE-U allows cell phone carriers to boost coverage in their cellular networks by using the unlicensed 5GHz band that has been already populated by WiFi devices.

For the second scenario, the tests carried out could lead us to the next conclusions:

- LTE-Advanced can provide tens of Gb/s/km2.
- cmWave can provide hundreds of Gb/s/km2.
- mmWave can provide several Tb/s/km2.
- cmWave has a stable performance over the various frequencies used, whereas mmWave provides more capacity with certain deviation of the considered bands. The reason for this is the additional bandwidth that mmWave has and the sectorized antennas used in the access points of these types of systems.
- Macro cells will be deployed for coverage purposes and 5G smaller cells will be used for capacity needs.

In this scenario, the idea is to create a HetNet. A HetNet is basically a network that uses multiple types of access nodes. That is, different types of cells (micro cells, macro cells etc.). The idea with this scenario is, as mentioned in the previous point, to use macro cells and smaller cells for different purposes. However, doing so brings the need of a load balancing technique for optimizing the network capacity and therefore the users experience. The balance is done by measuring the estimated available throughput per link and afterwards doing an estimate of the link capacity, as well as the potential number of other served users per cell based on the system type and the cell size. With these two measurements, the user can then decide which cell will offer higher throughput and then connect to the selected cell.

Another possible way of increasing the cell edge performance in this scenario would be adding dual connectivity of cmWave and mmWave in the user devices.

For scenario three, the study performed by Nokia [29] lead us to the next conclusions:

- The first conclusions that could be extracted of this test and with this scenario pointed out that full coverage with full spectrum range was not possible, given the antenna configurations and for the real city characteristics and area measurements.
- It was considered that the ideal representation of scenario two wasn't realistic enough for this scenario. And for this reason all the small cells were deployed differently with cmWave and mmWave access points co-located to provide full outdoor coverage.

Next figure shows the possible 5G deployment for Tokyo.

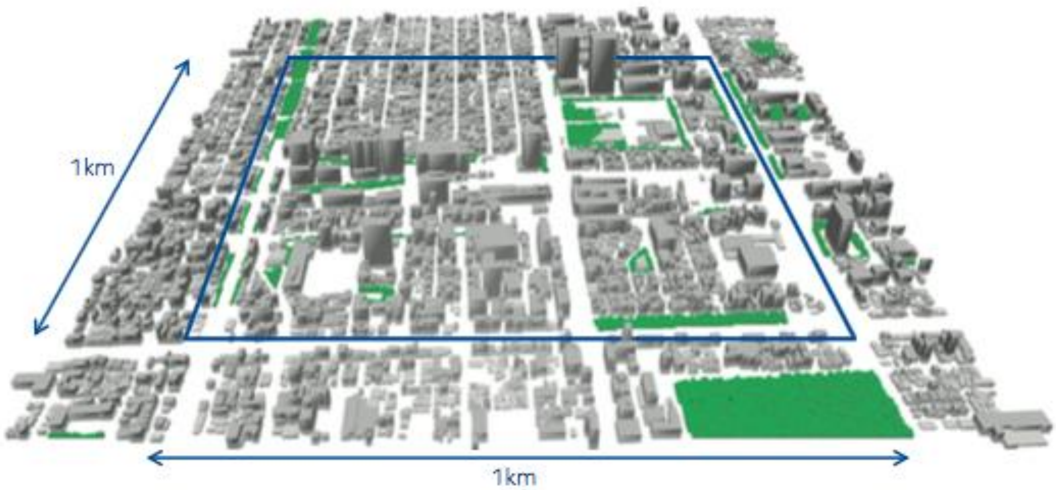

Figure 15. Possible 5G deployment in Tokyo [29].

For figure 15. LTE-Advanced provides 100% coverage, cmWave provides 97% coverage and mmWave 68% outdoor coverage.

Figure 16 shows the coverage and throughput maps of Tokyo 5G deployment.

