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Leadership with 5G in Europe: Two contrasting images of the future, with policy and regulatory implications

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ABSTRACT

European policy makers have shown a keen interest in the success of 5G because ubiquitous and high capacity electronic communication infrastructure is recognized as a cornerstone of economic development and productivity growth. The second generation, GSM, is considered the leading example, reaching its peak of deployment in 2015 with 3.83 billion subscribers served by over 700 operators in 219 countries and territories.

With 5G rapidly shaping up in the R&D and standardization environments, and a call for leadership with 5G in Europe by policy makers, it is timely to investigate what lessons can be learned from the success of 2G that can be applied to 5G. More broadly, this calls for research into the commonalities and differences between successive generations of mobile technology, their introduction and the market adoption that followed. This also calls for an investigation into the possibility of multiple futures of 5G and how that impacts the opportunity for leadership. As one future may be more desirable than the other, depending on the perspective of the actor involved, a policy debate will be required to determine the most desirable future. As well as a discussion of the policy and regulatory actions required to enable a particular future.

Hence, the two-part research question being addressed in this paper is: *What explains the success of 2G-GSM and how can it be applied to create success with 5G in the European Union*?

To respond to the research question this paper first identifies the leadership lessons to be drawn from the success of 2G-GSM in relation to its successors 3G and 4G. Secondly, the contribution describes two stylized images of possible futures of 5G, called "Evolution" and "Revolution", as input to the policy debate on the options for leadership with 5G. These images reflect two extremes in terms of possible futures of 5G. "Evolution" follows the pattern of previous generations and current trends. "Revolution" represents a clear break with these trends and a path towards leadership with 5G, as it exploits the opportunities of standardized APIs for service creation, being enabled by network virtualization as an architectural foundation of 5G. These open and uniformly applied APIs allow the market entry of a multitude of virtual mobile network operators (VMNOs) serving particular industry verticals or economic sectors with tailored feature sets and qualities of services. They allow a market momentum to be built that constitutes leadership with 5G in Europe.

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1. Introduction

With the introduction of each new generation of mobile communications technology comes a new opportunity for leadership. With the success of 2G-GSM in mind, European politicians would like to see an EU leadership role with 5G, which is scheduled to be introduced in 2020. However, since the introduction of GSM in 1991 much has changed. An assessment of the factors that have enabled the GSM market momentum to build and be maintained shows that most of these factors are not applicable anymore. The industry has moved from regional standards to a global one. The mobile services market has been liberalized and the role of government has changed from being in the lead to acting as a facilitator of industry development. Nonetheless, a leadership opportunity with 5G remains feasible, enabled by the virtualization of the 5G architecture and the focus of 5G on serving so-called vertical industries, such as automotive, public transport, media and entertainment, financial services, energy utilities, manufacturing, health and public safety.

With the success of GSM, introduced in 1991, reaching its peak in deployment in 2015 with 3.83 billion subscribers and 700 operators in 219 countries and territories, it should not come as a surprise that the call for European Union leadership in the development and deployment of mobile communications is raised with each successive generation. European Union policy makers have a keen interest in the success of the next generation because ubiquitous and high capacity electronic communication infrastructure is recognized as a cornerstone of economic development (EC, 2010). This also applies to 5G.

The economic interest can be illustrated by the anticipated revenues globally. While the current mobile operator service revenues are expected to grow 1.5% on an annual basis – from US$1.5 billion in 2016 to 1.7 billion in 2026, the digitalization revenues for ICT players are expected to grow by 13.3% annually – from US$939 million in 2026 to $3.2 billion in 2026. Out of the latter US$1.2 billion is expected to be 5G enabled revenues for ICT players. Energy utilities and manufacturing are expected to assume a major share with 20% and 19% respectively. The addressable market for mobile operators in 2026 is expected to consists of US$193 billion as network developer, $507 billion as service enabler and $582 billion as service creator. (Ericsson, 2017).

Hence, the two-part research question being addressed in this paper is: *What explains the success of 2G-GSM and how can it be applied to create success with 5G in the European Union?*

To answer the research question the first part of the paper investigates the concept of leadership and success. Subsequently it identifies the conditions that have led to the success of GSM using historical analysis. The findings are compared with the developments around 3G and 4G and with the steps in the development of 5G undertaken so far.

The second part of the paper is aimed at creating the basis for the policy debate to create success with 5G in the European Union. For that purpose two contrasting stylized future images are constructed. Taking a more conservative perspective, the market trends can be interpreted as an evolutionary development in mobile technology. 4G – true to its name Long Term Evolution – is giving way to a gradual introduction of 5G, as the needs of the mass market consumer are well served by 4G and the demand for new features of 5G is remaining modest. Hence, operators prefer expanding the current 4G infrastructure and are prudent with investment in 5G. This leads to the construction of the "Evolution" scenario as the base line. Such an evolution scenario is also described in the "5G myth" by Webb (2016). The use of the terms 'evolution' and 'revolution' in the context of scenarios or images of the future in general or in the context of 5G in particular is not new. Examples of earlier use related to mobile respectively 5G are De Vriendt, Laine, Lerouge & Xu (2002) and Kachhavay and Thakar (2014).

The "Revolution" scenario represents a clear break with the trends underpinning the "Evolution" scenario. It shows how a new industry momentum can be created that constitutes a leadership role with 5G for Europe. For that purpose it exploits the opportunities provided by APIs for service creation, which are enabled by network virtualization as part of the 5G architecture. These APIs, when standardized, open and universally deployed, allow the market entry of a multitude of so-called virtual mobile network operators (VMNOs), dedicated to serve particular industry verticals or economic sectors with tailored feature sets and dedicated qualities of service.

These VMNOs may have different origins, they may evolve from (Lemstra, Cave & Bourreau, 2017):

a) the IT/CT departments of the firms in the vertical industries;
b) from specialized providers of ICT services to these vertical industries;
c) from the service divisions of fixed and mobile incumbent operators;
d) from the service divisions of mobile virtual network operators (MVNOs); and
e) from start-ulistaps that recognize the new opportunities for developing services and applications.

By unlocking the knowledge on the needs of the verticals that resides within these organizations across all verticals simultaneously, the market momentum can be created that leads to a high demand for 5G across Europe. And as firms within the verticals compete for end-users, they will compete for providing the best virtual mobile services as well. This is expected to result in a very dynamic retail market for mobile communication services.

The tailored mobile communication services, being bundled with IT-services, will unlock a higher willingness to pay compared to the mass market consumer services, the main stay of the "Evolution" scenario. This extra margin will flow from the retail market through the wholesale market to incentivize 5G network investments by the mobile infrastructure operators. This provides for a virtuous circle of demand and supply that is expected to lead to a leadership role for Europe in the development, deployment and exploitation of 5G services. Such a development is in-line with the European Union objective of creating a vibrant Digital Single Market (DSM).

The possibility of different 5G futures calls for a policy debate of which future is most desirable. The "Evolution" scenario is likely to evolve under the proposed Electronic Communications Code. (EC, 2016b). Enabling the "Revolution" scenario will require additional policy and regulatory measures to achieve leadership with 5G in Europe. Hence, there is a fork in the road ahead that needs to be navigated by policy makers and regulators as it will lead to different possible futures. Whereby one future outcome may be more desirable than the other, depending on the perspective of the various actors. These measures are outlined in the final part of this paper.

The remainder of the paper is structured as follows: in Section 2 the research approach is described. In Section 3 the European leadership role in mobile communications is explored. It also derives the regularities across the subsequent generations 1G through 4G and provides an interpretation in the light of 5G. Section 4 introduces the two stylized images of the future of 5G. It describes the "Evolution" image as the outcome of the current developmental trajectory. This outcome is compared with the GSM success factors identified in Section 3. Further in this Section the "Revolution" image is described and the policy and regulatory actions that would be required to enable this image are captured. To facilitate the policy debate Section 4 closes with a comparison between the two images and a discussion of the pros and cons of each image from the perspective of the different stakeholders. Section 5 provides the conclusions and recommendations.

2. Research approach

This contribution can be divided in two parts with respect to the research methods being applied: a backward looking part and a forward looking part. In the backward looking part the leadership dimensions are explored and success is defined from a theoretical perspective. These notions are then applied to analyze the subsequent generations of mobile technology deployed in Europe, from 2G through 4G. The outcome of the backward looking part on creating market leadership informs the forward looking part in which the two contrasting stylized images of the future of 5G are constructed and the policy and regulatory implications are identified.

The backward looking part concerns a secondary literature study complemented with interviews with industry experts to fill gaps in the information covered by the literature.[1] It provides a mini-case description of the developments for each generation of mobile technology which are subsequently used for the analysis of the leadership roles that can be identified.

