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European markets in 5G spectrum management

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European markets in 5G spectrum management

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Abstract

Over the last years, the mobile industry has been characterized by a lack of entrance from new players, leaving the power to govern the market to the usual incumbents. Since 5G is expected to bring a big wave of change in all the mobile market structure, with the introduction of new technologies, the usage of new business models, and also the entrance of new types of players, it can be assessed whether new players actually entered the market through 5G auctions.

The mobile spectrum management is a delicate matter, since spectrum is a scarce resource and may cause interference if two or more operators use the same band. The European Commission, but above all, the National Regulatory Authorities, must commit themselves to allocate frequencies in the most correct way possible, in order to ensure the provision of the most efficient services. If 2G frequencies were assigned on the basis of regulators' choice, with 3G, but mostly with 4G, bands were assigned by means of auctions, and so it has been and will be also for 5G.

The main purpose of this work has been to understand if 5G, and in particular 5G auctions, will allow the entrance of new players in the mobile communication industry. By collecting data about instruments that regulators can use and the outcome of each auction, a qualitative analysis of the results obtained has been made, considering which was the situation of the national market before and after the tender. The auctions examined are those which are considered to be the pioneer bands of 5G: 700 MHz, 3.6 GHz and 26 GHz bands. Moreover, since 5G auctions have been held in only eight European countries, also the previous auctions of these bands were considered.

The results obtained have showed that there is a lack of entrance on the part of new players, both as regards operators that are already operating on the mobile market and new types of firms. As regards 5G auctions, new players won some blocks only in Italy and in Ireland, while in the other countries potential entrants were excluded or did not even try to take part in the auction.

The main reasons of this lack of entrance have been assessed, coming to the conclusion that regulators do not provide the right incentives to improve competition, but rather, they focus on high revenues that they can earn, or other issues. In addition, 5G requires much higher investments than the ones for previous generations, given that the installation of new base stations and innovative solutions is required.

KEYWORDS: mobile market, 5G, spectrum auctions, competition, new entrants

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List of abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
CEPT	European Conference of Postal and Telecommunications Administrations
DSM	Digital Single Market
EC	European Commission
EECC	European Electronic Communications Code
eMBB	Enhanced Mobile Broadband
EU	European Union
FDD	Frequency Division Duplex
FT5G	Fibre To 5G
FWA	Fixed Wireless Access
GDP	Gross Domestic Product
GSM	Global System for Mobile Communications
GHz	Gigahertz
IoT	Internet of Things
ITU	International Telecommunication Union
LTE	Long Term Evolution
MHz	Megahertz
mMTC	Massive Machine Type Communications
mmWave	Millimeter Wave
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
M2M	Machine-To-Machine
NRA	National Regulatory Authority
OTT	Over-The-Top
RR	Radio Regulations
RSC	Radio Spectrum Committee
RSPG	Radio Spectrum Policy Group
RSPP	Radio Spectrum Policy Programme
SDL	Supplementary Downlink
TDD	Time Division Duplex
URLCC	Ultra-Reliable Low Latency Communications
VMNO	Virtual Mobile Network Operator
WRC	World Radiocommunication Conference
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation

To my angel, my dad

1. Introduction

1.1. Background

The mobile market is steadily growing: in 2017, Europe saw 465 million mobile subscribers, a 3.3% of GDP created and €550 billion of economic value generated. These values are expected to keep increasing: GSMA has foreseen that in 2025 these values will be 481 million, 4.1% and €720 billion, respectively.

The advent of 5G should bring a breath of fresh air across the entire mobile industry: given that it will introduce new technical innovations (i.e. Internet of Things, Augmented Reality, virtualization), it can enable the development of new business models and the reorganization of the mobile market structure.

Spectrum is a scarce resource with huge significance, and it is essential that regulators manage it in the most effective way both at international and national level, since the allocation and assignment of spectrum depend on their choices. Spectrum licenses have been increasingly awarded by means of auctions, in the sense that the choice is up to the market, and who offers the highest amount of money, wins a certain band of spectrum.

Through the planning of auctions, regulators can decide to adopt and apply different types of instruments that can facilitate the entrance of new players or can enhance an effective use of the spectrum.

1.2. Purpose of the work

Many studies on how to set an auction as good as possible with regard to an effective use of spectrum were made, but very few studies focus on who are the operators that win the spectrum, by distinguishing between incumbents and new entrants, and on how regulators can promote competition by means of auctions. Moreover, in a new and innovative field such as 5G, studies concerning 5G auctions have not been made yet. However, competition is one of the most important issues that regulators must take into account and ensure, in a manner that social welfare is optimized and consumers can benefit from the positive effects that competition brings, for instance lower prices and efficient services.

Therefore, by taking into account the big innovation brought by 5G, this study aims to assess if there have been new entrants, or the spectrum has been remaining in the incumbents' hands, as regards spectrum auctions that have been already held in Europe for assigning 5G bands. Data collected have showed a negative outcome concerning the entrance of new players, and for these reasons, the next step has aimed to understand which the reasons of this lack of entrance are.

Hence, this thesis is organized as follows:

- Chapter 2 explains briefly what radio spectrum is and which are the related issues, focusing on why it is so important that a correct management is made at international, European and national levels;
- Chapter 3 aims to describe how the previous mobile generations evolved in the past;
- Chapter 4 introduces the big novelty of 5G, by describing which innovations it will bring, the related issues and how regulation should adapt to it;

- Chapter 5 describes, in a theoretical way, how regulators can assign spectrum, auction formats and instruments that regulators can use to enhance competition or to promote an effective use of spectrum;
- Chapter 6 provides a qualitative analysis of the data collected in the dataset, by describing 5G auctions, previous auctions of the pioneer bands of 5G and the format of future auctions; it specifies which was the situation before and after the auction, which type of instruments were used by each national authority and the outcome of the auction;
- Chapter 7 tries to explain the reasons of such a little entrance, in particular it distinguishes between the format imposed by regulators and what they could do to improve competition with auctions, and the high investments required by 5G;
- Chapter 8 is the final chapter that provides the conclusions of the previous analysis and how 5G can promote competition with innovative methods;

1.3. Methodology

The first part of this work concerned a theoretical study of the literature as regards spectrum management and spectrum auctions, with a particular focus on the European context. Hence, books, papers available on the Chalmers website and on Google Scholar, and documents of European bodies were consulted. Subsequently, a detailed analysis of what 5G is and which novelties it can bring was made, by consulting documents of European bodies and mobile research companies.

Once the theoretical study was concluded, the collection of the documents of auction rules was made, in order to analyze how every country organized the assignment. Then, the related results were assessed, with the purpose to check which were the winning bidders, and mostly, if new players entered the market.

It was decided to consider all the 28 countries within the European Union, and also Norway and Switzerland, since these two countries border with Union countries. For this work, the pioneer bands of 5G, namely the 700 MHz band, the 3.6 GHz band and the 26 GHz band were considered.

Moreover, since not all 5G auctions have been held in Europe, but only in 8 countries, also the previous auctions of the pioneer bands for 5G made by 2015 were considered, taking into account that these bands are technology neutral and operators can decide to use them for 5G in the future.

5G AUCTIONS	AUCTIONS FOR PIONEER BANDS
Finland, Ireland, Italy, Latvia, Spain, Sweden, Switzerland, UK	Czech Republic, Finland, France, Germany, Hungary, Latvia, Romania, Slovakia

Table 1. Auctions taken into account

Finally, in order to evaluate future trends, also invitations to tender and auction rules of forthcoming auctions in Europe were considered. In this case, auctions of Austria, Denmark, France, Germany and Norway were considered.

In order to find this information, websites of each NRA were analyzed, which sometimes were only in the original language and not in English. Hence, through the use of Google Translate, websites of France, Germany, Latvia, Italy, Romania, Slovakia, Spain and some parts of Finland were translated.

For other countries, instead, it was necessary to contact the office of authorities directly, in order to request missing data; this was made for Belgium, Finland, Ireland, Latvia, Norway, Romania and Spain. Moreover, DotEcon, a consulting firm, was contacted, and it provided a database containing information about auctions. However, this database has not been updated for years, and so it was not used.

Once sufficient data were obtained, a database was created. For each country, the following data concerning the auction design were included: band, auction format, objectives of regulators, number and dimensions of blocks, license duration, reserve price and the method of calculation, set-aside mechanisms, spectrum caps, obligations (coverage, roll-out, access), use-it-or-lose/lease-it mechanisms, spectrum trading and leasing. As regards the results, the incumbents, the new entrants, the winners, the price paid by each winner and the total price were considered.

Finally, data were analyzed in a qualitative way, explaining which were:

- The body in charge for regulating spectrum;
- The situation before the auction, by providing a description of incumbents, their market shares (the number of SIMs that were sold is taken as the market shares' indicator) and the amount of spectrum owned;
- The auction rules, with a focus on instruments at disposal of regulators;
- The auction results, with a focus on which type were the winners of.

Moreover, some plots were created by using Excel, in order to correlate the final price with the reserve price or with other factors. At the end, an explanation on which can be the reasons of the lack of entrance was made, by considering what regulators can change in spectrum auctions and the amount of investments required.

2. Spectrum management

2.1. Introduction

Firstly, it can be useful to provide a general overview of spectrum. In this chapter, a briefly description of what spectrum is and why it needs to be managed will be provided, then the main international and national bodies which are involved in the regulation of spectrum will be outlined.

National governments manage the radio spectrum at both international and national level, in order to guarantee enough spectrum to maximize socio-economic welfare, reduce as far as possible interference across boundaries and inside the nation, and foster spectrum efficiency. Governments work firstly on an international level: they establish together which bands will be allocated in a way that interference is kept to a minimum, industry prices are reduced, coordination is enabled, enhancing also economies of scale. Afterwards, regulators must strive to assign frequency bands to mobile operators or service suppliers in an efficient manner (GSMA, 2017a).

2.2. Radio spectrum

Radio spectrum has become an indispensable resource for each of us. Nowadays, due to the growing necessity of data exchange, faster transmission and better quality of media, every device used in everyday life, like mobile phones, satellite TV or Wi-Fi, rely on radio spectrum (GSMA, 2017b).

Radio spectrum is a radio wave that constitutes a portion of the electromagnetic spectrum together with other wavelengths: infrared, visible light, ultraviolet, x-rays, gamma rays and cosmic rays.

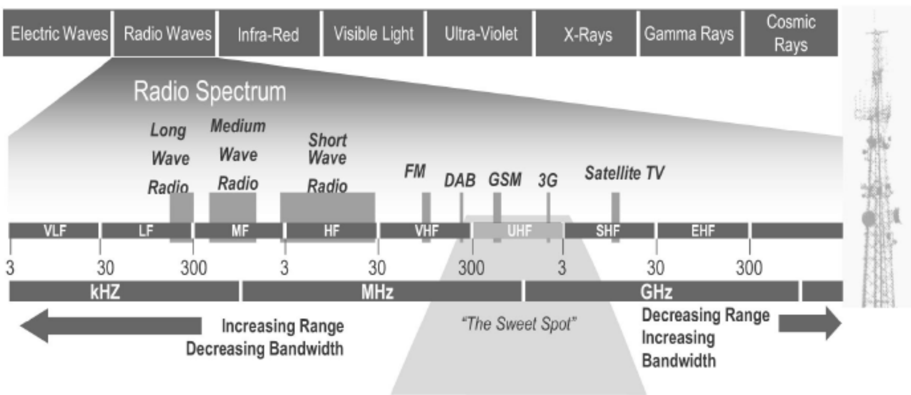

Figure 1. The electromagnetic spectrum. Source: UK parliament

An electromagnetic wave is a transversal oscillation generated from an electric charge's vibration in electric and magnetic fields; a wave is able to travel through the vacuum, carrying its energy at the speed of the light ($c = 3 \times 10^8$ meters/second).

Waves are generally represented by their frequency, whose unit of measure is Hertz (due to the physicist who proved the existence of electromagnetic waves) and by their wavelength.

Frequency (f) can be described as the property of the wave that defines the number of cycles taking place in one period, while wavelength (λ) measures the distance between the same point of two consecutive crests.

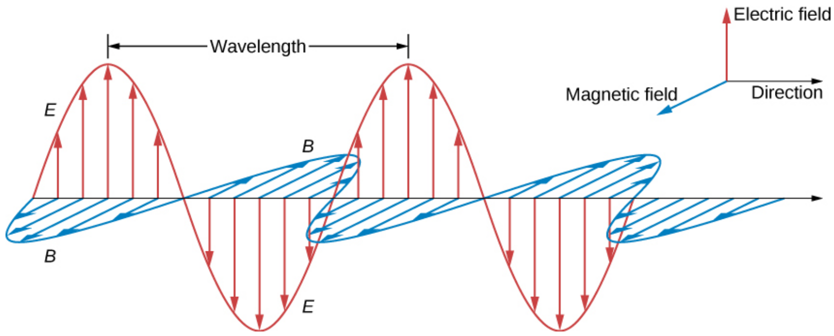

Figure 2. Electromagnetic wave. Source: Openstax

These two measurements are directly related to each other in an inverse relationship:

$$f = \frac{c}{\lambda}$$

Low frequencies cannot provide high capacity in terms of amount of data or information carried, but can propagate for long distances, affording a very good coverage. On the contrary, higher frequencies, i.e. millimetre waves, ensure more effective data transfers, at the expense of a broader coverage.
As mentioned above, radio waves are usually measured in Hertz, but the most commonly used units are Kilohertz (kHz), Megahertz (MHz) and Gigahertz (GHz), equivalent to, respectively, 1,000 Hertz, 1,000,000 Hertz and 1,000,000,000 Hertz.
In particular, radio spectrum ranges from 3 kHz to 3000 GHz, and can be divided in 9 sections (ITU, 2012), as shown in Table 2.

Name	Acronym	Frequency	Wavelength	Usage
Very low frequencies	VLF	3-30 kHz	10,000-100,000 m	Submarine communications
Low frequencies	LF	30-300 kHz	1,000-10,000 m	Amateur radio operators; military applications
Medium frequencies	MF	300-3,000 kHz	100-1,000 m	AM radio
High frequencies	HF	3-30 MHz	10-100 m	Shortwave broadcasts; citizens band radio
Very high frequencies	VHF	30-300 MHz	1-10 m	FM radio; television broadcasting
Ultra high frequencies	UHF	300-3,000 MHz	0.1-1 m	Mobile phones; wireless LAN; Bluetooth
Super high frequencies	SHF	3-30 GHz	0.01-0.1 m	Wireless LAN; satellite radio
Extra high frequencies	EHF	30-300 GHz	1-10 cm	Millimetre wave scanning; remote sensing
Tremendously high frequencies	THF	300-3,000 GHz	0.1-1 cm	Experimental medical imaging

Table 2. Frequency bands of radio spectrum. Source: different sources

Hence, a wide range of different bands provides diverse uses of the spectrum. In fact, Mobile Network Operators (MNOs) are concerned with both high and low frequencies. The former are valuable for rural areas, since they are able to cover long distances, without the necessity to set up a large number of base stations; on the contrary, the latter fit perfectly with chaotic and urban cities, where there is the need to ensure the distribution of a huge amount of data, in order to satisfy a lot of end-users (GSMA, 2017b).

2.3. Interference: the reason why radio spectrum needs to be managed

The radio spectrum is considered as a not-homogeneous, non-exhaustible and non-storable resource, meaning that, respectively, it can be used for different services thanks to its propagation characteristics, it does not exhaust if it is used, and it cannot be stored for the future.

Further, due to the nature of spectrum, in a certain place and period of time, mobile connections can be exposed to a serious problem, namely interference, if the transmission is made on the same or contiguous portions of frequencies.

Thinking about throwing a little rock in a pond, could be a reasonable example to describe interference phenomena: the waves created by the fall of the single pebble into the water can be seen evidently; but, if a large number of stones are dropped, it becomes difficult to distinguish the single wave (Sims, Youell

& Womersley, 2016). Interference, therefore, is the harmful effect induced if two or more devices, which are located in close sites, transfer their data on the same radio frequency and during the same period. Moreover, the problem may occur even when users transmit on contiguous frequencies (Cave, Doyle & Webb, 2007).

At the beginning, the radio spectrum did not pose such a serious issue, on account of the great availability of spectrum and the limited applications of it. Nevertheless, due to the ongoing growth of technology, many devices and systems require a big amount of spectrum, causing the supply is exceeded by the demand.

Hence, the technological progress has meant that, nowadays, the radio spectrum should be considered as a scarce resource. The consequences of this spectrum shortage will impact on the entire society, for the fact that it implies significant costs, reduction of available services and loss of attractive business opportunities.

Further, spectrum efficiency depends on several factors which regulators should take into account with the purpose of optimising the use of this resource.

Among these drivers can be found:

- The already mentioned interference between signals transmitted on the same or the contiguous frequency band;
- The presence of available infrastructures and effectiveness of mobile networks;
- The authorities' spectrum management and regulation: decisions about how and in what context a certain frequency band is allocated (i.e. for public or private purposes), which kind of technology will be used and how much funding will be allocated (SEC (2010) 1035);
- The efficiency of spectrum assignments.

Hence, governments must engage in spectrum regulation with the aim of guaranteeing the maximum socio-economic benefit; this objective could be reached by enabling numerous users to provide their services, whilst making sure that signals do not interfere with each other, or at the very least, ensuring that the interference would not undermine the sending and reception of signals (Cave, Doyle & Webb, 2007).

2.4. Spectrum regulation: international and national bodies

As the technology evolves, institutions must constantly reconsider and revise policies concerning spectrum management. That is because the spectrum demand increases in parallel with increasing possible uses – either private or public - of telecommunication devices, while the supply remains finite. The introduction of the fifth generation (5G) mobile technology, will lead to radical changes in many industries, such that health, automotive, media and entertainment, manufacturing and agriculture.

Consequently, authorities must adopt an efficient spectrum management strategy with the aim of guaranteeing enough spectrum for the improvement of actual functions and for the deployment of new services (5G Manifesto, 2016).
As mentioned above, regulators should avoid harmful interference that causes transmission problems. Since radio waves go beyond geographical borders, an international organization, called International Telecommunication Union (ITU), has been created to coordinate different institutions in order to avoid this cross-border interference.
In the specific case of Europe, it is the responsibility of the National Regulatory Authorities (NRAs), which could be a particular government unit or an independent institution, to ensure an effective spectrum management at a national level.
Furthermore, both national and international regulators have the aim to prevent harmful interference, to guarantee that an adequate amount of spectrum is available, to improve spectrum efficiency and flexibility and to ensure that there are no anti-competitive behaviours (COM (2010) 471).
In accordance to the international regulatory framework, nonetheless, the ITU is responsible for the allocation of radio spectrum, while assignment lies with national authorities. For allocation we mean the activity conducted when a particular frequency band is chosen to cover a specific service, whereas assignment is intended to be the process of granting the use of a particular frequency band to specific users, and thereby they can provide their services (Massaro, 2017).

2.4.1. International regulation

ITU is the specialized agency of the United Nations, responsible for international radio spectrum regulation. ITU is composed of 193 member nations and of more than 700 private or academic institutions. A global conference, called World Radiocommunication Conference (WRC), is organised by ITU every three to four years. The purpose is to discuss about the review of the Radio Regulations (RR), the international treaty which specifies which services or uses will be covered by a particular frequency band (Massaro, 2017). However, the objective of the RR is not to impose on countries the use of a specific frequency band to a specific service, in accordance with ITU provisions, but every member is obliged to ensure that harmful interference to other countries' servicers is not caused. For example, a member country can decide to use a particular frequency band for TV broadcasting instead of mobile, provided that it will not interfere with signals of other countries (Sims, Youell & Womersley, 2016).
In accordance with the RR, the world can be split into three regions: Region 1, Region 2 and Region 3, as shown in Figure 3.

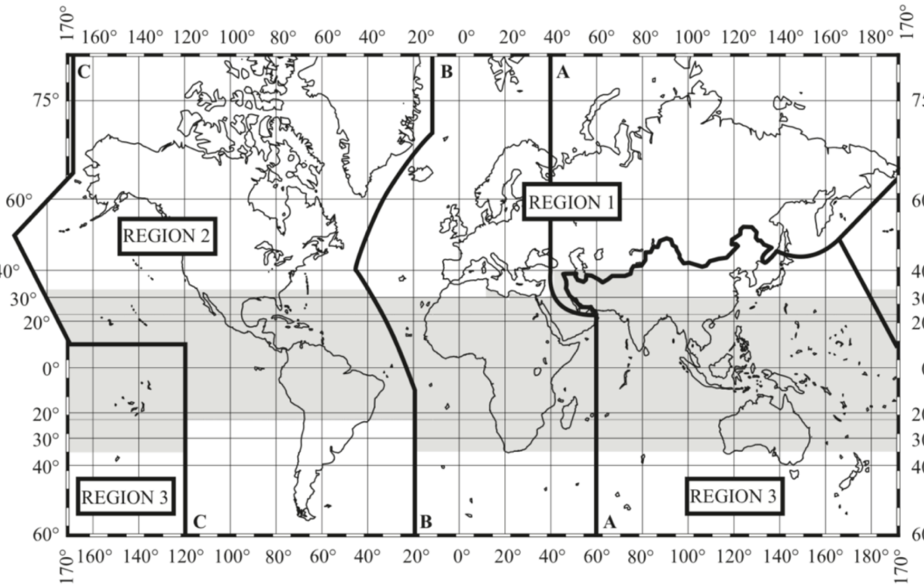

Figure 3. The three ITU Regions. Source: ITU (2012), Radio Regulations

Region 1 consists of Europe, Africa, the Middle East and the first part of Soviet Union. Region 2 includes North America, South America and Greenland. Finally, Region 3 is composed of South Asia, East Asia and the huge part of Oceania.

Every country belonging to a specific Region must coordinate with its neighbouring countries so as to avoid international interference. With the objective of coming up with a general agreement on spectrum regulation and frequencies allocation between countries within the same ITU Region, regional organizations have been established. Every regional organization presents at WRC the shared propositions for the revision of RR.

As regards Region 1, organizations responsible for enhancing cooperation among member states are four: the European Conference of Postal and Telecommunications Administrations (CEPT), representative of European countries, Arab Spectrum Management Group, African Telecommunications Union, and finally, Regional Commonwealth in the Field of Communications.

Therefore, spectrum regulation can be considered having a three-layers framework: international, regional and national levels, as described in table below (Massaro, 2017).

Regulatory context	Radio spectrum activity		Entity
International	Allocation	Designating frequency bands to radio-based services	ITU
Regional	Allocation	Formulating common proposals to review radio spectrum allocation	CEPT; ASMG; ATU; RCC
National	Assignment	Granting service providers authorisations for using the frequency bands	NRAs

Table 3. Three-level regulation of radio spectrum. Source: Massaro (2017)

2.4.2. European regulation

One of the most important objectives of the European Union (EU) is the creation of a single common market across Europe. Not only European bodies, but also national regulators and companies are committing to establish the so-called internal market. The internal market would mean that everything, from people to services, can move around Europe without any barrier (Massaro, 2017). Coordination among European countries give rise to economies of scale and interoperability, which can enhance and improve innovation and the effective usage of spectrum frequencies. In recent years, the European Commission (EC) has coined the term Digital Single Market (DSM) to describe the elimination of regulatory barriers in a way that consumers, companies, and mobile operators can benefit from it.

At European level, there are several organizations which work in close collaboration in order to achieve the objective of spectrum harmonization in Europe, by seeking to ensure that every country cooperates with the other member states. Some institutions consist of the 28 countries belonging to the EU, while others even include other nations located on European territory, for example Switzerland and Norway.

The EC is one of the primary EU institutions, which has the function to represent the 28 countries of EU with regard to submit regulation to Parliament and Council, to create guidelines concerning European policies and to handle at a cross-border level (ECC & ETSI, 2011), hence it constitutes the body involved in enhancement of spectrum harmonization in the EU.

The Radio Spectrum Policy Group (RSPG) and the Radio Spectrum Committee (RSC) are two entities which provide assistance to the EC. The RSPG was established in 2002 with the Decision 2002/622/EC and its role is to give help and opinions to Commission about the spectrum policies on technical, political, commercial and social issues (Massaro, 2017), i.e. establishment of spectrum policies, check of spectrum availability, improvement of spectrum harmonization (Decision 2002/622/EC; Mazar, 2016). It can be considered as the advisory of EC, which assists the EC in developing the Radio Spectrum Policy and in spectrum conflict resolution. In addition, RSPG shall support the EC in drafting the Radio Spectrum Policy Programme (RSPP), which aims to establish the single market and to maximise socio-economic welfare, by encouraging spectrum harmonization (COM (2010) 471; Decision 2002/622/EC). The RSC was also created with the Decision 2002/622/EC, and it assists the

EC in elaborating and implementing technical measures to guarantee the radio spectrum harmonization and the provision of information about spectrum usages on time.

The aforementioned CEPT was established in 1959, with the objective of enhancing the radio spectrum and satellite orbits harmonization. Originally it consisted of 19 members, which were mainly monopoly-holding postal and telecommunications authorities. During the first ten years it extended to 26 members, and now it counts 48 members. The CEPT is the European entity which handles international coordination and standardization issues among the current 48 European countries, in order to advantage Europe in operating, regulation and commercial terms (Mazar, 2016). Regulatory bodies work together with a view to enhance efficiency and cooperation, by harmonizing radio spectrum and telecoms. CEPT elaborates harmonization projects, shared by every CEPT member, to be submitted to regulators outside European borders (Decision 676/2002/EC).

2.4.3. National regulation

Even if European bodies are making efforts to create a unique market across Europe, the final decision on spectrum assignment is taken at a national level by the NRAs. NRAs may belong to the local Ministry of Telecommunications or to other Government's institutions, otherwise it may be an autonomous body (Massaro, 2017). NRAs are responsible for spectrum assignments in the territory under their jurisdiction: they decide which frequencies will cover a specific service and how much spectrum[1] is made available to users (Finger & Künneke, 2011). By entrusting licenses to a specific operator, NRAs normally ensure the exclusive use of that particular frequency and the absence of interference (ITU, 2004). In accordance with ITU regulations, before proceeding with license assignment, regulators must be certain that a user will not cause any harmful interference to other users located in neighbouring countries (ITU, 2015a).

Furthermore, NRAs' regulation can be divided into three aspects: economic, technical and social regulation. The economic regulation aims to enhance economic efficiency, by fostering competition among users. The technical regulation concerns the maximisation of the use of spectrum frequencies, where they are available, without leaving any bands unutilized. Conversely, the objective of social regulation is the supply of the same kind of services to all citizens, regardless of the standard of living or area of residence (Geradin, 2000; ITU, 2004).

Finally, NRAs seek to balance private and public interests, considering both market and governmental requirements, for example defence or aeronautical needs. In both cases regulators must be able to assign spectrum bands to a specific service as effectively as possible, bearing in mind that the most efficient range of spectrum band for that service might be already used by another service (Finger & Künneke, 2011).

[1] This usually relates to the notion of "bandwidth", to indicate the range of frequency assigned.

As regards private users, several means of spectrum assignment are available:

- "First-come, first-served" approach, useful when spectrum supply is exceeded by the demand (ITU, 2004);
- "Beauty contest" approach, which consists of the choice on the part of regulators, in accordance to the assessment of different criteria, for instance monetary reserves and technical expertise (Massaro, 2017);
- "Spectrum auctions", a market-based assignment process, where the user which offers the highest bid achieves the exclusive license to use a specific portion of spectrum bands.

Notwithstanding technological advancements, spectrum demand is increasingly overtaking supply, auctions result the most efficient way of spectrum assignment. Indeed, they are faster than beauty contests and tend to assign spectrum to the most willing user.

2.5. Conclusions

In this chapter, it can be understood how the management of spectrum is a delicate matter, which, if not handled with the greatest attention, it may generate serious problems. Hence, international and national regulators must strive to ensure the most effective usage possible, by coordinating themselves and by controlling that operators maximise the efficiency of spectrum.

3. How mobile generations have evolved

3.1. Introduction

Since the purpose of this thesis is to assess if competition is enhanced in the 5G period, a brief description of what a mobile generation is and an overview on how the previous generations (1G, 2G, 3G and 4G) evolved can be made. Finally, the past and previous trends of the mobile sector will be provided.

3.2. Mobile generations

Governments and policy makers are constantly striving to set a worldwide standard, in line with the evolution of generations. This will be to ensure the aforementioned harmonisation, which may give rise to global economies of scale, which in turn enable a decrease of costs for mobile companies and a subsequent price reduction for consumers.

Before starting the explanation about how mobile generations evolved, it should be necessary to make few considerations relating to the terms of generation and standard. With regard to the telecommunication sector, "generation" is the word used to express the evolution from a previous system to another new one. The new system is usually a technical improvement built on the old technology; but nonetheless it encompasses a novelty factor, with the result that the latest system is markedly different from the former ones. A clear separation can, indeed, be observed between the various mobile generations, each of which has brought an innovation in mobile communications.

The term "standard", instead, means a set of specifications that defines how the system should be. A standard can emerge *de facto*, if it arises in the market as a result of the decision of a dominating incumbent, it can arise *de iure*, when the governments or regulators impose to use it, or by agreement if two or more players collaborate to create a single standard. The establishment of a common standard involves both private and public entities and is crucial for ensuring social welfare: it is essential either for avoiding the so-called standard wars, which can slow down the diffusion of the standard, or for achieving positive network externalities, which give rise to an increase of the number of consumers and economies of scale (Tadayoni, Henten & Sørensen, 2018).

3.2.1. Mobile cellular networks

Mobile systems were born in the first decades of 1900s. Every system consisted of a single high-power transmitting antenna located in a base station with the aim to receive and send signals in the surrounding area (GSMA, 2017b). However, managing signals in this way caused a significant drawback: due to the fact that only one transmitter should have covered a vast territory and that the majority of frequencies were used for public purposes, only a limited number of users was served (Prasad & Sridhar, 2014).

In order to overcome this problem, in 1947, Bell Labs proposed a cellular network based on the division of the territory in hexagonal cells, each of which had a low-power transmitter (GSMA, 2017b) as shown in figure 4. By using more than one base station, a wider area was covered.

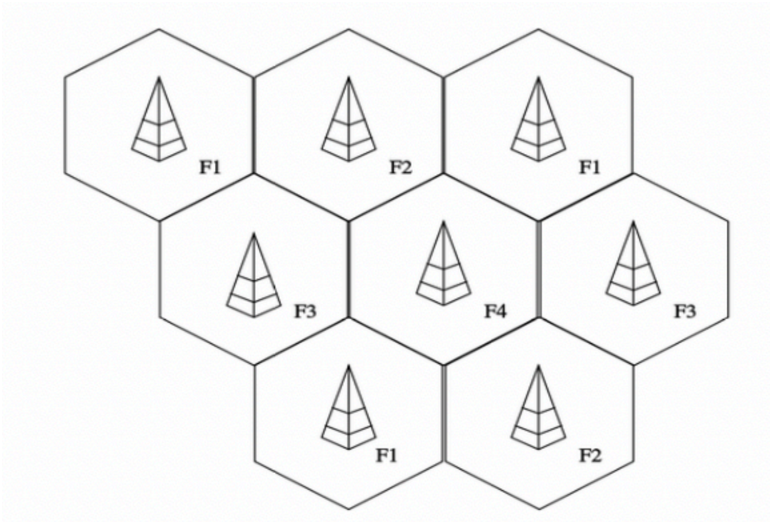

Figure 4. Example of cellular network. Source: Wikipedia

Furthermore, this type of division allows the re-use of the same frequency in non-contiguous cells (GSMA, 2017b), while adjacent cells use a different range of frequencies in order to avoid interference. This means that different users can call or transmit data at the same time (Prasad & Sridhar, 2014), apart from the fact that more capacity is available than in the previous single transmitter.

3.2.2. First generation

The first mobile generation was characterised by a large heterogeneity among different countries. Distinct frequencies and standard were used depending on the country, so that neither roaming nor interoperability were possible (Tadayoni, Henten & Sørensen, 2018).
Examples of the first-generation technologies include (GSMA, 2017b):

- Advanced Mobile Phone System (AMPS), which was used in the United States on 800 MHz frequency;
- Nordic countries applied the Nordic Telecommunication System (NMTS), which used 450 MHz and 900 MHz bands;
- Total Access Communications System (TACS), which was developed in the UK and used the 900 MHz band.

The reason behind these heterogeneous uses of cellular technologies was that mobile transmissions were considered as secondary and supplementary compared to government telecommunications system (Prasad & Sridhar, 2014).

3.2.3. Second generation

In the early 1980s, the second generation (2G) was born in Europe, in order to offset to the lack of harmonization typical of the first generation.

The novelty brought by the 2G consisted of digital signals, namely a flow of intermittent pulsing which could be encoded in a binary code (a sequence of zeros and ones). This change has led to a greater spectrum efficiency, and thus, to an enhanced capacity and a communication reliability.

In order to guarantee roaming and spectrum harmonization across Europe, countries and operators had to collaborate together to create a common standard. For this reason, the CEPT established a working party with the purpose to set up and employ a collection of shared standards, based on the 900 MHz band, for a pan-European telecommunications service (Prasad & Sridhar, 2014). Hence, in 1987 operators, by signing the Memorandum of Understanding, agreed on the use of a common standard at the identical frequencies. This standard became known as the Global System for Mobile communications (GSM). The GSM used the 850 MHz, 900 MHz, 1800 MHz, 1900 MHz, and, it supported not only voice calls, but also Short Message Services (SMS) (GSMA, 2017b).