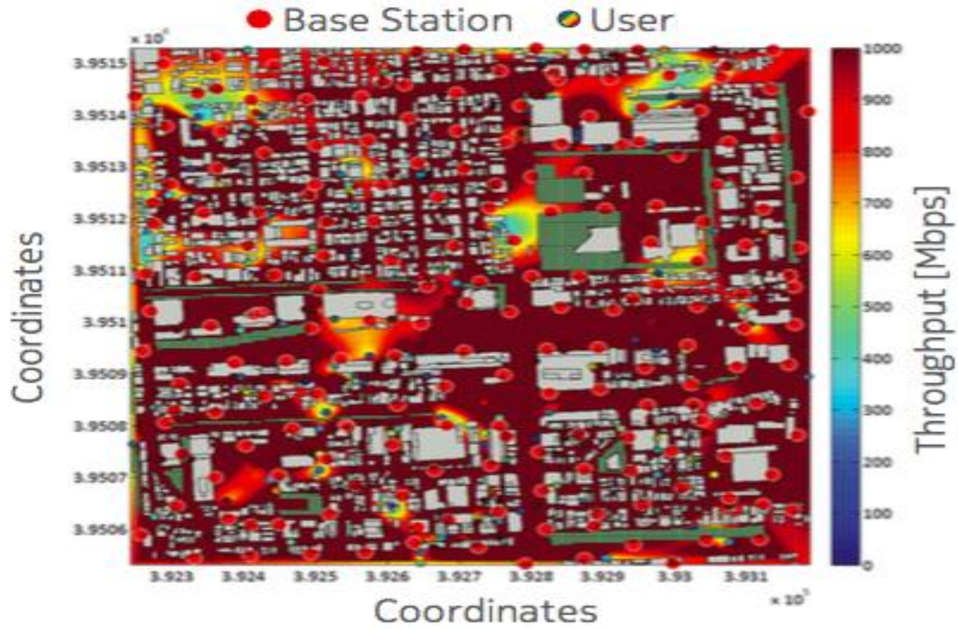

Figure 16. Coverage and throughput map of Tokyo 5G deployment [29].

4. Socio-economic evaluation

In order to accurately analyse the economic impact that 5G will have in society, and according to Economic Impact Analysis of IHS Economics and IHS Technology [30], “two main drivers of impact would come through the investments made in 5G: technology and the productivity improvements enabled by the technology”. In order to analyse 5G’s macro and microeconomic impact, it is important to determine how much economic activity is generated by the 5G value chain, what will be the impact of the use of 5G technology in all other industries and what will be the overall growth of the global economy thanks to 5G technology.
Aspects such as the spectrum and policies and regulatory aspects in 5G can also give us some insight of the impact it will have in society and in our economies. Later on in this section all these characteristics will be analysed.

4.1 5G value chain

Using an input output analysis model, we can come to the conclusion that 5G will require on-going investments by the firms in the 5G value chain. These firms will be of different types for example network operators, infrastructure equipment manufacturers, content and application developers and so on. Moreover, a general development will take place in numerous areas like for example:

1. Standard development, which is predictably necessary given the new use cases for 5G. The development of new air interface and next-generation network architecture will come with a new global 5G standard. This standard will include a number of technical issues and some of them include scalable frequency-division multiplexing based waveforms, a new flexible framework for lower latency and forward capability and new antenna techniques to make use of higher spectrum bands.
2. Utilisation of both licensed and unlicensed spectrum as well as shared spectrum. This will enable a more efficient use of the existing spectrum resources including the high frequency bands, the mid-bands and sub-bands.
3. New network deployments. Given all the use cases predicted for 5G, provider companies will continue to invest on new deployments in order to be able to cope with the requirements for what users and companies are demanding. These investments will most likely provide revenue, as the prediction is that 5G networks will be sufficiently successful.

5G value chain is estimated can generate up to 22 million jobs, according to Qualcomm CEO, Steve Mollenkopf. 5G will support a wide range of industries and experts come to the conclusion that this new technology is much more than only a technology [31].