The forward looking part of the research concerns the construction of two images of the future of 5G, an 'evolutionary' and a 'revolutionary' image. These images are constructed to enable the debate on the leadership with 5G as derived in the backward looking part. The construction of the two images of the future has been inspired by the work on scenario building performed by Shell. [2] (Shell, 2013).

Scenario planning typically consist of the construction of an orthogonal set of scenarios based on two key drivers resulting in four possible but extreme futures. These futures are subsequently used to test the resilience of the firm strategy. (Van der Heijden, 1996; De Geus, 1997, 2002). This paper does not aim to construct orthogonal scenarios, but intends to stimulate the debate on policy and regulation with respect to the development of 5G. Hence, the aim has been to create two contrasting stylized images.

The "Evolution" image is constructed based on the extrapolation of current trends in the mobile industry, in particular the continuation of the industry structure, with the mobile network operators (MNOs) in a leading role, serving the mass market of consumers. This can be considered the base line scenario, the status quo. In the "Revolution" image the prospect of creating a leadership role for Europe is taken as the starting point. Given the global nature of the 5G standard, this leadership is perceived to be in the use of 5G, i.e., in the provision of mobile services combined with IT services tailored to the needs of vertical industries and specific economic sectors. The tailoring of services in terms of features and qualities is made possible by virtualization and open access APIs, offered as integral parts of the 5G architecture.

Note that virtualization originated as a method of logically dividing the system resources provided by mainframe computers between different applications. It is now widely applied in cloud computing. It also refers to providing functionality in software rather than in various forms of hardware. Application programming interface (API) refers to a set of subroutine definitions, protocols, and tools for building application software. As such, APIs represent a set of clearly defined methods of communication between various software components, which facilitate the programming of services by third parties.

The key to success with 5G is building early market momentum. This is achieved through unlocking the knowledge of the business needs of the vertical industries by empowering various parties to become virtual mobile network operators (VMNOs). This outcome is used to construct the "Revolution" image. It is based on the capabilities of 5G as currently perceived and proposes the policy and regulatory actions that create the early momentum in the adoption of 5G, thereby providing the foundation for the ultimate success of 5G in serving vertical industries.

To develop the images of the future and to create internally consistent and complete images, each image has been drafted by the author along the industry dimensions, using the five forces framework to characterize an industry as identified by Porter (1980).[3] As a second device the SEPT model by Wheelen and Hunger (1983) has been used, to which the Environmental dimension has been added. These images have subsequently been revised as a result of two rounds of interaction with operators and regulators in the context of the research project for CERRE.[4]

The construction of the images has been informed by literature, for the policy and regulatory dimension by: Melody (1997, 2002);

[1] The interviews have been conducted with: Herbert Ungerer, co-author of the Green Paper that started the liberalization process of the telecoms services sector in Europe and involved in the GSM frequency directive; Bert Dorgelo, former standards expert at Philips and participant in the GSM project; and Han van Bussel, network architect at T-Mobile Netherlands.

[2] The most recent set of Shell scenarios comes under the heading "New lens scenarios - A shift in perspective for a world in transition." (Shell, 2013). For a further appreciation of scenario thinking see Schwartz (1991, 2003). For a more recent guide on scenario planning in organisations see for instance Hines and Bishop (2015). For a recent discussion on scenarios as methodology see Ramirez, Mukherjee & Vezzoli (2015).

[3] While the original purpose of the Five Forces Framework was to assess the profitability of an industry, in this research project the five dimensions are used to check and assure that a complete and consistent stylized image of the future is created.

[4] It is CERRE policy not to disclose the names of members sponsoring particular projects.

Koppenjan and Groenewegen (2005); Enserink et al. (2010); Melody (2011); Melody and Lemstra (2011). For the EU policy making by: Lemstra, Anker & Hayes (2011); Van Gorp et al. (2011); Akalu (2014); Lemstra, Groenewegen, De Vries & Akalu (2014); Lemstra, Voogt & Van Gorp (2015); Anker (2017). Furthermore, it builds on the insights obtained from the radio spectrum use cases debated in meetings of the Cognitive Radio Platform NL. (CRplatformNL, 2018). And the meetings organised by the Ministry of Economic Affairs of the Netherlands on policy formation with respect to the use of the radio spectrum.[5]

3. The leadership role and success

In the context of 5G, a new generation of mobile infrastructure, leadership relates to technology leadership, i.e., the creation of a dominant design based on a standard that leads to economies of scale in the industry. Economies of scale first of all benefit the equipment supply firms and through competition the mobile operators and ultimately the end-users. Success is typically measured in terms of infrastructure deployment and subsequently service adoption based on the technology. This can be measured at launch, to assess the momentum, and over time, to assess its overall success.

In a standards-driven industry, such as telecommunication, the level of success is typically measured in the degree of adoption of the standard by firms and/or countries; the provision of terminals/applications that comply with the standard; and the procurement of terminals/equipment complying to the standard by end-users. (GSM Association, 2007; EC, 2013).

In network industries, such as telecommunications, leadership also concerns reducing uncertainty on end-user uptake as early commitments to R&D are required by equipment manufacturers and subsequently deep investments in infrastructure build-out by operators before services can be offered and demand can become tangible. To achieve strong early adoption Shy (2001) and Gottinger (2003) point to the importance of capturing the benefits of positive network externalities and the realization of economies of scale through the use of standards. The broad and deep participation of leading firms in the industry is a proxy for the future success of the technology. Creating effective collaboration among (competing) firms constitutes a leadership role.

In the early days of mobile communications, in Europe, the operators were state-owned monopolies and hence firm strategy and government policy were interlinked. At that time economies of scale were typically bounded by the size of national markets, as each national market featured one operator, one dominant equipment supplier and a national standard.[6] This gave firms in the large countries a 'natural' advantage in terms of scale over those in smaller countries, such as in the USA over those in countries in Europe, and today – following industrial catch-up – in China over any other country.

Hence, the main *raison d'être* for the European Union is the creation of Community-wide markets that increase the economies of scale from the national to the regional level. The key objective is harmonization of industrial policies, of technological developments, of economic and social progress. The instruments include laws, regulation, directives, and guidelines next to competition policy. As telecommunications is an enabling technology for the development of the economy and society at large, telecommunications has become a cornerstone of EU policy formation and implementation. This explains the interest of EU politicians in the success of a new generation of mobile technology.

Another critical factor for the success of a new generation of mobile technology is expanded access to the radio frequency spectrum to accommodate higher data rates and higher number of users. As custodians of the radio frequency spectrum, the nation states have remained responsible for the allocation and assignment of radio spectrum usage rights within their national territory. Hence, the harmonized use of radio frequency bands requires collaboration among nation state governments.[7]

Thus, to understand the leadership role in relation to the development and the deployment of subsequent generations of mobile technology it is important to consider the role of government actors next to the role of industry actors. For the case of the European Union this implies consideration of national government actors next to regional government actors, i.e., the policy makers at Member state level and at the European Union level. It should be noted that the European Union, as an international organization, was shaped in parallel to the technological developments described in this paper.

Based on a relatively broad study Sandholtz has identified four conditions under which the potential for international organizational leadership is greatest (1993 p251-252):

a) the greater the initial grant of authority to the international organization, the greater its ability to lead in new areas;
b) when leaders and staff of the international organization are substantively knowledgeable and well prepared, they can help shape technical discussions and agreements;
c) the capacity of international organizations to exercise initiative depends in part on the personal characteristics of their leaders;
d) and considered most important, international organizations register the greatest impact on interstate cooperation during periods of policy adaptation.[8]

[5] So called Nationaal Frequentie Overleg (NFO).

[6] For instance Deutsche Telekom in Germany with Siemens as main supplier, in Sweden Televerket with Ericsson and in the Netherland the PTT and Philips.

[7] The allocation of use is agreed upon at the global level by Administration under the auspices of the ITU. To align positions the world is divided in three Regions. Region 1 includes Europe, Africa, the former Soviet Union, Mongolia, and the Middle East west of the Persian Gulf, including Iraq. (ITU, 2017).Within Region 1 the CEPT *Conférence Européenne des administrations des Postes et Télécommunications* coordinates the interests of 48 European states. (CEPT, 2017).Within the EU harmonization efforts are pursued through the Radio Spectrum Policy Group (RSPG), in which member states participate. The RPSG is a high-level advisory group that assists the European Commission in the development of radio spectrum policy. (RSPG, 2017).

[8] Note the observation by Sandholtz that international organizations do not act or lead, their officials do (Sandholtz, 1993). This of course also applies to the leadership of the firm as organizational entity.

In summary, in the context of next generation mobile technology and services, leadership can be defined as: creating the conditions for market momentum to build and be maintained. In creating these conditions industry actors, manufacturers and mobile operators, play a key role, next to government actors at regional and national level. The right combination of conditions and the appropriate timing thereof may provide for leadership in the development and deployment of 5G in the European Union. Hence, the following sections are aimed to capture and assess the insights on leadership (or the lack thereof) for previous generations of mobile technology to subsequently be used to assess the opportunities for leadership with 5G.