It was already predominant in 2002 (see Figure 5), but it achieved the highest level in 2015, getting 3.83 billion subscriptions and 700 operators in more than 200 countries, compared to its US competitor, the CDMA[2] standard, which reached only 374 million subscriptions.

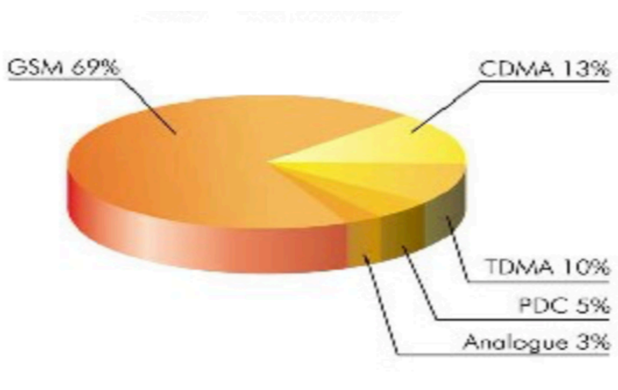

Figure 5. World mobile subscribers at the end of 2002. Source: ITU

The cooperation among countries has been completely effective: as regards operators, it fostered interoperability and economies of scale and scope; while from the consumers point of view, it made possible to create network effects and to cut the prices down.

[2] CDMA is the acronym of Code Division Multiple Access, and it refers to the standard which was developed in the US and is based on the fact that communications are separated by a code. Then, two upgrades were made: TDMA, which divided connections by time and FDMA, which split them by frequency.

The great success of the second generation is due also to the coordinated efforts made by the governments to improve competition and to introduce new entrants. Apart from setting up a national duopoly, some national regulators enacted laws and directives which imposed the presence of new entrants. The most striking example is the German case: the use of mobile devices increased from 9% to 46% after the entry of the new player Mannesmann D2; the new entrant put so much pressure in terms of competition on the incumbent Deutsche Telekom, that Germany constituted a good 79% of the European communications market (Lemstra, Cave & Bourreau, 2017).

To conclude, in 1999 the General Packet Radio Service, known as GPRS, was implemented; it has given birth to an intermediate generation, the 2.5G, whose speed was from 56 to 114 Kbps[3].

3.2.4. Third generation

Despite its great success, 2G entailed two big drawbacks: the first one concerns the interference caused from the TDMA, an upgrade of the CDMA, to some GSM devices; the second one refers to the fact that GSM cells covered a very restricted area (Prasad & Sridhar, 2014).

Hence, the birth of the early smartphones, the development of web services for portable computers and the growth of the Internet required higher connection and communication speed.

For this reason, in the late 1980s, ITU set up the International Mobile Telecommunications for the year 2000 (IMT-2000) with the purpose to create a harmonized standard in all ITU regions. However, United States did not agree with the ITU objective: the US did not want to limit its member states to a single standard, but instead, sought to ensure more flexibility among countries. Hence, it was impossible to create a single worldwide standard. Nevertheless, Europe and Japan cooperated on developing a new plan called Third Generation Partnership Project (3GPP), whose standards were divided into the Universal Mobile Telecommunication System (UMTS) and the CDMA2000 (Prasad & Sridhar, 2014; Lemstra, 2018).

Most of the 3G systems used the 800 MHz, 850 MHz, 900 MHz, 1700 MHz, 1900 MHz and 2100 MHz bands. They were supported by Wideband CDMA (W-CDMA) technology, which used the same network of the GSM, but assured greater speed for Internet connections or video downloading, also reaching speed rates around 300 Kbps.

3G frequencies were the first bands auctioned. The 2G success had brought to such a huge wave of optimism that mobile operators were willing to pay a large amount of money to award the licence (Lemstra, 2018). Nevertheless, the excessive expectations and the way governments planned the

[3] Kbps, or kilobit per second, is a unit of measure which indicates transmission capacity, or just the speed of data. It transfers 1000 bits per second. For the next generations different scales are used: Mbps, which amounts to 1 million bits per second, and Gbps, which is equivalent to 1 billion bits per second.

auctions[4], raised licenses price; moreover, the Internet bubble burst led to a loss of the market momentum and to a delay of the roll-out of technologies (Lemstra, Cave & Bourreau, 2017).
However, the competition remained very fierce and new entrants still played a fundamental role, albeit market shares were lower compared to the 2G ones.
Here, too, a middle generation can be found. In 2005 the High-Speed Packet Access (HSPA) was developed in order to ensure a 14.4 Mbps speed for downloads (GSMA, 2017b).

3.2.5. Fourth generation

As technology became more advanced and possible uses of the Internet increased, the speed of devices had in turn to raise. That is why ITU, in 2008, issued the specifications which 4G might have: large mobility connections would have 100 Mbps as the maximum speed, while the small ones would reach 1 Gbps peak.
As opposed to previous generations, a single common standard was globally accepted, allowing the entire sector to achieve economies of scale. The standard, known as Long Term Evolution (LTE), is the spontaneous development of the previous second and third generation standards and has ensured that new services, for instance online gaming or HD movie streaming, could be used (Prasad & Sridhar, 2014; Lemstra, 2018).
Two versions of LTE can be found. On the one hand, the Frequency Division Duplex (FDD) LTE divides a set of frequencies into the uplink frequency, namely the bandwidth with which the signal is transmitted from the device to the antenna, and the downlink frequency, that is the one used for transmission from the antenna to the device. On the other hand, the Time Division Duplex (TDD) LTE uses the same frequency band both for uplink and downlink, but it divides it into time slots on the basis of the uses that have to be done (Prasad & Sridhar, 2014).
In this case, governments have learned the lesson from the earlier generations, and undertook to promote the coordination of the 4G introduction among countries in order to achieve market momentum, but nevertheless public interests were being put first at the expense of auction efficiency (Lemstra, 2018).

3.3. Mobile evolution: past and current trends

Due to the continuous evolution of technology, the greater availability of networks and the steady decline of the prices, the telecommunications sector is growing continuously.
In 2017, the mobile telecommunications industry generated \$3.6 trillion worldwide, which correspond to 4.5% of the global GDP[5]; while in Europe, during the same year, the sector created €550 billion, the 3.3% of the European GDP, considering both the direct and indirect impacts (GSMA, 2018).

[4] Governments designed auctions in a way that public revenues were optimized, and not the efficiency.
[5] GDP stands for Gross Domestic Product and measures the economic utility created by finished products and services in a particular territory, which can be a nation, a continent or the entire world.

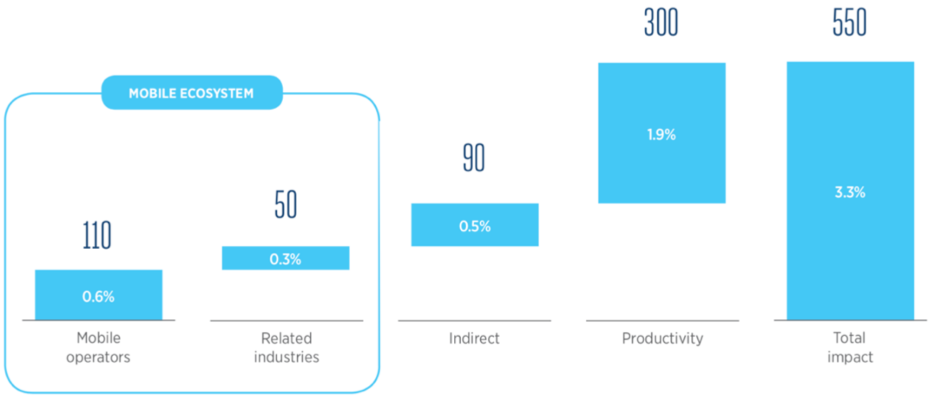

Figure 6. Impact of the mobile ecosystem in Europe in 2017. Source: GSMA (2018)

More specifically, Figure 6 shows that the mobile ecosystem, that represents the direct effects and includes mobile operators and related sectors, i.e. infrastructure providers, device manufacturers and service providers, produced nearly €160 billion (0.9% of GDP).

Furthermore, there is an indirect component composed of the purchases of components from suppliers and it counted €90 billion (0.5% of GDP). Finally, the improvement of productivity for companies and employers generated by the communications system should be taken into account (GSMA, 2018). For example, connections and data access have become more effective due to the introduction of mobile services and Internet applications. €300 billion (1.9% of GDP) were generated thanks to the productivity portion (GSMA, 2018).

The graph below shows the development of some important ICT dimensions, which allows to make few considerations on the mobile market and, more generally, on the communications one.

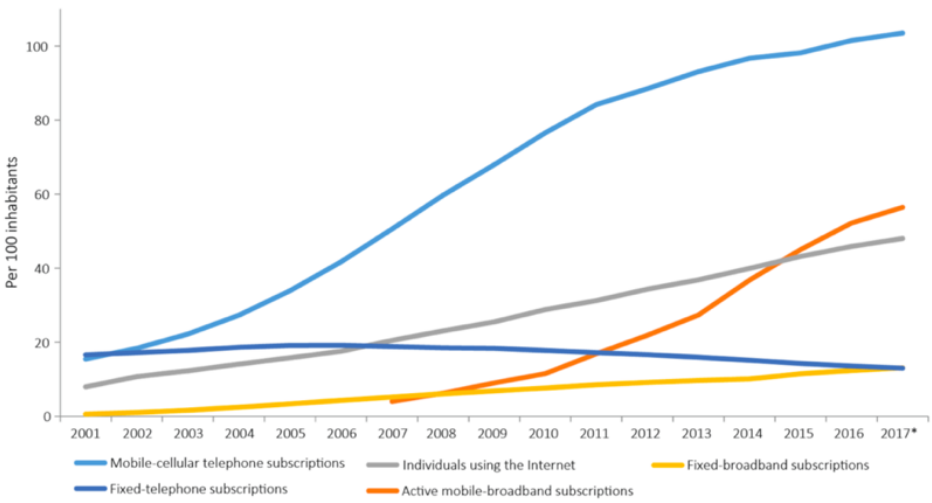

Figure 7. ICT global development. Source: ITU (2017), Measuring the Information Society Report

Firstly, it can be noted that from 2005 to 2011 mobile cellular subscriptions increased significantly, reaching the saturation in 2017.

Furthermore, also the broadband[6] trend is positive, both as regards fixed broadband, whose subscriptions have grown by approximately 183% from 2007 to 2017, and mobile broadband, whose subscriptions per 100 inhabitants have changed from 4 in 2007 to 55 in 2017.

Mobile telephone services are taking over fixed telephone services: the former, in fact, constitute more than 90% of voice subscriptions, while the latter are increasingly decreasing, as shown in Figure 9 (ITU, 2017).

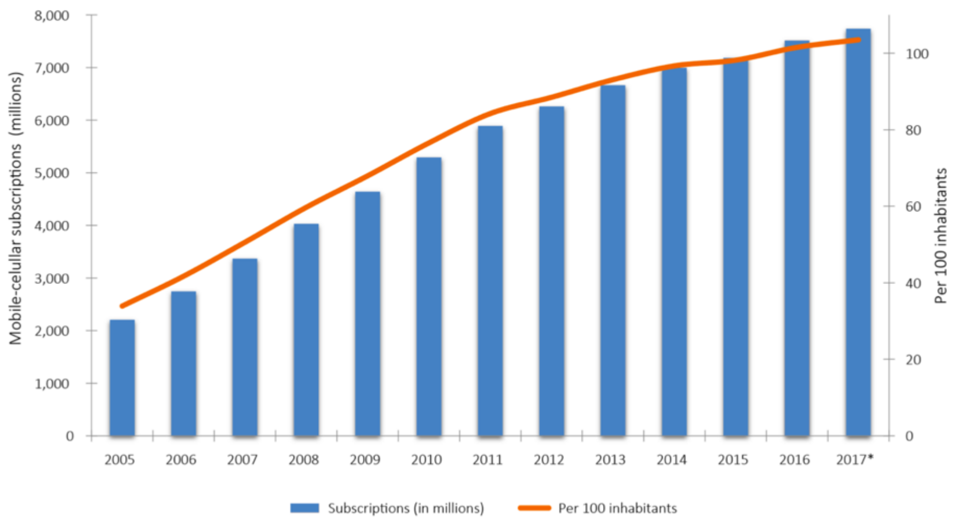

Figure 8. Global mobile-telephone subscriptions. Source: ITU (2017), Measuring the Information Society Report

There are several reasons why mobile subscriptions are rising sharply. The network coverage of mobile-cellular services is particularly wider, thus enabling the reaching of non-urban areas, for instance rural areas or developing countries. Additionally, mobile-telephony prices have been reduced, and therefore some users have decided to keep the mobile line together with the fixed line at the same time, while others have chosen only mobile subscriptions, replacing fixed services (ITU, 2017). Moreover, the introduction of smartphones has led to the availability of different high-quality services, i.e. access to e-mails, video calls or streaming, which were previously possible only through a computer connected to a home line.

[6] Broadband refers to speed services of 256 Kbps or more.

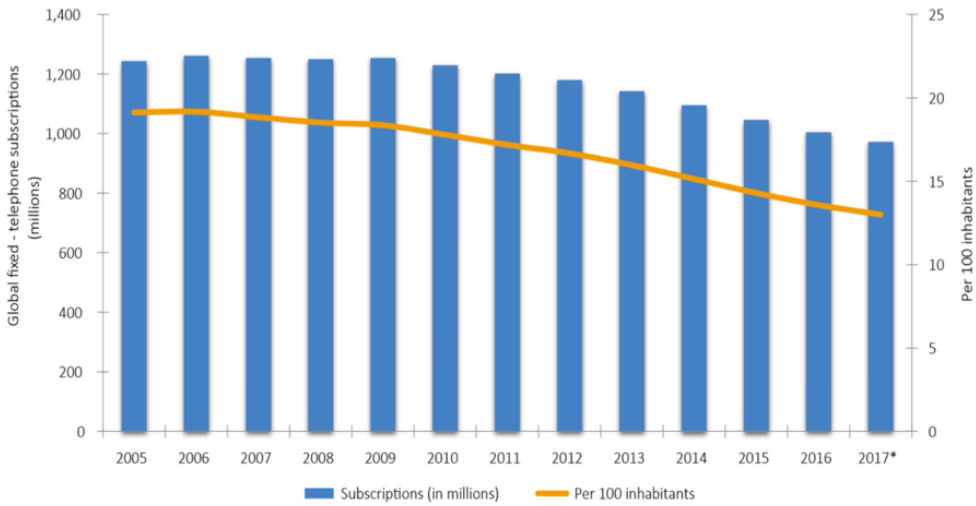

Figure 9. Global fixed-telephone subscriptions. Source: ITU (2017), Measuring the Information Society Report

Figure 8 indicates the trend of global mobile subscriptions between 2005 and 2017: the amount of subscriptions was 2.20 billion in 2005, 5.29 billion in 2010, 7 billion in 2015 and has grown to nearly 7.6 billion in 2017 (ITU, 2017). At the end of the third quarter of 2018, 8 billion subscriptions were recorded.

As shown in Figure 10, except for the African continent, the global population has been overcome by the number of subscriptions. In fact, 8 billion subscriptions are counted, while subscribers are only 5.6 billion (Ericsson, 2018).

This fact means that subscriptions are outnumbering also the subscribers, which suggests that people purchase more than one subscription, with a view to use one mobile phone for personal purposes and another one for business, or to buy a SIM card when they go abroad.

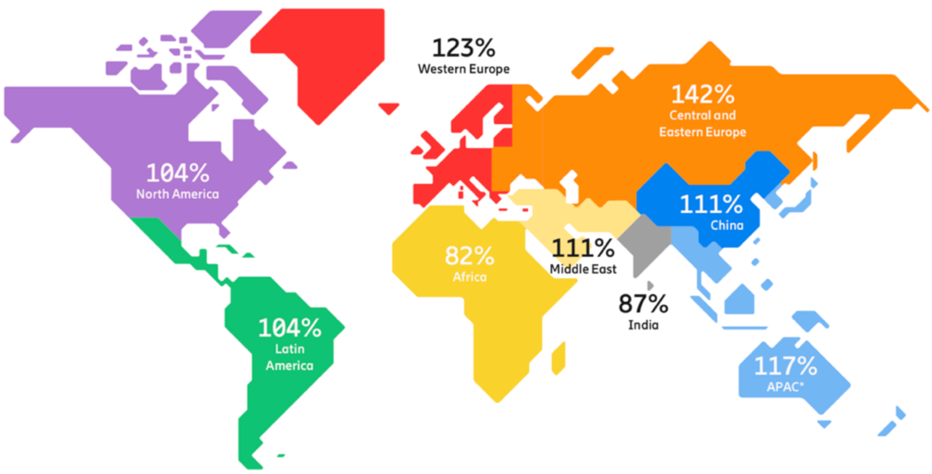

Figure 10. Subscription penetration in the third quarter of 2018 (percentage of population). Source: Ericsson (2018)

3.4. Conclusions

As it can be noted, the shift from one generation to the next one has brought to a technology improvement, but every generation has always showed some issues at a regulatory level, which in some cases penalized mobile stakeholders. Apart from that, trends have demonstrated that mobile has been more and more used, and together with this, new technologies are emerging; hence, a new shift to a new generation is mandatory.

4. The new mobile generation: 5G

4.1. Introduction

After having analysed briefly the previous generations, now the focus can be kept on the 5G. The main technologies introduced by 5G, and the changes that it could bring in the future are assessed.

4.2. Future trends

As regards the future, the mobile sector will be contributing increasingly to the economic structure of Europe. If in the 2017 the communications industry produced €550 billion and the GDP amounted to 3.3%, in the 2022 these values are expected to be €720 billion and 4.1%, respectively (GSMA, 2018). On the other side, in terms of costs, the EC has estimated that the 28 Member States will spend €56 billion in total in 2020.

The new mobile generation, the 5G, will be introduced in Europe around 2020 and it is designed to live together with the 4G in the early stages of deployment, but also by delivering several technical improvements, for example higher data rates, lower latency and greater efficiency.

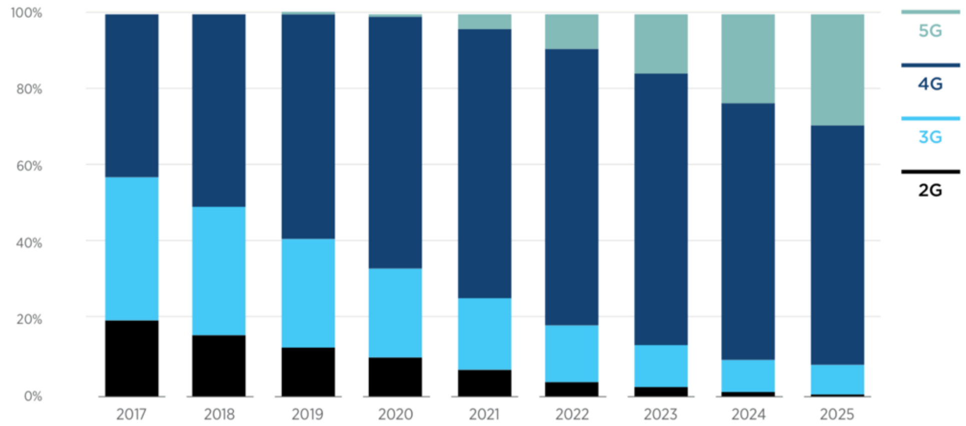

Figure 11. European connections divided by mobile generation. Source: GSMA (2018)

The new mobile generation incorporates a series of innovations, which will contribute to a redesign of business models for firms, to technical improvements within several industries and, more in general, to a social and economic benefit.

The need to shift to the 5G deployment is due to the fact that the development of new services and applications requires an upgrade of broadband solutions so as to guarantee improved speed, performance and reliability. Hence, the 5G represents both an improvement of services provided by the previous generations and an addition of innovative services.

One of the most important phenomena that is taking in place in the recent period, is the so-called Internet of Things (IoT). It consists of a widening of the Internet connectivity to any non-technological, everyday device. Every object can also interact with the others, in order to create a network of more devices connected to the same Internet line; this capability bears the name of "Machine-To-Machine (M2M) communications". The IoT embraces a lot of different fields: smart energy, smart grids, smart cities, smart homes, health monitoring, self-driving cars, precision farming, Intelligent Transport System and Industry 4.0.

Cisco's analysis has foreseen that, by 2022, M2M connections will account for 63% of all Internet connections (Barnett, T; Andra U. & Khurana T., 2018).

The figure below shows the evolution of every industry vertical in Europe: smart homes are and will be the prevailing applications in terms of number of M2M devices connected, followed by smart offices.

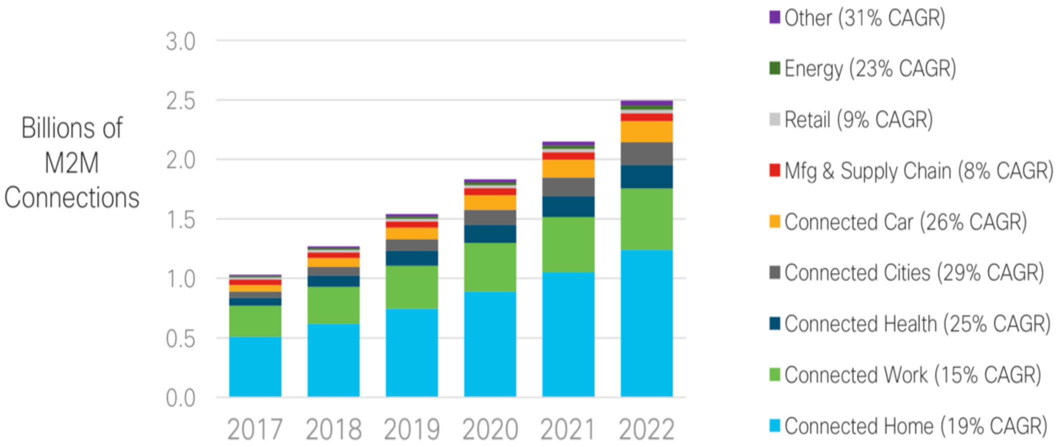

Figure 12. European M2M connections divided by industry. Source: Barnett, T; Andra U. & Khurana T (2018)

4.3. 5G novelties

4.3.1. 5G technologies and 5G usage scenarios

ITU-R has set eight objectives to achieve technical enhancement for IMT-2020[7]. As shown in the figure below, principal requirements are: peak data rate, user experienced data rate, spectrum efficiency, mobility, latency, connection density, network energy efficiency and area traffic capacity. Every measure ought to have a greater value than the IMT-advanced's one (4G), taking always care not to have a greater energy consumption or higher resource usage.

[7] IMT-2020 (International Mobile Telecommunication 2020) system specifies the key requirements for the development and the deployment of 5G. IMT-advanced, instead, included the specifications for 4G.

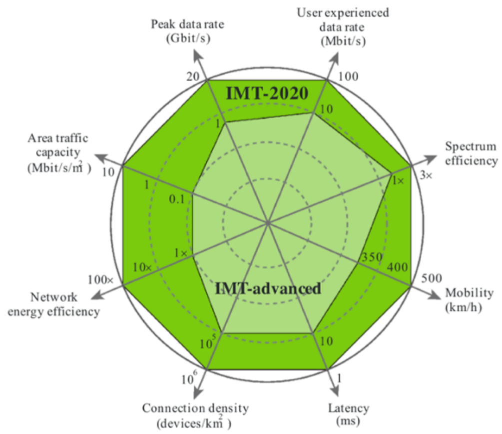

Figure 13. The eight capabilities of IMT-2020. Source: ITU (2015b)

For example, peak data rate, which is the highest data transfer speed obtainable, is supposed to have a value of 10 Gbps, or under specific circumstances, it should reach 20 Gbps, in contrast to 4G, whose maximum value is 1 Gbps. The minimum data rate which is obtainable for a user in a specific area, the so-called user experienced data rate, will reach 100 Mbps. Latency is the time that passes between the transmission and the reception, and it would measure 1 millisecond, compared to the 10 ms of IMT-advanced (ITU, 2015b).

The new services which will be brought by 5G deployment, can be summed up into three use cases (see Figure 14) (DotEcon & Axon, 2018; ITU, 2018):

- Enhanced Mobile Broadband (eMBB): this scenario aims to ensure that a user can have connection everywhere, at any time. It includes a better coverage and a superior network connectivity, ensuring that small cities are covered by a high-speed band, users can benefit from high-speed home streaming and from services on demand, and finally augmented and virtual reality can be implemented;
- Massive Machine-Type Communications (mMTC): the massive number of devices connected characterise this use case. The availability of structures equipped with low-power sensors allows the deployment of IoT applications, smart cities and smart homes in crowded cities, and the usage of smart agriculture in rural areas;
- Ultra-Reliable and Low Latency Communications (URLCC): this case is characterised by very high reliable and low latency connections, which can guarantee the maximum security and safety. This enables the use of autonomous vehicles, the communication among cars and remote monitoring.

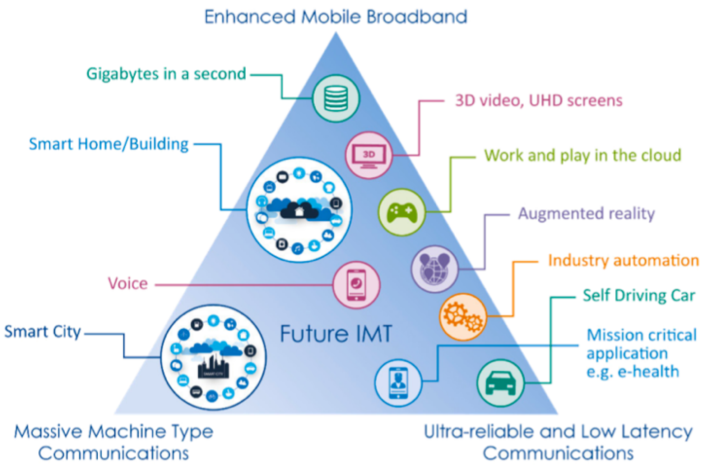

Figure 14. 5G usage scenarios. Source: ITU (2018)

The purpose is to adapt these capabilities to the three usage cases. Hence, every requirement plays a different role and has a different relevance in respect of the context, as shown in the figure below.

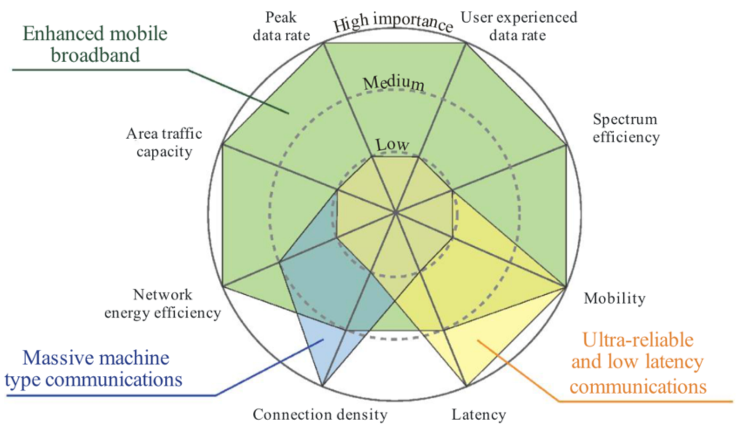

Figure 15. The relevance of the eight requirements in the three use cases. Source: ITU (2015b)

For the "eMBB" case, peak data rate, user experienced data rate, spectrum efficiency, mobility, network energy efficiency and area traffic capacity assume the most important role; for example, spectrum efficiency is essential to improve a better connection in both urban and rural areas.

The lowest possible latency, and mobility are the key factors of the "URLCC" case, on the ground that a great speed of transmission is crucial to ensure the proper functioning of security applications and automated vehicles.

In order to comply with the "mMTC" case, a significant connection density, namely the maximum number of devices connected in a certain area, is crucial for ensuring that the greatest possible amount of systems can connect and transmit.

4.3.2. Virtualization

Over the past years, due to the roll-out of new devices, services and applications, the amount of data transmitted via networks is increasing more and more, and therefore mobile stakeholders are continuously looking for cost effective, flexible and innovative solutions, in order to satisfy this massive demand. For this reason, network architectures and infrastructures must be reorganized in order to keep up with the pace of demand and traffic increment.

Furthermore, infrastructures and, more generally, hardware facilities have several issues: physical instruments are so bulky that they have space problems, operating costs are becoming more and more higher, skilled staff performing technical tasks on hardware is lacking (Lemstra, 2018).

Consequently, it has been decided to introduce network virtualization, which consists in dividing a single physical network into several virtual interfaces, in a way that only software applications are enough, without the need for hardware structures (Zhang, 2018).

Network Function Virtualization (NFV) is the deployment of many software applications that work on a universal hardware instead of using and developing a specific hardware, like for example routers or firewalls. Software Defined Networking (SDN) reconfigures network in real-time, so that other users can have access to the network and manage resources by themselves.

Network slicing enables to create several virtual networks from the same physical infrastructure; each virtual network owns different features that permit to offer a particular service for satisfying a specific user segment (DotEcon & Axon, 2018; ITU, 2018).

This method allows to reduce costs and to reuse resources for different purposes. Moreover, it removes the entry barriers, enabling the entrance of new players in the mobile ecosystem, for example verticals, that will be discussed in the next section.

4.3.3. Verticals

Virtualization increases innovation and enables to create new business models, besides the fact that many industries can be reshaped and can tailor their services in their own way for a specific industrial sector, without the need of building a physical network. These sectors are known as “verticals” and they will give rise to a redefinition of many industries, and consequently they will be useful to create innovative products and services, as well as enhance economic growth and productiveness within them.

Among verticals can be found (i.e. GSMA, 2017b; DotEcon & Axon, 2018):

- Automotive and transport: self-driving cars, vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P);
- Entertainment: Virtual Reality, Augmented Reality (AR);
- Utilities: smart grid, smart metering;
- Healthcare: remote monitoring, wireless surgery, smart wearables, Artificial Intelligence (AI);

Thanks to verticals, a new type of players might be introduced in the market, the Virtual Mobile Network Operators (VMNOs). They would have the role of retailers and their purpose is to serve vertical industries. They can be verticals themselves, and thus derive from the information technology division, or from the ICT services' suppliers, from a specific division of mobile operators or from start-ups (Lemstra, Cave & Bourreau, 2017).

4.3.4. Spectrum sharing

With the increase of the technical capabilities offered by 5G, the need for spectrum increases more and more in turn. For this reason, it has been necessary for regulators to think about other solutions other than the usual exclusive property rights, obviously with always taking into consideration the fact that harmful interference must be avoided.

Spectrum can be shared both for low and high frequencies, in different ways on the basis of their nature. Since high frequencies are characterized by a low propagation, they can be shared by dividing the band in a geographical area, but they can also be shared in terms of time batches, hence a user can utilize it in a specific period. Instead, low frequencies can provide a really broad coverage, and thus sharing them on a geographical basis can be risky for the problem of harmful interference. Hence, for this type of bands, a dynamic use of sharing is required, in the sense that spectrum can be used when the owner or other operators do not utilize it.

In summary, spectrum sharing is a valuable resource for the pace brought by 5G and regulators are making efforts to make it possible, given that spectrum can be used in the most efficient way, since spectrum which is not used by the owner can be utilized by other players and coverage can be improved. Moreover, particular users who would use it in restricted area can be attracted.

4.4. Pioneer spectrum bands

As happened in the previous transitions from one generation to the next one, the new mobile technology leads to several improvements, for example spectrum efficiency, and therefore, a greater amount of spectrum is required so as to ensure that this progress can occur.

In order to meet coverage and capacity objectives set out by governments with regard to the next mobile generation, both low, middle and high frequency ranges are needed.

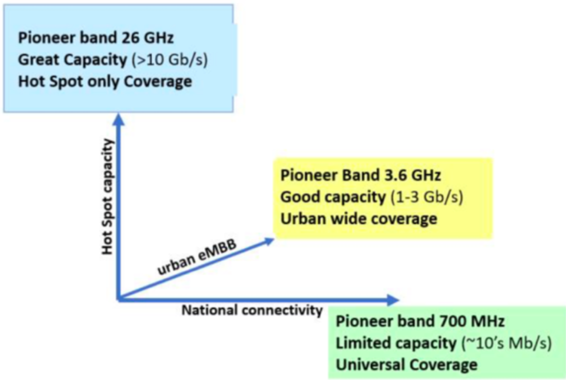

Figure 16. Pioneer 5G spectrum bands. Source: 5GPPP (2018)

As regards spectrum below 1 GHz, the EC has decided that the pioneer band should include the range from 694 to 790 MHz (700 MHz). This wide-coverage band is intended to serve both rural areas, by providing broadband services and widespread coverage, and crowded areas, by offering the opportunity to use new digital services in indoor environments (Decision 2017/899).

The 3400-3800 MHz band is useful for covering a fairly broad area, and also for providing a good capacity. This frequency range is supposed to be the first pioneer band that will be used for providing 5G services. In addition, this band is already harmonized across the European territory, and it allows to exploit economies of scale and consequently to produce low-cost devices.

Finally, the real novelty of 5G is the introduction of bands above 24 GHz in order to enable the provision of greater data rates. European regulators have identified 24.5-27.5 GHz as the high-level pioneer band. It ensures that operators and other stakeholders can provide high-capacity services, create new business models and pursue innovative strategies.