4.2 5G economic contribution

5G will contribute to the growth in sales through an increased efficiency, and trough the enablement of the creation of new business models. The economic impact will affect the potential global sales activity across multiple industry sectors. It will virtually affect positively every industry sector and the potential global sales activity estimated across these industry sectors enabled by 5G could reach $12.3 trillion in 2035. Sectors like manufacturing will see the largest share of economic activity, almost $3.4 trillion or 28% of the total. This is because the implementation of any of the 5G use cases will stimulate the spending on equipment that is produced by the manufacturing sector. Following this sector, the information and communications sector will also have a share of these benefits achieving a high economic activity that will lead to $1.4 trillion. Next table summarizes the economic output for the different sectors.

Industry	Economic output in million $
Ag. Forestry and fishing	510
Arts and entertainment	65
Construction	742
Education	277
Financial and insurance	676
Health and social work	119
Hospitality	562
Information and communication	1421
Manufacturing	3354
Mining and quarrying	249
Professional services	623
Public service	1066
Real estate activities	400
Transport and storage	659
Utilities	273
Wholesale and retail	1295

Table 6. Predicted economic output for the different sectors thanks to 5G [30].

4.3 Economic growth

The sales enablement and the value chain activity resulting from the deployment, development and commercialisation of 5G will be large and positive and we can therefore consider 5G a source of global expansion and growth.

The initial investments done by the 5G value chain and the use case productivity improvements were used to analyse the global economic growth thanks to 5G. The general annual net contribution of 5G is shown in the next graph.

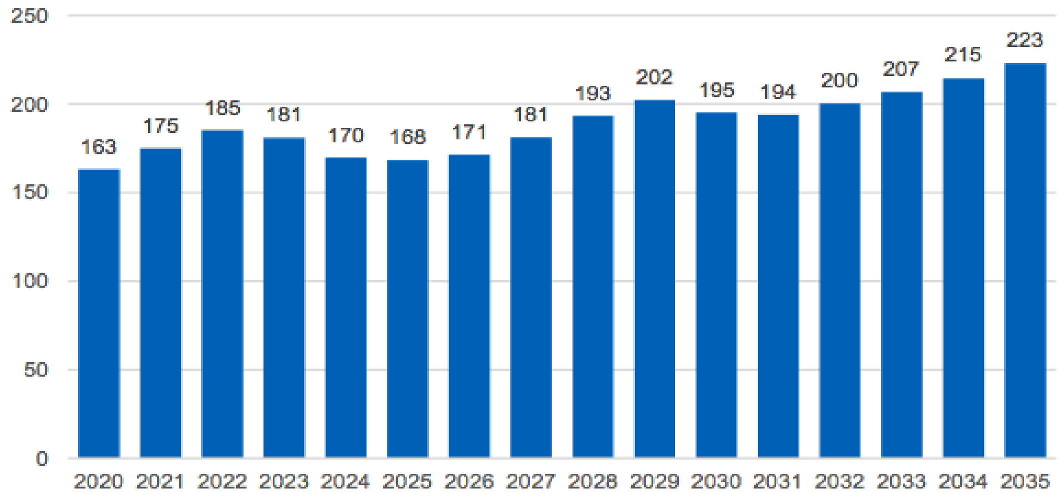

Figure 17. Annual net contribution of 5G to global growth in US$ [30].

4.4 5G spectrum analysis

The spectrum analysis for 5G takes into consideration how will this new technology make use of the previous generation of mobile communication systems spectrum and what will be the new needs of mmWave spectrum bands when the demands change.

This analysis is done based on the different possible environments and sharing scenarios in order to determine the factors that will drive the European Union 5G spectrum requirements.

The current amount of spectrum being used to serve the requirements for the 4G technology are not sufficient to cope with the needs of spectrum that 5G will bring. However it is not yet clear how much spectrum will be needed to support the future traffic growth from public users and verticals. The extra spectrum will definitely come from the bands above 6GHz, from a range of 24GHz to 86GHz as included in the WRC-19.