In detail, in Sections 3.1 through 3.3 the developments of mobile technology and services in Europe are captured for the generations 2G, 3G and 4G in the form of mini-case descriptions. The focus is on 2G-GSM as the success of this generation is considered the leading example for shaping the potential leadership with 5G in the European Union. In Section 3.2 the emerging role of the European Commission in shaping Community markets is introduced. Subsequently, Section 3.4 provides reflections on the leadership roles across the generations. This is based on a summary of the key events and the identification of the factors that have contributed to creating the 'conditions for market momentum to build and be maintained'. Again with special emphasis on 2G-GSM. Section 3.5 concludes with the potential areas for leadership within 5G, with a focus on the role of policy makers and regulators.[9]

3.1. The development of 2G

The relative success of the analogue cellular systems –1G– led in a number of European countries to concerns by the operators regarding (near) future capacity limitations and hence to exploring options for expansion of analogue systems into the 900 MHz band. This band had been reserved through the CEPT for mobile communications in 1978. Following the initiative of the French PTT in 1981 and initial discussion among European PTTs, the Dutch Administration proposed a recommendation to the CEPT to start procedures leading to "the construction of a pan-European automatic telephone service in the 900 MHz band". This proposal appealed to many European Administrations and resulted in a working party being created within CEPT to develop a specification: the Groupe de travail Spécial pour les service Mobiles (in short: GSM). The system should resolve the capacity shortage of the analogue systems and provide for harmonization of the European market, resolving the incompatibility between the multiple standards being used. The GSM Group started its work in December 1982. (Hillebrand, 2002; Manninen, 2002; Gruber, 2005).

Meanwhile the European Union had taken shape. Having started from collaboration in the industrial areas of coal, steel and atomic energy in the 1950s it evolved into a European Economic Community and was on the way to what would become the European Union. See Fig. 1 for an overview of highlights in the development of the EU in relation to those in the ICT sector.

As Sandholtz observed: "Altering European telecommunications regimes is not an automatic market-driven process; rather, it requires collective political action." (Sandholtz, 1993, p. 254). He identified the Commission of the European Communities (CEC) as the engine pulling the European Communities toward a common, liberal and modernized telecommunications regime as the. This because the CEC has the sole power to propose EC legislation and once approved by the Parliament and Council it can issue rules and directives for their implementation. Moreover, the CEC has authority to act in the areas of competition policy and enforcement (antitrust). Furthermore, the CEC is considered to have command of relevant technical information that can be the basis for entrepreneurial and intellectual leadership. From 1981 until 1985, the CEC through vice president Etienne Davignon had the "entrepreneurial leader par excellence". (Sandholtz, 1993, p. 256).

In 1987 the Commission of the European Communities published a landmark document: "Green Paper on the development of the common market for telecommunications services and equipment" (CEC, 1987). The first and politically acceptable step in the process of liberalization was aimed at introducing competition in terminal equipment and at the services level, while the infrastructure could remain under monopolistic control. A series of Directives followed that would provide the legislative framework for the implementation of this first phase of liberalization on the national level (Cawley, 2001):

1988: Competition in the markets in telecommunication terminal equipment;

1990: Competition in the markets for telecommunication services;

1990: Establishment of the internal market for telecommunications services through the implementation of open network provisioning.

Following the publication of the Bangeman Report (Bangeman Group, 1994) addressing the implications of the 'information society' early in 1994, the European Council by the end of 1994 officially recognized the principle that telecommunications infrastructures should be liberalized, whereby January 1st 1998 was the date set "by which all remaining restrictions on services competition would be lifted." (Cawley, 2001, p. 4).

Ungerer emphasized the role of entrants in building market momentum: "At the end of 1993 digital was accounting for only 9% of mobile terminals and new entrant Mannesmann D2 in Germany accounted for 46% of the European GSM market. With the competitive pressure from Mannesmann on Deutsche Telecom, the German market represented 79% of the digital market in Europe." (Ungerer, 2016).

The Commission of the European Communities concluded that telecommunications offers the key infrastructure for the development of the all-pervasive New Information Technologies. However, the Commission also observed that telecommunication infrastructure was based on national markets and therefore was too fragmented. Moreover, the European industry was based on 'national champions' and

[9] In this paper the focus is on leadership from the perspective of successive generations within a single region – Europe. A comparison by generation across regions falls outside the scope of this paper. See for this discussion for instance: Kano (2000); Lyytinen and Fomin (2002); Gandal, Salant & Waverman (2003).

Year	Events shaping the EU		Events shaping the ICT industry
	Event name	Topic	
1947			Transistor invented by Bardeen, Brattain & Schockley at Bell Labs
1947			Cellular principle invented by Bell Labs
1952	Paris Treaty	European Coal and Steel Community	
1958	Rome Treaty Euratom	European Economic Community European Atomic Energy Community	
1970			First five nodes of ARPANET live
1971			Invention microprocessor by Hoff at Intel
1981			First cellular system in service in Kingdom of Saudi Arabia, NMT450
1982			CEPT initiates GSM project
1984			Internet hosts convert to TCP/IP
1987	Single European Act	European Political Cooperation on the creation of a single market	
1987	Green Paper	On Common Market for telecommunications	
1988		Liberalization terminal equipment	ETSI established
1990			WWW and HTML invented by Berners-Lee at CERN
1992			GSM launched by 13 operators
1993	Maastricht Treaty	Transformation of earlier institutions into the European Union	Introduction Mosaic browser by Andreesen at NCSA
1995	Schengen Treaty	Creation of Schengen border as the EU perimeter, abolishment of internal borders	
1996		Liberalization of mobile communications	Pre-paid mobile services introduced
1999			Introduction GPRS
2000			First UMTS auction, UK
2001-2002			First UMTS launches, Norway and Austria; first camera phone
2004			Facebook founded by Zuckerberg
2007			Introduction iPhone by Apple Inc.
2009	Lisbon Treaty	Reformed the EU, introducing qualified majority voting, enhanced power of the European Parliament alongside the Council of Ministers	WhatsApp founded by Acton and Koum

Fig. 1. Time line of events in the development of the EU and in the ICTs.

was lagging behind competitors from the USA and Japan. Hence, the Commission concluded that within its aim to create "Community-wide leading-edge markets which could drive the long term economic revival of the Community", a "Community-wide telecommunications space" and "Community-wide telematics markets" should be created (CEC, 1983). The next step was a plan with six "lines of action", leading to a number of proposals which were accepted by the member states at the end of 1984 (CEC, 1984). They included: the creation of a Community-wide market for terminals and network equipment; the collaboration in R&D to develop the next generation of telecommunication infrastructure; adoption of procedures to ensure uniform application of international standards; and mutual recognition of type approval of equipment.

Furthermore, the Commission endorsed the GSM project. In 1987, this was followed by Directive 87/372/EEC on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community, with a target date for the launch of GSM by 1991, with a defined minimum set of services which included roaming.

Also in 1987, operators from thirteen countries signed a Memorandum of Understanding to commit to the network roll-out and cooperation on commercial and operational matters, such as tariff principles (e.g., calling party pays) and accounting (Manninen, 2002).

In 1988, as a result of a lobby from the European Commission, the CEPT created the European Telecommunications Standards Institute (ETSI). All telecommunication standardization activities within CEPT were transferred to this newly formed institute, in which manufacturers, operators, administrations and user groups are represented. In 1989 the GSM Group became a Technical Committee within ETSI. A year later Phase 1 of the GSM-900 specifications was released, with open interfaces to foster competition in network deployment. (Hillebrand, 2002; GSM Association, 2004).

Part of the liberalization process of the telecommunications market was the introduction of competition in the field of mobile communications. In most European countries, the introduction of GSM was used to introduce a second license in the market for mobile telephony. In all EU[10] countries the incumbent which already deployed and operated the analogue cellular network obtained the first license. The second license was typically issued through an administrative method based on the evaluation of a detailed bid, i.e., a beauty contest or comparative hearing.

In the fall of 1992 GSM was launched in 7 countries by 13 mobile operators. (Manninen, 2002; Gruber, 2005; GSM Association, 2009). The deployment of GSM reached its peak in 2015 with 3.83 billion subscribers and 700 operators in 219 countries and territories. CDMA (Code Division Multiple Access) the 2G standard developed by Qualcomm in the USA (Mock, 2005), also reached its peak in 2015 with 374 million subscribers. This represents a ten-fold difference between the two major second generation digital mobile technologies. (GSA, 2018; GSM Association, 2018).

3.2. The development of 3G

In 1984 Bellcore, the jointly owned R&D facilities of the Bell Operating Companies, showed its interest to set-up a technical liaison with the GSM Group aimed at achieving compatibility between North American and European systems. However, based on technical, institutional and political considerations the invitation was declined by CEPT (Manninen, 2002).