Figure 17. Pioneer bands and their uses. Source: Huawei (2018)

The EC is also focusing on other spectrum bands above the 24 GHz, which can be used concurrently with the pioneer bands. The so-called millimetre Waves (mmWaves) are characterized by high energy and capacity, which are balanced by a very narrow coverage.

4.5. Evolution or revolution?

The fact that 5G can bring an evolutionary or revolutionary change within the mobile environment should be discussed.

Firstly, it can be assessed if the determinants of the 5G innovation come from a technological evolution, irrespective of the consumers' demand or, by contrast, from market needs and society in general, by adapting the technological development to these requirements. 5G evolution is undoubtedly driven by technology: research and innovation have led to a set of new technologies, like the IoT, smart homes, AR and AI, which in turn have required a significant development of mobile solutions, in order to support these changes. In this case the demand is inactive and passive, and it will adjust to the technology subsequently.

With regard to the distinction between the two changes, the evolutionary case is an incremental change of the previous mobile generations that includes technical improvements, but it does not imply a substantial variation in the structure of the system, by keeping the previous mobile incumbents in power. The revolutionary case, on the contrary, represents a substantial rupture with the previous solutions, and, it can lead to a considerable modification of the mobile industry structure and to the introduction of new players; for example, virtualization will allow the entry of the VMNOs, which are verticals, or serve them in a tailored manner, or even Over-The-Top (OTT)[8] providers, like Facebook and WhatsApp.

These two cases represent the two extremes, but a combination of them will be most likely to emerge, having regard also to the fact that the result depends on the decision of many actors such as mobile operators, vertical firms, regulators and countries (Lemstra, Cave & Bourreau, 2017).

4.5.1. The evolutionary case

The evolutionary case, which constitutes only an incremental development of 3G and 4G, provides that incumbent operators will maintain their leadership position. The fact that bands above 24 GHz will be introduced, does not allow the entry of new mobile operators, since also other bands, which have already assigned, are required for providing coverage and capacity.

Furthermore, incumbents are not encouraged to make new investments, but rather, they prefer to exploit the old ones, due to the fact that there is a presence of sunk costs[9] and, as shown in Figure 18, costs

[8] OTT stands for services and contents (i.e. streaming or TV contents) providers through Internet access. There are several types of OTTs, and the most famous ones are Amazon, Netflix, WhatsApp and Facebook.

[9] Sunk costs make the marginal costs of the previous technology lower than those of the new technology.

become greater along with the transition to a new technology. This situation can slow down the introduction of 5G, and therefore its adoption can be delayed.

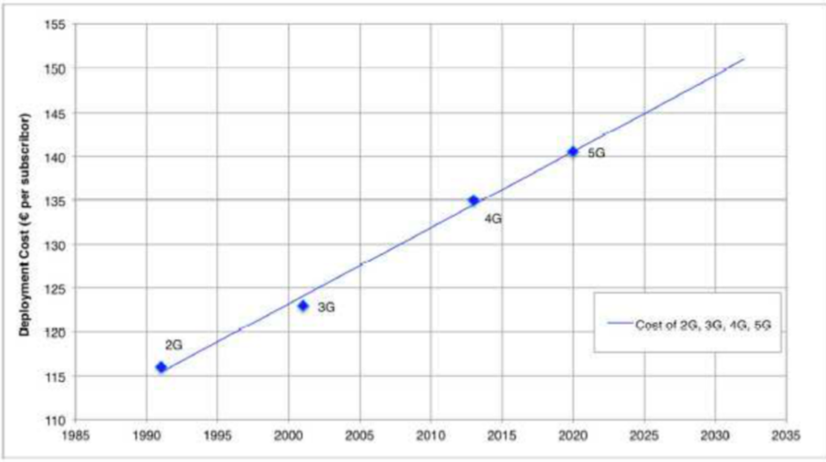

Figure 18. Costs per subscriber of mobile generations. Source: Lemstra, Cave & Bourreau (2017)

As regards virtualization, the task of delivering virtual telecom services will be always in the mobile operators' hands: in order to defend their future leadership in mobile services provision and maintain their dominant position, they will probably integrate vertically, by concluding tying agreements with software service suppliers. By using their strong market position, mobile operators oblige their partners to not serve other possible competitors. This fact increases market power of incumbents, which can add more value to their offers, and constitutes certainly another barrier to entry for smaller players.

Briefly, in summary, mobile market in the evolutionary case will remain an oligopoly composed of a small number of high-power incumbents.

Instead, regulators want to continue to pursue a lean policy like the one of 3G and 4G, by leaving the market the task of self-regulating. The "5G Action Plan" aims to the encouragement of European countries to cooperate with regard to a coordinate launch and introduction of 5G, to harmonization of bands and to the assurance that a right amount of spectrum is allocated at a proper time. Hence, this action plan has the purpose to ensure coordination among member countries in order to facilitate economies of scale and scope, but it does not aspire to impose a strict regulation (Lemstra, 2018).

4.5.2. The revolutionary case

This use case, on the contrary, describes a completely radical and disruptive change in the mobile sector and in business models.

Before introducing the changes that the revolutionary case can bring, a distinction shall be made among the different types of operators:

- MNOs: these operators are the owners of the network infrastructures and are those who hold the frequencies acquired from the spectrum assignments. If they have excess capacity, they can decide to lease their networks to other operators. For example, Italian MNOs are Vodafone, Tim and Wind Tre;
- Mobile Virtual Network Operators (MVNOs): they offer their services relying on the MNOs' infrastructure. They can provide only connection and application functions, but also customer care, marketing and sales services;
- VMNOs: they are the new type of operators and they will be introduced below.

Hence, the new generation is characterized by the novelties carried by the virtualization, which are the adjustment of applications to several industries based on their requirements, made by new actors, called VMNOs, which give priority to their customers, to the relationship with them and to how optimize their satisfaction.

Hence, the revolutionary case introduces a new type of market players, the VMNOs, which compete also with OTT providers at the retail level in offering specialized services to specific vertical industries. While, if only mobile operators should serve different sectors, they would fail and would slow the roll-out of 5G, since they have an inertia in changing from a paradigm to another one, and they lack sector skills and expertise, which are essential to guarantee an effective service (Lemstra, Cave & Bourreau, 2017).

In these circumstances, a huge change in the mobile industry and business models will take place, and for this reason, higher investments and greater efforts in the communications industry will be required to keep the pace with these modifications.

A significant change in the value chain would take place: as shown in the figure below, few mobile operators own network infrastructure and spectrum licenses, and provide connection to a multitude of VMNOs at network level, which compete with each other and in turn offer tailored and specific services to a particular vertical industry at the retail level.

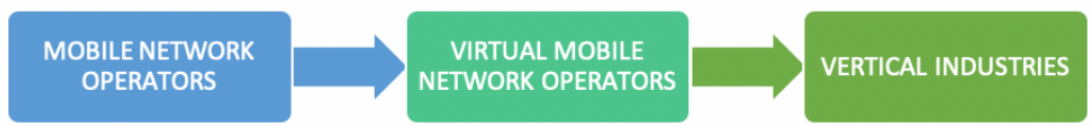

Figure 19. The new value chain

Regulators in this case should apply a greater control, but also in this case, a flexible policy is essential to ensure that virtualization achieves the best possible results, in terms of both enhanced competition and improved innovation.

4.6. Will 5G replace fixed wireline?

As already mentioned in the previous sections, 5G technology will lead to different novelties and changes in the mobile sector, among them the introduction of the high-frequency bands, the so-called mmWaves. These bands are able to provide high capacity, granting a maximum speed rate of 1 Gbps, almost like the speed assured by the fixed fibre connections.

With the advent of the 2000s onward, mobile subscriptions have been constantly increasing relative to fixed subscriptions, which basically have remained stationary (Figure 20). This is due to the fact that, with the introduction of smartphones, a person can carry out more and more functions and applications on his mobile device, from the access to e-mails and cloud services, to the music on streaming (i.e. Spotify) and more recently to the control of any electrical appliance (smart home).

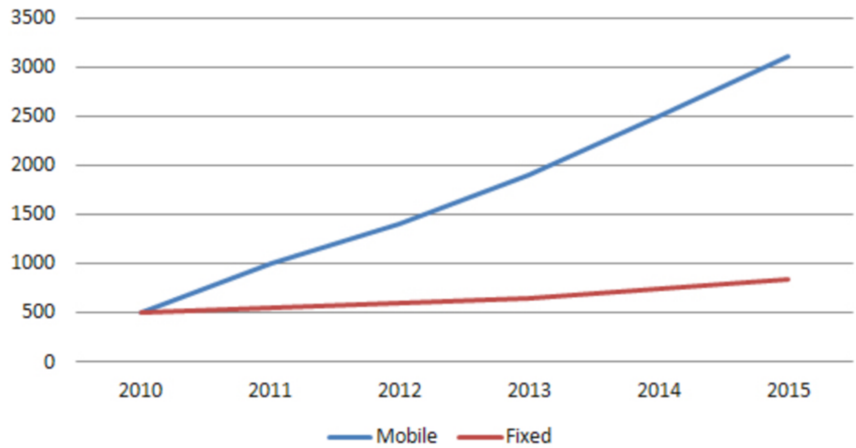

Figure 20. Mobile subscriptions and fixed subscriptions. Source: Wireless Intelligence

Since 5G technology is promising to offer very greater performances than previous generations, software developers are increasingly concentrating on mobile applications and customers are more and more favouring mobile use, one may wonder if mobile wireless, and 5G, can substitute fixed lines definitively.

Before trying to answer this question, a brief description on how mobile wireless and fixed wireline systems work is necessary. Three different types of fixed solutions are present: coaxial cables, copper cables and fibre. Nowadays, a lot of hybrid fibre-copper solutions are being widely used in the fixed sector, since they are able to provide better performances than the single technologies; among them VDSL and G.fast can be found.

For simplicity, only the differences between fibre and mobile will be explained. The ways in which signal is transmitted differ for fibre wireline and mobile wireless. In fact, fibre is composed of a cable, in which slim filaments of glass or plastic pass, and it is usually installed under the ground; the signal, in the form of a beam of light, is propagated for long distances, by making it bang against the walls thanks to the reflection phenomenon.

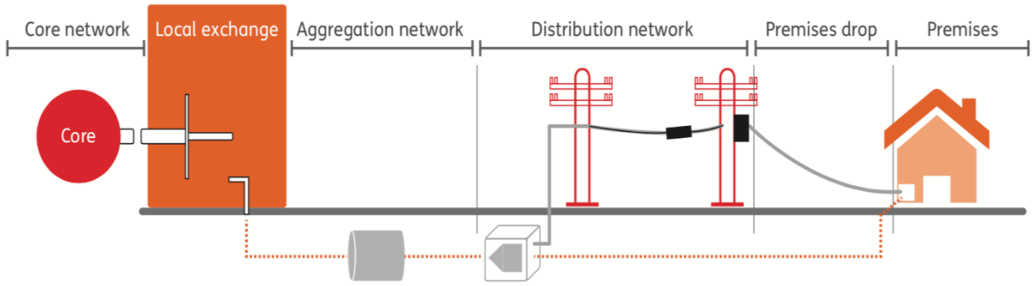

Figure 21. Example of fiber line. Source: Ovum (2018)

Instead, as already discussed, mobile signals are transmitted by an antenna in form of a wave that travels in the electromagnetic field.

Figure 22. Example of wireless line. Source: Ovum (2018)

Coming back to the initial question, supporters of the complete substitution of fixed lines with mobile ones, affirm that:

- Mobile is prevailing on fixed both from the supply side and from the demand side;
- 5G is able to offer the same performances guaranteed by the fixed fibre;
- 5G can provide better performances in rural and less densely populated areas, where fixed lines and fibre are not able to provide a very effective service;
- The deployment costs and time of wireless are less than installing fibre (for example FTTH requires a Capex of €360 billion, while 5G a Capex of €200 billion), and furthermore, the installation of wireless systems requires a less invasive intervention, since it does not need to knock the walls down;
- Operators can exploit economies of scale that would create by the installation of only similar systems and the usage of the same technology.

Despite a replacement would be useful for many stakeholders of the telecommunications sector, supporters of the preservation of fixed lines may argue that:

- MmWaves are able to provide high capacity, but, on the other side, they are exposed to the problem of interference, they cannot penetrate foliage and buildings, so the installation of an extra microcell is necessary to propagate signals inside the buildings, and they suffer from the line of sight problem, which consists in the fact that an antenna can propagate the signal as far as it "sees"; hence, as regards densely populated areas, fixed lines proof that they are still the best in providing services;
- It is true that the costs of installing wireless would be less than fibre, but the costs for connecting and running (electricity, maintenance, replacement) the wireless would be superior, thereby resulting in the same or higher total costs of ownership, as depicted in Figure 23 (Ovum, 2018);

5G-FWA	42%	22%	40%	104%
FTTP	78%	14%	8%	100%
	Build	Connect	Run	TCO
	CAPEX		OPEX	TCO

Figure 23. Costs per connection for 5G-FWA and for FTTP. Source: Ovum (2018)

- It is true that mobile phones are able to support more and more services, but there are applications which require the use or the download of a so huge amount of data, that it is impossible to run them on a mobile device;
- There is still a high uncertainty of some performances of 5G, as well as the placement of new 5G stations.

Furthermore, 5G will need itself of the use of the fibre. The deep fibre network, in fact, is the term used for describing that the last-mile connection is wireless, and the fibre is necessary to deploy networks at the backhaul level[10] (Thompson & VandeStadt, 2017). In addition, 5G is giving birth to applications which will necessitate of a high reliability: for example, self-driving cars require the installation of fibre in order to assure that connection is always guaranteed (Figure 24).

[10] Last-mile is the term used for the connection from the premises (houses) to the station, while backhaul is the connection from the stations to the backbones.

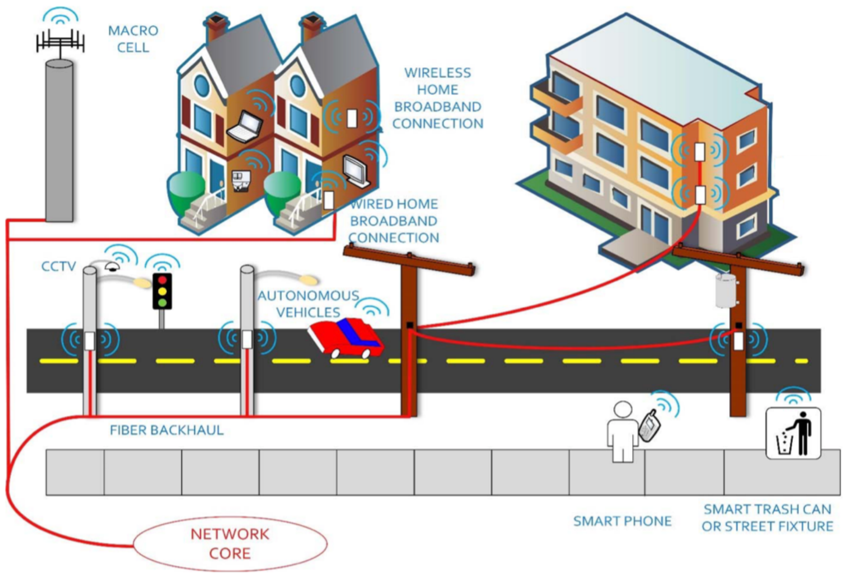

Figure 24. Example of how fiber and wireless coexist. Source: CTC

However, both 5G and fibre require long times for their development, and it is impossible to develop either one of them (Bourreau, M. et al, 2017).

In light of these considerations, it is very likely that the 5G will not play the role of substitute of fixed wireline, instead, fixed wireline and mobile wireless will be complements for each other, and they will work together in a way that some synergies will improve the quality and the capacity of the connections. The usage of fixed and mobile resources in a mixed way turns out to be the best solution for providing, in a rapid and economic way, effective services able to meet the demand.

The way the technologies (fibre, copper, wireless) will be mixed together depends on the conformation of the territory (urban and rural areas) and on the availability of resources (i.e. lines, antennae). For example, the so-called Fibre To 5G (FT5G), in fact, is the notion which describes a hybrid system which puts together 5G wireless (used for the building-station connections) and fibre (used for the station-backbone and backbone-backbone connections), in order to increase the rate of speed for connections. In this case, an extensive use of wireless is made, while fibre is used when necessary (Williamson, 2017). Another example can be the Fixed Wireless Access (FWA), that is a system composed of fixed stations linked together by a wireless line, which provides very high speeds.

It is noteworthy, however, that, due to the fact that people are moving towards a mobile-only usage and that applications developers are elaborating more and more applications adjustable to smartphones, the mobile is having an expansion that is greater than the fixed, and this fact is also bringing fixed operators to add at their business also the mobile field and thus compete with the traditional MNOs.

4.7. Regulation for the new mobile ecosystem

Finally, it could be useful to evaluate the role of the regulation in this context full of novelties. The mobile market, and, more generally, the digital and telecommunications ecosystem is characterized by continuous breaths of fresh air, in the sense that, thanks to technology improvements, new products and new services are increasingly getting to the marketplace. For this reason, it is imperative to assess if regulation policies keep up with the pace of innovation and the dynamic market which is establishing.
There is the risk that, if the regulators do not adapt to the emerging changes, costs can result higher, innovation can be slowed down and hence consumers may not benefit of it. Authorities must strive to ensure the best possible regulation in order to facilitate the right flow of innovation and the appropriate investments that will allow the supply of efficient 5G services.
For example, the presence of the so-called verticals will bring to the introduction and delivery of new types of products and services. Moreover, the ecosystem of mobile market can change radically, since the traditional final consumer becomes only one of the potential costumers, because, like it was said previously, every vertical will become a different business for mobile operators.

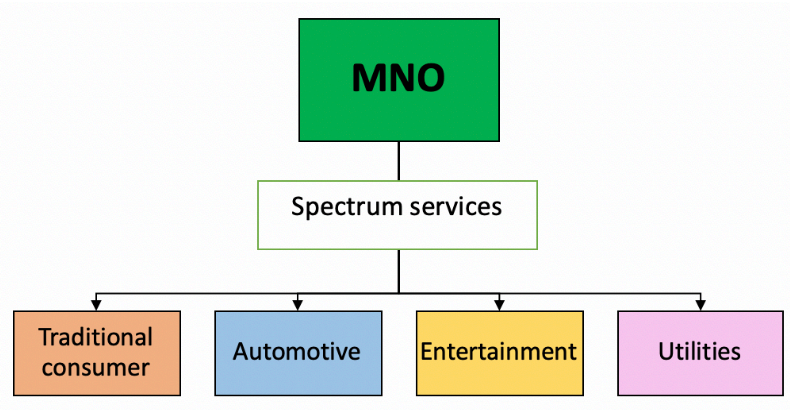

Figure 25. New potential structure

The figure above provides the hypothetical situation that could occur if an operator serves both the traditional consumer and the vertical industries. However, it is possible that mobile operators are not able to provide these verticals with a tailored effective service they need for their specific activity. Hence, a specific vertical can be interested to have some frequencies for its own, thus becoming a competitor of MNOs in the acquisition of spectrum (left side of Figure 26), or even it can enter into a partnership with an operator in order to place themselves at the same level (right side of Figure 26).

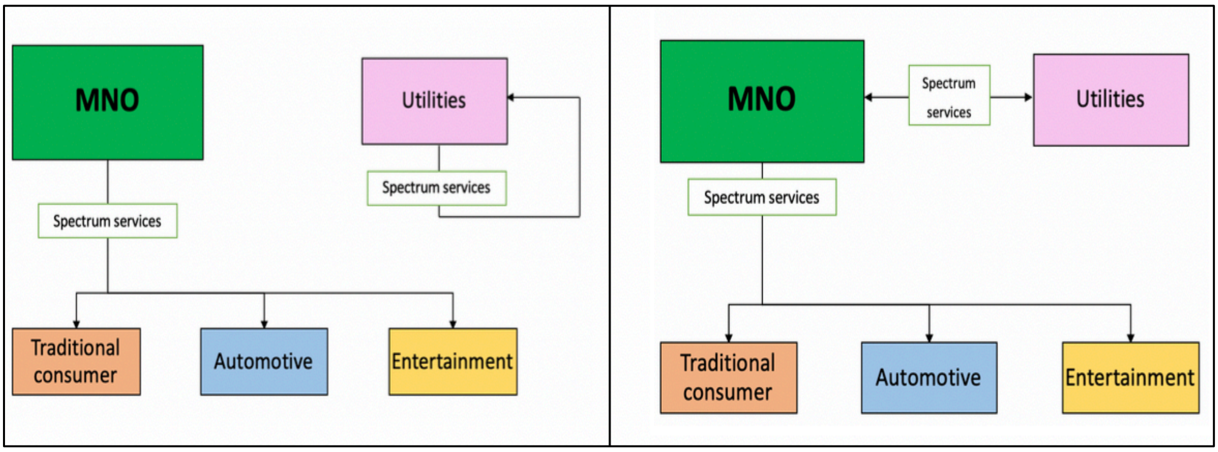

Figure 26. Variants of the potential new structure

Regardless the type of situation that it will be created, regulation must leave room for firms to innovate their products, by lowering *ex-ante* constraints in order to ensure the right amount of investments and by intervening only if competition is harmed.

Instead, as mentioned above, a new type of players, called OTTs, entered the market, by offering several services, like voice calls, messages, video, music; they can serve consumers for free (i.e. WhatsApp, Facebook), by making them to pay if they use a certain amount of data (i.e. Skype) or by making them to pay for the contents they offer (i.e. Netflix).

It is clear that these new service providers are competing with the traditional mobile operators. Suffice is to say that after the advent of WhatsApp, the volumes of the normal messages are decreased consequently (Figure 27).

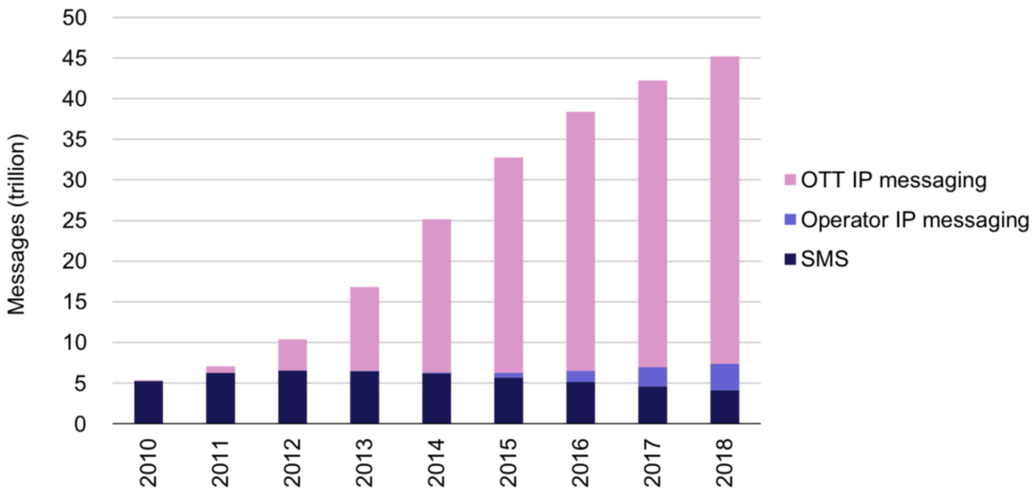

Figure 27. Messaging volumes. Source: Sale (2014)

The concerns that arose from events of this type in terms of regulation are that the OTTs and traditional mobile operators are regulated in two different ways, giving birth to a discriminatory regulation. In fact, mobile operators are regulated by the strict *ex-ante* regulation made for telephone firms, while OTTs are just subject to the general antitrust rules (GSMA, 2016). This difference leads to weakening and to negative impacts for incumbent operators, since, other than they have to face high network and infrastructure costs that others do not, they are constrained by a stricter regulation.

Imposing the same *ex-ante* regimes also to OTTs, or new players in general, could be counterproductive, considering that innovation may be affected, and so, also the overall social welfare. Moreover, it would be impossible to assign the same criteria to such a wide variety of players.

The best solution could be to make the regulation technology-neutral (Bourreau, M. et al, 2017), in the sense that it does not have to be based on the services offered or on the type of the firm, but only on the purpose that regulators want to achieve: in this case regulation would be called functionality-based, it focuses on objectives which are wanted to be achieved and directs the efforts on reaching these objectives, not considering which technology is used (GSMA, 2016).

It is clear that a regulation is still needed with the aim to ensure that anti-competitive behaviours are avoided, and that competition is guaranteed, but *ex-ante* regulation must be kept to the minimum possible, in order to make sure that costs will not raise too much, and consumers can receive a high-value product.

However, due to innovation, the uncertainty for regulation increases, and an *a priori* market analysis in terms of competition becomes more difficult. Hence, *ex-post* regulation must not be static, since it may slow technical progress and penalise the final consumer, but it shall be flexible, which will reason on a case by case basis and will be able to adapt to constant changes on the market.

4.8. Conclusions

It is clear from this chapter how 5G, besides the improvement of 4G services, will provide both novelties that are going to change radically the telecommunication sector and a total support for different sectors (verticals), other than the enhancement of the entrance of new types of firms and the use of new business models.

Hence, regulators must at the same time leave freedom for facilitating investments and innovations, but they must control that competition is always ensured and that competitors are treated in the same way.

5. Spectrum assignments

5.1. Introduction

Since the purpose of the next chapter is to assess if 5G auctions facilitate the entrance of new players, it is useful to describe the different ways to assign spectrum, as well as, the types of auctions and their upsides and downsides. Finally, the instruments to enhance competition that regulators have at their disposal are listed, so as the practical cases can be compared with the theory.

5.2. Assignment methods

After the international allocation of frequency bands from ITU, the member states are in charge of assigning the spectrum, by applying the method they deem it more appropriate to achieve the highest level of efficiency.

Nowadays spectrum auctions are the default method used to award spectrum licenses. Nonetheless, governments and regulators had been using different means of assignments: 1G and 2G spectrum was assigned through beauty contests, auctions were introduced to assign 3G bands, together with beauty contests, and finally most of 4G and 5G assignments were and will be carried out through the use of auctions (Lemstra, 2018).

A brief explanation of the main methods used to assign spectrum is given: lotteries, first-come-first served methods, beauty contests and auctions are described below.

Method name	Time consumption	Efficiency level	Revenues generation
Beauty contest	Time consuming	Marked by red-tape	Not much
Lottery	Time efficient	Least efficient	Not much
First-come, first-served	Time efficient	Less efficient	Not much
Auction	Time efficient	Efficient	More revenues

Table 4. Assignment methods. Source: Jilani (2015)

5.2.1. Beauty contests

Beauty contests, also called administrative methods, consist in a companies' application and a following selection by regulators of the winning operators, which may receive a specific spectrum band on the basis of several criteria, such as financial conditions, experience developed, geographical coverage, technical and business competences, decided by governments too. Hence, the governments hold all the power in the choice.

The good thing of beauty contests is that the governments can choose who will be the most appropriate winner, the selection is in line with the objectives of governments and companies can achieve bands at a very low price.

However, the use of beauty contests leads to several drawbacks. First of all, beauty contests are excessively time consuming; regulators use a large amount of resources and spend long time analysing companies' claims, thereby delaying the introduction of new technologies to the market. Secondly, operators are willing to fake and overstate criteria in their applications, leading to an absence of transparency and credibility. Moreover, they have an incentive for corruption, collusion and lobbying, thus weakening competition.

5.2.2. Lotteries

Lotteries concern the choice of the winning bidders using random draws, without any selection criteria. In contrast to beauty contests, lotteries are faster and cheaper in terms of resources, since there is no need to examine hundred pages of claims. Moreover, they eliminate the risk of anti-competitive behaviours.

Nonetheless, some weaknesses occur for this type of assignment. The first thing that can be noticed is that this method draws no distinctions among the companies: regardless of the type and the efficiency level of the company, the winner is chosen only on the basis of the fate, beside the fact that lotteries do not offer the opportunity to apprehend if the winning firm has the technical capabilities to manage the license or is the most willing to use the license. Moreover, lotteries do not generate revenues for governments, unless they demand some payments for the acquisition of the licence or ask for a usage fee.

In addition, where the spectrum trading is granted, it is very likely that there will be speculation: if a winner is not interested in using the licence, it can sell it at exaggerated prices to other companies.

Governments, to solve some of these issues, could investigate whether the applicants might use the licence in an effective way, but that would involve a lot of resources.

5.2.3. First-come, first-served mechanisms

The first applicant who requests for the licence, will win it. This method is inexpensive, not time-consuming and entices the most willing user to commit itself as much as possible to be the first who applicates for the licence.

Unfortunately, the "first-come, first-served" technique leads to the same disadvantages of the abovementioned methods: two or more firms might collude and combine their efforts to win the license, speculation is very likely and no revenues can be created.

These three administrative methods were suitable for the past, when demand of spectrum, and hence the number of potential users, were very limited, compared to the supply. With technology evolution, demand has increased more and more and thus these approaches do not work anymore for ensuring an effective and efficient assignment of the bands, since firms tend to have improper and anti-competitive behaviours.

5.2.4. Leave it to the market: auctions

The theoretical goal of the auctions is to change the responsible for assigning spectrum licences: if before it was a government's task to decide which operator would be the winner, now, by using spectrum auctions, it is a matter of the market.

As opposed to administrative methods, auctions oblige users to prove that they are willing to make an efficient use of the spectrum, by spending a large amount of money in order to achieve the licence.

According to the theory, auctions have some particular goals in common (Cave, Doyle & Webb, 2007):

- Efficiency: spectrum is entrusted to who is most willing to use it and hence gives it the highest importance;
- Revenues: auctions allow governments to earn a higher amount of money;
- Competition: in contrast to the other types of assignments, auctions ensure that operators compete with each other;
- Transparency: governments cannot be corrupted by operators.

5.3. Types of spectrum auction

Two different forms of auction can be distinguished (Cave, Doyle & Webb, 2007):

- Open auctions: the establishment of process is dynamic and consists of an ascending or descending bid made by the bidders or proposed by the auctioneer. If bids are increased in each round until the amount of blocks awarded results the same of the amount of tenderers, the process takes the name of English auction. On the contrary, an auction is called Dutch auction if the auctioneer diminishes the price at each round until someone agrees with that price;
- Sealed-bid auctions: the process is not progressive, but rather static, since bidders make they offers through a sealed and secret bid by means of a digital platform. The winning bidder is the one who has offered the highest price, and he will have to pay the price that he proposed, if the award is a first-price auction, otherwise, in a second-price auction, he must pay the second highest price proposed.

Obviously, open auctions are more effective, since bidders can obtain an increasing number of information, as the award proceeds. On the other side, open auctions may lead to anti-competitive behaviours, since bidders are tempted to collude and to exclude who is not colluding. Conversely, sealed-bid auctions do not permit tacit agreements among pretenders, given the fact that bidders cannot help each other (Cramton, 2001).

5.3.1. Auction formats

Different types of auction design are available, and they differ according to the goals of regulators and governments and to what they want to gain from auction results. In some cases, regulators aim to enhance competition and rapid innovation, diminish concentration of the market and favour the entrance of new players. In the opposite cases, regulators do not aspire to obtain an efficient auction, but their objective is to earn as much money as possible, with the consequence of negative effects on market structure.

The auction format can be influenced also by other elements, for example the amount of blocks to be auctioned, the time of spectrum availability, the number of potential bidders willing to acquire spectrum and the presence of agreements with bordering countries.

Now the main forms of auction will be set out[11]:

- First-priced sealed bid auction: who offers the highest price is the winner of the block and pays a price equal to his bid.

Advantages	Disadvantages
It is a very basic process and it can be concluded in short terms	Tenderers are frightened by the winner's curse[12], and so they may offer a very low bid
Very suitable for little lots and when every operator can receive a lot	The same amount of frequencies may be awarded with very different bids
Competition is enhanced: the entrance of new players is favoured	There is no information about prices (no discovery process)

Table 5. Pros and cons of first-sealed bid price auction

- Second-price sealed bid auction: who offers the highest price wins the lot, but in this case, he has to pay the price of the second highest bid.

[11] The tables listed below have been taken from Cave, M.; Doyle, C. & Webb, W. (2007), *Essentials of Modern Spectrum Management.*

[12] Winner's curse is the effect that takes places when the one who wins the block overpays it compared to the real value of the spectrum.

Advantages	Disadvantages
The process can be concluded in short terms	Governments may earn less if the first price is much higher than the second
Since they have to pay only the second highest price, bidders are not worried to fall into the winner's curse, and they offer the price that reflects the real value	There is no information about prices (no price discovery process)
Very suitable for little lots and when every operator can receive a lot	

Table 6. Pros and cons of second-sealed bid price auction

- Simultaneous ascending auction: a set of licenses is offered together at the same time and in every round, a bidder can offer a bid for any blocks he wants to acquire, according to how many eligibility points he has. In the first round, the auctioneer starts from the minimum price for each block and then, in the next rounds bidders must bid with a higher price than the previous one; the auction finishes when no bidder submits other offers.

Advantages	Disadvantages
Effective process	The process is very slow and requires many resources
Very suitable for a big number of lots	Bidders may collude
Very suitable for fierce competition, when a lot of players want spectrum blocks	
There is a clear price information (price discovery process)	

Table 7. Pros and cons of simultaneous multiple round ascending auction

- Ascending clock auction: the auctioneer offers one price and bidders can accept it or refuse it. The auction finishes when the number of bidders is equal to the number of blocks auctioned.