For the mobile spectrum currently deployed the spectrum sharing approach is an authorised by exclusive licensing mechanism where the licences are awarded by a national regulator. This is done this way because it ensures sufficient number of spectrum blocks available for the market and creates competition. In 5G, an approach to spectrum sharing will be access to spectrum on a licence-exempt basis where devices can freely access the spectrum and coexist in the same spectrum band at the same time in the same location.

The spectrum needs are summarised in the next table. This data is collected by analysing the use cases of transport and automotive, utilities and healthcare.

Use Case Type	Max spectrum requirement (MHz)		Balanced sharing and total spectrum quantities (MHz)		Technical and sharing challenges
Motorway Use Case: Transport & Automotive & Public	<1 GHz	404.0	100%	404.0	Potentially not enough available spectrum that can be shared in Sub-1 GHz and 1 – 6 GHz bands. Refarming of 2G and 3G spectrum bands to be concluded by 2025 Highly demanding spectrum limits opportunity for dedicated spectrum for service providers
	1 – 6 GHz	4041.4	100%	4041.4	
	>6 GHz	9587.6	75%	16,778.4	
Utilities Use Case: Power Supplier	<1 GHz	303.4	100%	303.4	Potentially not enough available spectrum that can be shared in Sub-1 GHz and 1 – 6 GHz bands. Refarming of 2G and 3G spectrum bands to be concluded by 2025 Highly demanding spectrum limits opportunity for dedicated spectrum for service providers Above 6 GHz can support dedicated spectrum for service providers
	1 – 6 GHz	2581.2	100%	2,581.2	
	>6 GHz	836.1	0%	3,344.5	
eHealth Use Case: Healthcare	<1 GHz	135.2	50%	338.1	Potentially not enough available spectrum that can be shared in Sub-1 GHz band. Refarming of 2G and 3G spectrum bands to be concluded by 2025 Highly demanding spectrum limits opportunity for dedicated spectrum for service providers Above 6 GHz can support dedicated spectrum for service providers
	1 – 6 GHz	704.2	50%	1,760.4	
	>6 GHz	451.3	0%	1,805.1	

Table 7. Summary of spectrum needed for the given use cases [30].

4.5 Policy and regulatory considerations

The European Commission recently decided that the minimum number of network operators would be four in order to obtain competition in the mobile sector. Each operator also needs to have a minimum of licensed exclusive spectrum to be competitive. An operator that has fewer spectrum than the required will not be able to provide the set of demanded services necessary to successfully compete in the market and will not be able to stay in it in a long term. As long as each operator has the minimum spectrum required to be sustainable the spectrum holdings do not need to be equal and in fact will contribute to innovations and adaptations that bring new ideas to the market.

Some of the challenges developing spectrum policy and regulations for achieving 5G are among others:

1. Timing of spectrum release (identification of spectrum bands, changes in regulatory policies…).
2. Timing for operators to reform 2G and 3G spectrums.
3. Study of options of making spectrum available and allowing controlled sharing in the spectrum below 1GHz to maximise the spectrum efficiency.
4. Business case analysis of the costs and benefits of sharing and dedicated spectrum.
5. Needs and requirements of access to virtual networks and networks sharing in relation to policy and regulation.

4.6 Direct and indirect impact of 5G in telecommunication and information technology companies (Oracle)

Oracle is a technology company that offers an integrated array of all types of applications, servers, storage, databases and cloud technologies that enrich the modern businesses.

It is a flexible company that provides to each of its clients a specific personalised service thanks to the many products that has developed. It includes all types of software, systems and cloud deployment models, both public, on-premises and hybrid clouds, to make sure that the technology used best serves the needs of the business of the client.

Regarding Oracle Cloud, it has an integrated stack platform, infrastructure and application services. It provides advanced scalability and security and enables technical agility across the enterprise as well as a connexion of people with clear insights and efficiency through simplified workflows.

But what are the Oracle Cloud Solutions' benefits? Modern cloud services help companies seize new business opportunities and innovate faster. Oracle delivers a comprehensive portfolio of integrated cloud solutions for business, IT and development needs including Software as a Service SaaS, platform as a service PaaS, infrastructure as a service IaaS and data as a service DaaS. The key point of Oracle Cloud services is that it helps businesses offload IT management in their companies so that they can focus on their priorities.