In 1985, the concerns on the development of diverging standards for mobile telephony led within the ITU to the decision to develop a harmonized standard for a Future Public Land Mobile Telecommunication Systems (FPLMTS). Interim Working Party 8/13 was established to investigate the scope for a global 3G standard to provide personal telecommunication services through the use of hand-held terminals anywhere; on land, on sea and in the air. (CCIR, 1990).

In Europe, research on a future mobile system started in late 1985 with a one-year Definition Phase project within the Research and Development in Advanced Communications Technologies for Europe (RACE) program. In 1988 this led to the inclusion of a full project in the RACE program on a 3G system which should be operational in the twenty first century. That project developed the idea of a Universal Mobile Telecommunications System (UMTS), a system supporting circuit-switched voice and packet-switched data. (Anker, 2017; Garrard, 1998; Hillebrand, 2002). The ITU defined as part of the IMT2000 project the requirements on data rates for 3G as 144 kbit/s for mobile speeds (car and train), 384 kbit/s for pedestrian speed and 2 Mbit/s for indoor stationary use. The introduction of High Speed Packet Access (HSPA) improved the data rates, first to 14 Mbit/s on the down link and later to 5 Mbit/s on the up link. HSPA + provided a further upgrade to 42 Mbit/s down and 22 Mbit/s up. (Wikipedia, 2017b). HSPA has become denoted as 3.5G.

Following a European proposal, which was backed by Japan, the World Administrative Radio Conference of 1992 (WARC-92) identified the sub-bands 1885–2025 MHz and 2110–2200 MHz for the implementation of FPLMTS. No firm allocation or designation could be reached as the United States wanted to ensure that the spectrum could be used as flexible as possible. Hence, it was not possible to agree on a single standard within the ITU. Therefore the original objective of one global standard was abandoned. Subsequently, Japan and Europe decided to join their efforts in the creation of a standard for IMT-2000 (International Mobile Telecommunications for the year 2000). This led to the adoption of W-CDMA as basic technology. In December 1998, a body called the Third Generation Partnership Project (3GPP) was established to 'co-operate in the production of a globally applicable 3rd Generation Mobile System based on evolved GSM core networks'. It was founded by the following regional standardization bodies: ARIB (Japan), ETSI (Europe), ANSI T1 (United States), TTA (Korea), TTC (Japan), and was later joined by CWTS (China). The 3GPP standard became known under the name of UMTS. A second body, 3GPP2, was established to develop the next generation standard CDMA2000. This group consisted of the American manufacturers Lucent Technologies, Motorola, Nortel and Qualcomm. (Anker, 2017; Hillebrand, 2002; Lembke, 2001).[11]

The success story of 2G-GSM combined with the success of the Internet, raised the expectation for mobile broadband communications. This was reflected in the initial willingness to pay by operators at the auctions for 3G-licenses. The first auction was held in the UK, where five licenses were on offer. The gross proceeds of the auction amounted to US$ 33.3 bln, or US$ 650 per inhabitant (Lennin & Paltridge, 2003; OECD, 2005). The auction principle was also applied in Germany yielding € 613 per inhabitant, Italy € 240, the Netherlands € 171 and France € 169. The level of proceeds was determined largely by the auction design, but also fed by the promise of the mobile Internet during the peak of the telecom boom. (Lemstra, 2006; Melody, 2001; Van Damme, 2001).

In October 2000 the first commercial offering of 3G–services was introduced by SK Telecom in Korea, based on CDMA2000 technology. NTT DoCoMo of Japan followed in October 2001 with the first 3G service based on the W-CDMA technology of 3GPP. Most Western European countries assigned licenses for 3G services in the years 1999–2002, Central and Eastern European countries completed the process in the period 2004–2007 (Curwen, 2009). During the euphoric period the expectation on mobile broadband communication was booming, as reflected by the auction proceeds. However, in Europe the deployment and service launch was delayed due to the industry downturn in the aftermath of the euphoric period and the very high investments made in 3G licenses. The first operators in a country launched commercial services between 2003 and 2004, the second through the fourth launched in the period 2004–2007.

3.3. The development of 4G

The initiative for 4G began with an investigation by the 3GPP standards body in 2004. In 2006 this is followed by the NGMN Alliance

[10] For ease of reference the EU is used to include its predecessor the EEC.

[11] Both the 3GPP and the 3GPP2 standard used CDMA technology. Ericsson and Qualcomm were in a dispute over CDMA patents since the inception of the cdmaOne standard in 1989. In 1999 the dispute over intellectual property rights was settled. Subsequently, 3GPP and 3GPP2 started a cooperation in order to allow interoperability and interworking between UMTS and CDMA2000. This made it easier to develop mobile terminals which could use both technologies, allowing worldwide roaming for customers.

study outlining the requirements as perceived by the mobile operators. In 2008, the ITU specified the requirements for 4G standards as IMT-Advanced, setting the peak data rate at 100 Mbit/s for high mobility communications (cars and trains) and 1 Gbit/s for low mobility communication (pedestrian and stationary).

With UMTS having been based on GSM and with data communication having become dominant, the next generation of mobile technology was bound to be All-IP. Orthogonal Frequency Division Multiple Access (OFDMA) multi carrier transmission was applied to provide the much higher data rates compared to what could be achieved by CDMA, the spread spectrum technology used in 3G. A new architectural feature of LTE is network function virtualization (NFV), a new operational approach applying virtualization techniques well-known from the data-center world. (4G Americas, 2014).[12] Combined with new features in Release 11 through 13, LTE will be able to support PPDR-as-a-Service (Public Protection and Disaster Relief – services in support of police, fire brigade and ambulance). (Nokia, 2014).

The 4G standard developed by 3GPP is denoted LTE – Long Term Evolution. The first release provided for a peak rate of 100 Mbit/s on the downlink and hence did not meet the 4G requirement set by the ITU. In 2008, 3GPP specified LTE-Advanced, which by using carrier aggregation meets or even exceeds the ITU requirements.

In December 2009, LTE was first placed in commercial service by TeliaSonera in Stockholm, Sweden (using Ericsson equipment and Samsung dongles) and in Helsinki, Finland (using Huawei equipment). November 2010 the first LTE-enabled smartphone was introduced commercially by Samsung. The second smartphone followed by HTC March 2011. (Wikipedia, 2017a).

According to Curwen, the deployment of LTE based on nation-wide incumbent network launches reached 110 in Western Europe in 2016. The number of non-nationwide/non-incumbent network launches, including MVNOs, stood at 50. (Curwen, 2016).

3.4. Reflections on the leadership role in 2G and 3G/4G in Europe

The reflections on the leadership role in subsequent generations of mobile technology take the timeline of events as the starting point to identify the factors that have contributed to the 'conditions that have enabled market momentum to build and be maintained' for each generation. This process is guided by the factors identified at the beginning of this chapter. On the supply side: creation of economies of scale, e.g., through the development of a standard, adoption of this standard and the emergence of a dominant design. On the demand side: stimulating early adoption as a result from, e.g., pent-up demand, coordinated introduction by operators, new market entry and competition. On the policy side: creating a single market in the EU, harmonization of frequency bands to be used, funding collaborative R&D, stimulating the application of a single standard and stimulating the coordinated roll-out of the new technology. The diverse contributing factors are identified as part of the summaries that follow.

3.4.1. Leadership in 2G

With reference to Section 3.1, the market momentum building can be summarized and the supply-side, demand-side and policy related factors can be identified. (CEC, 1983, 1984, 1987; Garrard, 1998; Hillebrand, 2002; Manninen, 2002; Gruber, 2005; GSM Association, 2009).

The initiative for the development of 2G was taken by mobile operators in the UK and France perceiving capacity limitations in the (near) future as a result of the (relative) success of 1G (*demand factor*). The goal became the creation of an automatic mobile telephone system for pan-European use (*supply side*). In providing leadership NMT became the role model. The initiative led to a standardization effort within CEPT (*supply factor*), an existing organization of telecom Administrations which was given a new task. The targeted frequency band was 900 MHz, already allocated by the CEPT (*policy factor*). In parallel, within the Nordic countries studies into NMT900 were initiated as a next analogue generation with higher capacity. During the development process of the standard within the CEPT the decision was made to go digital and to aim for the consumer mass market with the 'handy' (*demand*). Differences between Germany and France regarding the type of technology to be adopted were ultimately resolved between the two national government ministers (*policy*). National governments used the opportunity of 2G to introduce competition, typically through a duopoly (*policy*). The Commission of the European Communities recognized the opportunity and importance of mobile communications as part of its broader policy of creating Community-wide markets and it took a number of actions (*policy*):

- endorsement of the GSM project within the CEPT;
- issue of a directive on the use of the harmonized frequency band for the designated technology to be standardized by CEPT;
- Directive on the mutual recognition of certified terminals; and
- the creation of the European Telecommunication Standards Institute (ETSI) by the CEPT, to allow for a broader participation of stakeholders in the standards efforts, including manufacturers and end-users.