Advantages	Disadvantages
Effective process	If the auctioneer overestimate prices, a second auction must be done, since it is a sequential process
Very suitable when there are very different lots	
Very suitable when more than one band is auctioned	
Transparency is granted	

Table 8. Pros and cons of ascending clock auction

- Combinatorial clock auction: it consists of a unique process composed of multiple rounds in which different licenses are auctioned. Bidders can bid differently on the set of licenses they prefer. The first phase is called "clock phase", and bidders can offer one bid in each round and in the next ones, they may respond to the bids of the other participants by increasing their price. In the final stage, instead, bidders make sealed package bids, in which their express their preferences on licenses.

Advantages	Disadvantages
It can be adapted to different types of auctions	The process is so complexed that potential bidders may be discouraged from taking part in the auction
Very suitable where there is a little number of licenses auctioned at the same time	Regulators may have difficulties in implementing the process

Table 9. Pros and cons of combinatorial clock auction

- Hybrid auctions: auctions and administrative assignments are combined together.

Advantages	Disadvantages
Governments can choose the winner on the basis of other parameters, not only on the basis of the price	Corruption and collusion are likely
More discretion in choosing the qualified bidders	Time and resource consuming

Table 10. Pros and cons of hybrid auction

5.4. Which instruments could regulators use to enhance competition and an efficient use of spectrum?

Thanks to the exponential increment of the demand of spectrum in relation to the supply, competition among operators and other mobile players has augmented too. For this reason, regulators had to adopt, as the principal means to assign frequencies, auctions, which, according to the theory, should attribute spectrum to the player that values it most.

In compliance with the practice, however, the outcome of the auction was not always the most effective, also due to the fact that competitors adopted a non-competitive attitude. In view of this fact, regulators adopted some instruments to improve competition and to ensure that bidders behave in a fair and transparent manner.

5.4.1. Reserve price

Reserve price is the minimum price set by governments and it usually coincides with the initial bid of the first round. Reserve price should correspond to the social and commercial value that regulators think

that spectrum has, and it is imposed in order to make sure that spectrum is not sold at a lower price than its value and to ensure that the auction does not protract for a long time.
According to 5G auctions which have already been held, regulators set the reserve price on the basis of different parameters:

- Previous auctions: price emerged from the auctions done for 3G and 4G assignments can be used as a benchmark to determine the reserve price (i.e. Italy and UK). In order to use this method, the previous and the current auctions must be held in a market that has more or less the same features, hence, regulators base this price on the previous auctions of the same country;
- Country features: the reserve price can be built also on demographic and territorial aspects of the Nation. For example, the size of the population or the size of the territory can be used to determine the starting price (i.e. Ireland);
- Auction features: the price can be set taking into account other parameters of the auction, like licence duration;
- Spectrum value: reserve price can be determined on the basis of the economic value of the spectrum and future profits that the use of band could ensure.

Setting spectrum price is a complex task, and regulators must pay the utmost attention in doing this work. In fact, if reserve price is set too low, the governments will not benefit from auction revenues, bidders can collude with each other, since they could take advantage of a rapid ending of the auction. On the other side, if it is set too high, potential bidders may give up on taking part in the auction (Cave, Doyle & Webb, 2007). Moreover, reserve price appears to be higher due to the high revenues that governments want.
Finally, if the auction will be clear and efficient, where competition is not reduced, it will be very likely that the final price will be unrelated to reserve price (Cave, Doyle & Webb, 2007).

5.4.2. Spectrum caps

Spectrum caps are restrictions in acquiring a certain amount of spectrum from every operator.
Spectrum caps, in 5G auctions, were applied in different ways:

- To the overall spectrum auctioned, limiting the amount of MHz that an operator can acquire;
- To particular blocks, which are thought to be the most important;
- To spectrum in total, considering also the spectrum previously acquired;
- To specific participants, in order to limit only their acquisition of spectrum.

Spectrum caps are necessary to ensure that a single bidder does not obtain all the spectrum auctioned, thus preventing that a monopoly could be created, with terrible consequences for consumers, for example extremely high prices. Spectrum caps are also used in order to prevent that always the same operators get more and more spectrum, hence letting new potential players enter the market, even if it will be seen that spectrum caps only balance the situation among incumbents.

Nonetheless, spectrum caps are considered to have also an important drawback: since a bidder cannot acquire more than a given amount of spectrum, efficient and productive operators are penalized in favour of the inefficient ones, because the first ones are not able to acquire enough spectrum to ensure quality of services (Cave & Nicholls, 2017).

5.4.3. Set-aside mechanisms

Set-asides are portions of spectrum of a particular band reserved for players in a particular condition, which in most cases are new entrants.

Set-aside mechanisms are good instruments to enhance competition and to make changes to the market structure if the regulator is not satisfied with it. However, the reserved block can fall into the hands of an inefficient and inexperienced operator, with the effect that the positive effects on social welfare led by the increased number of competitors are overstepped by these negative effects due to the lack of efficiency (Cave & Nicholls, 2017).

Set-asides are not often used by governments, since they consider spectrum caps enough to ensure competition.

5.4.4. Obligations

Regulators often apply specific requirements to the licence and the winner of a specific band must fulfil them so as not to pay a fine or to lose the exclusive rights.

Obligations are used with the purpose of ensuring an efficient use of the spectrum and of avoiding that an operator awards some specific bands only for excluding other players.

In 5G auctions, obligations may be of three types:

- Coverage obligations: the licensee must cover a specific percentage of population and/or a certain percentage of the territory within the prescribed time limits specified in the regulations; it can happen, for the coverage of rural areas, that the winning bidder is required to pay less and to allocate the difference in covering these particular areas;
- Roll-out/usage obligations: it is an obligation related to coverage issues and winning bidders must begin certain operations within the legal deadlines, for example the placement and deployment of radio networks or the provision of services;
- Access obligations: this is the less common type of requirement, and it obliges operators to share their bands with new entrants or with third parties which are not mobile operators.

5.4.5. "Use-it-or-lose-it" and "use-it-or-lease-it" mechanisms

They are methods related to the roll-out obligations, since they may be set by the regulators as a consequence of not having fulfilled the requirement. "Use-it-or-lose-it" mechanism has the effect of taking off the licence, while "use-it-or-lease-it" tool forces the winner to rent the licence out.

This rule is useful when a regulator wants to avoid that a bidder acquires a certain amount of spectrum only with the aim to deprive other players from having it.

5.4.6. Prohibition of collusion

Collusion is most likely to occur when:

1. The number of participants is very low, and hence the competition level is reduced;
2. Regulators opt to an open auction.

Although collusion among bidders is strictly forbidden, with the consequence of the exclusion from the tender, players tend to have cooperative behaviours before and during the auction, because of the large amount of money at stake.

Apart from the elimination from the tender procedure, regulators can adopt disclosure obligations before the qualification round, in order to have complete information about tenderers and their business, and thus, consider operators which have any kind of relationship as a single competitor.

5.4.7. Duration of the licence

The licence duration is the period that elapses between the moment in which the winner can begin to use the band and the moment in which the licence concludes, and it usually ensures that the licensee has exclusive rights.

How long this duration is set has important implications on the quality of services provided: if the licence lasts for a significant amount of time, operators will be stimulated to invest in networks and in technologies, while, if there are short-term licences, winners are not encouraged.

By setting this duration for a considerable period, some drawbacks can grow. Firstly, this constitutes a strong entry barrier for new players, which cannot acquire that spectrum in short terms. Moreover, if a new technology emerges, it is difficult to adapt a specific band to it, and hence, the development is slowed down.

5.4.8. Spectrum trading and spectrum leasing

If spectrum trading or leasing are allowed, the spectrum owner can respectively transfer or rent out a specific block or more lots to another operator after the auction, in the secondary market.

These methods are used by regulators to please other interested operators, including new entrants, which could not win spectrum before and that now it is not used by the licensee, which in turn will obtain a certain amount of revenues from the sale.

Trading enhances an efficient use of the spectrum, since it can be acquired by the one that gives it more value. Trading and leasing must be controlled by regulators: if the transactions costs for the new player are really significant, the efficiency may get lost.

5.5. Conclusions

Despite beauty contests and "first-come-first-served" mechanisms are still used, since the 1990s, more and more governments adopted auctions instead of the other types of assignments, given that, if market is able to auto-regulate, it can give rise to a more efficient and effective outcome, in which spectrum is awarded by the one who is most willing to use it in the future. As it has been seen from the tables above, each auction format has its advantages, but it comes with examine carefully which is the auction design that fits with the objectives of governments.

From the previous auctions, it has been shown that simultaneous multiple round auctions and combinatorial clock auctions are the most used by governments. The first one is ideal when governments have a huge number of spectrum blocks at their disposal, while the second one is suitable for a small number of lots.

In the last sections, it has been described how regulators can intervene in promoting competition and in allowing the entrant of new players. Spectrum caps and coverage obligations are the most used tools for avoiding a high concentration of the market and for ensuring that the licensee achieve equity goals, respectively.

6. 5G assignments in Europe

6.1. Introduction

In this chapter, the data obtained from the research on the regulations published by NRAs and then collected in the database, will be assessed from a competitive perspective, by analysing if the tools available to regulators, described in the previous chapter, are applied and if yes, how they are used.
Especially those bands that were identified from the EC as the "pioneer bands"[13] were examined in the analysis, but also the possible decisions made by the single countries on the other possible bands to be awarded were considered.
Spectrum assignments have been divided into three sub-groups:

- 5G auctions which have been already held: only Finland, Ireland, Italy, Latvia, Spain, Sweden, Switzerland and UK assigned spectrum for 5G purposes;

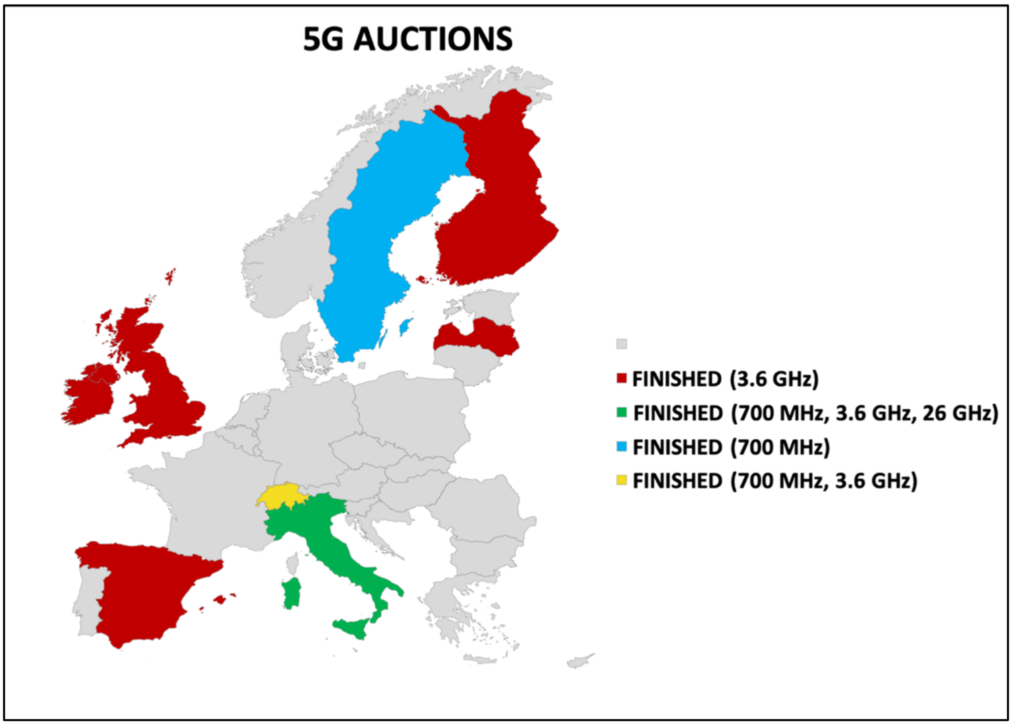

Figure 28. 5G auctions already held on the basis of the band awarded

- Assignments of the pioneer bands for 5G which were held from 2015 onwards but not for 5G purposes;
- 5G assignments that will be held in the future. The first assignments will be the ones in Austria, Denmark, France, Germany and Norway.

[13] Pioneer bands of 5G are the 700 MHz, 3.4-3.8 GHz and 26 GHz.

For the first two groups, both the assignment rules and the results of them were considered, so as to compare them and to assess if the effectiveness of regulations is assured. As regards future assignments, it is obvious that the results are not yet present, but the extracted data can be used to predict the possible trends.

6.2. Organization of 5G assignments

Before starting to assess in detail the auctions which were already held in Europe and the associated results, it can be useful to describe briefly the functions of regulators.

As already mentioned in the first chapter of this thesis, the CEPT sets out the guidelines that member states of Europe should follow in order to achieve the harmonisation of the radio spectrum market across Europe. Since these guidelines are not mandatory rules, the final decision is up to the NRAs, which can decide which spectrum bands are to be awarded, which type of assignment is the most appropriate and which rules apply to the tender and to the license.

Country	NRA	Acronym
Austria	Austrian Regulatory Authority for Broadcasting and Telecommunications	RTR
Belgium	Belgian Institute for Postal services and Telecommunications	BIPT
Bulgaria	Communications Regulation Commission	CRC
Croatia	Croatian Regulatory Authority for Network Industries	HAKOM
Cyprus	Office of Electronic Communications and Postal Regulations	OCECPR
Czech Republic	Czech Telecommunication Office	CTU
Denmark	Danish Energy Agency	
Estonia	Technical Regulatory Authority, Ministry of Economic Affairs and Communications	TJA, MKM
Finland	Finnish Communications Regulatory Authority, Finnish Transport and Communications Agency	FICORA, TRAFICOM
France	Autorité de régulation des communications électroniques et des postes	ARCEP
Germany	Bundesnetzagentur	
Greece	Hellenic Telecommunications and Post Commission	EETT
Hungary	National Media and Communications Authority	NMHH
Ireland	Commission for Communications Regulation	COMREG
Italy	Autorità per le Garanzie nelle Comunicazioni, Ministry of Economic Development	AGCOM, MiSE
Latvia	Public Utilities Commission	SPRK
Lithuania	Communications Regulatory Authority	RRT
Luxembourg	Institut Luxembourgeois de Régulation	ILR
Malta	Malta Communications Authority	MCA
Netherlands	Agentschap Telecom	
Norway	Norvegian Communications Authority	NKOM
Poland	Office of Electronic Communications	UKE
Portugal	Autoridade Nacional de Comunicações	ANACOM
Romania	National Authority for Management and Regulation in Communications	ANCOM
Slovakia	Regulatory Authority for Electronic Communications and Postal Services	RÚ
Slovenia	Agency for Communication Networks and Services	AKOS
Spain	Ministry of Economy and Competitiveness, Ministry of Industry, Trade and Tourism, National Commission on Markets and Competition	MINECO, MINETUR, CNMC
Sweden	Swedish Post and Telecom Authority	PTS
Switzerland	Federal Communications Commission	COMCOM
UK	Office of Communications	OFCOM

Table 11. List of NRAs in Europe

The table above presents the list of the NRAs of the European countries considered for the analysis. These countries that were taken into account are those which are part of the EU, with the addition of also Norway and Switzerland, in order to make a more accurate analysis. As can be noted from the table, NRAs can either belong to a Ministry, for example the Communications Ministry, or be a separate independent regulatory body.

As regards the awarding process, these bodies are in charge of setting out the procedures relative to actions which precede the assignment, organizing the most appropriate type of tender in order to allocate spectrum in the most efficient manner, other than the fact that they are responsible for establishing rules for the maintenance of an effective competition and for controlling that participants do not assume anti-competitive behaviours before, during and after the licence awards.

The figure below describes actions carried out by regulators which were found in 5G auctions. Firstly, regulators launch a consultation, which usually contains a preliminary draft of the main rules of the auction and aims to collect comments and feedbacks from mobile operators, telecommunication firms and consultants in the business. If regulators receive valid and appropriate proposals for rules amendments, they can modify the previous regulations and publish a new consultation containing a new one. After the consultation process, regulators invite every potential bidder to apply for the auction, by including the definitive auction rules and financial and technical criteria which must be respected to get into the tender. Once the call to tender is finished, regulators evaluate each application and determine which applicants comply with the criteria and which ones must be excluded. Then, the real auction process can start and perform according to the procedure specified in the rules. At the end, the winning bidders are chosen and get assigned the licence to use the spectrum.

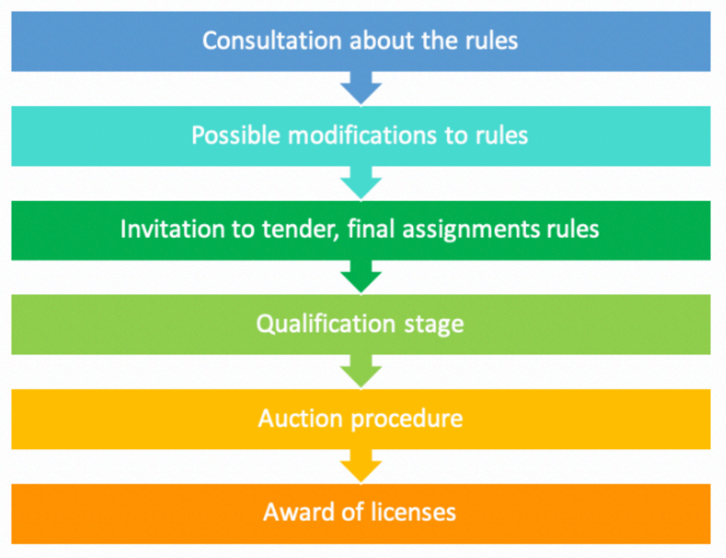

Figure 29. NRAs procedure for auctioning spectrum

Regulators must pay close attention during this process and must exclude from the tender bidders that assume an incorrect behaviour, like colluding with other participants or making actions aimed at excluding who can be potentially dangerous for their business.

6.3. 5G European auctions

In this chapter a description of the eight 5G European auctions is made. Firstly, the regulators in charge of assigning licenses and controlling the effectiveness of the competition are outlined, then the situation regarding the players in the mobile market before the auction is briefly described, and finally auction design and auction results are assessed.

6.3.1. Finland

Since the 1st January of 2019, the Finnish Communications Regulatory Authority (FICORA) has been merged with The Finnish Transport Safety Agency (Trafi) to create a new body called Finnish Transport and Communications Agency (TRAFICOM).

Before 2019, FICORA was the body in charge for regulating communications in Finland, including the radio spectrum, the assignment of frequencies and issues related to them. After the merger, TRAFICOM is now the authority responsible for promoting the high effectiveness of the spectrum assignment and spectrum usage.

As regards the situation before the auction, three were the operators who owned a spectrum licence: Telia, Elisa and DNA. Telia, previously called Telia Sonera, is the merger result of two companies: Swedish Telia bought the Finnish Sonera in the early 2000s; Telia operates on an international territory, serving both Nordic and Baltic countries of Europe. Elisa is a Finnish company which serves Finland and Estonia. Finally, DNA is the third largest Finnish firm.

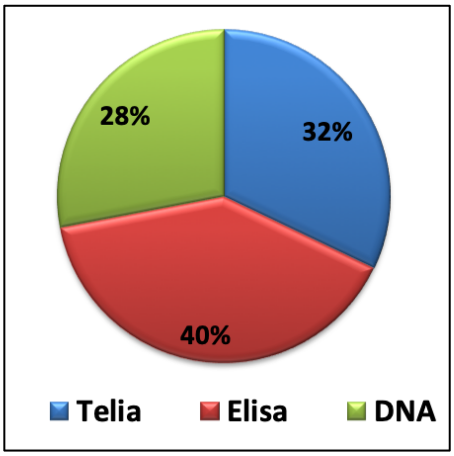

Figure 30. Percentage of SIM cards sold by each operator in Finland

Figure 30 shows the percentage of SIM cards owned by every operator in relation to the total number of SIMs. This measure can be representative of the market shares of every MNO operator in mobile market. The biggest company on the Finnish territory is Elisa, which holds the 40% of the market, but, however, the distribution of market shares is enough balanced.

It could be interesting to assess also how spectrum is distributed, in order to evaluate if operators hold more or less the same amount of spectrum, or there is a company that keeps much more spectrum compared to the others.

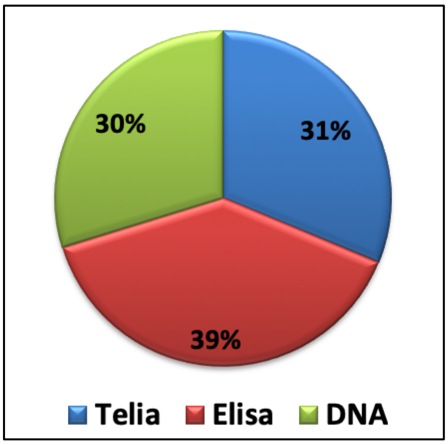

Figure 31. Percentage of amount of spectrum held by each operator in Finland

Elisa holds the biggest percentage of spectrum, 252 MHz, while Telia and DNA hold 202 MHz and 192.4 MHz respectively. Here again, it seems that spectrum is distributed equally among the three users. By comparing the two graphs, in this case the operator that has sold the biggest number of SIM cards, is the same that owns the biggest amount of spectrum, but it is not necessarily always true.

5G Finnish auction

The Finnish auction aimed to enhance the rapid introduction and development of 5G technologies across the territory and to improve the capacity and quality of the already existing networks. It was held in September 2018 and 390 MHz of the pioneer band 3.4-3.8 GHz were auctioned. The regulator decided to auction three big blocks of 130 MHz (see Figure 32).

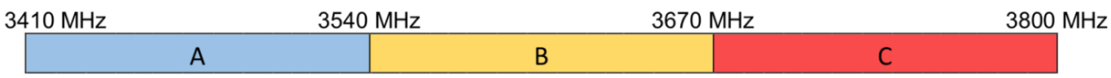

Figure 32. Bands auctioned in Finland. Source: TRAFICOM

The Finnish regulator has opted for a simultaneous multiple round ascending auction, and the reserve price was set at €21 million for blocks A and C, while €23 million was the starting price for block B, without explicating which parameter was used to establish it.

As regards instruments described in the previous chapter, Finland did not apply so strict rules. Firstly, blocks for new entrants were not reserved, while an operator, or a consortium, can acquire only one block. Instead, TRAFICOM imposed some obligations to the license owner:

- Roll-out/usage obligations: operators must start the operations within two years from the moment in which the license becomes valid;
- Coverage obligations: the license owner must cover at least the 35% of its new spectrum;
- Access obligation: operators must provide their bands to universities for research purposes.

In order to avoid spectrum hoarding, also a "use-it-or-lease-it" mechanism was applied: if operators do not serve a specific area, like schools or shopping centers, with their frequencies, they are obliged to rent their frequencies to a client, or to someone chosen by the client, in order to serve that area.

Finally, spectrum leasing and spectrum transfer are permitted on condition that the regulator has previously evaluated if the change of ownership would not harm competition and would not cause interference.

The participants in the auction were only the three incumbent operators, which won one spectrum block apiece. In particular, Telia won the block A paying €30.258.000 for it, Elisa won the block B paying €26.347.000 for it and DNA won the block C paying €21.000.000 for it.

The table below compares the reserve price set by the regulator and the final price resulted from the auction. As can be seen, block C was sold at the same price of the starting price and the final price differed by 27 million from the reserve price. Obviously, the fact that the final price is very similar to the reserve price, can be due to the fact that only the three incumbents participated in the auction and that each of them could acquire only one block out of three.

Block	Reserve price (€)	Price (€)
A	21 million	30,3 million
B	23 million	26,4 million
C	21 million	21 million
TOTAL	55 million	77,6 million

Table 12. Prices of the 5G Finnish auction

Hence, no new players participated or entered into the market after the auction, leaving the situation unchanged: spectrum remains in the three incumbent MNOs' hands (Figure 33).

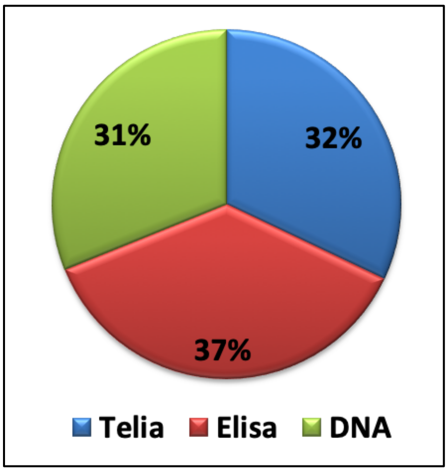

Figure 33. Percentage of the amount of spectrum held by each operator after the 5G auction in Finland

6.3.2. Ireland

In Ireland, the body in charge for the regulation of communications sector is the Commission for Communications Regulation (ComReg), and it operates in the telecommunication, broadcasting, postal and radio spectrum sectors, and for this latter, it has the task of assigning spectrum frequencies and their licenses.

Before the 5G auction, the Irish market was dominated by three big MNO operators: Vodafone, Eir (Meteor) and Three. Vodafone is one of the biggest mobile operators on the Irish territory; it has offered 2G and 3G services across Ireland, and now it is providing 4G services and it is owning the 90% of 4G Irish networks. Eir is an Irish company which offers both fixed, broadband and mobile services, and it is the leader of the broad telecommunications market in Ireland. Finally, Three is a subsidiary of the Hutchinson group; it entered the market by offering 3G services and now it is offering also 4G services. Moreover, in 2013, Three acquired the Irish subsidiary of the English company O2, with the promise to enhance the entrance of two new MVNOs.

In the figure below, the number of SIM cards is considered as an approximation of the market share of each operator. Three and Vodafone share the first position, by holding nearly the same market share; Eir, instead, owns only the 20% of the market.

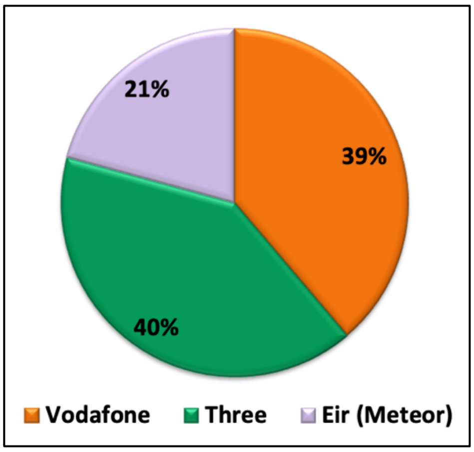

Figure 34. Percentage of SIM cards sold by each operator in Ireland

With regard to the amount of spectrum owned, Three has almost the half of the total spectrum (180 MHz), while Vodafone and Eir own approximately 100 MHz. This fact can be attributed to the acquisition of O2's spectrum by Three.

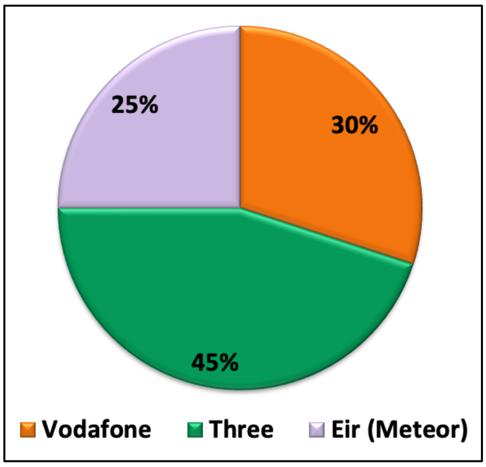

Figure 35. Percentage of amount of spectrum held by each operator in Ireland

5G Irish auction

In 2017, the Irish regulator auctioned the medium-frequency 3.4-3.8 GHz band with the aim of enhancing the deployment and the utilisation of electronic communications services, including the new generation.

As opposed to the previous auction, which was held for the entire national territory, Ireland decided to divide the territory into nine regions, five urban and four rural areas, in order to simplify the use of both mobile and fixed lines.

Region	Type
Border, Midlands & West	Rural
South-West	Rural
East	Rural
South-East	Rural
Dublin City & Suburbs	Urban
Cork City & Suburbs	Urban
Limerick City & Suburbs	Urban
Galway City & Suburbs	Urban
Waterford City & Suburbs	Urban

Table 13. List of regions in Ireland

For each region, ComReg auctioned one TDD block of 25 MHz in the 3410-3435 MHz band (block A) and 65 TDD blocks of 5 MHz in the 3475-3800 MHz band (block B).

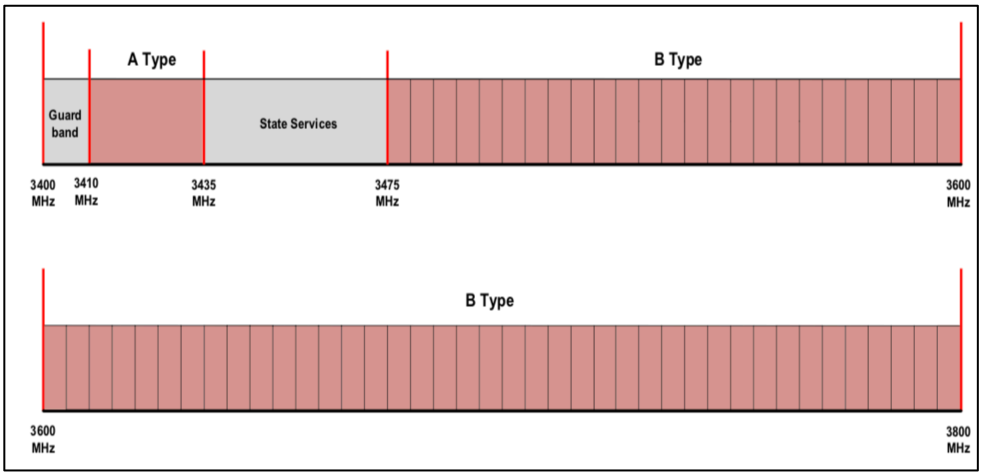

Figure 36. Bands auctioned in Ireland. Source: ComReg

As shown in the figure below, the reserve price varies in relation to the region and the type of block. However, for block A it ranges from €8.000 to €178.000, while for block B it varies from €1.600 to €35.600.

Region	Reserve Price per A-Lot, €	Reserve Price per B-Lot €
Border, Midlands & West	114,000	22,800
South-West	72,000	14,400
East	64,000	12,800
South-East	44,000	8,800
Dublin City & Suburbs	178,000	35,600
Cork City & Suburbs	34,000	6,800
Limerick City & Suburbs	16,000	3,200
Galway City & Suburbs	14,000	2,800
Waterford City and Suburbs	8,000	1,600

Figure 37. Reserve prices for each Irish region. Source: ComReg

Ireland opted also for another auction format: the combinatorial clock auction, a process used to tender more blocks in only one procedure. In this way, bidders were able to make an offer for the combination of blocks they preferred in each region, and to change it on the basis of bids of the other participants.
The auction consisted in one main stage, where the participants made their own bids and specific blocks A for each region were assigned, while the number of blocks B for every operator was decided. Then, an assignment stage was held, and specific blocks B were assigned too.
With regard to regulator's instruments, ComReg did not provide a reserved block for new entrants and a duration of 15 years was set for every license. Moreover, a spectrum cap of 150 MHz for every region was applied to every participant.
As concerns obligations, neither coverage nor access obligations were imposed; instead, winners were required to fulfil some roll-out obligations: the winning bidders must install and use a certain number of base stations, which depends on the region and on the amount of spectrum won by the licensee (see the table below).
Moreover, spectrum trading and spectrum leasing are allowed, but they must be notified to the Irish regulator, which will approve them if they do not harm competition.

Region	Licensee holding up to and including 100 MHz in the 3.6 GHz band (N° of base stations)	Licensee holding over 100 MHz in the 3.6 GHz band (N° of base stations)
Border, Midlands & West	15	25
South-West	15	25
East	15	25
South-East	15	25
Dublin City & Suburbs	10	15
Cork City & Suburbs	2	4
Limerick City & Suburbs	2	4
Galway City & Suburbs	2	4
Waterford City & Suburbs	2	4

Table 14. Roll-out obligations in terms of number of base stations to build in the Irish territory

With regard to the auction process, ComReg decided to keep the identity of the participants as a confidential information which has never been published; hence, in this case, only the details about winning bidders are available.

Region	Vodafone	Three	Eir	Imagine	Airspan
Border, Midlands & West	85 MHz	100 MHz	80 MHz	60 MHz	25 MHz
South-West	85 MHz	100 MHz	80 MHz	60 MHz	25 MHz
East	85 MHz	100 MHz	80 MHz	60 MHz	25 MHz
South-East	85 MHz	100 MHz	80 MHz	60 MHz	25 MHz
Dublin City & Suburbs	105 MHz	100 MHz	85 MHz	-	60 MHz
Cork City & Suburbs	105 MHz	100 MHz	85 MHz	-	60 MHz
Limerick City & Suburbs	105 MHz	100 MHz	85 MHz	-	60 MHz
Galway City & Suburbs	105 MHz	100 MHz	85 MHz	-	60 MHz
Waterford City & Suburbs	105 MHz	100 MHz	85 MHz	-	60 MHz
Reserve price (€)	2.049.600	2.176.000	1.790.800	705.600	894.000
Total reserve price (€)	7.616.000				
Final price (€)	19.734.032	20.372.900	15.662.010	9.769.320	9.635.250
Total final price (€)	78.173.512				

Table 15. Winners and prices of the Irish auction

The single reserve prices of the table above were calculated by multiplying the amount of blocks A and B won by each operator by the reserve price of the single block for every region. Then, the final reserve price was obtained by adding together all these single reserve prices. It can be noted that the final reserve price differs significantly from the total definitive price; this is due in part of the fact that the final price includes also the usage fees that the winner will pay in the future, but mostly due to strong competition for securing the lots.