All this Oracle Cloud based applications have direct benefits on the businesses as they offer the practical information to clients and enables them to make decisions with a more clear view, from a well informed point of view. These services provide benefits in areas such as finance, human resources, commercial and marketing areas and supply chain areas. This new intelligent applications will make it easier and more intuitive to interact with the data of an enterprise.

However, what does all this have to do with 5G? Well, a thing that all these products have in common is that they need to have available high speeds and low latency, and at the same time consume the less amount of energy possible characteristics that we know 5G can provide. Low latency and high speeds will allow a more efficient data transport between the Cloud and the mobile devices services, that will result in a higher demand of this services by the clients (Mobile Cloud Services MCS). This benefits both Oracle and its clients as it reduces costs and speed up businesses strategies to increase incomes.

Moreover, 5G will allow the construction of backup and recovery architectures in Oracle and in its clients where the servers and databases will be able to be placed at very long distances without any problems or latencies when accessing them or when establishing a communications between them.

As mentioned previously, one of the main drivers and key points of the deployment of 5G will be the development of Internet of Things. Oracle is a company that is constantly developing pioneer technologies and leads the most recent technological innovations. It is for this reason that Oracle will, without a doubt, support the development and the implementation of IoT. This service will also be provided to all of Oracle's customers incrementing once again Oracle's income and business evolution.

Finally, for Oracle, communications are a very important aspect of our day to day work. It is through them that we can meet with our clients and establish the requirements, the evolution, changes and phases of our projects. As well as the internal communications with the different headquarters all over the world (which are numerous). It is therefore utterly important that our mobile and fixed communications systems are efficient and trustworthy. 5G will improve this mobile communication systems resulting in a higher productivity and more efficient and easier way of communication with our clients and company peers.

5G in general will affect Oracle's productivity and increase its income favourably through the improvement of the products and services that it offers its clients. As it is a private company, even though the initial investment on 5G systems will be high, this technology will be profitable and there will be a quick recovery of the investment

5. Project planning and budget

In order to efficiently evaluate the planning and budget for this project we have to take into consideration the main analysis carried out about the possible drivers, barriers, the best possible deployments and most important of all the regulatory aspects and legislation that will help or slow down the development of the fifth generation of mobile communication systems.

It is important to point out the main line of work carried out for the analysis of these aspects mentioned before, in order to identify in one hand the critical and non-critical tasks and in other hand the direct and indirect costs which will affect both the planning and the budget correspondingly. This chapter will therefore be divided in two sections. One of them will clarify the different phases of the project, making a clear distinction between the tasks and the other section will make a full analysis of the costs involved in this thesis.

5.1 Project phases

We can classify four main phases for the project and distinguish the critical and non-critical tasks of it as follows:

Phase 1: documentation and first analysis.

Task 1: search and analysis of documentation about current technologies.

Description: carry out an initial search of the current technologies that are being used as well as those that are being developed for future deployments.

Objectives:

- To obtain a general idea of the road map for 5G.
- To learn about the different aspects to be improved in 4G.
- Analyse how 5G's legislation and regulation has to be developed to speed up the deployments.

Phase 2: contents and structure design.

Task 2: structure design.

Description: decision of how the document and analysis will be structured.

Objectives:

- Clarify the important aspects that should be analysed.
- To manage to carry out an efficient investigation focusing on the key aspects of 5G such as drivers, barriers etc.

Task 3: decision of contents included in the analysis.

Description: given that the fifth generation of mobile communication systems is a very broad and extended topic, it is important to decide what contents must be in the document and are key roles in the whole investigation.

Objectives:

- Include in the document only the relevant content.
- Decide what aspects have to be developed and investigated on for the overall analysis of the regulatory aspects and the legislation on 5G.

Phase 3: Development and draft of the content.

Task 4: draft of the first version of the document.

Description: this task involves the writing of the first draft of the content included in the document.