Through a Memorandum of Understanding, the operators agreed on a common launch date and the initial set of services to be offered (*demand*). This MoU evolved into a formal organization in which operators collaborate on operational matters – the GSM Association.

In essence the NMT and the GSM project were alike, with GSM taking on a larger geographical scope. Hence, the four basic conditions to create market momentum in 1G[13] also applied for 2G, with the European Union as geographical scope:

[12] See for a discussion Section 3.5.1.

[13] Reference is made to development of NMT450 as part of 1G. While in all other European countries national standards applied, the Nordic Administrations and equipment industry collaborated on the development of a common standard for 1G, resolving technical, economic and legal differences across Denmark, Finland, Norway and Sweden. (Botto, 2002; Ericsson, 2007; Haug, 2002; Lehenkari & Miettinen, 2002; Manninen, 2002; Meurling & Jeans, 1994).

(1) the harmonized use of a particular radio frequency band;
(2) the development of an open standard;
(3) agreement on operational procedures such as services set, automatic hand-over and roaming; and
(4) availability and mutual recognition of terminal devices.[14]

In addition, the 2G the market momentum was created through:

(5) opening the mass market of consumers for mobile telephony, facilitated by the 'handy';
(6) operators coordinating the launch of 2G-GSM across the EU through an MoU;
(7) the creation of an EU-wide market through roaming;
(8) introduction of competition (duopolies);
(9) reserving the harmonized spectrum for the digital standard under development, to pre-empt competition from emerging higher capacity analogue standards.

With the development of 2G, the leadership roles shifted as a result of the shaping of the EU and the liberalization of the telecommunications services market: from being national in scope to become regional; from being dominated by operators/Administrations to become driven by operators, equipment manufacturers and governments/regulators, each in their independent roles; and from being led by governments (Administrations) at the national level to become facilitated by the Commission of the European Communities at the regional level.

With respect to 'market momentum being maintained', the addition of General Packet Radio Service (GPRS) to provide packet-switched services for data kept GSM relevant as society embraced the Internet. This enhancement became denoted as 2.5G. More recently EC-GSM-IoT was defined to serve the Internet-of-Things with extended coverage and low power communications. The solution is part of 3GPP Release 13 targeted for market introduction in 2017. (GSM Association, 2017). Nonetheless, GSM's ultimate success is in serving the population in underdeveloped countries, where fixed telecommunications infrastructure was lacking and mobile adoption was facilitated by prepaid service. (Minges, Mannisto & Kelly, 1999).

3.4.2. Leadership in 3G in comparison with 2G

With reference to Section 3.1 and 3.2 we may conclude that through the efforts of the equipment manufacturers, and supported by operators, GSM deployments moved beyond the European borders. The scope of the equipment business became global. Hence, the development of the next generation specification had to assume the interests of GSM operators outside Europe as well.

Following liberalization and stimulated by the euphoric period at the end of the 1990s, incumbent mobile operators in one EU country became entrants in another. In this period, Vodafone developed to become a pan-European player. These developments implied that EU policy makers had to move beyond the goal of creating a single European market to consider the wider interests of the EU-based telecom industry.

Although, the IMT-2000 project within the ITU was originally aimed at developing a completely new system, through European interests 3G/UMTS was modelled by the industry actors as a multimedia system based on existing GSM technology to capitalize on the success and footprint of GSM. In European community policy it was positioned as an interoperable pan-European personal communications service, which could be introduced globally. (Lembke, 2001).

In 1998 the US industry and political officials launched a campaign against the European 3G-UMTS developments in ETSI. The main objective was to keep the European market open for other technologies, whereby the IPR position of US companies, in particular Qualcomm, was to be leveraged. The conflict changed the policy position of the EC from 'creating a single market through enforcing a single technology' to 'creating a single market through interworking'. Nonetheless ETSI was expected to assure the availability of a 'coherent set of standards' in support of the Community's harmonization policy. Moreover, conflicting standards would not be accepted in Europe. (Lembke, 2001).[15]

For an appreciation of the differences between 2G and 3G use is made of the 'leadership role' and the 'roadmap to market' as identified for 2G by Hillebrand (2002), see Table 1 and Table 2.

The basic conditions identified for 2G to create market momentum also apply to 3G. The anticipation for 3G was building during the euphoric period in the late 1990s, with the prospect of mobile broadband internet – condition #5. The EC had set strict deadlines for the licensing process to assure UMTS could be launched by January 1, 2002 at the latest, allowing a near simultaneous launch by the operators – condition #6. (EP, 1999). In practice the award of licenses was concentrated around the year 2000. However, the combination of euphoria and the design of the auctions, to maximize proceeds for the governments, led to very high license fees in many countries.[16] Coinciding with the collapse of the bubble, this contributed to a lack of market momentum building. Forge (2004 p 13) argued that:

[14] See for the changing role of standards in telecom Kano (2000). Note, there is an ongoing debate whether a standard is to be selected in the market by operators or to be agreed upon upfront by the industry and/or the governments. See for instance Gandal, Salant & Waverman (2003).
[15] See for a detailed discussion of the conflict between the USA and the EU Lembke (2001).
[16] See for a discussion on the role and impact of auctions in 3G: Cave and Valletti (2000); Bohlin (2001); Melody (2001); Van Damme (2001); Klemperer (2003); Gruber (2007).

Table 1
Inputs to the leadership role: 2G and 3G compared.

2G – GSM	3G – UMTS
The technology development efforts of France, Germany, Sweden and Finland	**S**: National government led R&D is replaced by EU coordinated and co-funded R&D; **D**: this dilutes the relationship to national industrial interests and policies but fits the EU model
The efforts of the French and German operators to plan a next generation system for a mass market	**N**: No new addressable market is created, no similar transition applies; **S**: but installed base could be leveraged
The very positive market take-up of cellular radio services in the Nordic countries	**S**: The prospect of the mobile internet drove demand expectations strongly
The effort that had to be made by the DTI to bridge between its European partners and its domestic competitive players Cellnet and Vodafone	**S**: Strong competition was typical for all national markets in Europe
A shrewd move by the Commission to table a directive on safeguarding the frequency bands for a Pan-European cellular radio system;	**S**: Such a move was not needed in the 3G context
The close working relationship that the GSM group achieved between key national officials	**D**: The European project changed the role of national officials, **N**: shifting it from inter-state to EU level.
A slice of good luck and well-judged timing	**N**: A slice of bad luck in terms of how the timing turned out

Legend: **S** - Action similar to 2G; **D** - different action compared to 2G, but conducive; **N** - no similar action; DTI: Department of Trade and Industry, the UK.
Source: Author for 3G based on Hillebrand for 2G (2002).

Table 2
The road map to market: 2G and 3G compared.

2G – GSM	3G – UMTS
The top plane – the political level to generate the political will to make an agreement on GSM happen:	
The agreement between the French and German Heads of State of November 1984 and the commitment of the UK in 1986	**N**: No similar political level engagement by Member States
The opening up of a new range of frequencies	**S**: Similar action with 24% more bandwidth being allocated
Linking the release of new spectrum to the market with a new technology	**S**: Similar action through auctions; **D**: freeing up previous allocations by introducing technology neutral assignments
The EC Directive to reserve the frequency bands for the GSM technology	**S**: The EC Directive on a timely assignment process; no threat of alternative standards being considered for deployment; **D**: large installed base of 2G/2.5 G
The second plane – obtaining the commitment of the cellular radio operators to purchase the new networks and open a service on a common date	
At least three large markets had to come on stream in the same time to generate the desired economies of scale	**S**: Timely assignment of licenses including major markets; N: deployment delays due to economic set back in the aftermath of the telecom/internet bubble
Competitive pressure was required to drive volume	**S**: Highly competitive market; **N**: being depressed in the aftermath of the telecom/internet bubble
The use of a common standard allowing for new revenues from international roaming at almost zero incremental costs	**D**: No change in market structure, no new gains in moving to the next generation
The third plane – the technical standardization effort	
Focusing the R&D efforts of the supply industry	**S**: Preceded by EU R&D program, standardization process in ETSI; **D**: participants changed from only European to becoming global in 3GPP
Providing mediation between buyers and suppliers of networks	**S**: Similar situation; **D**: buyers and suppliers changed from predominant European to become global
The fourth plane – the industrialization by the supply industry	
To be able to recognize the market and its size to have the confidence for the deep investments required	**N**: Expectation regarding the mobile internet are very high during the euphoric period and turn negative after the bubble burst, just after the first major licenses have been awarded
The semi-conductor industry to be pulled behind the equipment manufacturers	**S**: The semi-conductor industry is aligned, **N**: but impacted by the telecom industry set back

Legend: **S** - Action similar to 2G; **D** - different action compared to 2G, but conducive; **N** - no similar action.
Source: Author for 3G based on Hillebrand for 2G (2002).