Furthermore, since the Irish regulator did not publish the losing participants, it cannot be known whether some other potential new players tried to acquire some blocks. Apart from that, it can be noted that two new operators were awarded some lots. In fact, Airspan won all the nine A blocks and eight B blocks for every urban region, while Imagine secured 12 B blocks for every rural area.

The two figures below represent the new situation for the four rural areas, where two new players entered (Airspan and Imagine), and for the five urban areas, where only one new operator entered the market (Airspan).

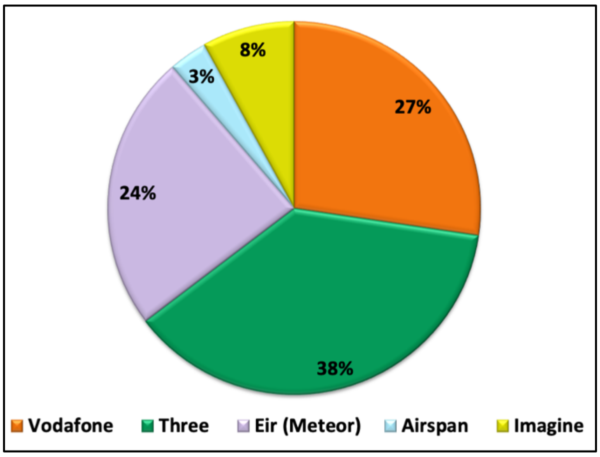

Figure 38. Percentage of the amount of spectrum held by each operator after the auction in rural areas of Ireland

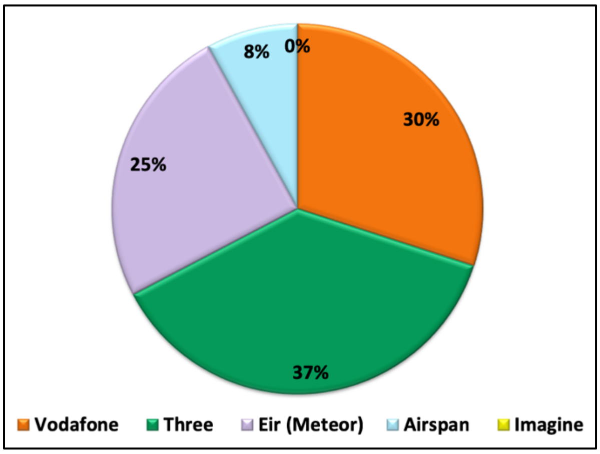

Figure 39. Percentage of the amount of spectrum held by each operator after the auction in urban areas of Ireland

Airspan Spectrum Holding is the mobile operator of the US group Airspan, which provides 4G mobile services at global level. Despite it is a new entrant on the Irish market, it can be considered as a global leader of the mobile wireless services.
Imagine, instead, was already present on the Irish market as the biggest Wireless Internet Service Provider that provides broadband for homes to rural areas. Since the regulator has not specified that spectrum must be used for mobile purposes, probably Imagine will use this spectrum for improving its coverage and efficiency.

6.3.3. Italy

The *Autorità per le Garanzie nelle Comunicazioni* (AGCOM) is an independent body which, together with the Ministry of Economic Development (MiSE), is responsible for ensuring a correct execution of competition in the telecommunications sector.
Until 2016, four big incumbent operators were present on the Italian market: TIM, Vodafone, Wind and Tre. TIM is part of Telecom Italia group and provides mobile services in Italy and in Brazil. Vodafone is instead an English firm, which offers its products to a large number of territories. Wind was an Italian company operating on the Italian market. Finally, Tre was the brand for mobile products of the Chinese group Hutchison 3G. TIM was the leader in terms of market shares, followed by Vodafone, Wind and Tre.
The situation has changed when, at the end of 2016, Wind and Three created a joint venture. Since the sum of the market shares of Wind and Tre was less than the 40%, the EC, AGCOM and MiSE approved the merger, but with the mandatory condition of the entrance of a new player on the market: the French mobile operator Iliad. Wind Tre was obliged to make agreements on the infrastructure with the new operator and to sell to Iliad a part of its spectrum, until it would have built its own network.

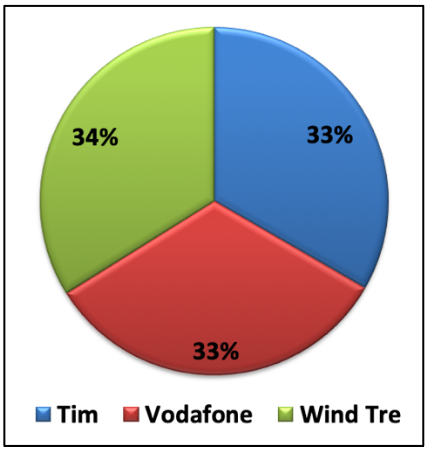

Figure 40. Percentage of SIM cards sold by each operator in Italy

As it has been done for the previous cases, the number of SIMs sold by MNO operators was used as a proxy of the market shares (Figure 40). Here the situation was almost perfectly equal, since the three operators were diving the market for one third.
Also in this case, the amount of spectrum owned by every operator was assessed: Wind Tre had more spectrum (259 MHz), than its competitors (TIM and Vodafone have around 159 MHz), in fact, Wind Tre owned nearly the 50% of spectrum (Figure 41).

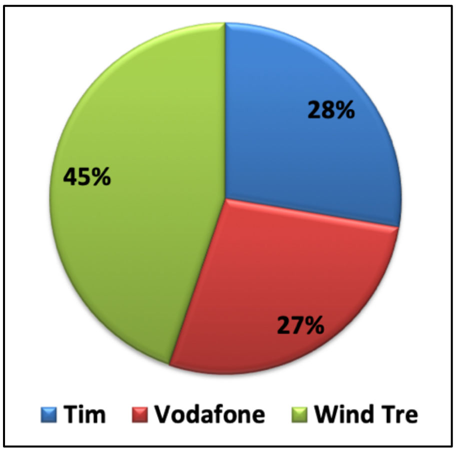

Figure 41. Percentage of amount of spectrum held by each operator before the entrance of Iliad in Italy

Instead, the figure below shows how the spectrum was reallocated after the entrance of Iliad on the Italian market. In accordance with the agreements made after the merger, Wind Tre was obliged to cede part of its spectrum, 70 MHz to be exact, in order to ensure that Iliad could provide its services and to rebalance the situation.

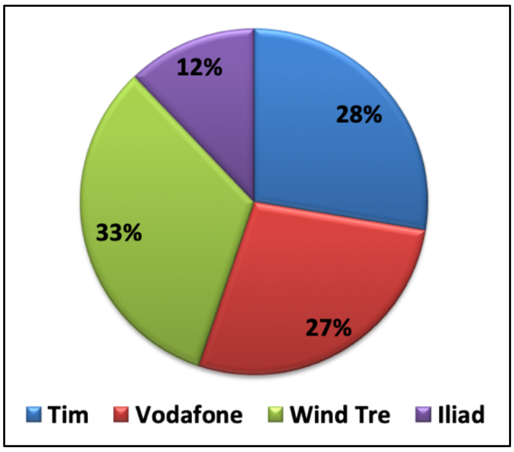

Figure 42. Percentage of amount of spectrum held by each operator after the entrance of Iliad in Italy

It should be taken into account that Iliad is not considered as an incumbent for the 5G auction, since it was given the spectrum only on the basis of the decision made by the European and Italian regulators after the merger, besides the fact that the amount of spectrum is much less compared to others to deliver efficient services.

5G Italian auction

The purpose of the Italian auction was to encourage the transition towards 5G technology, and to ensure the fastest roll-out of its infrastructure, as well as the biggest possible level of coverage.

As opposed to the previous cases, the Italian regulator opted for conducting a multiband auction, comprising all the three pioneer bands for 5G: 75 MHz of the 700 MHz band, 200 MHz of the 3.6-3.8 GHz band and 1000 MHz of the 26.5-27.5 GHz band were auctioned.

700 MHz band: AGCOM decided to divide spectrum into 6 FDD blocks of 5 MHz, and it was auctioned as paired spectrum in the uplink and downlink directions (blocks A1-A6); in addition to these 2x5 MHz blocks, also three single Supplementary Downlink (SDL) blocks of 5 MHz were tendered (blocks B1-B3).

Moreover, due to the merger between Wind and Tre, in order to avoid an excessive concentration on the market, other than allowing the entrance of a new player on the Italian market, AGCOM decided to reserve two blocks of 2x5 MHz out of the 6 blocks to a new entrant. A new entrant was defined by the regulator as one of those operators who do not own any frequency in the mobile radio spectrum yet, or as the subject who entered the market as a result of anti-concentrative measures of the merger. The regulator opted for the reservation of two blocks of this band, since it is the more appropriate band for delivering high coverage services, both in outdoor spaces and indoor areas.

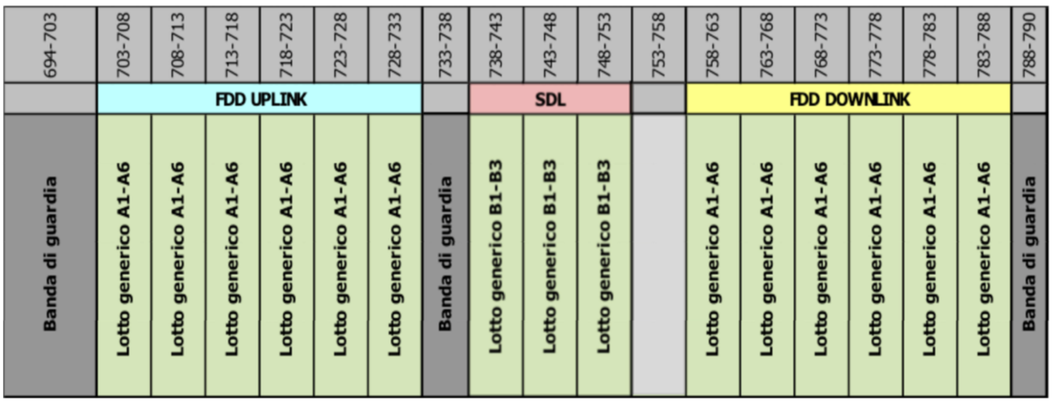

Figure 43. Blocks auctioned in the 700 MHz band in Italy. Source: MiSE

The reserve price of the FDD blocks was set in line with the reserve price of the 800 MHz auction held in 2011 in Italy, with an increase up to 5% on the basis of the Italian population, of the spectrum auctioned and of the license duration.

Block	Reserve price (€)
Generic FDD block	338.236.396
Reserved FDD block (2 blocks together)	676.472.792
Generic SDL block	84.559.099

Table 16. Reserve prices of the 700 MHz band in Italy

The license duration was set at 15 years and 6 months, extendable to a maximum of 8 years, in order to allow future possible new entrants to receive the bands.
As regards obligations, Italian regulator set very strict rules about coverage obligations:

1. The incumbent must cover individually the 80% of the population and must ensure a download speed of 30 Mbps within 36 months, while the new entrant has 12 months more to fulfil the obligation. The coverage must include every municipality which has more than 30.000 inhabitants;
2. Winners must cover in a collective way the 99,4% of population within 54 months;
3. Winners must cover in a collective way all the main motorways and high-speed railway lines within 42 months;
4. Successful bidders must cover individually some specific tourist areas, out of a total of 2400, assigned by the authority within 66 months; new entrants have 78 months.

AGCOM imposed also one usage obligation for the SDL band, which obliges successful bidders to install radio networks and provide services within 36 months from the award or from the availability of the licenses. Furthermore, to enhance the participation of new entrants, incumbents must lease frequencies of the 700, 800 and 900 MHz to new entrants for 30 months: the period is extended to 60 months if new entrants are not active in that area.
Finally, in order to limit the amount of spectrum acquirable by an operator, a spectrum cap was imposed: a user can acquire 2x15 MHz of the 700 MHz FDD band and 2x30 MHz in total among the 700, 800 and 900 MHz bands.

3.6-3.8 GHz band: this band was divided into three generic blocks of 80 MHz, 20 MHz and 20 MHz, and into one specific block of 80 MHz. The difference between a generic block and a specific one is that the position in the frequency range of the latter is specified before the auction, while the position of the former is defined after the tender is finished.

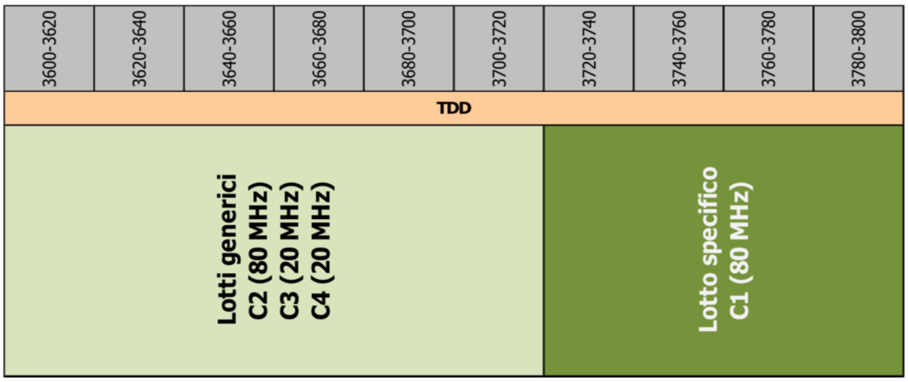

Figure 44. Blocks auctioned in the 3.6-3.8 GHz band in Italy. Source: MiSE

The reserve price was set considering the final price of the 3.4-3.6 GHz auction that was held in 2008 and could be incremented up to 30% on the basis of the population, of the amount of spectrum and of the license duration.

Block	Reserve price (€)
Specific block (80 MHz)	158.374.470
Generic block (80 MHz)	158.696.043
Generic block (20 MHz)	39.674.011

Table 17. Reserve prices of the 3.6-3.8 GHz band in Italy

The license duration was set at 18 years, extendable to a maximum of another 8 years.

The regulator decided for imposing coverage, usage and access obligations for this band too. The coverage obligations are listed below:

1. If an operator has won only 20 MHz, he must cover the 5% of population within 48 months, while if it has won only 40 MHz, he must cover the 10% of population within 48 months;
2. Every successful bidder who won at least 80 MHz must be able to provide services at the retail or wholesale level to the potential consumer that asks for them within 6 months and must guarantee a download speed of 30 Mbps;
3. Every successful bidder must submit to the Ministry an obligation list composed of at least 10% of Italian municipalities with no more than 5.000 inhabitants. Winners are obliged to provide services to cities of their list within 72 months, with intermediate milestones at 36 and 60 months for connectivity service at both retail and wholesale levels; each municipality with no more than 5.000 inhabitants which is not included in the obligation list, is part of a "free list"; a third party is allowed to take the frequency in leasing to cover areas included in this second list, by paying a fee proportionate to the bidding price of the licensee. This last obligation can be considered as

a "use-it-or-lease-it" mechanism, since the spectrum owner has to lease his frequencies for a certain area if it does not use them.

Moreover, successful bidders are obliged to install radio networks and provide services within 24 months from the award or from the availability of the licenses. Lastly, an access obligation was imposed: a licensee who owns more than 80 MHz, must lease his frequencies to operators who do not have any license.

In addition, a spectrum cap of 100 MHz among the 3.6-3.8 GHz band and the 3.4-3.6 GHz band (excluding rights which last until 2023) was set.

26.5-27.5 GHz band: for this band, 5 TDD blocks of 200 MHz were auctioned. Moreover, due to the nature of the high frequencies which are characterized by a high capacity and low coverage, blocks are expected to be shared amongst the winners, in the sense that every operator would use the same portion of band in different areas.

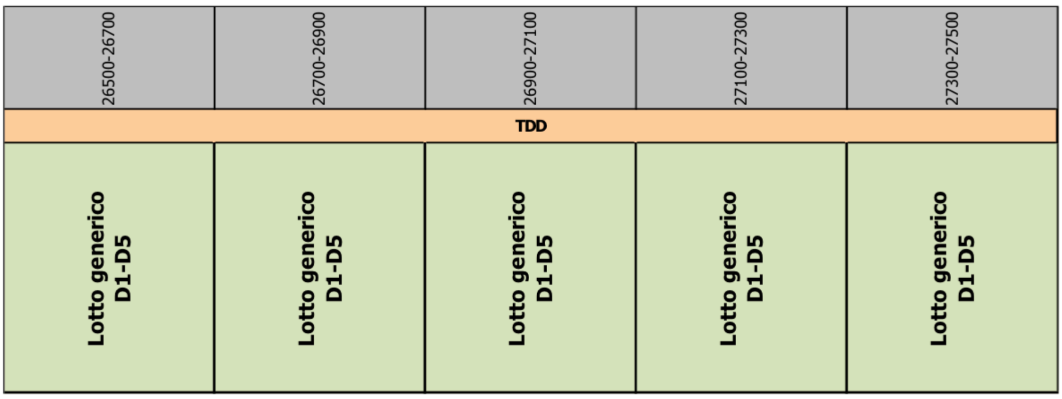

Figure 45. Blocks auctioned in the 26.5-27.5 GHz band in Italy. Source: MiSE

The reserve price for this mmWaves band was set on the basis of the WLL award in the closer band. In this case, the 5 blocks were all the same, hence a single reserve price was decided: €32.586.535 for every lot. The license duration, instead, was set at 19 years.

Because of the nature of the high frequencies, which are not able to cover a wide area, no coverage obligations were imposed, but instead, both roll-out and access obligations were defined. The former concerns the fact that successful bidders are obliged to install radio networks and provide services within 48 months from the award or from the availability of the licenses, while the latter imposes on the licensees to allow other parties, which are not telecom operators, to have access to their networks for developing 5G services, for example network slicing.

Finally, also for this band, the licenses are subject to a spectrum cap: an operator can acquire 400 MHz, thus 2 blocks of 200 MHz, at most.

The format used for awarding frequencies was the simultaneous multiple round ascending auction, in which all the three bands were awarded together in a single auction, giving the priority to the assignment of the reserved block in the 700 MHz band, because, in the event that it was not assigned, it would be split into two blocks and awarded with the other lots.

Moreover, before describing the results of the auction, it can be said that, in order to avoid speculative behaviours, spectrum trading is allowed only 24 months after the release of the license.

Seven were the firms that applied for the auction: besides the three incumbents, also Iliad, Fastweb, Linkem and OpenFiber submitted their demands for participating in the tender. Fastweb is a Italian company specialized in offering fixed line services, but it provides also mobile services as a MVNO. Linkem is an Italian operator present in the market of the wireless broadband connections, which used to offer also mobile services until 2017. OpenFiber is an Italian operator active in providing optic fiber. The results of the auction are described below. Even if Linkem and OpenFiber applied for the tender, they did not make any bid during the auction, not even for the reserved block.

Band	Blocks	Winner	Reserve price (€)	Final price (€)
700 MHz	Reserved block	Iliad	676.472.792	676.472.792
	Generic block 1	Vodafone	338.236.396	345.000.000
	Generic block 2	TIM	338.236.396	340.100.000
	Generic block 3	TIM	338.236.396	340.100.000
	Generic block 4	Vodafone	338.236.396	338.236.396
Total			2.029.418.376	2.039.909.188

Table 18. Results of the 700 MHz band auction in Italy

Iliad was the new entrant who won the reserved block and paid a price equal to the reserve price. This means that, no other potential entrants made any bid for this block. The generic blocks were sold to TIM and Vodafone, while the SDL blocks remained unassigned. Moreover, it can be noted that the final price does not differ substantially from the reserve price.

Band	Blocks	Winner	Reserve price (€)	Final price (€)
3.6 -3.8 GHz	Specific block	TIM	158.374.470	1.694.000.000
	Generic block (80 MHz)	Vodafone	158.696.043	1.685.000.000
	Generic block 1 (20 MHz)	Wind Tre	39.674.011	483.920.000
	Generic block 2 (20 MHz)	Iliad	39.674.011	483.900.000
Total			734.654.931	4.346.820.000

Table 19. Results of the 3.6-3.8 GHz band auction in Italy

For the 3.6-3.8 GHz the price situation is completely different: if the total reserve price was set at around €700 million, the final price exceeds the €4 billion, meaning that a large number of raisings was made. Also in this case, Iliad has proved to be very "competitive", awarding another non reserved block.

Band	Blocks	Winner	Reserve price (€)	Final price (€)
26.5-27.5 GHz	Generic block 1	TIM	32.586.535	33.020.000
	Generic block 2	Iliad	32.586.535	32.900.000
	Generic block 3	Fastweb	32.586.535	32.600.000
	Generic block 4	Wind Tre	32.586.535	32.586.535
	Generic block 5	Vodafone	32.586.535	32.586.535
Total			162.932.675	163.693.070

Table 20. Results of the 26 GHz band auction in Italy

As regards to the mmWaves band auction, besides Iliad, which won another unreserved block, another new entrant, Fastweb, acquired a block. Each of the three remaining blocks was assigned to each incumbent.

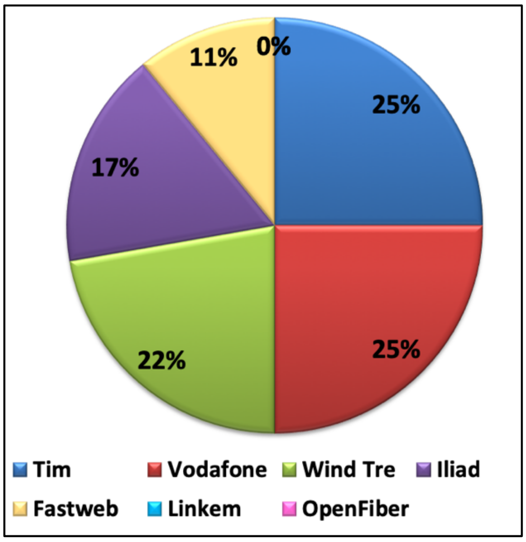

Figure 46. Percentage of the amount of spectrum held by each operator after the auction in Italy

The figure above represents the situation after the auction: now Iliad owns an amount of spectrum comparable with the others, and a new player has won a certain amount of spectrum. This implies that in the future, after having built their own network, two new MNO operators will be present on the Italian market.

Hence, to conclude, the differences among the four potential entrants can be assessed. Iliad is the fourth mobile operator in France, and it counts 13 million customers and a market share of nearly the 20%.

Fastweb, instead, is the third operator of fixed broadband lines, counting a market share of 15% of the fixed market, and it has been operating on the mobile market as a MVNO since 2008, having a market share of the 16% of the MVNOs market. Therefore, these two operators are players which are not new to the telecommunications sector in general, since one is a foreign mobile incumbent and the other one is an incumbent of the fixed market. This means that they dispose of the knowledge and financial resources to invest also in the Italian mobile market.

Instead, with regard to the two excluded operators, Linkem owns only the 2.2% of the Italian fixed broadband market, while OpenFiber is an Italian subsidiary of Enel established in the close 2016, which is still developing its fiber network. Some differences can be noted compared to the former two operators: Linkem has a very low market share, while OpenFiber is basically new and it still needs to develop its core business completely. Moreover, the great reserve price and the strict obligations imposed by the operators may have scared them.

6.3.4. Latvia

In Latvia, the Public Utilities Commission (SPRK) is an independent body which regulates different sectors, such as energy sector, postal sector and communications sector, including radio spectrum.

Latvian territory is characterized by the presence of three MNOs: LMT is part of the Telia group and it provides 2G, 3G and 4G mobile services; Tele2 is a Swedish mobile operator, which is present in different European countries, including Latvia; the last Latvian operator is Bite.

As can be seen from the figure below, the leader of the market is LMT, followed by Tele2 and then by Bite.

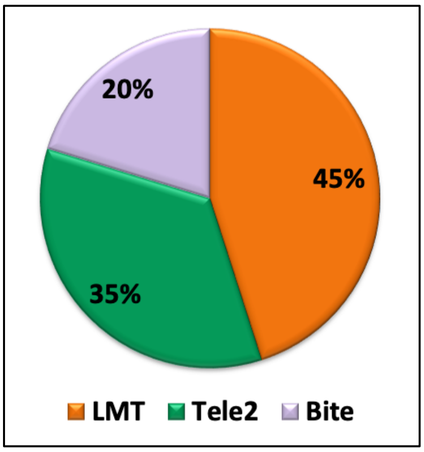

Figure 47. Percentage of SIM cards sold by each operator in Latvia

The situation of LMT is the same with regard to the amount of spectrum owned, while in this case Bite owned more spectrum than Tele2[14]. In particular, LMT had 356 MHz, Tele2 172 MHz and Bite 200 MHz.

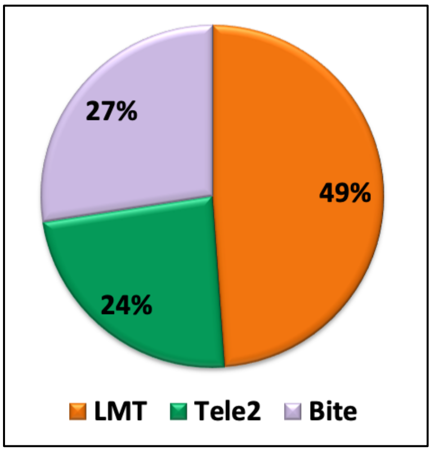

Figure 48. Percentage of the amount of spectrum held by each operator in Latvia

5G Latvian auction

Before starting to talk about the auction, it has to be said that not all the data were retrieved during the assessment, consequently, some information can be missing, for example the auction format that was used.

For this auction, the Latvian regulator decided to auction only one block of 50 MHz (3550-3600 MHz) at the reserve price of €250.000, hence giving way to a single winner to use this license for 10 years.

In order to limit the amount of spectrum owned in the medium frequencies, SPRK imposed a spectrum cap of 100 MHz on the total 3.4-4.2 GHz band, thus excluding in advance the MNO LMT, since it acquired 100 MHz in the 3.4-3.7 auction of 2017.

As obligations, Latvia imposed some coverage requirements to be fulfilled year by year:

- Receive one authorization of use in at least one city within the end of 2019;
- Receive one permission of use in at least 2 cities within the end of 2020;
- Receive one permission of use in at least 5 cities within the end of 2021;
- Receive one permission of use in at least 7 cities within the end of 2022;
- Receive one permission of use in each city of the Republic within the end of 2023.

Moreover, the Latvian regulator allows spectrum transfer, but the operator that acquires the band cannot exceed the limit of 100 MHz.

[14] For the calculation of the amount of spectrum, it was also considered the bands won by LMT in the auction held in 2017, which will be also described later.

Two players took part in the auction: the incumbent Tele2 and the potential new entrant Lattelecom, a provider of Internet, telecommunications and entertainment services. At the end, the incumbent was awarded the block for €6,25 million, leaving the potential new entrant empty-handed.

The figure below provides the new spectrum distribution among the usual three MNOs, as no new players entered. Now Tele2 owns more spectrum than Bite.

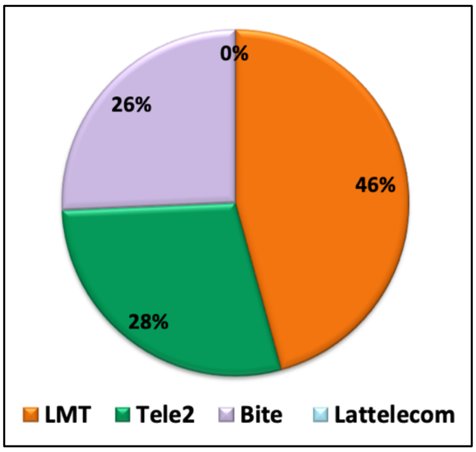

Figure 49. Percentage of the amount of spectrum held by each operator after the auction in Latvia

6.3.5. Spain

Radio spectrum in Spain is regulated primarily by the Ministry of Industry, Trade and Tourism, but also by the Ministry of Economy and Competitiveness and National Commission on Markets and Competition in a secondary way.

Before the 5G auction, in Spain four big operators were present: Movistar, Vodafone, Orange and Yoigo. Movistar is a firm owned by Telefonica group that provides mobile services to Spain and South America. Vodafone is the already mentioned English mobile company that operates at the international level. Orange, instead, is a French multinational company, which is present in French, Spanish, Belgian and African territories. The fourth operator is Yoigo, the mobile branch of the Spanish telecommunication group Masmovil that offers 2G, 3G and 4G services.

Figure 50 shows that the first three MNOs share almost equally the market, while the last operator, Yoigo, owns only the 10% of the market.

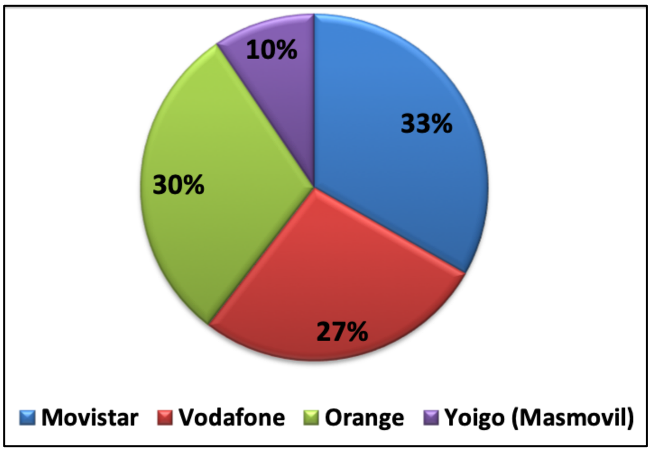

Figure 50. Percentage of SIM cards sold by each operator in Spain

The situation is the same with regard to the amount of spectrum that each operator has before the auction: Movistar and Orange own nearly 200 MHz of spectrum, Vodafone has almost 170 MHz and finally Yoigo is the owner of only 100 MHz.

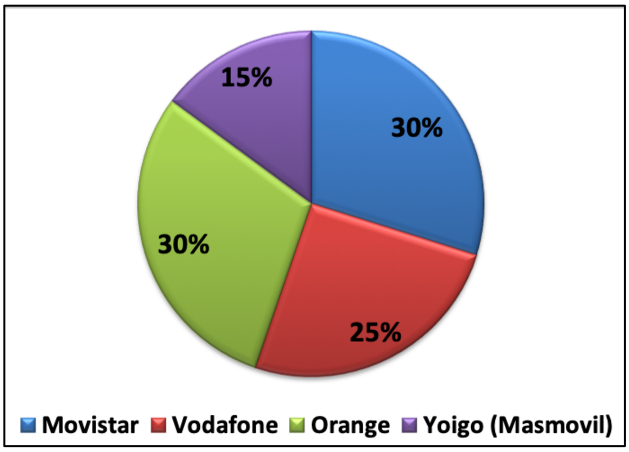

Figure 51. Percentage of the amount of spectrum held by each operator in Spain

5G Spanish auction

In July 2018, the Spanish regulator launched the first 5G Spanish auction with the purpose to sell the entire 3.6-3.8 GHz band, dividing it into 40 small blocks of 5 MHz with a reserve price of €2,5 million apiece.

The Spanish regulator has declared that it decided to auction such small blocks in order to facilitate the entrance of new players or the acquisition by operators which have a little market share. However, the Ministry did not provide any reserved block for new entrants. Whilst no set-aside mechanism was applied, a spectrum cap was used: each bidder cannot keep more than 120 MHz in total, including also the 3.4-3.6 GHz band.

Moreover, since the Spanish regulator considered that there is a lot of uncertainty in the deployment of 5G network, no kind of obligation was imposed. The licensees must only demonstrate that the spectrum is being used in an efficient and effective way.

The duration of the licence was set at 20 years, in order to ensure that every operator can have some returns on the investments made for the implementation of 5G services.

As regards the format of the auction, a simultaneous multiple round ascending auction was held: at each round, a participant can make only one bid for each lot, and then, the bidder that made the highest offer wins a generic block; after that, the bidder that made the highest absolute bid can choose the specific blocks, and so forth.

Despite the good intentions of the Spanish government that divided the spectrum into small blocks in order to enhance the entrance of players different from the incumbents, no new players applied for the auction, hence, no one new entered the market. Instead, all the four incumbents participated in the auction.

At the end of the auction, only Movistar, Vodafone and Orange were awarded some blocks: Movistar won 10 blocks (50 MHz), Vodafone won 18 blocks (90 MHz) and Orange won 12 blocks (60 MHz), while Yoigo was excluded from the auction. In any case, Yoigo has already at its disposal 40 MHz in the 3.4-3.6 GHz, and he acquired other 40 MHz in the same band concomitantly with the tender.

Winner	Number of blocks	Reserve price (€)	Final price (€)
Movistar	10	25.000.000	107.462.458,60
Vodafone	18	45.000.000	198.141.528,48
Orange	12	30.000.000	132.044.533,56
Yoigo	-	-	-
Total		100.000.000	437.648.521

Table 21. Results of the Spanish auction

Therefore, the situation has remained unchanged, since each of the four operators acquired some bands, and no one new entered the market.