Objectives:

- Carry out the analysis and writing of the main ideas for the topic.
- Writing of the chapters previously described in the index and structure of the document.
- Put together and write the conclusions and the information found for 5G deployment.

Phase 4: possible modifications and final revision.

Task 5: analyse the possible modifications of the document.

Description: re read the document in order to analyse if there can be any possible modifications of the structure or content of it.

Objectives:

- To make an efficient document with clear information useful for the investigation.

Task 6: final revision and draft

Description: make a final revision of the document taking into consideration the format, content and bibliography of the thesis.

Objectives:

- Finish up the document and make sure everything is correctly written and presented.

Next table (table 8) shows the different phases with the tasks that are part of each phase.

Name of the Task/Phase	Start Date	End Date	Number of Days
Phase 1: Documentation and first analysis	**01/02/17**	**15/03/17**	**43**
Task 1: search and analysis of documentation about	01/02/17	15/03/17	43

current technologies			
Phase 2: Contents and structure design	**15/02/17**	**14/03/17**	**27**
Task 2: Structure design	15/02/17	28/02/17	13
Task 3: Decision of contents included in the analysis	28/02/17	14/03/17	14
Phase 3: Development and draft of the content	**14/03/17**	**14/04/17**	**28**
Task 4: draft of the first version of the document	14/03/17	14/04/17	28
Phase 4: Final revision and draft	**18/04/17**	**30/05/17**	**42**
Task 5: Analyse the possible modifications of the document	18/04/17	04/05/17	16
Task 6: final revision and draft	04/05/17	30/05/17	26

Table 8. Different phases of the project.

Moreover, we can see a Gantt diagram in figure 18 of these phases to be able to have a graphical representation of how the project was structured.

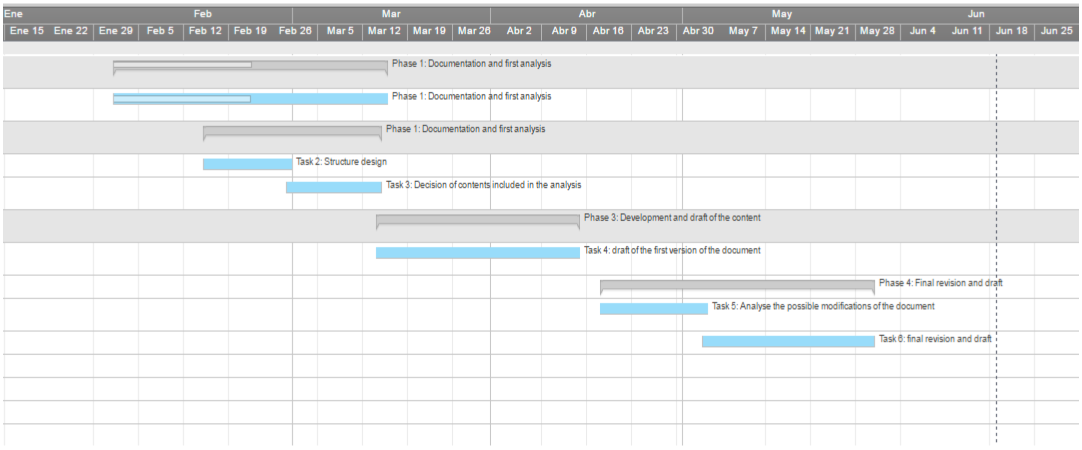

Figure 18. Gantt diagram of the project phases.

5.2 Budget

We can point out various types of costs involved in this project. In one hand we identify the direct costs and in the other we have the indirect ones.

5.2.1 Direct costs:

Costs of personnel: in order to be able to determine the cost that comes from the personnel we have to calculate the time spent on the project by the different members involved in it:

1. Raquel Pérez Leal spent thirty hours of time in total on this project.
2. Raquel Arnaiz del Pozo spent five hours a day during five days of the week for four months. That is a total of four hundred hours.

Next table shows the figures for the previous description of the time spent by each member and the costs involved in them. For this table, we have to take into consideration that the professional fees of a senior engineer is equivalent to 32,67€ per hour and a junior engineer is 20,52€ per hour.