> "… high auction costs have handed down a quintuple whammy for 3G: (1) extraordinary high entry costs, creating an extremely effective barrier to entry, which excluded small dynamic players, and their pressure to make roll-out happen; (2) starving operators of the funding to bring 3G technology to market, while pushing up debt levels; (3) inhibiting investment by the leading equipment suppliers in 3G networks and handsets, as they could see the market was being held back by the incumbent; (4) delaying the build of a high volume equipment market for 3G with falling prices, so equipment prices for network equipment and handsets remained far higher than for 2G and 2.5G; and (5) launching services based on immature expensive technology with poor reliability and performance, leading to degraded reputations for quality of service for operators, and making introduction of the new service quite problematic against competition from a more mature and stable 2.5G technology."

Moreover, as Bohlin argued, differences in the license assignment method, beauty contest or auction, led to fragmentation rather than harmonization of the European market, as the financial impact for operators were structurally different. Moreover, different auction designs and outcomes tax operators differently (Bohlin, 2001).

The down-turn in the mobile telecom industry at the turn of the century can be blamed on the auctions. However, the broader implosion of the industry, fixed and mobile, is due to the collapse of the telecom/internet bubble (Lemstra, 2006). In summary, for the mobile sector the 'conditions enabling market momentum to build' were put in reverse.

It should be noted that the context changed significantly between the launch of 2G and the launch of 3G and further into the 4G era

(Curwen & Whalley, 2008; Garrard, 1998; Hillebrand, 2002; Lemstra, 2006):

a) the market had been fully liberalized and become highly competitive – condition #8;
b) the European-wide market was established – condition #7;
c) licenses to use the radio frequency spectrum were auctioned;
d) the position of European equipment manufacturers and mobile operators changed as the industry had become global;
e) the role of nation states changed as part of the liberalization process and as part of the European Union project;
f) 2G established the mass consumer market, while 3G and 4G are largely representing replacement markets for voice and enhancement markets for data; and
g) the role of the device market had become much more important, the choice of smartphone and related applications platform have become leading in the decision making process of consumers.

3G first launched in Asia and the USA and a few years later in Europe. With some delay, the unabated growth in the Internet also led to the broad take-up of 3G in Europe. Again entrants were the leaders such as Hutchinson in Italy and in the UK. However, the market momentum was much smaller than with 2G-GSM – the market share 2 years after launch was 2% versus 15%; after 3 years 5% versus 29%. Also 27% of licenses awarded were not used; with 13 of the 19 unused licenses having been awarded through auctions. In Europe, the building of market momentum as experienced with 2G-GSM did not repeat itself with 3G. To the extent leadership was applied it failed to lead to early success. (Gruber, 2007; Steinbock, 2002).

3.4.3. Leadership in 4G in comparison with 2G

With reference to Section 3.1 and 3.3 we may conclude that through LTE and LTE-Advanced the 3GPP standards platform realized the first global standard for mobile communications. This allowed the industry to pursue global economies of scale. Given the global participation in this standardization effort, the outcome cannot be claimed as being the result of 'European leadership'. Nonetheless, considering the historical developments, in particular the global deployment of GSM, the role of ETSI and the creation of the 3GPP, seeking the collaboration with Japan, all point to important if not crucial contributions from the European side.

In terms of leadership with 4G in Europe, the nine conditions to create market momentum applied also to 4G. However, with a global standard in place only condition #1 'harmonized use of a particular frequency band', #6 'operators coordinating the launch of the next generation' and #8 'introduction – now maintaining – competition' remained as points of special policy and regulatory attention. Did Condition #5 apply, i.e., did 4G open a new market? Yes and no. Yes – the new market of M2M and IoT, but it is not exclusively served, many competing technologies exist. No – the consumer market remains, but is served with a much higher data rate. Note that for machines different types of lock-in apply, which had to be resolved.

Condition #6 – the coordinated launch, relates closely to the way auctions are applied. It appears that to a large extent the lessons from 3G had been taken into account with the auction procedures applied in relation to 4G. However, the tension between serving the telecom industry and maximizing government income from proceeds remained. Moreover, the way auctions were set up strongly influenced the way market entry could be realized at the infrastructure level.[17]

To keep LTE relevant in a changing user environment, Narrow-Band LTE was introduced (3GPP Release 13) to serve the market of the Internet-of-Things with a low cost, low power communications solution to counter competition from dedicated network such as LoRA and SigFox, operating in unlicensed spectrum at 5 GHz. (Rysavy Research, 2015; TNO, 2016).

Some observers expect that with LTE being broadly deployed 3G rather than 2G will be retired (Rysavy Research, 2015).

3.4.4. Regularities in next generation mobile communication – 1G through 4G

As captured in the description of the leadership roles above, a recurring pattern can be observed. For Europe these events and actions, generally called attributes, have been captured in Table 3 for the generations 1G through 4G. A column denoted 5G has been added to capture those attributes that could already be observed. Note that in this contribution only the main attributes are shown, representing 10 out of the 42 attributes identified in the research project. For information on the other attributes see Lemstra, Cave & Bourreau (2017).

3.5. Leadership opportunities with 5G

Considering the conditions that contribute to building market momentum, the four basic conditions apply. With 4G established as a global standard and the 5G standard being developed in 3GPP these aspects appear to be well in hand. See also Table 3, right-hand columns. Competitive markets are expected to drive the launch. First announcements of the use of pre-5G, for instance at the Olympic Winter Games in South Korea, have appeared. GSMA remains as the platform for coordination among mobile operators.

However, with a global scope the alignment of all conditions becomes more complicated. For instance, there is much more variance in the higher frequency bands that may be allocated. The re-allocation of the 700 MHz band typically takes place if and when available. The market is fully competitive and given the experience with 4G the entry of new players through auctions is not very likely. Hence, an auction of bands for 5G does not constitute a condition for building broad-based market momentum. Furthermore, the launch of new

[17] See for instance Gruber (2007) on the relationship between auctions and market entry and consolidation.
[18] Related to deployments outside Europe.

Table 3
Recurring pattern 1G through 5G.

Attributes	1G – NMT		2G – GSM		3G – UMTS		4G – LTE		5G	
	Key actor/entity	Date	Key actor/entity	Date	Key actor/entity	Date	Key actor/entity	Date	Key actor/entity	Date
Initiative for next generation development	Swedish Administration operators	1969	UK + FR incumbent operators	1981	Govt. representatives in FAMOUS	1991	3GPP study into LTE NGMN 3GPP LTE-Advanced	2004 2006 2012	EC FP7 METIS initiative; ITU WP5D	2011 2011
Research into next gen requirements and technology	Nordic Incumbent operators	1970	FT + DT, incumbent operators	1984	RACE 1 RACE 2 ACTS	1985 1990 1995			METIS 5GPPP METIS-II	2012 2013 2015
Allocation of mobile bands	ITU CEPT		ITU-WARC CEPT	1979 1982	ITU-WRC CEPT	2000	ITU-WRC CEPT		ITU-WRC targets 400 MHz; ITU WRC	2015 2019
Assignment method	Assignment		Assignment; Beauty contest		Auction; Beauty contest		Auction		Auction	
Political endorsement	Implied in collaboration between Administrations		Quadripartite agreement EC Directive on use of 900 MHz	1986 1987	3G Green Paper, Set-up UMTS-Task Force and -Forum	1993 1995			EC Directive on 700 MHz	
SDO and start standardization	NMT Group	1970	CEPT (<1989); ETSI(>1989) 3GPP (>1999)	Dec 1982 2015	ETSI 3GPP	1996 1999	3GPP MTC	2013	3GPP RAN	2015
Commercial & operational coordination	NMT Group		MoU Association	1987	GSMA UMTS-Forum	1996	GSMA NGMN Forum	2006	GSMA NGMN	
Coordination of introduction; target date	NMT Group		Operators through GSM MoU; 1991	1987	EC Directive	1999			EC 5G Action Plan Early intro Large scale	2018 2020
First commercial service	NMT450 TACS	1981 1985	GSM900 DCS1800 PCS1900[18] GSM800[5]	1992 1993 1995 2002	WCDMA UMTS	2001 2002	Norway and Sweden	2009		
First retirement	Telia Finland	Dec 2002	Macau	June 2015						

Sources: 4G Americas (2014); 5G Americas (2016); 5G Infrastructure Association (2015); 5GPPP (2016); Cox (2014); Curwen and Whalley (2011); Filippi et al. (2016); Hillebrand (2002); Lehenkari and Miettinen (2002); Lemstra and Hayes (2009); Manninen (2002); Meurling and Jeans (1994); Mock (2005); Nokia (2014); NGMN Alliance (2015, 2016); Osseiran, Monserrat & Marsch (2016); Rysavy Research (2013, 2015); TNO (2013, 2014a, 2014b); Van den Ende, Van Sambeek, Berkers, Van den Broeck, and Van de Sluis (2016).

smartphones is much more frequent that the launch of a new infrastructure generation. Availability of new devices will be a commercial decision fed by major markets introducing 5G.