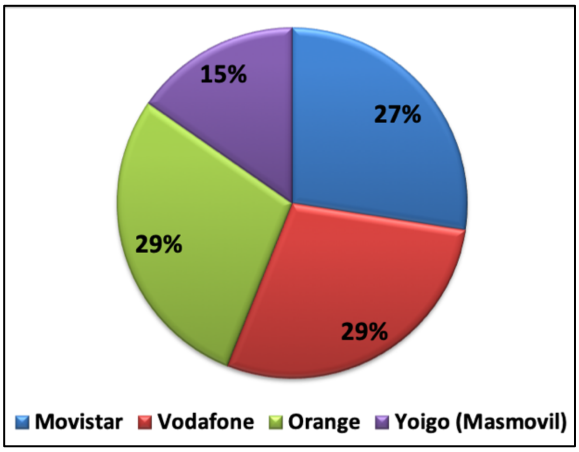

Figure 52. Percentage of the amount of spectrum held by each operator after the auction in Spain

6.3.6. Sweden

The Swedish Post and Telecom Authority (PTS) is the body owned by the Ministry of Enterprise and Innovation, in charge for regulating the electronic communications sector (telephony, Internet and radio spectrum).

Before the 5G auction, the Swedish market was composed of four big operators. Telia, the Swedish international operator, that provides different types of services; also the Norwegian operator Telenor offers mobile, broadband and TV services at a global level; Tele2 is the Swedish company that operates mainly in the Nordic countries, in Latvia, Estonia and Lithuania, and offers a multiplicity of services; finally, Tre (H3G) is owned by the Chinese group Hutchinson operating worldwide.

The figure below shows the market shares of the four incumbents, without considering the number of SIMs of the joint ventures between them[15]. Telia owns the largest market share, followed by Tele2 and Telenor, if one considers only the single firms.

[15] Unfortunately, no data about the number of SIM cards sold by the two joint ventures Net4Mobility and Svenska UMTS AB were found. Hence, this figure has to be considered carefully, since the market shares of the two joint ventures are missing.

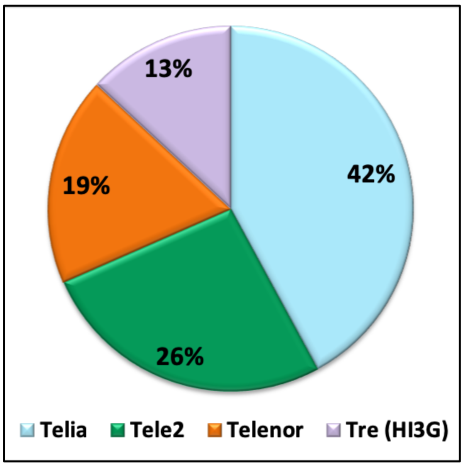

Figure 53. Percentage of SIM cards sold by each operator in Sweden

Figure 54 instead, shows the amount of spectrum owned considering both single operators and joint ventures. In particular, Svenska UMTS AB is a joint venture created in 2002 between Telia and Tele2 for delivering 3G services, while Net4Mobility was established by Tele2 and Telenor in order to provide both 2G and 4G services. The situation here is completely different and more balanced, since the joint venture Net4Mobility (and so Tele2 and Telenor together) owns more spectrum than Telia itself; hence, this joint venture can be considered as an incumbent as big as the single operators, if not even bigger. This statement will be confirmed also in the 5G auction.

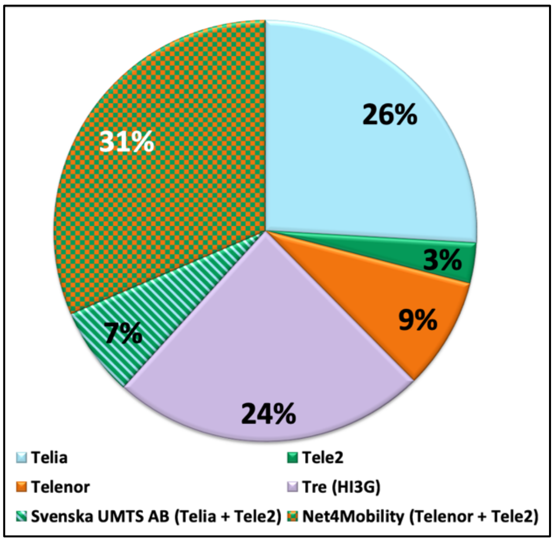

Figure 54. Percentage of the amount of spectrum held by each operator, including joint ventures in Sweden

5G Swedish auction

This Swedish auction has aimed to ensure that fast and reliable services can be provided to all the Swedish territory.

The band at hand that was auctioned was the 700 MHz (713-788 MHz) band, and the Swedish regulator opted for dividing the spectrum into four FDD blocks and four SDL blocks (Figure 55), each of them with a licence duration of 22 years:

- FDD blocks are paired and one block is composed of 2 blocks of 2x10 MHz (FDD1 and FDD2), while the two other blocks are 2 separate blocks of 2x5 MHz apiece (FDD3 and FDD4);
- SDL blocks are four single blocks of 5 MHz.

694-703	703-708	708-713	713-718	718-723	723-728	728-733	733-738	738-743	743-748	748-753	753-758	758-763	763-768	768-773	773-778	778-783	783-788	788-791
	Upplänk							Nedlänk										
	Marksänd tv tom 2018-12-31		FDD1	FDD2	FDD3	FDD4		SDL1	SDL2	SDL3	SDL4	Marksänd tv tom 2018-12-31		FDD1	FDD2	FDD3	FDD4	

Figure 55. Blocks auctioned in Sweden. Source: PTS

The reserve prices are respectively:

- The FDD block of 2x10 MHz starts with a reserve price of SEK 200 billion (around €19 billion);
- The two FDD blocks of 2x5 MHz start with a reserve price of SEK 100 billion (around €9,5 billion) apiece;
- Every SDL block has a reserve price of SEK 50 billion (around €4,5 billion).

PTS did not provide any spectrum reservation for new entrants, but instead set a spectrum cap of 40 MHz on the blocks acquirable, regardless of whether blocks are FDD or SDL. The regulator has considered to apply a generic spectrum cap, in order to keep the situation balanced as before.

As regards obligations, PTS imposed a roll-out obligation only for the FDD block of 2x10 MHz, in order to improve services in the entire Swedish territory. Swedish regulator applied an innovative way for the coverage obligations, with the purpose of encouraging the licensee to invest in infrastructure for serving areas with a low coverage: starting with the reserve price of SEK 200 million, up to a maximum of SEK 300 million, the spectrum owner does not have to give this money in the form of cash, but it can use them for its investments.

Two types of territories in Sweden were considered in lack of coverage (Figure 56):

- Type 1: area that does not have coverage for both voice and Internet services of 10 Mbps;
- Type 2: area that does not have only Internet services of 10 Mbps;

Hence, SEK 100 million of the total amount shall be used for covering areas of type 1, while the remaining sum may be used for covering areas which do not have data services of 10 Mbps, such as areas of type 2.

Some time constraints were also imposed for the coverage obligations, the license owner must:

- Have installed an amount equal to the 25% of the total amount of the coverage obligation within the end of 2021;
- Have installed an amount equal to the 50% of the total amount of the coverage obligation within the end of 2022;
- Have installed an amount equal to the 75% of the total amount of the coverage obligation within the end of 2023;
- Have installed an amount equal to the 100% of the total amount of the coverage obligation within the end of 2024;

The fact of permitting to allocate a certain amount of money for investments, is a clear demonstration of how an auction can be held in an effective way, since the government does not aim to earn the largest amount of money, but rather, aims to stimulate the efficient use of the spectrum and to encourage investments.

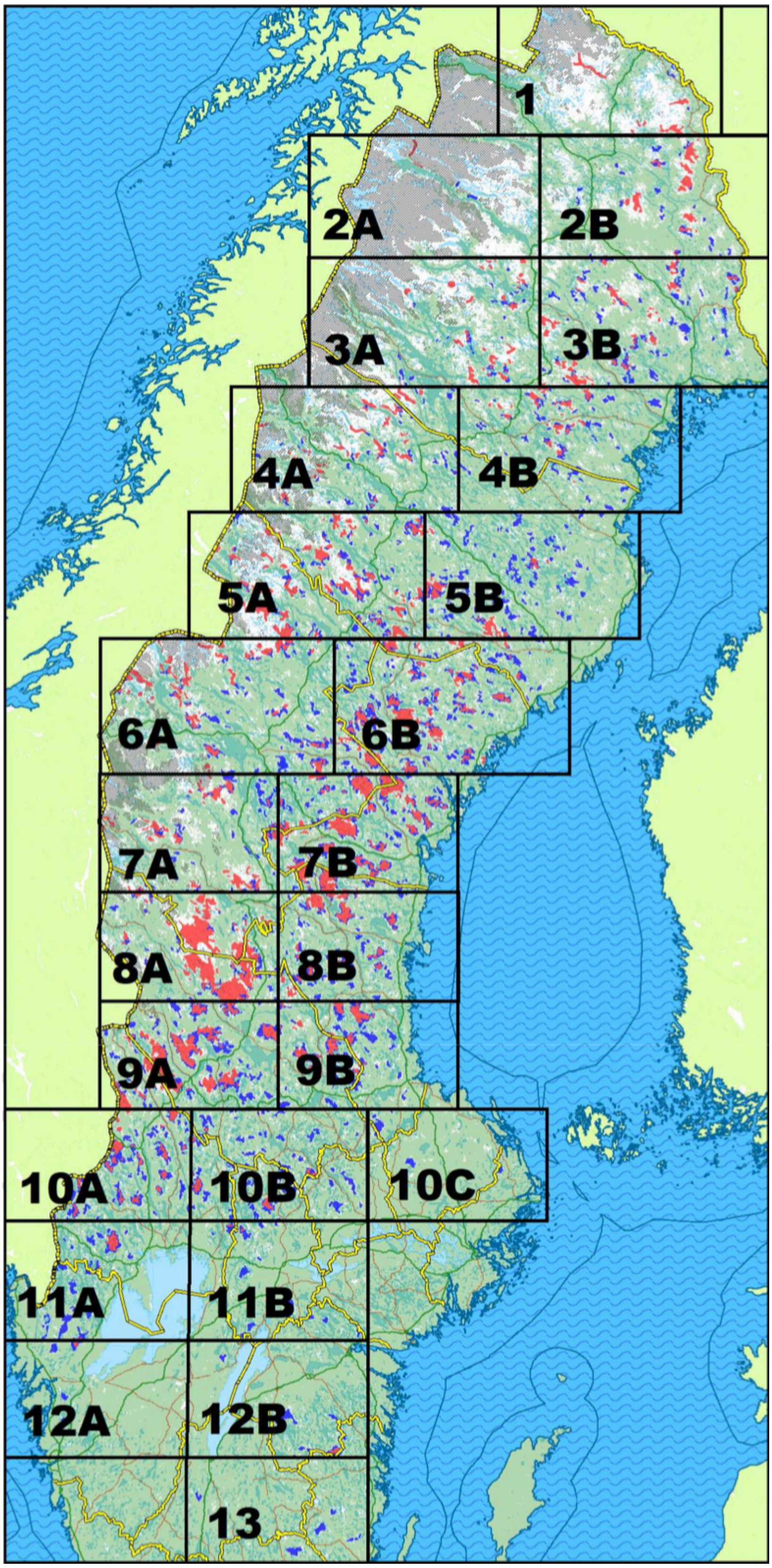

Figure 56. Map of Sweden, representing areas of type 1 with red and areas of type 2 with blue. Source: PTS

Since both single operators and joint ventures between them operate in Sweden, the regulator permitted the participation in the auction of groups, on condition that, if they decide to participate with the joint venture, the single firms cannot take part in the auction. In fact, only Telia, Net4Mobility (neither Tele2 nor Telenor) and Tre showed up at the tender. Furthermore, the PTS permits spectrum trading and spectrum leasing on the secondary market.
Also Sweden adopted the simultaneous multiple round ascending auction as tender format, setting as starting price of each block its reserve price; in the event that the price for the 2x10 MHz block exceeds SEK 300.000.000, the winner must pay the difference in cash. Two stages were held: the main stage aimed to discover the highest price for the generic blocks and the assignment stage assigned the specific frequency block to each winner.

Block	Winner	Reserve price	Final price
Block 2x10 MHz (FDD1-FDD2)	Telia	200.000.000 SEK 19.082.805 €	1.382.657.650 SEK 131.924.932 €
Block 2x5 MHz (FDD3)	Net4Mobility	100.000.000 SEK 9.541.402 €	720.968.398 SEK 68.790.497 €
Block 2x5 MHz (FDD4)	Net4Mobility	100.000.000 SEK 9.541.402 €	720.968.398 SEK 68.790.497 €
4 SDL blocks	Not assigned		
Total		400.000.000 SEK 38.165.610 €	2.824.594.446 SEK 269.505.926 €

Table 22. Winners and prices of the Swedish auction

Even though at the beginning the reserve price was already high, the final price had been grossly raised, meaning that the competition between the three participants was very fierce, with Tre defeated. No new players participated or won some blocks in this auction either, leaving the market with the same four big operators and the two joint ventures.

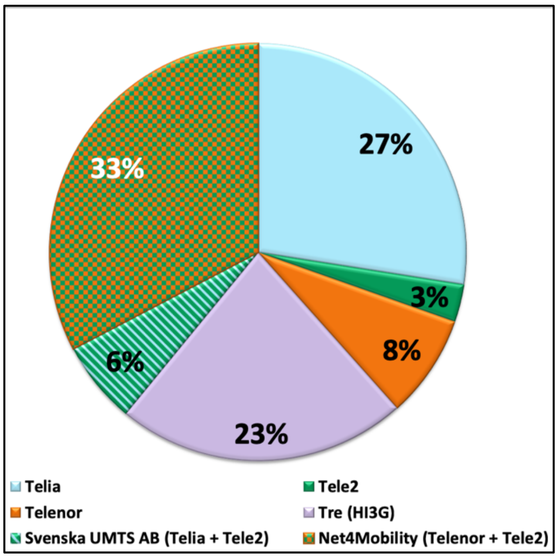

Figure 57. Percentage of the amount of spectrum held by each operator after the auction, including joint ventures in Sweden

6.3.7. Switzerland

The most recent 5G auction was held in Switzerland in February of 2019, with the purpose to release other bands for solving the actual 4G bottlenecks, and so for improving this type of services, but also for introducing the new 5G technology.

The body in charge of assigning frequencies and controlling radio spectrum in general in the Swiss territory is the Federal Communications Commission (COMCOM), which is independent from any Swiss Ministry and sometimes it works closely with the English regulator, OFCOM, by instructing it with some tasks.

In the Swiss territory, three big operators provide their services to population: Salt, Sunrise and Swisscom. The former is an operator that offers both mobile and Internet services across the Swiss territory; it used to be part of the Orange group, but now it is owned by the French group Iliad; Sunrise is a Swiss operator that provides mobile and fixed services in Switzerland; the latter is a Swiss telecommunications firm, which offers fixed, Internet and mobile services.

The figure below provides the amount of SIM cards that were sold by each operator. Swisscom dominates undoubtedly the Swiss market, holding a market share that is more than half; Sunrise and Salt operators have more or less the same market share, around 20%.

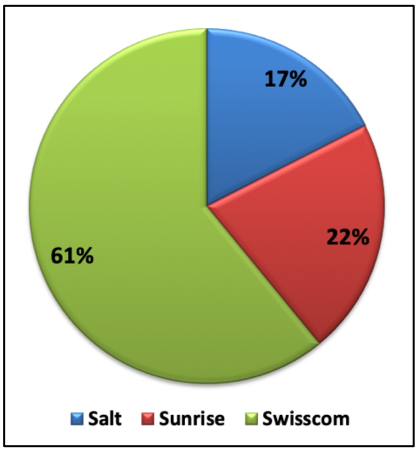

Figure 58. Percentage of SIM cards sold by each operator in Switzerland

The situation is quite the same concerning the amount of spectrum owned: Swisscom holds the biggest quantity of spectrum (253 MHz), while Salt and Sunrise have approximately the same amount (around 159 MHz).

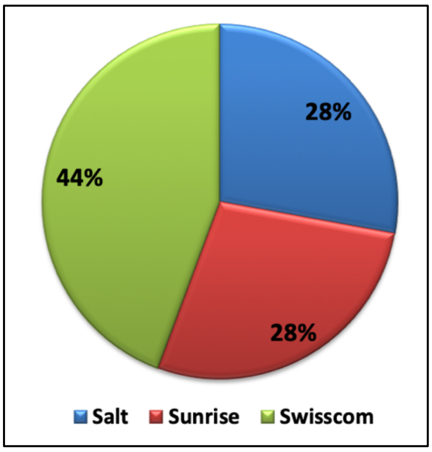

Figure 59. Percentage of the amount of spectrum held by each operator in Switzerland

5G Swiss auction

As already mentioned before, COMCOM opted for a clock multiband auction, which included the 700 MHz band (703-733, 738-753 and 758-788 MHz), the 1400 MHz band (1427-1517 MHz), the 2.6 GHz band (2565-2570 and 2685-2690 MHz) and the 3.6 GHz band (3500-3800 MHz). The Swiss regulator stated that some bands were for improving 4G services, while others were needed for the new 5G services: it has been assumed that the 1400 and 2600 MHz bands were for 4G, while 700 MHz and 3.6 GHz bands were for 5G; for completeness all the four bands in the auction were considered.

The regulator decided to award 6 blocks of 2x5 MHz in the FDD 700 MHz band, 3 blocks of 5 MHz in the SDL 700 MHz band, 18 blocks of 5 MHz in the SDL 1400 MHz (they are divided in three categories:

lower, core and upper bands), 1 block of 2x5 MHz in the FDD 2.6 GHz band and finally 15 blocks of 20 MHz in the TDD 3.6 GHz band. All the licenses have a duration of 15 years, except the 2.6 GHz band, that has a duration of only 10 years.
With regard to the instruments at the disposal of the regulator, COMCOM used some spectrum caps to limit the purchasing of only one company; in fact, an operator can acquire:

- 3 blocks in the FDD 700 MHz band;
- 5 blocks among the SDL 700 MHz and the core band of the 1400 MHz bands;
- 6 blocks in the 3.6 GHz band.

COMCOM defined also a usage obligation, which imposes on a licensee the usage of the frequencies acquired, and a coverage obligation, which discriminates based on the fact if the licensee has FDD 700 MHz bands or not:

- If it has some blocks of the FDD 700 MHz band, it must cover at least the 50% of population within the end of 2024;
- If it does not have them, it must cover at least the 25% of the population within the end of 2024.

This difference was made because the 700 MHz band is suited for improving coverage, and so, if an operator owns it, it is easier to cover more population.
Finally, spectrum trading and leasing are allowed after the regulator's consensus, that assesses if competition may be harmed.
In the auction, four companies took part: the three incumbents and one new entrant, Dense Air. Dense Air is a subsidiary of the Airspan Group which provides mobile services as a MVNO in Ireland, Belgium and Portugal.
The tables below show the results of the auctions, divided by each band. The Swiss regulator did not provide the price paid by every operator for each block, hence only the overall price paid by every operator will be provided. Moreover, the block of the 2.6 GHz band remained unsold

Band	Winner	Number of blocks won	Reserve price
700 MHz	Salt	2 FDD blocks (20 MHz)	33.600.000 CHF 29.562.069 €
	Sunrise	1 FDD block (10 MHz) 2 SDL blocks (10 MHz)	25.200.000 CHF 22.171.552 €
	Swisscom	3 FDD blocks (30 MHz)	12.600.000 CHF 11.085.776 €
	Dense Air	-	-
Total			71.400.000 CHF 62.819.398 €

Table 23. Amount of 700 MHz blocks won and the respective reserve price in Switzerland

Band	Winner	Number of blocks won	Reserve price
1400 MHz	Salt	2 blocks (10 MHz)	8.400.000 CHF 7.390.517 €
	Sunrise	3 blocks (15 MHz)	12.600.000 CHF 11.085.776 €
	Swisscom	10 blocks (50 MHz)	42.000.000 CHF 36.952.587 €
	Dense Air	-	-
Total			63.000.000 CHF 55.428.881 €

Table 24. Amount of 1400 MHz blocks won and the respective reserve price in Switzerland

Band	Winner	Number of blocks won	Reserve price
3.6 GHz	Salt	4 blocks (80 MHz)	6.720.000 CHF 5.912.413 €
	Sunrise	5 blocks (100 MHz)	8.400.000 CHF 7.390.517 €
	Swisscom	6 blocks (120 MHz)	10.080.000 CHF 8.868.620 €
	Dense Air	-	-
Total			25.200.000 CHF 22.171.552 €

Table 25. Amount of 3.6 GHz blocks won and the respective reserve price in Switzerland

Winner	Reserve price	Final price
Salt	48.720.000 CHF 42.865.001 €	94.500.625 CHF 83.143.871 €
Sunrise	46.200.000 CHF 40.647.846 €	89.238.101 CHF 78.513.779 €
Swisscom	64.680.000 CHF 56.906.984 €	195.554.002 CHF 172.053.008 €
Total	159.600.000 CHF 140.419.832 €	379.292.728 CHF 333.710.659 €

Table 26. Results of the 5G Swiss auction

Therefore, this auction raised in total around €300 million, and the three incumbents Salt, Sunrise and Swisscom acquired respectively, 110 MHz, 135 MHz and 200 MHz. Unfortunately, the potential new entrant on the Swiss market was excluded and thus it did not win any block.

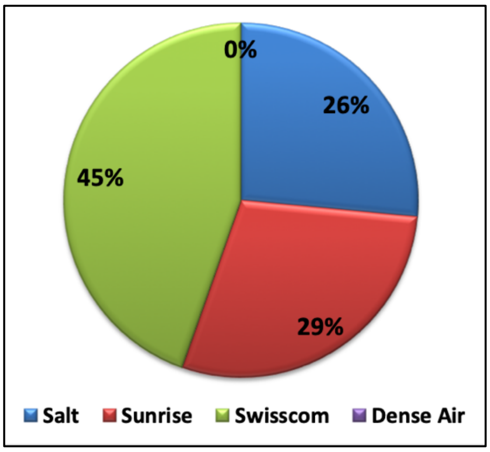

Figure 60. Percentage of the amount of spectrum held by each operator after the auction in Switzerland

6.3.8. United Kingdom

The last European country in which a 5G auction was already held is United Kingdom. The radio spectrum, as well as mobile, telephone and broadband services, is regulated by the autonomous body Office of Communications (OFCOM). OFCOM was responsible to set down the auction rules and to monitor that competition was ensured.

The United Kingdom has four incumbents: O2, owned by the English group Telefonica, provides mobile services across the UK, other than operating in Ireland, Germany and Czech Republic; Vodafone, the already mentioned operator that offers mobile and fixed services worldwide; EE was a mobile and Internet service provider born from a joint venture between Deutsche Telekom (with T-mobile) and Orange, and in 2016 it was acquired by the BT Group, the multinational firm which offers telecommunications services; the fourth operator is Three, the subsidiary of the Hutchinson group. In 2016, the Hutchinson Group tried to acquire the mobile operator O2, but the EC and the English regulator rejected this takeover, since it could only reduce the competition and increase the final prices, resulting in a loss of benefit for the consumers.

The figure below shows that EE dominates the English market in terms of number of SIM cards owned, while the second position is occupied by O2 Telefonica, followed by Vodafone and lastly Three, which owns only the 12% of the market.

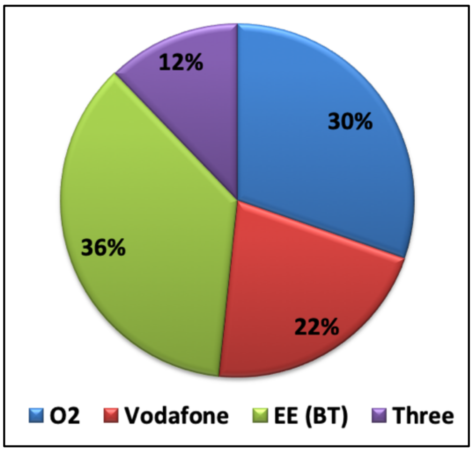

Figure 61. Percentage of SIM cards sold by each operator in UK

A little bit different is the figure representing the amount of spectrum owned. EE also in this case owns the biggest quantity of band (275 MHz), but here Three is the second operator in terms of spectrum owned (214,6 MHz), followed by Vodafone (181 MHz) and then O2 (91,40 MHz). By comparing the two graphs, it can be demonstrated that the market share can be independent from the amount of spectrum owned.

By referring to all cases, it is very like that the operator who sold the highest number of SIM cards is the one which also owns the biggest amount of spectrum, but that does not mean that the two measures are always correlated.

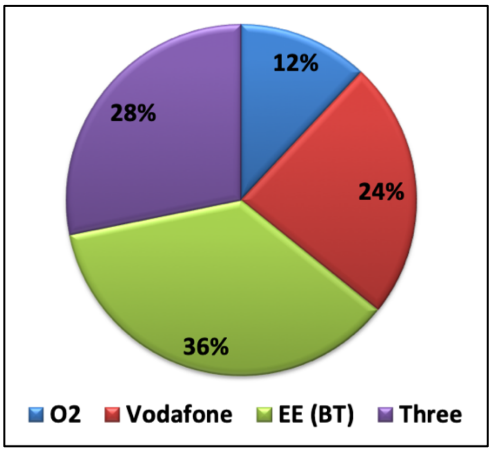

Figure 62. Percentage of the amount of spectrum held by each operator in UK

5G English auction

The regulator decided to hold a multiband auction, which included the 2.3 GHz and 3.4-3.6 GHz bands: the first band was auctioned in order to improve the quality of 4G services, while the second one has the

purpose to begin the development and the deployment of 5G services. For completeness, it will be discussed also how the 2.3 GHz band was auctioned and which were its results.
OFCOM auctioned 40 MHz of the 2350-2390 MHz band, which were divided into four blocks of 10 MHz, with a reserve price of £10.000.000 (€11.404.550) apiece, calculated on the basis of the final prices of the English 2.6 GHz auction held in 2013, and with an extendable license duration of 20 years.

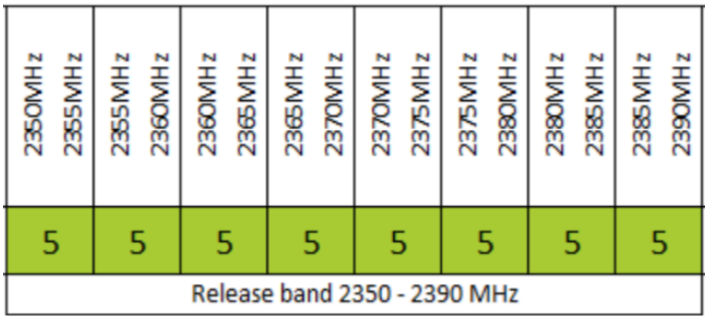

Figure 63. Bands auctioned for the 2.3 GHz band in UK. Source: OFCOM

As regards the band dedicated to the new mobile generation, 70 MHz uplink and 80 MHz downlink of the 3410-3480 and 3500-3580 MHz bands were auctioned in blocks of 5 MHz (30 blocks in total). Each block started with a reserve price of £1.000.000 (€1.140.455) and has a licence duration of 20 years which can be renewed.

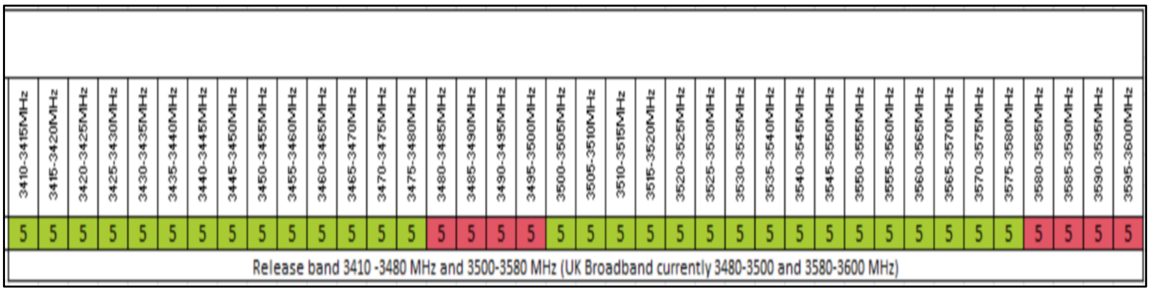

Figure 64. Bands auctioned for the 3.4-3.6 GHz band in UK. Source: OFCOM

Since OFCOM was of the opinion that these two bands are committed for adding capacity and not for increasing coverage, no kind of obligation was imposed. Moreover, it did not provide any "use-it-or-lose-it" mechanism, explaining that it is complicated to define what the word "use" means, that operators may not acquire it if they do not see a real opportunity and finally that investments might be undermined. Instead, the regulator set some spectrum caps for every operator:

- 255 MHz for the band that can be used right after the auction, including the already hold bands;
- 340 MHz for all the spectrum owned before and after the auction, including the 5G band (it is the 37% of the entire spectrum);

Hence, since EE (BT) already owns 275 MHz, it could not bid for the 2.3 GHz band and could only acquire a maximum of 85 MHz for the 5G band; Vodafone could not win more than 160 MHz for 2.3 and 3.4 GHz bands; Three could not win more than 125 MHz for 2.3 and 3.4 bands. Moreover, the regulator considered that the imposition of these spectrum caps is enough to limit the purchasing of spectrum by the largest incumbents, and hence, it did not set any reserved block for new entrants. Finally, an operator can trade its spectrum on the secondary market if the regulator approves the transfer or the leasing.

With reference to the award procedure, also the English auction was run as a simultaneous multiple round ascending auction, in which the first stage, called the main stage, was for deciding how many blocks were won by each operator, and then the assignment stage, after another round of bids, was for assigning a number of specific blocks equal to the amount won before to each operator (who has offered the highest bid can decide first).

With regard to the 2.3 GHz band, O2 was awarded all the entire band, and paid a price far superior than the reserve starting price.

Band	Blocks	Winner	Reserve price	Final price
2.3 GHz	Generic block 1	O2	10.000.000 £ 11.404.550 €	51.474.000 £ 58.703.780 €
	Generic block 2	O2	10.000.000 £ 11.404.550 €	51.474.000 £ 58.703.780 €
	Generic block 3	O2	10.000.000 £ 11.404.550 €	51.474.000 £ 58.703.780 €
	Generic block 4	O2	10.000.000 £ 11.404.550 €	51.474.000 £ 58.703.780 €
Total			40.000.000 £ 45.618.200 €	205.896.000 £ 234.815.122 €

Table 27. Winners and prices of the 2.3 GHz band auction in UK

Also the 5G auction raised much more money than the starting prices. In this case, all four incumbents won some blocks: O2 and BT (EE) were awarded 8 blocks apiece, paying each of them, respectively, £39.715.000 (€45.293.170) and £37.824.000 (€43.136.569); Vodafone won 10 blocks, paying £37.824.000 (€43.136.569) for each of one; Three won 4 blocks, paying £37.824.000 (€43.136.569) for each block.

Band	Winner	Number of blocks	Reserve price	Final price
3.4 GHz	O2	8 blocks (40 MHz)	8.000.000 £ 9.123.640 €	317.720.000 £ 362.345.362 €
	BT (EE)	8 blocks (40 MHz)	8.000.000 £ 9.123.640 €	302.592.000 £ 345.092.559 €
	Vodafone	10 blocks (50 MHz)	10.000.000 £ 11.404.550 €	378.824.000 £ 432.031.724 €
	Three	4 blocks (20 MHz)	4.000.000 £ 4.561.820 €	151.296.000 £ 172.546.279 €
Total			30.000.000 £ 34.213.650 €	1.150.432.000 £ 1.312.015.926 €

Table 28. Winners and prices of the 3.4-3.6 GHz auction in UK

Hence, starting with a reserve price of £70.000.000 (€79.831.8509), the total price of the auction is £1.356.328.000 (€1.546.831.049)

Notwithstanding OFCOM's conviction that spectrum caps were enough to limit incumbent acquisition and to promote the entrance of new players, a new entrant, the American Airspan, attempted to acquire some blocks, but it did not win anything, like its subsidiary in Switzerland.

Hence, the English market has remained with the same four operators providing mobile services. O2 now owns a bigger amount of spectrum.

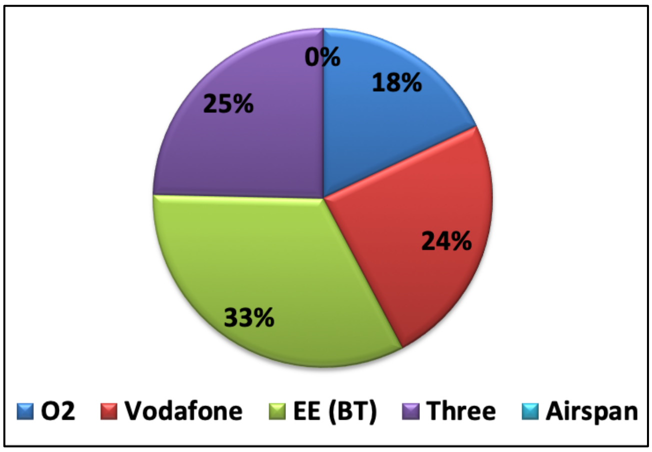

Figure 65. Percentage of the amount of spectrum held by each operator after the auction in UK

6.3.9. Overall results of 5G auctions

Before starting to talk about the results of the auctions in terms of competition, a plot containing the values of the reserve prices and final prices calculated with the standard unit of measure (€/MHz/pop)[16] is depicted below.