Name	Professional Fees
Raquel Pérez Leal	980,1€
Raquel Arnaiz del Pozo	8.208€
Total	**9.188,1€**

Table 9. Costs of personnel.

General costs: these costs include those that have to do with the equipment and material used in order to carry out the investigation and writing of this consultancy plan. These costs are as follows:

1. Personal laptop used for the gathering up of the information, the analysis of the documentation and for writing and creating both the document and the presentation of the thesis. The initial cost of this laptop was of 1000€ and giving it was used during the 100% of the time the price including the depreciation period is of 66,67€.
2. Internet connexion plan costs 50€ per month. Given the time spent is 4 months it would be a total of 200€.
3. Office material used such as paper, pens, printing etc. costs approximately 40€ in total.
4. The lease for the office used had a cost of 300€ per month what makes a total of 1.200€.

Next table summarizes the general costs described previously:

Type of Cost	Cost
Personal Laptop	66,67€
Internet connexion	200€
Office material	40€
Lease	1.200€

Total	**1.506,67€**

Table 10. General costs.

The total direct costs are therefore the sum of the costs mentioned before, and these add up to 10.694,77€ in total.

5.2.2 Indirect costs

The indirect costs can be calculated with the direct costs. These costs are a 15% of the costs of personnel in the direct costs. That is it would be a 15% of 9.188,1€ that is 1.378,22€.

5.5.3 Total budget

Next table summarizes the total costs of the project including both direct and indirect costs and shows a budget for the project.

Type of Cost	Total Cost
Direct costs	10.694,77€
Indirect costs	1.378,22€
Subtotal	**12.072,99€**
V.A.T. (21%)	2.535,33€
Total	**14.608,32€**

Table 11. Total budget.

The total budget is therefore **FOURTEEN THOUSAND SIX HUNDRED AND EIGHT WITH THIRTY TWO EUROS**, including V.A.T. of 21%.

6. Conclusions and future work

6.1 Conclusions

"The printing press. The Internet. Electricity. The steam engine. The telegraph. Each of this discoveries or inventions is part of an elite class of socio-economic mainsprings known as General Purpose Technologies (GPT). Established through pervasive adoption across multiple industries, GPT's often are catalysts for transformative changes that redefine work processes and rewrite the rules of competitive economic advantage. The profound effects arising from these innovations range wisely, from the positive impacts for human and machine productivity to ultimately elevating the living standards for people around the world.

HIS Markit views 5G as a catalyst that will thrust mobile technology into the exclusive realm of GPT's" [27].

Taking a close look at the analysis carried out in this document we can be closer to arriving to the same conclusion as mentioned above, and outline certain important aspects about 5G.

This new technology is needed more and more everyday given the evolution of the applications and the way of life of human beings. It is not only a personal user experience improvement, but it will affect many other areas. As mentioned before, enterprises and companies of all sectors will be able to modify their business models and the services they provide to their clients. This will result in an economic growth in nearly all the industries worldwide. Moreover, 5G will change people's lives and futures thanks to the evolution of apps and the investigations that will be carried out in health and sciences areas. In general, we can outline among all the benefits of 5G the next aspects:

1. Increase in the GDP of the countries that deploy 5G.
2. Improvement in multimedia services as well as applications that make use of data in order to provide users with their services.
3. New jobs that come from all the industries that have to produce either tools or infrastructures in order to deploy 5G.
4. Restructure of the frequency band that will result in easier and quicker deployments of the next generations of mobile communication systems.

However, even though these things are highly important as they will mark a milestone in history, it will be impossible to achieve a correct deployment and an installation of 5G without a guided work timeline and the consensus of the many companies, bodies, organizations and commissions involved. The standardization process that has to take place will have a key role in order to achieve this. Standards that will be developed for the tools used to construct 5G will mark the pace for the deployments. Moreover, the regulation regarding the frequency bands affected by this new technology is also a determination to 5G. It has even been discussed a possible second Digital Dividend in order to allocate all the technologies needed.