The question that remains is: What are the areas left in relation to 5G that provide opportunities for Europe to re-assert a leadership role if they are unlikely to be found in the derived conditions for leadership? They may be found in the differences in functionality and features of 5G compared to 4G. The major differences are (NGMN Alliance, 2015; Osseiran, Monserrat & Marsch, 2016):

a) higher data rates;
b) higher traffic density;
c) higher reliability;
d) support of higher user speeds (km/h);
e) lower latency:
f) connectivity for many more devices; and
g) lower power in support of the Internet-of-Things (IoT).

These capabilities can be considered as largely evolutionary, improvements based on ongoing technological progress. However, what is different is the focus on serving so-called vertical markets with tailored feature sets and differentiated quality of services, which are made possible with 5G based on virtualization and the use of application programing interfaces (APIs). (5GPPP, 2016; NGMN Alliance, 2016; Varrall, Mumford, Yip & Sims, 2016).

3.5.1. Virtualization as internal driver for 5G

Virtualization is certainly an internal driver for operators to deploy 5G. Virtualization already started in the fixed network with AT&T taking the lead (AT&T, 2013a). The motivation to move towards NFV can be summarized as dissatisfaction with the current

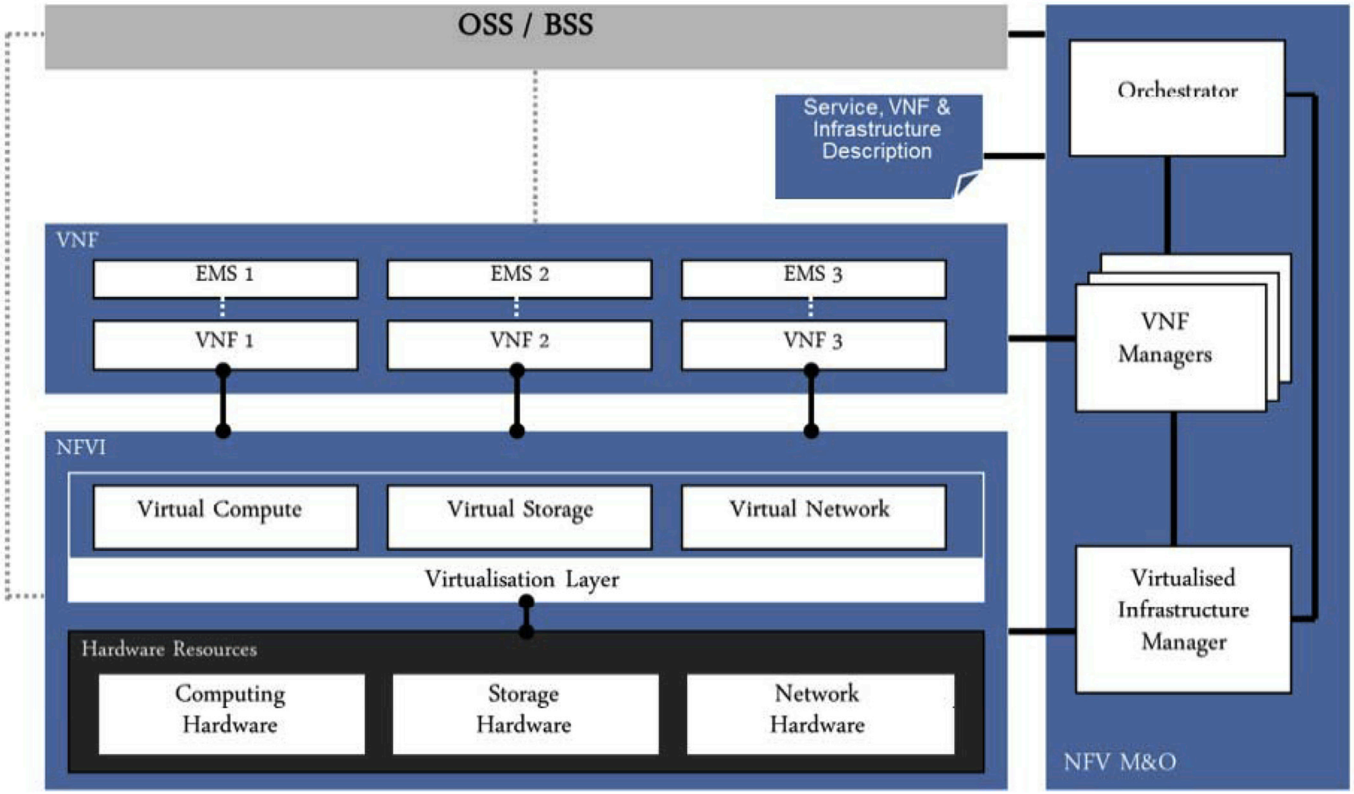

Fig. 2. ETSI ISG network virtualization framework.
Source: ETSI (2013).

model for deploying new network services. It has led to a large and increasing variety of proprietary hardware appliances and the introduction of a new service requires yet another variety, for which finding the space and power to accommodate these boxes is becoming increasingly difficult. This difficulty is compounded by "increasing costs of energy, capital investment, and rarity of skills necessary to design, integrate and operate increasingly complex hardware-based appliances." (AT&T, 2013a). Moreover, AT&T argues, hardware lifecycles are becoming shorter as technology and service innovation accelerates, which further constrains innovation. The compelling reasons for applying virtualization are: lower capital expenditures, benefiting from economies of scale in the IT industry; lower operating costs; faster deployment of new services; energy savings; and improved network efficiency. AT&T senior management announced as target 75% of the network to be virtualized by 2020. (AT&T, 2013b). The current level is said to be 55%. (AT&T, 2016). In a survey of 50 operators globally 89% expected to use a virtualized core before 5G deployment would start. (Ericsson, 2016).

ETSI has standardized the framework, including interfaces and reference architectures for virtualization. See Fig. 2 showing the ETSI framework, in which virtualized network functions (VNFs) are the nodes or applications by which operators build services. [19] (ETSI, 2013). Other standards and industry groups involved include 3GPP, The Open Network Foundation, OpenStack, Open Daylight, and OPNFV. (4G Americas, 2014).

Virtualization and the decoupling of radio access technologies (RATs) from the core network (CN) functionalities support the principle of network slicing. In that way the various 5G use cases with different requirements on the radio interface and on data processing in the core network can be combined and supported by one integrated mobile communications network. (4G Americas, 2014; Rysavy Research, 2015; Osseiran, Monserrat & Marsch, 2016

3.5.2. *Virtualization and vertical markets as external driver for 5G*

The subsequent question is whether vertical markets can constitute a leadership role for 5G in Europe. Serving industry verticals has a long history in European mobile communications, however, it remained limited to two verticals with dedicated spectrum assignments: the European railways, as part of GSM, and the public protection and disaster relief sector (PPDR - police, fire brigade and ambulance services) as part of 4G. The GSM-R functionality has become part of the general GSM specification, such that the functionality was available to address other similar niche markets. PPDR is accommodated as part of 4G release 13 through 15. In Europe, the PPDR sector was previously served through a dedicated system called TETRA (Terrestrial Trunked Radio)[20] operating in a dedicated frequency band. The sector has concluded that for the transition from narrowband to broadband it will have to rely on LTE and LTE-Advanced, as a dedicated broadband system is not an economically viable option (TCCA, n.d.). Whether this will be LTE in a dedicated band or PPDR-as-a-Service is subject of ongoing debate, with the UK having opted for the latter. However, these two vertical markets are relatively small compared to the consumer mass market.

Extending vertical markets across all vertical industries, all economics sectors and the government could constitute a leadership role with 5G. The critical element will be the creation of market momentum. While mobile operators have recognized the opportunities in serving vertical markets and have taken initial steps to serve these markets on the basis of LTE, this paper posits that to create market momentum two conditions are essential: the vertical industries need to be unlocked across the board and they need to be unlocked simultaneously.

To achieve this, the knowledge on the needs of the verticals that resides within these organizations need to be unlocked. Comparing the number of mobile operators with the number of vertical industries, and potentially differentiation among firms in an industry, suggests that the locus of service creation should shift from MNOs to the verticals, to those entities that have the inside knowledge of verticals, such as the IT/CT departments of the firms in the vertical industries, specialized providers of ICT services to these vertical industries, the service divisions of fixed and mobile incumbent operators, the service divisions of mobile virtual network operators; and start-ups that recognize the new opportunities for developing services and applications. Those entities are to become Virtual Mobile Network Operators (VMNOs). And as firms within the verticals compete for end-users, they will compete for providing the best virtual mobile services as well. This is expected to results in a very dynamic retail market for mobile communication services, building the required market momentum.