As shown in the figure, Sweden is the country with the highest price, followed by UK and then by Switzerland and Italy, while the lowest price is for Finland.

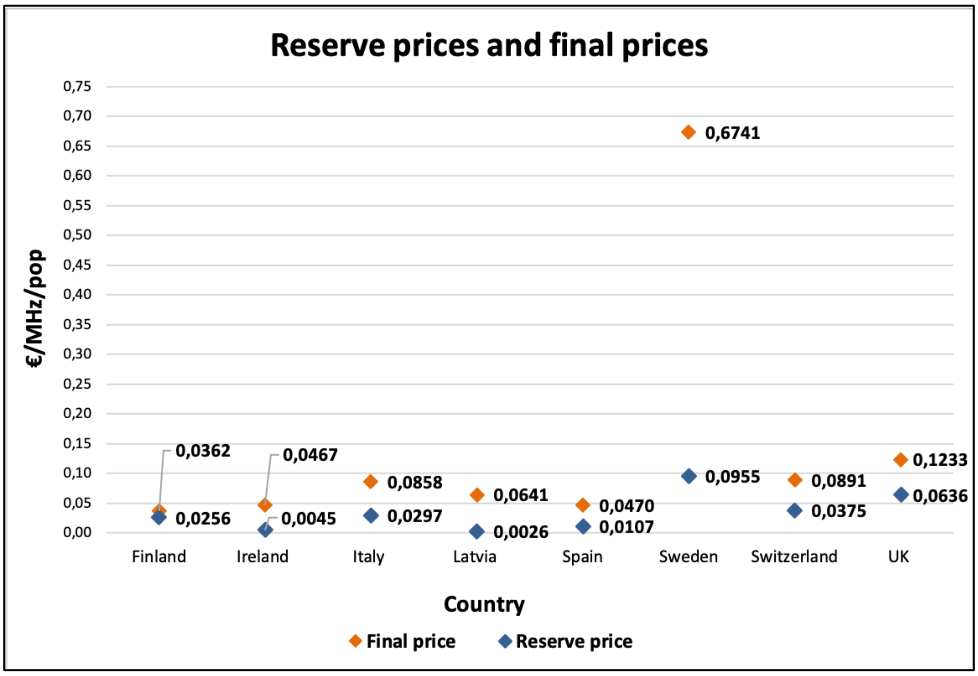

Figure 66. Reserve and final prices expressed in €/MHz/pop

An observation can be made regarding competition: since Switzerland has the second highest price, this can be a reason why Dense Air was excluded, and the same is for the English case with Airspan; but, in other cases, it seems that the price does not affect the entrance of new players on the market: Finland, for example, has the lowest price, but did not even see a new operator participating in the auction, while Italy, which had one of the highest prices, has welcomed two new entrants.

Turning now to the competition issues of these auctions, the table below contains the main instruments used by the regulators to enhance competition and an effective use of the spectrum. Some differences can be noted: only Italy provided a set-aside mechanism, and always Italy is the one that imposed the most rigid rules; also Finland has imposed all the three types of obligations, but these ones are very

[16] The measure €/MHz/pop is used for making auction prices comparable among countries. In this case, it is obtained by dividing the total price (reserve or final) of the auction by the amount of MHz sold and then by the population.

permissive and do not constitute a problem; on the contrary, the countries which imposed less rules were Spain and UK.

In any case, given the lack of new entrants, regulators must revise and amend the way they set the rules down. However, this issue will be resumed in the next chapter.

Country	Spectrum for new entrants	Spectrum cap	Coverage obligation	Roll-out /usage obligation	Access obligation	Use-it-or-lease/lose-it
Finland		**X**	**X**	**X**	**X**	**X**
Ireland rural		**X**		**X**		
Ireland urban		**X**		**X**		
Italy	**X**	**X**	**X**	**X**	**X**	**X**
Latvia		**X**	**X**			
Spain		**X**				
Sweden		**X**		**X**		
Switzerland		**X**	**X**	**X**		
UK		**X**				

Table 29. Instruments used by regulators in the 5G auctions

Instead, the other table provides how many incumbents are present in each country, how many new players entered the market and how many potential new operators were excluded. Then, the figure below shows the situation in terms of number of competing MNOs before and after the auction.

Only Italy and Ireland had welcomed new entrants, while in Latvia, Switzerland and UK the potential new operators which tried to enter the market were excluded and in the other countries not even a new operator tried to participate in the auction. The fact that either players that tried to enter the market but did not succeed, or new players did not even apply for the auction is alarming: this means that there are some reasons that prevent new entrants from participating in the auctions or winning some blocks.

However, it can be noted that the number of players constituting the market is very low, since the number of incumbents varies from 3 to 4 operators. It is quite clear that the mobile market tends to be a natural "monopoly", in the broad sense of the term, in itself, but also these issues will be discussed later.

Country	Number of incumbents	Number of winning entrants	Number of losing entrants
Finland	3	0	0
Ireland rural	3	**2**	It cannot be known
Ireland urban	3	**1**	It cannot be known
Italy	3	**2**	**2**
Latvia	3	0	**1**
Spain	4	0	0
Sweden	3 incumbents 2 joint ventures	0	0
Switzerland	3	0	**1**
UK	4	0	**1**

Table 30. Number of incumbents and new entrants for 5G countries

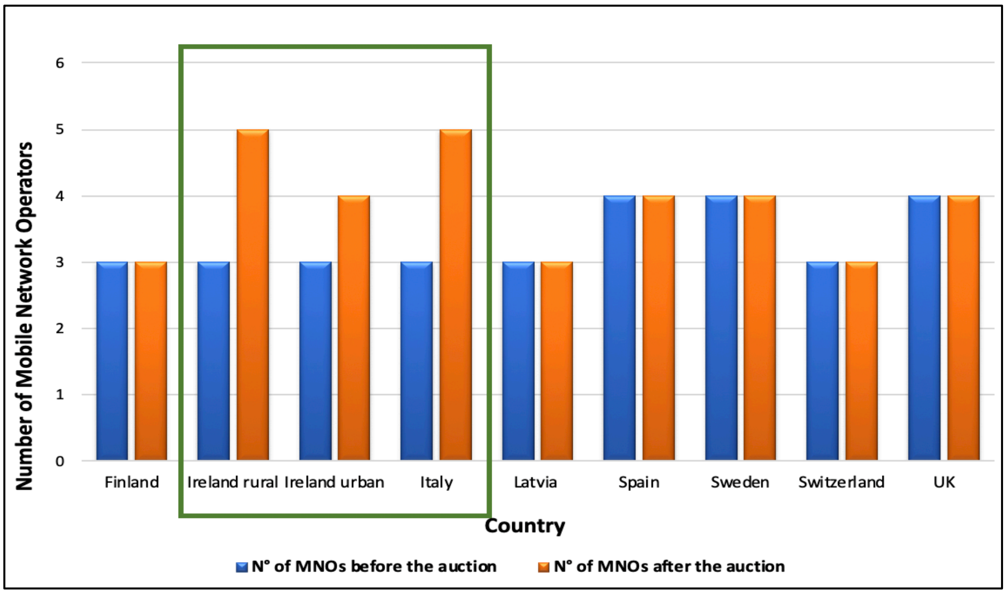

Figure 67. Situation of the market (number of MNOs) before and after the 5G auctions

6.4. European auctions for pioneer bands

For completeness, since all the 5G auctions have not been completed yet, the auctions for 5G pioneer bands that were held not for 5G purposes, but always for mobile aims will be provided in this chapter, also because the bands awarded are technology neutral, and hence, the operator can decide to convert its services in 5G services. In this case, auctions will be described and analyzed in a less detailed manner, only to check if new players entered the market or not.

6.4.1. Czech Republic

In 2017, the Czech regulator, Czech Telecommunications Office (CTU), awarded 5 blocks of 40 MHz in the 3600-3800 MHz band with a simultaneous multiple round ascending auction.

It imposed two different spectrum caps depending on whether the participant was an incumbent (40 MHz) or a new entrant (80 MHz); if after the first round, no new player has bid, the spectrum cap for incumbents would become 80 MHz. Moreover, the regulator imposed a usage obligation, which states that the licensee must use at least 50% of its band within 2 years and the total band within 4 years to provide commercial services, and a coverage obligation, without specifying any constraint.

The applicants in the auction were:

- The 3 incumbents: T-Mobile (Deutsche Telekom), O2 and Vodafone;
- 3 new potential entrants: Nordic Telecom, Poda, Suntel Net.

After the end of the auction, only four operators were awarded some spectrum: two incumbents, Vodafone and O2, and two new entrants, PODA and Nordic Telecom; while the incumbent T-Mobile and the new entrant Suntel Net were excluded from the auction.

Blocks of 40 MHz	Winner	Reserve price	Final price
3600-3640	Vodafone	29.000.000 CZK 1.123.341 €	203.000.000 CZK 7.863.389 €
3640-3680	PODA	29.000.000 CZK 1.123.341 €	203.000.000 CZK 7.863.389 €
3680-3720	O2	29.000.000 CZK 1.123.341 €	203.000.000 CZK 7.863.389 €
3720-3760	Nordic Telecom	29.000.000 CZK 1.123.341 €	203.000.000 CZK 7.863.389 €
3760-3800	Nordic Telecom	29.000.000 CZK 1.123.341 €	203.000.000 CZK 7.863.389 €
Total		145.000.000 CZK 5.616.707 €	1.150.000.000 CZK 44.546.297 €

Table 31. Results of Czech auction

Hence, the figure below provides the amount of spectrum owned before the auction, when there were only the three incumbents which were operating on the market, and after the auction and the entrance of two new players. The fact that an incumbent could acquire only one block enhanced the entrance of new players.

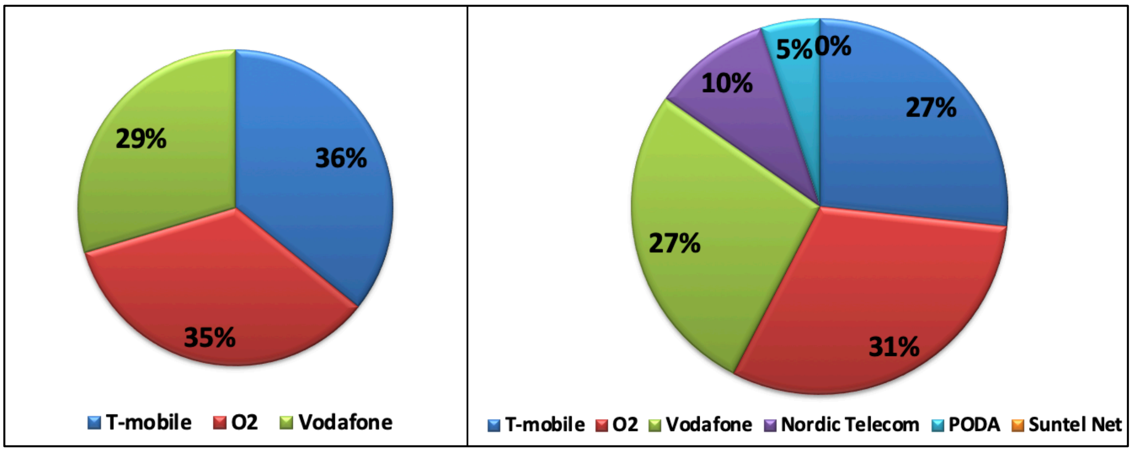

Figure 68. Amount of spectrum owned before (left) and after (right) the auction in Czech Republic

6.4.2. Finland

FICORA auctioned also 6 blocks of 2x5 MHz in the 700 MHz band (703-733 MHz and 758-788 MHz) in 2016, in order to improve the quality of 4G services across the Finnish territory. Here again, the format used was the simultaneous multiple round ascending auction.

The regulator did not reserve any block for new entrants but imposed that an operator could acquire only 2 blocks out of the six. Furthermore, the winning bidder is subject to both usage and coverage obligations: the former requires that the winner must begin operations within two years, the latter obliges the operator to build a network that covers the 99% of the population within three years and to guarantee also indoor services.

In this auction, only the three incumbents applied: Telia, Elisa and DNA. As in the 5G Finnish auction, the final price does not differ too much from the starting price, since only the three incumbents had bid for the blocks and could acquire only two portions apiece.

Blocks of 2x5 MHz	Winner	Reserve price (€)	Final price (€)
703-708 and 758-763	DNA	11.000.000	11.000.000
708-713 and 763-768	DNA	11.000.000	11.000.000
713-718 and 768-773	Elisa	11.000.000	11.000.000
718-723 and 773-778	Elisa	11.000.000	11.000.000
723-728 and 778-783	Telia	11.000.000	11.000.000
728-733 and 783-788	Telia	11.000.000	11.330.000
Total		66.000.000	66.330.000

Table 32. Results of the 700 MHz Finnish auction

As shown in the figure below, the situation has remained unchanged[17].

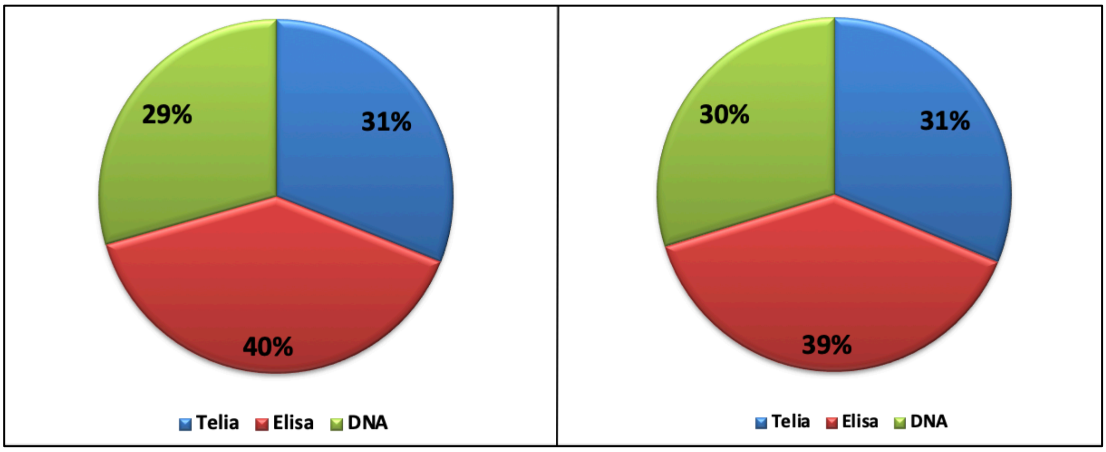

Figure 69. Amount of spectrum owned before (left) and after (right) the auction in Finland

6.4.3. France

ARCEP, the French regulator for electronic communications, conducted a 700 MHz (703-733 and 758-788 MHz) ascending clock auction in 2015 for improving 4G services, but also for future innovations. As the auction above, 6 blocks of 2x5 MHz were awarded.

With regard to spectrum caps, a bidder could only acquire a maximum of 3 blocks awarded for this auction, and in addition, the bidder cannot hold more than 2x30 MHz of the 700 MHz, 800 MHz and 900 MHz band.

Moreover, some coverage obligations were imposed to the winning bidders:

- It must provide a downstream speed of at least 60 Mbps if it owns 2x10 MHz or more, and it must provide a speed of 30 Mbps if it owns only 2x5 MHz;
- It must cover the 98% of the urban population within 12 years and the 99,6% of the urban population within 15 years;
- The regulator identified some priority areas: the licensee must cover the 50% of population of these areas within 7 years, the 92% within 12 years and the 97,7% within 15 years;
- The licensee must cover all the main roads within 15 years.

Only the four incumbent operators participated in the auction: Bouygues Telecom, Free Mobile (Iliad), Orange and SFR (Altice), and no new players tried to award the blocks. Also in this case the reserve price was very similar to the final price.

[17] Obviously, the blocks awarded in the 5G Finnish auction are not considered in this figure.

Winner	Number of blocks won (2x5 MHz)	Reserve price (€)	Final price (€)
Bouygues Telecom	1 block (10 MHz)	416.000.000	467.164.000
Free Mobile	2 blocks (20 MHz)	832.000.000	932.734.001
Orange	2 blocks (20 MHz)	832.000.000	933.078.323
SFR	1 block (10 MHz)	416.000.000	466.000.000
Total		2.496.000.000	2.798.976.324

Table 33. Results of the French auction

Even in the French case, the situation remained basically the same, with four incumbents that are still governing the market and with no other players.

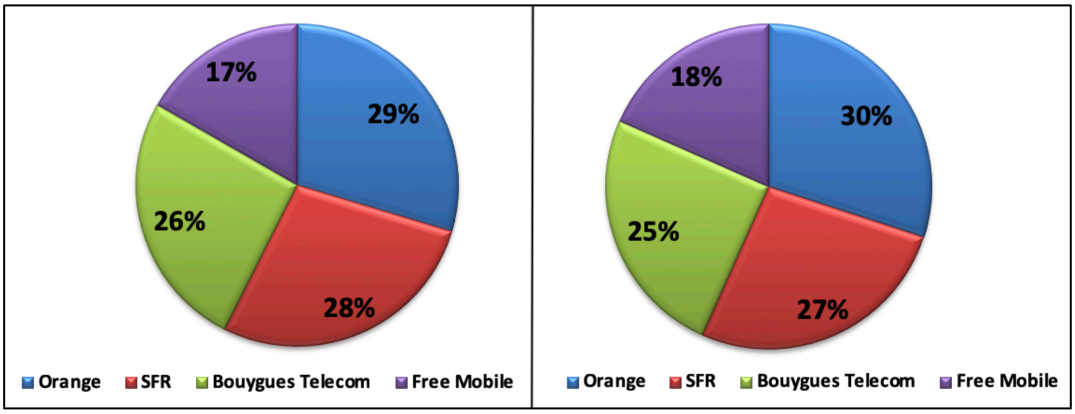

Figure 70. Amount of spectrum owned before (left) and after (right) the auction in France

6.4.4. Germany

In 2015, the German regulator, Bundesnetzagentur, awarded the 700 MHz, 900 MHz, 1800 MHz and 1.5 GHz bands for 4G purposes, by holding a simultaneous multiple round ascending auction. In this section, only the auction of 700 MHz pioneer band will be described.

Like the French and the Finnish regulators did, the German regulator decided to auction 6 blocks of 2x5 MHz in the 703-733 MHz and in the 758-788 MHz bands.

For this auction, neither blocks for new entrants nor spectrum caps were set, but instead, a coverage obligation was imposed: the licensee must ensure at least a transmission rate of 10 Mbps and must cover the 98% of households, whereby it must achieve at least 95% of every federal region and 99% of every main city; moreover the licensee must guarantee a 100% coverage of the main transportation routes. The obligation is different concerning the new entrants: they must cover the 25% of population and the 50% of population within 4 and 6 years respectively.

Despite the German regulator set a less strict obligation for new players, only the three German incumbents (Vodafone, Telefonica, and Deutsche Telekom) applied for the auction and won some blocks.

Blocks of 2x5 MHz	Winner	Reserve price (€)	Final price (€)
703-708 and 758-763	Telefonica	75.000.000	166.397.000
708-713 and 763-768	Vodafone	75.000.000	165.509.000
713-718 and 768-773	Telefonica	75.000.000	166.847.000
718-723 and 773-778	Deutsche Telekom	75.000.000	166.567.000
723-728 and 778-783	Deutsche Telekom	75.000.000	171.649.000
728-733 and 783-788	Vodafone	75.000.000	163.476.000
Total		450.000.000	1.000.445.000

Table 34. Results of the German auction

In the figure below the situation before and after the multi-band auction is depicted, considering also the other bands acquired by the operators. If before most of the spectrum was in the Telefonica's hands, after the auction, the amount of spectrum is distributed in a more balanced way, but here too, no new players entered the market.

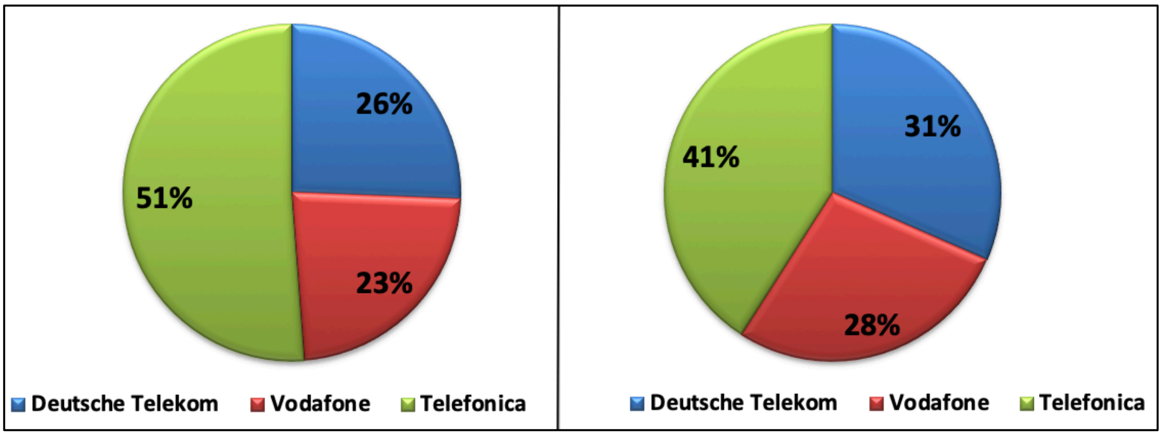

Figure 71. Amount of spectrum owned before (left) and after (right) the auction in Germany

6.4.5. Hungary

The Hungarian regulator opted to award 3.4-3.8 GHz spectrum by means of a sealed bid auction during the 2016. In particular, 16 blocks of 2x5 MHz in the 3410-3590 MHz band and 40 blocks of 5 MHz in the 3600-3800 MHz band were auctioned.

Other than imposing a spectrum cap, the regulator set also a spectrum floor: in fact, a bidder has to acquire a minimum of 4 blocks and a maximum of 6 blocks in the 3410-3590 MHz band, and a minimum of 4 and a maximum of 20 blocks in the 3600-3800 MHz band; however, an operator cannot bid for more than 100 MHz overall.

Moreover, the licensee must begin the operations within 4 years from the beginning of the license.

Here, only two operators participated in the auction: the just entered operator (in a Hungarian auction of 2014) DIGI and the incumbent Vodafone; the two incumbents, Deutsche Telekom and Telenor, did not applied for taking part in the auction.

At the end, Vodafone acquired 6 blocks of 2x5 MHz, while DIGI won 4 blocks of 5 MHz and the other blocks remained unassigned. The price paid was pretty much the same of the reserve price.

Winner	Number of blocks won	Reserve price	Final price
Vodafone	6 blocks of 2x5 MHz (60 MHz)	648.000.000 HUF 2.036.937 €	648.600.000 HUF 2.038.823 €
DIGI	4 blocks of 5 MHz (20 MHz)	216.000.000 HUF 678.979 €	248.000.000 HUF 779.568 €
Total		864.000.000 HUF 2.715.916 €	896.600.000 HUF 2.818.392 €

Table 35. Results of the Hungarian auction

After the auction, only Vodafone and DIGI turned to have more spectrum than before, while the other two incumbents, since they did not acquire any more spectrum, own a diminished percentage of spectrum. It is also noteworthy that, because of its recent entrance, the DIGI operator holds a very little amount of spectrum compared to others, but anyway it is considered as an incumbent, since for this auction it was already holding some spectrum.

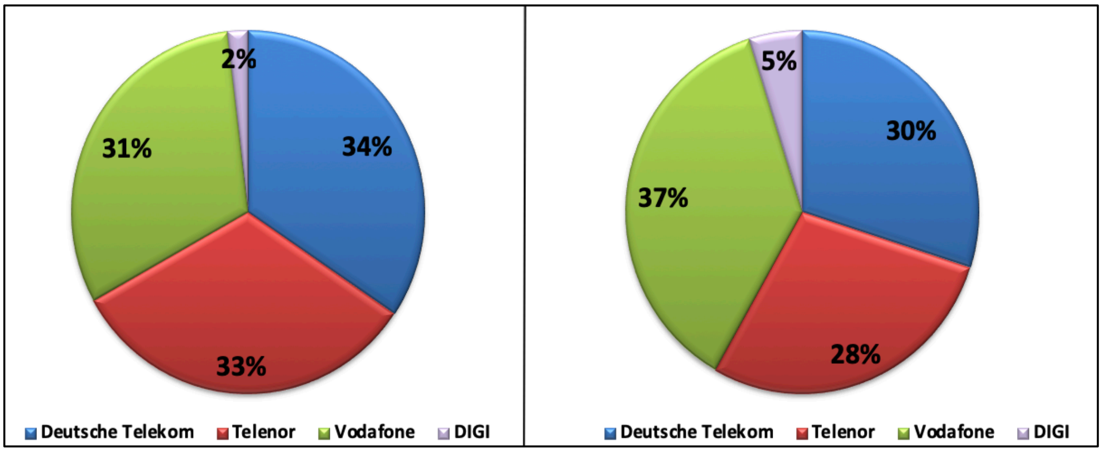

Figure 72. Amount of spectrum owned before (left) and after (right) the auction in Hungary

6.4.6. Latvia

As in the 5G Latvian case, it was not possible to get all the information necessary for the assessment, however, this auction is discussed with the available data.

The SPRK auctioned 2 blocks of 50 MHz in the 3400-3450 MHz and 3650-3700 MHz bands, setting a reserve price of €250.000 apiece.

The same obligations of the 5G auction were imposed:

- Receive one authorization of use in at least one city within the end of 2019;
- Receive one permission of use in at least 2 cities within the end of 2020;
- Receive one permission of use in at least 5 cities within the end of 2021;
- Receive one permission of use in at least 7 cities within the end of 2022;
- Receive one permission of use in each city of the Republic within the end of 2023.

Only one operator applied for acquiring the two blocks, LMT, which it obviously paid the same amount of the reserve price.

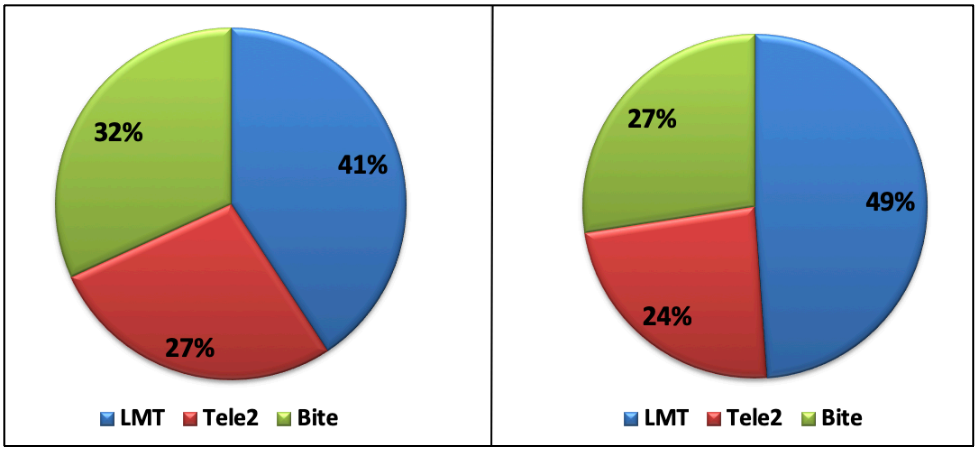

Figure 73. Amount of spectrum owned before (left) and after (right) the auction in Latvia

6.4.7. Romania

In 2015, ANCOM, the Romanian regulator of communications, auctioned 16 blocks of 2x5 MHz in the 3410-3600 MHz band and 36 blocks of 5 MHz in the 3600-3800 MHz band.

The regulator imposed only one roll-out obligation, namely that of installing 25 base stations within one year, 50 base stations within two years and 100 base stations within four years from the beginning of the license.

In this auction five actors participated:

- Three incumbent operators: Orange Romania, RCS&RDS and Vodafone Romania, but not Deutsche Telekom;
- Two new entrants: Radiocom (SNR), a broadcasting operator owned by the Romanian state and 2K Telecom, a provider of local networks, national transport and Internet access.

Every bidder won some blocks, also Radiocom and 2K: hence, two new players entered the Romanian market, even if the regulator did not reserve any block for them. Moreover, the final price did not differ grossly from the reserve price.

Winner	Number of blocks won	Reserve price (€)	Final price (€)
2K Telecom	2 blocks of 2x5 MHz	740.000	740.100
Orange	5 blocks of 2x5 MHz 9 blocks of 5 MHz	3.515.000	3.924.000
RCS&RDS	10 blocks of 5 MHz	1.850.000	1.880.000
Vodafone	4 blocks of 2x5 MHz	1.480.000	1.730.000
Radiocom	10 blocks of 5 MHz	1.850.000	1.850.001
Total		9.435.000	10.124.101

Table 36. Results of the Romanian auction

The figure below shows the percentage of spectrum owned by the incumbents before the auction, and by both the incumbents and new operators after the auction. Since 2K Telecom acquired only 20 MHz and Radiocom only 50 MHz, their amounts of spectrum represent a small part of the overall spectrum, not comparable with the portions of bands of the four incumbents.

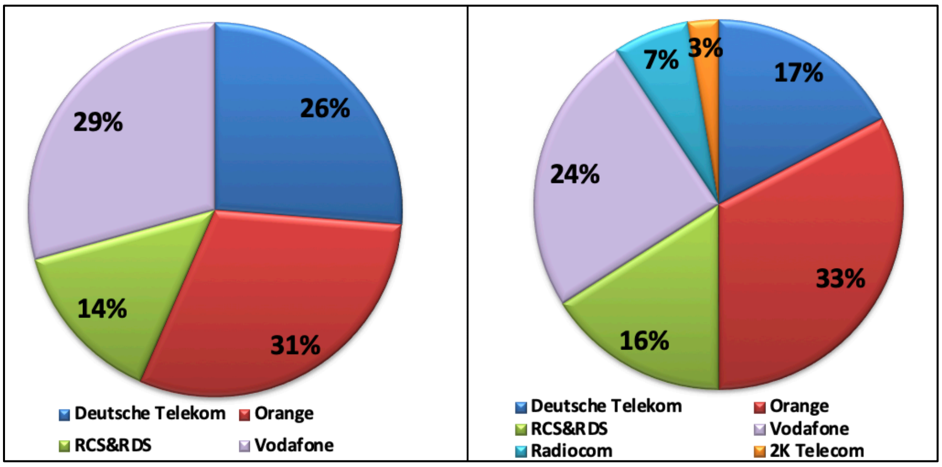

Figure 74. Amount of spectrum owned before (left) and after (right) the auction in Romania

6.4.8. Slovakia

Also Slovakia auctioned the 3.4-3.6 GHz band. In particular, it awarded 1 block of 2x20 MHz (3430-3450 MHz and 3530-3550 MHz) at the reserve price of €500.000, 1 block of 2x20 MHz (3450-3470 MHz and 3550-3570 MHz) at the reserve price of €500.000 and 1 block of 4x5 MHz (3490-3510 MHz) at the reserve price of €200.000, with a simultaneous multiple round ascending auction.

A spectrum cap of 40 MHz was imposed, and the licensee must comply with roll-out and coverage obligations:

- Install and use at least one access point in each district within 24 months;
- Install and use at least one independent access point in districts with less than 3.000 inhabitants;

- Guarantee a transmission rate of 5Mbps from the beginning of the license, 15 Mbps from the 1st August 2018 and 30 Mbps from the 1st August of 2020.

As regards the auction, data about the participants were not found, hence, only the winner can be known, which are Swan, that won the block of 4x5 MHz for €461.224, and O2, that won the 2 blocks of 2x20 MHz for €1.972.482.

The figure below provides the situation before and after the auction: on the right-side Swan and O2 own more spectrum.

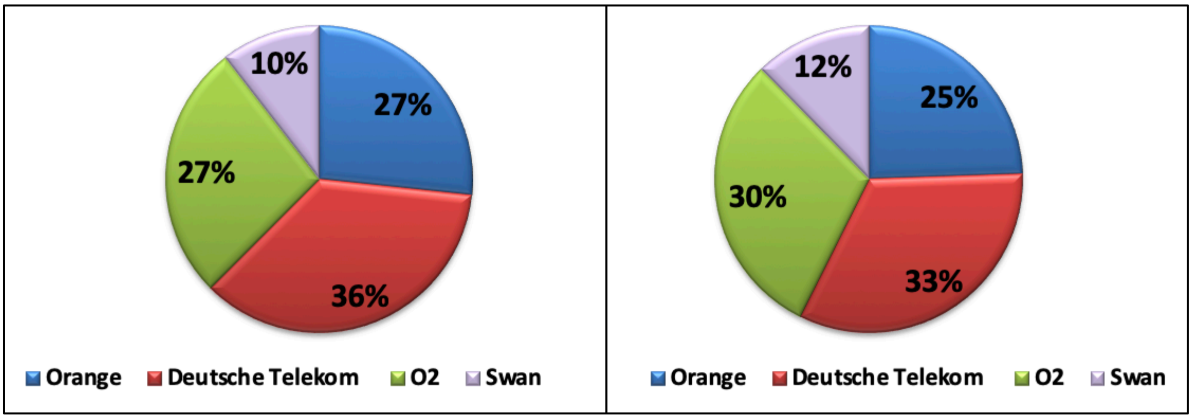

Figure 75. Amount of spectrum owned before (left) and after (right) the auction in Slovakia

6.4.9. Overall results of auctions for pioneer bands

This section contains the same figure and tables provided for 5G auctions.