All these aspects about 5G will have to be investigated and worked on not only for the deployment but also for the further needs that may arise in the future.

6.2 Future work

As a future work, it is important to continue investigating on these lines, as well as documenting each possible line of work and change in order that the future generations of mobile communication systems can be developed easily and in an organized way to avoid unnecessary costs, and enable an easy deployment.

With this project what is planned is to be able to have a clear view of the main barriers and drivers as well as the regulatory environment and the standardization needed to deploy and continue developing this new generation of mobile communication systems. This is achieved by taking into consideration the current technologies being used and by analysing what needs to be done for future ones. It is important to test and to make trials to see how this technology will affect humans and markets among others in order to be able to avoid mistakes in the future and make the next generations even better than this one.

7. Acronyms

1G First Generation
2G Second Generation
3G Third Generation
3GPP Third Generation Partnership
4G Fourth Generation
5G Fifth Generation
AMBR Aggregated Maximum Bit Rate
AN Access Network
APT Asia-Pacific Telecommunity
API
BSC Base Station Controller
BSS Base Station System
BTS Base Transceiver Station
CA Carrier Aggregation
CAPEX Capital Expenditure
CEO Chief Executive Officer
cmWave Centimeter Wave
DaaS Data as a Service
DeNB Radio Access Node
CN Core Network
DL Downlink
E-UTRAN
EPC Evolved Packet Core
EPS
ETSI European Telecommunications Standards Institute
EU European Union
FCC Federal Communications Commission
FDD Frequency Division Duplex
FDM Frequency Division Multiplexing
FDMA Frequency Division Multiple Access
GBR Guaranteed Bit Rate
GPT General Purpose Technologies
Non-GBR Non-Guaranteed Bit Rate
GDP Gross Domestic Product
GGSN Gateway GPRS Support Node
GPRS General Packet Radio Service
GPT General Purpose Technologies
GSM Global System for Mobile Communications
HSS Home Subscriber Server
HLR Home Location Register
HSPA High Speed Packet Access
Iaas Infrastructure as a Service

ICT Information and Communications Technologies
IoT Internet of Things
IMT International Mobile Telecommunications
IP Internet Protocol
ITU International Telecommunications Union
LTE-U Long Term Evolution Unlicensed
LTE Long Term Evolution
MCS Mobile Cloud Service
MIMO Multiple Input Multiple Output
MME Mobility Management Entity
mmWave Millimeter Wave
MNO Mobile Network Operator
MSC Mobile Switching Controller
MU-MIMO Multi User-MIMO
NFV Network Function Virtualisation
NR New Radio
OFDM Orthogonal Frequency Division Multiplexing
OPEX Operating Expense
P-GW Packet Gateway
PaaS Platform as a Service
QAM Quadrature Amplitude Modulation
QCI QoS Class Identifier
QoE Quality of Experience
QoS Quality of Service
RAN Radio Access Network
RAT Radio Access Technology
RN Relay Node
RNC Radio Network Controller
RSPG Radio Spectrum Policy Group
S-GW Serving Gateway
SaaS Software as a Service
SDN Software-Designed Networking
SDNRAN Software-Designed Networking Radio Access Network
SIM Subscriber Identity Module
SK Telecom South Korea Telecom
SP Service Provider
SGSN Serving GPRS Support Node
SPTF Spectrum Policy Task Force
SU-MIMO Single User-MIMO
TCP Transport Control Protocol
TDD Time Division Duplex
TDM Time Division Multiplexing
UE User Equipment
UHD Ultra High Definition

UL Uplink
UMTS Universal Mobile Telecommunications System
UNESCAP United Nations Economic and Social Commission for Asia and Pacific
US United States
UTRAN Universal Terrestrial Radio Access Network
VAT Value Added Tax
VLR Visitor Location Register
VoIP Voice over IP
VNO Virtual Network Operator
VNP Virtual Network Provider
VSwitch Virtual Switch
WCDMA Wideband Code Division Multiple Access
WiFi Wireless Fidelity
WLAN Wireless Local Area Network
WRC World Radiocommunication Conference

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