Firstly, the instruments used for each auction by the European regulators are given in the former table below. Here, not every country used spectrum caps, but rather, every regulator applied coverage obligations, or roll-out obligations or both, meaning that regulators had as primary purpose the use of frequencies and the coverage of the national territory.

Country	Spectrum for new entrants	Spectrum cap	Coverage obligation	Roll-out /usage obligation	Access obligation	Use-it-or-lease/lose-it
Czech Republic		X		X		
Finland		X	X	X		
France		X	X	X		
Germany			X			
Hungary		X		X		
Latvia			X			
Romania				X		
Slovakia		X	X	X		

Table 37. Instruments used by regulators in the auctions for pioneer bands

The second table, instead, provides the total amount of incumbents, and if there were new players that participated in the auction. It can be noted that only Czech Republic and Romania let in some new entrants, while in the other countries not even a new player tried to acquire some blocks.
Like the 5G countries, the number of incumbent operators varies from 3 to 4.

Country	Number of incumbents	Number of winning entrants	Number of losing entrants
Czech Republic	3	**2**	**1**
Finland	3	0	0
France	4	0	0
Germany	3	0	0
Hungary	4	0	0
Latvia	3	0	0
Romania	4	**2**	0
Slovakia	4	0	It cannot be known

Table 38. Number of incumbents and new entrants for "pioneer bands" countries

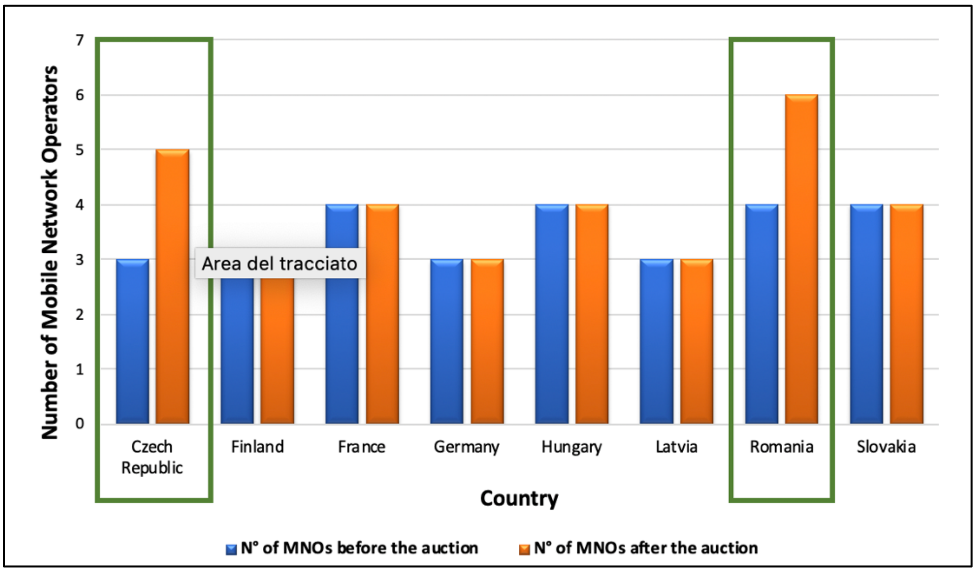

Figure 76. Situation of the market before and after the auctions for pioneer bands

6.5. Future 5G auctions

In this section, the most forthcoming 5G auctions, for which the invitation to tender, or at least the final auction rules have been already published, will be assessed in regulation terms.
The table below shows the bands auctioned, the format of the assignment, the publication and assignment dates.

Country	Band	Type of assignment	Release date of final rules	Expected date of assignment
Austria	3.4-3.8 GHz	Clock auction	September 2018	March 2019
Denmark	700 MHz, 900 MHz, 2.3 GHz	Multi round ascending auction	June 2018	It was expected for September 2018, but it was suspended
France	3.4 GHz	Beauty contest	December 2017	Ongoing
Germany	2 GHz, 3.4-3.7 GHz	Multi round ascending auction	November 2018	Spring 2019
Norway	700 MHz	Multi round ascending auction	January 2019	May 2019

Table 39. Future 5G assignments

Instead, the table below provides which instruments the regulator applied to the auction rules. Only three out of the five countries provide spectrum caps, while every regulator had set some coverage obligations. An interesting case is the German auction, which was set to enhance the entrance of new players, because the regulator imposed some coverage obligations, but it loosens them if it is about new players that want to enter the market. Nevertheless, no potential entrants applied for the auction. However, it seems that these countries do not provide so different rules then those already seen; hence, accurate predictions on the outcomes of auctions cannot be made.

Country	Spectrum cap	Coverage obligation	Roll-out /usage obligation	Access obligation
Austria	Number of blocks different for incumbents	A certain amount of regions, which varies on the basis of the spectrum owned		Allow third parties have access for network
Denmark	Amount of MHz	% of territory, min transmission rate	Number of base stations	
France		% of households, min transmission rate	Number of base stations	
Germany		% of households, min transmission rate. Different values for new entrants	Number of base stations. Different values for new entrants	
Norway	Amount of MHz	% of population, transport routes		

Table 40. Regulatory instruments for future 5G auctions

6.6. Conclusions

In summary, during the 5G auctions, new players entered only the Italian and Irish markets, while potential new MNOs were excluded from Italy, Latvia, Switzerland and UK, and in the other three countries no new players took part in the auction. As regards past auctions, the situation is the same: new entrants were seen only in Czech Republic and in Romania, while in the other countries no one new participated.

Hence, even if 5G is seen as a carrier of innovation from different points of view, 5G auctions did not welcome a high number of new players in the mobile market, and this is confirmed also by the auctions held for the pioneer bands of 5G. Moreover, it can be said that the potential entrants, that entered or were excluded, are new to the mobile MNOs market, but they already belong to the broader telecommunications sector. In fact, only operators who are MNOs in other countries, or MVNOs who based their business on MNOs' network, or even, fixed service providers tried to enter the market, but not the "new" players mentioned in the 5G chapter. Hence, it can be concluded that they should have other means to acquire spectrum or enter the mobile market.

The fact that the mobile market is dominated always by the few incumbents of the sector is a serious problem: a very concentrated oligopoly, like the mobile market is, might have a negative impact on the final consumer which does not benefit of the effects of competition, since operators are led to increase their prices and are not encouraged to invest in innovation and efficiency; other than the fact that in a concentrated market, operators tend to have collusive behaviors, for example by making deals on prices. For this reason, national regulators have to find or to enhance other ways for facilitating the entrance of new players on the market, and these ways will be discussed briefly in the last chapter of this work. In the next chapter, an analysis of the potential reasons for this lack of entrance will be provided.

7. Why no new players entered?

As it has been demonstrated in the previous chapter, 5G auctions and assignments of the pioneer bands of 5G did not allow the entrance of new players. As regards 5G auctions, only in Italy and Ireland some new players entered, while concerning the pioneer bands auctions, new firms entered only in Romania and Czech Republic; in the other countries, non-incumbent operators were excluded or did not even take part in the auction. This means that there could be some reasons acting as barriers to entry for new players.

Hence, this chapter will seek to assess which were these reasons, while the last one will check whether something can be done about it, or it is inevitable that the mobile market is composed always by only those three or four operators.

7.1. Inappropriate auction design

Regulators have increasingly opted for assigning spectrum by means of auctions, instead of beauty contests, because, according to the theory, auctions put spectrum in the most effective operator's hands. However, it often happens that the reality differs from the theory: the operator that wins the auction is not the most efficient operator which will do the best use of spectrum, but it is the one that has the greater willingness and availability to pay.

Now, a little comparison between the auction design and the auction results will be made in order to find whether a correlation between them exist or not.

- Finland: some obligations were imposed, but they were flexible so as to not constitute a threat; also the reserve price was low. The problem here can be the size of the blocks auctioned: FICORA divided 390 MHz of spectrum into three blocks, the same number of incumbents;
- Ireland: the regulator divided the Irish territory into rural and urban regions and imposed only a roll-out obligation to the winner; probably the entrance of new players was facilitated by this division, since one can decide to bid only for some regions rather than for others;
- Italy: this country was the only to provide a set-aside mechanism in the 700 MHz band for new entrants. Despite the very high prices and the strict obligations (but more flexible for new entrants), two new entrants entered the market: Iliad acquired blocks in all the three bands, while Fastweb acquired one block in the mmWaves band; however, two weaker players did not even bid, perhaps because of the high reserve prices.
- Latvia: since the regulator did not impose rules in favour of new players, the incumbent beat the new entrant;
- Spain: despite the regulator divided the band in a big number of blocks and did not impose any strict obligation, new players did not enter the Spanish market;

- Sweden: besides the SDL blocks, Sweden auctioned only 3 blocks, less than the number of incumbents; by setting a coverage incentive, it seems that Sweden was more focused on the coverage issues of the territory, rather than enhancing the entrance of new players;
- Switzerland: only a 50% coverage obligation was imposed for the license, and perhaps the absence of strict rules encouraged a new entrant to took part in the auction, but it did not win any block;
- UK: this case is similar, since the regulator imposed only spectrum caps and no obligations, a potential entrant tried to acquire some blocks but failed.

Therefore, a reason why new players did not enter the market can be due to the fact that regulators did not provide good incentives for operators that are new at the mobile market, or that the auctions rules are not designed in a way that promotes the entrance of new players.

Firstly, the amount of the total spectrum auctioned and in how many blocks it is divided may impact on the auction outcome. As happened for the case of Latvia, if the quantity of spectrum offered is very low, it is clear that the incumbent operators would be willing to raise prices in order to achieve it, without leaving the new entrants, which probably have less economic availability, the possibility to win the blocks; on the contrary, if the regulators award a big amount of spectrum, prices would remain lower and potential new entrants would have the opportunity to acquire some blocks. The same applies to the number of blocks auctioned: it is very likely that only incumbents will win few big blocks (i.e. Switzerland), while if blocks are many and small, the band can be distributed to more participants (i.e. Ireland).

The figure below tries to capture the correlation: on the X-axis is the amount of spectrum that was auctioned in MHz, and on the Y-axis is the final price resulted from the 5G auctions and the assignments of the pioneer bands for 5G. The plot confirms what it has just been said: there is a negative correlation between the two variables; in fact, when the spectrum awarded is not much, the price of the auction tends to increase, because every incumbent operator wants to win that little spectrum at all costs.

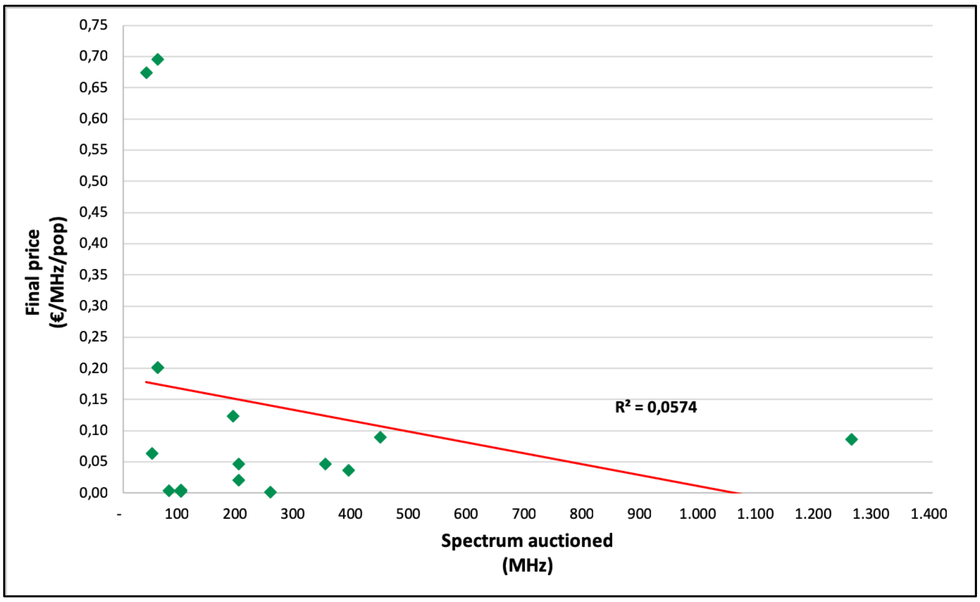

Figure 77. Correlation between the amount of spectrum auctioned and the final price

Second of all, reserve price should be set in a way that reflects the real value of the spectrum auctioned, but sometimes regulators are too attracted by the revenues that they could gain and thus, they ask a too high reserve price that leads small entrants, with no much money, to abandon the tender right from the beginning. This can be the reason why Linkem and Open Fiber did not even propose an offer for some blocks for the Italian auction.

Moreover, setting a high reserve price can lead to high final prices, which in turn can be also one of the reasons why new entrants are excluded; the figure below, in fact, shows that the final price increases with increasing reserve price. As it has been said in the previous chapter, that is not necessarily always true, but anyway sometimes it could be a reason why a new entrant abandons the tender.

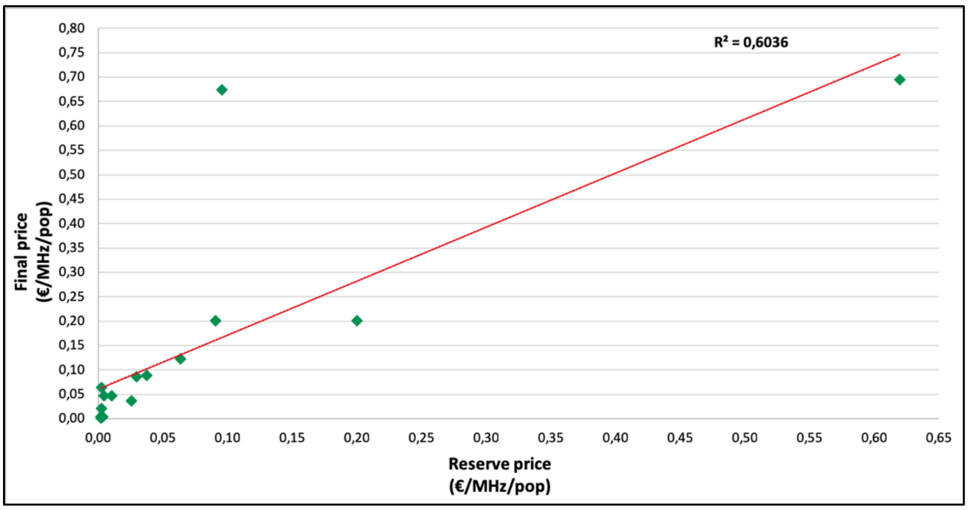

Figure 78. Correlation between reserve price and final price

A more general consideration on the price can be done: it is true that the auction price is considered as a sunk cost, which does not impact on the final price that is made for customers, but many studies (i.e. "Effective spectrum pricing in Europe, GSMA (2017c)) have shown that the auction price influences the subsequent investments of operators, with all the consequences of the provision of services.
Also the fact that regulators impose some obligations may prevent new entrants to bid for the bands: in fact, obligations are usually combined with some rules that force the operator that fails to comply with the terms imposed, to pay a penalty or worse, be deprived of its license rights. Hence, a new operator, with no infrastructure or base stations yet, would certainly take much more time for deploying its own network from scratch, and thus it avoids the risk of not being able to install its base stations or to cover a certain amount of population within the time limits. A good way to favour new entrants is provided by Italy: although it set a lot of obligations that have to be fulfilled, the regulator decided to allow more time to new entrants.
Instead, every country applied spectrum caps in order to limit the number of blocks acquired by a single operator, but they are not effective for the entrance of new players; in fact, it seems that the purpose of these instruments is to make the situation among incumbents harmonized, or to maintain it balanced, but it does not prevent the incumbent operators from acquiring the blocks in favour of new entrants. The English regulator, OFCOM, could have done a wrong assumption when it did not reserve any block for new entrants, justifying this choice by the explanation that a spectrum cap was enough: indeed, the outcome of the auction was that the incumbents divided the spectrum among themselves in an equitable manner, but the only new entrant was excluded.
Moreover, according to a long-term view, it is appropriate that a regulator sets the duration at 15 to 20 years to ensure that the licensee will have the right returns on its investments, but this also means that a new possible operator will not have the possibility to acquire that spectrum for a long period of time.
Furthermore, no country set a rule aimed to avoid spectrum hoarding (when a block is acquired by an operator only with the intention to steal spectrum from the other players in order to make them less competitive, if not exclude them from the market). It is true that Italy and Finland set a "use-it-or-lease-it" mechanism, but this rule has only an *ex-post* impact, which can be monitored after a while from the auction. In the meantime, one may lose interest in the spectrum, and there is also the eventuality that the owner of the spectrum leases the spectrum at improper prices.
The same goes for the fact that spectrum transfer and spectrum leasing are allowed on the secondary market. It is true that this system allows those who were not able to win some spectrum in the auction to acquire it at a later stage, but it is worth noting that, during the auction, one may acquire some blocks with speculative purposes, in the sense that it can resale them or lease them at significantly high prices.
Hence, by analysing instruments used by regulators, it seems that the most effective one is the set-aside mechanism, which reserves a specific block for new entrants, without leaving the opportunity to incumbents to exercise their power (i.e. by raising prices above the economic means of new entrants).

Unfortunately, the only country that set this type of instrument was Italy, while the others, perhaps for fear of leaving blocks unassigned, did not provide this mechanism.
In conclusion, both for 5G auctions and for assignments of the pioneer bands, European NRAs did not design the rules in a pro-competitive perspective, but they favoured other interests, like favouring the coverage of the territory or gaining big revenues from the auctions.
If regulators want to improve competition in the future, it will be necessary that they review and reorganize auction formats. For example, a regulator should do some changes to their future rules:

- Award an appropriate amount of spectrum, divided into blocks that exceed significantly the number of incumbents;
- Auction blocks on a regional basis, and not on a national territory, so that an operator can acquire only the spectrum for the area it is more interested in;
- Set a reserve price on the basis of the agreed value of the spectrum, and not for earning a large amount of money;
- Coverage and roll-out obligations are necessary to ensure a good provision of services on a specific territory, but regulators should change the related rules:
    - Give more time to new entrants to develop and build their networks, bearing in mind that, if incumbents have already an infrastructure at their disposal, new entrants must build their structure from scratch;
    - Set coverage obligations, but a certain amount of the auction price cannot be paid in cash, but devoted to investments in network, like Sweden did (this can be more efficient also for incumbents);
    - Give a reward if the operator reaches the coverage objectives within a given period, for example making it pay few annual fees, rather than punish it severely (this can be more efficient also for incumbents);
- Spectrum caps are efficient for limiting the purchase by a single operator (but they are not sufficient);
- Set a set-aside mechanism for new entrants and, in order to avoid that the reserved blocks remain unsold, auction them first, and in case no new entrant applies for them, award them as generic blocks;
- In order to avoid spectrum hoarding, during the qualification process, a regulator should ask applicants a short generic description of their future plans in the case they win some blocks, in order to check if their intentions are valid, or they want only steal spectrum from the others;
- Tight control on the prices that spectrum owners make to potential buyer on the secondary market for spectrum leasing and spectrum trading;
- Award spectrum in a timely manner: at present only 8 European countries out of the 30 that were assessed in this analysis auctioned spectrum for 5G. Being in late with the auctions make

the dream of a European DSM as a good rival of Asia and US blurred and discourages the entrance of the players that need more time to develop their infrastructure.

However, it has to be said that for some auctions, although the auction design was not such a big impediment, no new entrants tried to acquire the spectrum. This leads to consider that there are other reasons that act as a barrier for the entrance of new players.

7.2. 5G high investments

The second main reason of this significant lack of entry by new players, is the fact that 5G requires very high investments for its infrastructure and its maintenance.

As already showed in Figure 18, costs tend to increase for every technology change, and, specifically for 5G, there are several reasons why both Capex and Opex costs will increase:

- Better technical capabilities: for example, high speed or low latency, are required; hence, operators will need to use a big amount of money to ensure a certain high-quality service;
- MmWaves: the bands that exceed 24 GHz are characterized by a high capacity, but lack of coverage; hence, a huge number of small cells must be installed in order to ensure that the service works in an effective way;
- Different connections: with the introduction of the IoT, different types of communications will be created, like M2M communications; thus, since there will be more devices connected to each other, operators must develop a system able to buttress these connections;
- Bigger number of users connected: since 5G aims to cover rural areas and to provide different services, more consumers will use mobile connections; hence, it will be needed to install a system able to support this higher number;

The figure below compares the costs of 4G and the predicted costs for 5G, from the year of the introduction of the technology (here the first year is considered the 2009 for 4G and 2019 for 5G). It is clear that 5G requires right away of more investments in infrastructure, and also that, if 4G costs have decreased over the years, costs of 5G are expected to increase.

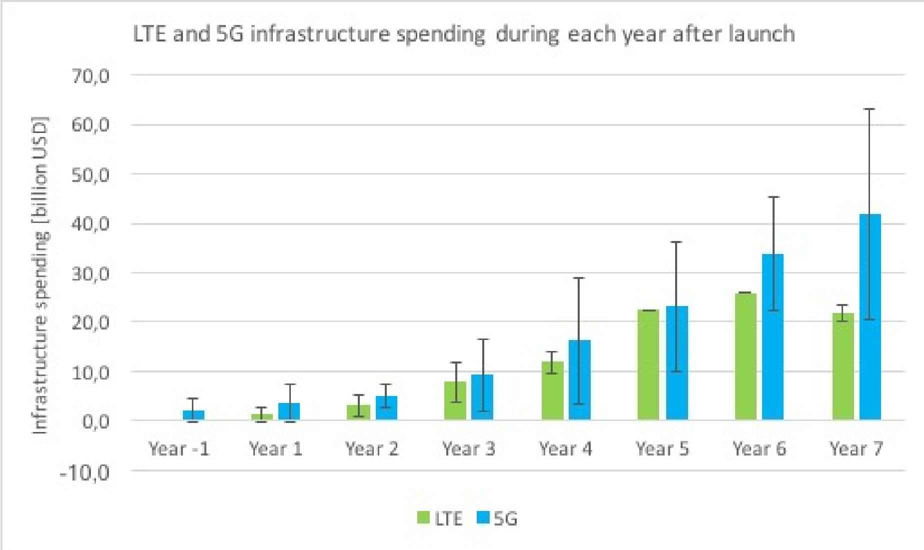

Figure 79. Infrastructure costs trends of 4G and 5G. Source: Edge of the Cloud[18]

As regards Europe, the EC made some predictions on the possible future costs of 5G (EC, 2014). First of all, every next generation always requires more spectrum than the previous one, and, as showed in Figure 18, the installation costs increase too with the generation change: 5G will require €141 per subscription in 2020, and €145 per subscription in 2025, in terms of development costs, therefore the 7% more than 4G (€135 per subscription) and around 20% more than 3G (around €123 per subscription). The EC provided a table containing the amount of investments necessary in every country of the EU for the deployment of 5G in 2020 (Table 41), accounting for a total of €56.6 billion. Instead, EC has foreseen that, in 2025, €58 billion will be required for the deployment across Europe, while operational costs will be from €67 to €88 billion per year.

Further, as shown in the table, costs for development of 5G change from country to country, due to the dimension and conformation (% of urban and rural areas) of the territory.

[18] The coloured bars represent the average values, while the black bars include the error.

Country	Costs (€m)	Country	Costs (€m)	Country	Costs (€m)
Austria	970	Germany	9.280	Poland	4.350
Belgium	1.230	Greece	1.220	Portugal	1.170
Bulgaria	840	Hungary	1.130	Romania	2.270
Croatia	480	Ireland	490	Slovakia	620
Cyprus	100	Italy	6.830	Slovenia	240
Czech Rep	1.200	Latvia	230	Spain	5.190
Denmark	620	Lithuania	330	Sweden	1.060
Estonia	150	Luxembourg	60	UK	7.040
Finland	600	Malta	50		
France	7.030	Netherlands	1.870		

Table 41. Deployment costs per country in 2020. Source: EC (2014) based on data from OECD, WDI and Eurostat

It was not possible to retrieve all the precise data about costs of deployment and usage of 5G across Europe, but a study made on future costs of UK was found[19]. Hence, the case of UK will be described briefly, in order to give the idea of how much 5G will cost.

The study considered the Total Cost of Ownership (TCO) as the sum of Capex costs[20], namely the costs for developing the infrastructure, and Opex costs[21], namely the costs for maintaining the network once it is active.

The two authors distinguished between nine cases, on the basis of the rate of transmission that has to be achieved and if the infrastructure is shared or not. In this case only the scenario with 50 Mbps of speed and no sharing, and the scenario with 50 Mbps with infrastructure sharing are provided.

Scenario	50 Mbps – No sharing	50 Mbps - Sharing
Capex (£ billion)	42	22
Opex (£ billion)	29	16
TCO (£ billion)	71	38
Capex savings	-	48%
Opex savings	-	45%
TCO savings	-	46%
Capex – URBAN (£ billion)	0,7	0,4
Capex – SUBURBAN (£ billion)	5,6	3,4
Capex – RURAL (£ billion)	35,6	18,2

Table 42. Costs in a normal scenario and a sharing scenario. Source: Oughton & Frias (2016)

[19] The referenced paper is “Exploring the cost, coverage and rollout implications of 5G in Britain” written by Oughton E. and Frias Z.
[20] Capex costs are intended as the sum of Capex costs of: macro cells, small cells, fiber and upgrades.
[21] Opex costs are intended as the sum of Opex costs of: macro cells, small cells and fiber.

What it can be noted from the table is that the majority of the costs are required to be spent in rural areas, rather than in urban areas, since the latter are already owning an infrastructure that provides nearly the total of the coverage, while the former need for an installation basically from scratch and the territory is more grueling. Moreover, the sharing of deployment costs and hence the infrastructure once it is built reduces by far costs, both Capex and Opex costs.

However, by continuing with the issue of the lack of entrance, it is clear that these costs are extremely high for a potential new player that wants to enter the market, also because it must be taken into account that the costs provided above are the additional costs of an infrastructure that has been already built. Hence, a new entrant, besides these costs, must consider all the costs of deployment that incumbents have already spent for the old generations over the past years, and thus, the development of a network from the ground up turns out to be prohibitively expensive.

In conclusion, some other considerations about the differences between new entrants and incumbents can be made:

- Complementarity with 4G: as just mentioned, the development of 5G will rely also on 4G infrastructure, which will allow to use base stations instead of constructing new ones.
  Moreover, the fourth generation is considered complementary also with regard to frequency bands. To reach great levels of efficiency, low, middle and high frequencies are required, but a new entrant could not have both of them, since it did not participate to previous auctions and regulators did not auction all the three pioneer bands;
- Economies of scale: incumbents have already a network at their disposal, and hence they can exploit economies of scale from it, getting a cost advantage and obviously all the benefits that this would bring.
- Finally, the existing agreements with suppliers and relationships with loyal customers are another factor that represents a competitive advantage of incumbents over new entrants.

7.3. Conclusions

As outlined in this chapter, there are solid barriers to the entrance of new players. On the one hand, European regulators have planned 5G auctions in order to achieve objectives that are different and sometimes go in the opposite direction of improving competition. In fact, one of the main purposes for 5G, is the coverage of almost the entire territory and the bridging of the digital divide between rural and urban areas, ensuring always a high transmission rate. Therefore, competition seems to be not the primary factor that underpins the 5G deployment for regulators.

Moreover, the required investments for developing an entire mobile structure make the entrance of a new player practically impossible, given the extremely high costs and long times of construction. It is more likely that a new entrant will buy an already launched system.

Finally, all the considerations made in this chapter confirm the fact that the mobile sector will remain a "natural monopoly"; the market is shared out among the same three or four incumbents, that own the entire spectrum and a network that has been developed from the previous generations and allows the exploitation of economies of scale.
However, in general, regulators must always keep competition as a primary objective, and hence, they must have at their disposal some other instruments to promote it.

8. Conclusions

8.1. 5G assignments

Auctions have been reconfirmed to be the most used format to assign 5G spectrum to operators, and they aim to leave the choice of the winners to the market, rather than making the regulators to decide through beauty contests. However, it is likely that the way the authorities set the regulations, can influence the outcome of the auction.

In fact, from the considerations made in the two previous chapters, it can be concluded that the enhancement of competition was not one of the primary purposes of regulators. By imposing coverage obligations with particular focus on rural areas and transportation roads, they mainly wanted to accomplish one of the most important 5G objectives, namely the guarantee that all citizens can have access to mobile services at every time and in every place. In fact, both 5G and pioneer bands auctions, saw few new participants in the tender, and even less new entrants that have been able to acquire some spectrum. Moreover, regulators may be attracted from the high revenues that the auctions can create.

If regulators want to facilitate competition by means of auctions, they could make some of the changes listed in the previous chapter. For example, use the set-aside mechanism more, and so reserve some blocks specifically for new entrants, or even, award a large number of blocks.

It is advisable that regulators try to keep the reserve price at an acceptable level, in such a way that it is the market that decides the value of the final price.

8.2. How regulators can enhance competition in other ways through 5G?

It has been also shown that the only potential entrants were firms new to the mobile market, but not new to the telecommunications sector in general. Therefore, the new players mentioned in the 5G chapter that could enter in the market did not even try to acquire some spectrum. However, regardless the type of company, regulators should have different instruments for enhancing competition in this sector.

Among the alternative ways, we can find:

- Trading on the secondary market: in recent years, regulators have allowed the use of the secondary market to trade spectrum; it is more likely that a new entrant will acquire the spectrum and the infrastructure when this is already launched. However, regulators must control that the owner does not sell the system at a too high price;
- Spectrum sharing: as already discussed in the 5G chapter, the sharing of spectrum bands is essential to compensate the lack of spectrum. Regulators have already begun to set the licenses as non-exclusive rights, so that one can share it on a geographical basis, for a certain period or

in a dynamic way. In this way, a more efficient use of the spectrum can be done, since the spectrum usage is higher and the coverage can be expanded;

- Infrastructure sharing: together with the spectrum sharing, regulators should favour also the sharing of infrastructure, with the promotion of co-investments programmes. In this way, not only more firms can have access to the same network, but the amount of money that a single company has to pay is lower.
- Virtualization: the other novelty of 5G is that a single hardware system can be split into many software interfaces. Hence, a single infrastructure can be used for multiple purposes. Also in this case, costs can be greatly reduced.

To conclude, generally speaking, *ex-ante* regulation should constitute neither a barrier to entry nor a limit for investments and innovation. Regulation should be adapted in a dynamic way according to each case and on the basis of the type of players under discussion, by bearing in mind that the final purpose is to improve the overall welfare.

8.3. Regulation at European level

This study focused on the analysis of how regulators, namely NRAs, can enhance competition at a national level, but it can be useful to assess which were the objectives of the entire EC and how they have changed over time. A comparison can be made between the four directives issued in 2002[22], which were updated in 2009[23], and the recent directive issued by the European Parliament and the Council in 2018[24].

In fact, if the "code" of 2002 aimed to promote competition as a primary objective along with investments issues, the new European Electronic Communications Code (EECC) has rather the purpose to enhance:

- The establishment of the so-called DSM and the removal of regulatory fragmentation[25], in order to achieve a beneficial harmonization and coordination between European countries, also for the assignment and the use of spectrum[26];
- The investments in high speed structures and the provision of effective services[27];

[22] Directive 2002/19/EC (Access Directive), Directive 2002/20/EC (Authorisation Directive), Directive 2002/21/EC (Framework Directive), Directive 2002/22/EC (Universal Service Directive).
[23] Directive 2009/136/EC (Citizens' Rights Directive), Directive/140/EC (Better Regulation Directive).
[24] Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code.
[25] Directive (EU) 2018/1972, Point (3); Directive (EU) 2018/1972, Article 1, Article 3, Article 4, Article 32.
[26] Directive (EU) 2018/1972, Article 36, Article 37, Article 45, Article 53, Article 54.
[27] Directive (EU) 2018/1972, Point (62), Point (74), Point (127); Directive (EU) 2018/1972, Article 1, Article 3, Article 45, Article 47, Article 49.

- The provision of mobile services to all European citizens at any time both in indoor and outdoor spaces, and the coverage of all European areas, including less densely populated and rural areas in order to bridge the digital divide between urban and rural areas[28].

Obviously, competition is always mentioned as an issue that regulators must keep the eyes on, and an intervention is required if there is any market distortion, but in the new EECC, competition is not seen as one of the primary objectives that regulators must try to achieve, but rather, is seen as a consequence of the good investments made by users and of the innovation that the new systems and services can bring. The code, in fact, refers to the term “infrastructure-based competition”, to describe the fact that competition is determined by an effective level of investments, both in infrastructure and in services provided (Directive 2018/1972, Article 3).

Therefore, if in 2002 the issue of competition was the centre of attention of the EC, the focus has turned to other objectives. Indeed, as early as 2009, the upgrades were made to promote an internal market, as an instrument able to promote a greater efficiency of services. With the issue of the new directive, this objective has been strengthened.

Hence, the way the EC has formulated its directives, can have a negative impact on the entrance of new players in the market, and also the EC should try to implement again the issue of an effective in its regulations, adapting it to the novelties that are brought by 5G.

Since this work focused on competition issues at the detailed NRAs’ level, for a future research, it can be reasonable and interesting focus the attention not at the national layer, but at the overall European level, by assessing why the EC has changed its purposes and how a new competition policy can be developed along with the others.

[28] Directive (EU) 2018/1972, Point (24), Point (63), Point (109); Directive (EU) 2018/1972, Article 3, Article 45.

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