Two more conditions have to be satisfied for market momentum to build: the application programming interfaces (APIs) need to be open access and these APIs have to be deployed universally across the European Union. The APIs are understood to be integral parts of 5G development and hence will become standardized. To the extend APIs have been applied in the telecommunication field in the past they have remained closed, i.e., to the benefit of the operators to improve their service provision. What is required to build the desired market momentum is that these APIs are made available by the MNOs, as wholesale providers, to the VMNOs, as retail providers. As many vertical industries operate across the Union, firms will require the services to be available across the markets they serve. Hence, universal deployment of APIs is required, thus a universal roll-out of 5G across the Union is required.

The tailored mobile communication services, being bundled with IT-services, will unlock a higher willingness to pay compared to the mass market consumer services. This extra margin will flow from the retail market through the wholesale market to incentivize 5G network investments by the mobile infrastructure operators. This provides for a virtuous circle of demand and supply that is expected to lead to a leadership role of Europe in the development, deployment and exploitation of 5G services. Such a development is in-line with the European Union objective of creating a vibrant Digital Single Market (DSM).

Enabling the conditions for a leadership role with 5G in the European Union is not the same as enabling the conditions which have

[19] For a general discussion of virtualization and Software Defined Networking see: Göransson and Black (2014); Stallings (2016). For a specific discussion in relation to 5G see: Chapter 3 in Osseiran, Monserrat & Marsch (2016).

[20] TETRA functionality is an extension of GSM functionality.

led to leadership and success with 2G-GSM. While enabling the basic conditions have become integral to the development of the next generation, and can be observed in the actions as part of the 5G developments to date, the enabling of the special conditions, i.e., leveraging VMNOs through virtualization and universal, open access APIs, requires conscious decision making. It constitutes a fork in the road ahead for all actors involved, in particular for the mobile network operators and the policy makers in the European Union. It relates to two different future trajectories with outcomes which may be perceived differently by the various actors involved.

To enable the debate on the possible futures and what policy and regulatory actions may be required to enable a particular future, two contrasting stylized images of the future have been constructed. They will be introduced and discussed in the following sections.

4. The two stylized images of the 5G future

To explore how the development and deployment of 5G may evolve based on industrial activity as well as policy and regulatory actions two stylized images of the future have been developed, called “Evolution” and “Revolution”. They represent respectively a continuation of the previous generations, i.e., 1G through 4G, and a clear break with the past developments made possible through technological developments, i.e., the virtualization of communications networking. The contrast between the images is in the two different industry structures they represent. On the one hand the continuation of an oligopolistic market structure of incumbent mobile network and services providers and on the other hand a market that is driven by a wide range of firms specialized in serving the requirements of (multiple) vertical industries. Through applications enabled by open access APIs, they provide seamless services, where necessary on a regional basis. The latter image reflects the opportunity for European Union actors to re-assert leadership in the development and deployment of the next generation of mobile technology and services, i.e., with 5G.

4.1. The “Evolution” image

This section describes in hindsight and in summary form the outcome of the perceived development path resulting in the “Evolution” image. In this Section the stylized image is compared with the GSM success factors derived in Section 3.

In the “Evolution” image the leading players are the incumbent mobile operators. Given the competitive market place and consumers having become used to getting access to more bandwidth with each new generation at roughly the same price, the profit margins are remaining small. Hence, the incumbents had a strong incentive to optimize past investments and to be prudent with new investments. The business case had become more challenging with each new generation, as the investment costs per subscriber increased while per subscriber revenue remained flat. (EC, 2016c).

LTE, being a high capacity All-IP system, removed past infrastructure bottlenecks and provided a controlled path towards the future, with the introduction of LTE-Advanced, as well as upgrades of functionality through annual releases. With the relative low and stable prices paid by end-users, largely irrespective of the increase in data rates offered, this evolutionary image fits the desire for a stable business model with relatively flat investment levels.[21] This provided for relatively stable and predictable performance.

As the 5G architecture evolved by adding new radio interfaces in bands above 24 GHz to the existing LTE core network, incumbents could serve the demand for higher data rates in an incremental way, particular in high density city areas, as and when demand became manifest. The replacement of the LTE core network by a 5G core network could be phased, based on new products becoming stable and being provided at lower costs.

As the newly available frequency band below 1 GHz, i.e., the 700 MHz band, was already auctioned for use by LTE and LTE-Advanced, there was no direct linkage between the release of this new spectrum and the introduction of the new 5G technology. The introduction of spectrum bands above 24 GHz was and still is of importance for network densification to provide higher data rates. But this did not provide a window of opportunity for infrastructure market entry as part of 5G. Hence, increased competition as a major driver of success related to GSM was lacking in the context of 5G.

With a well-functioning competitive market and in line with the policies for 3G and 4G, a light-handed EU policy was applied with respect to the introduction of 5G, including an Action Plan aimed at early experimentation and harmonized introduction. At the time of GSM, the policies were more forceful, including a Directive on the coordinated introduction being adopted.

The need to create sufficient scale at the outset of a new generation by having at least three large markets coming on stream at the same time had failed. This was due to differences in business priorities across the major incumbents in the major markets, the UK, Germany, France and Italy. The alignment efforts at the European level efforts had remained without results, in part due to Brexit.

The 4G and 5G standards are both global and hence no additional market momentum could be gained, as was the case at the time with GSM, when international roaming was introduced representing a new source of revenues. Note that the 1G market was largely a business market. Furthermore, in the EU roaming charges had been abolished in 2017.

With a global standard, equipment supply had become increasingly global, with China taking the lead by leveraging its large home market. Hence, the alignment of European stakeholders as a result of mediation between buyers and suppliers in the standardization process was still present but its importance had diminished.

Given the regularity of successive generations, the equipment suppliers were accustomed to the ten year cycle in terms of R&D investment, industrialization and deployment. See also Table 3. There was a strong incentive to keep up the pace, which translated in early technology trials with operators and showcasing of the new technology at major events, such as the Olympic Winter Games in 2018 in South Korea.

[21] The investment profile typically reflects investments in coverage in the early period and investments in capacity upgrades (densification) in the subsequent period.

In summary, the 'conditions to enable market momentum to build' that played an important role in the introduction of GSM were by and large present and relevant to the introduction of 5G, however, they pointed to an evolutionary rather than a revolutionary trajectory. The dynamics around the introduction of 5G being more akin to 4G than to 2G.

4.1.1. *Policy and regulatory actions enabling the "Evolution" image*

This section describes how the outcome of the "Evolution" image can be enabled through policy and regulatory action. It provides a forward looking perspective. The description is purposefully kept short with a focus on the policy actions as the 'Evolution' scenario builds on a continuation of trends, including the Electronic Communications Code, which are considered to be well understood.

Through the RACE research program the EU established a firm foundation for next generation specification work, which continued through 4G and into the 5G era with, e.g., the METIS projects. This thought leadership of the European industry is broadly recognized. (Rysavy Research, 2013).

These two developments logically led to the EC taking the initiative to engage into strategic collaboration agreements in the field of R&D with South Korea (2014), Japan (2015), China (2015) and Brazil (2016).

4.1.1.1. The 5G Action Plan. An important condition that contributed to the success of GSM was the alignment of the stakeholders towards a coordinated introduction. While in a highly competitive market such coordination is not likely to occur through the mobile operators[22] coordination is pursued by the European Commission through the development of the '5G Action Plan' launched 14 September 2016. This Plan of the Commission is supported by the Member States and the industry. (EC, 2016a). This plan recognizes the 'chicken and egg' problem associated with the introduction of a next generation of mobile communications and intends to reduce the uncertainties between the supply and demand side through adequate coordination.

At large, the 5G Action Plan fits the recurring pattern by addressing the actions required for a coordinated introduction of 5G in Europe. See Table 3. Being a result of collaboration with the stakeholders it reflects the plans of these stakeholders, such as initial deployment in commercially attractive areas, the use of 5G for PPDR services in line with current LTE developments, and the standards work in 3GPP. The Action Plan emphasizes the role of early trials to assure a timely general roll-out of 5G and it calls upon all Member States to engage in the timely roll-out together with the industry stakeholders, including the development of national 5G deployment roadmaps as part of the national broadband plans. The latter is in line with the Digital Agenda implementation process in terms of target setting and monitoring. A new element is the proposal to set-up a venture financing facility in support of innovative European start-ups.

The fact that spectrum assignments have been made technology neutral[23] suggests that it is up to the incumbent operators to decide when and which bands currently assigned to them they wish to transition to 5G. Hence, no closely coordinated roll-out is expected as was the case with GSM.

The above image suggests that the European Union is not going to lead in terms of being the first in 5G deployment; however, it can be a 'fast follower'.

4.1.2. *Regulatory action*

From a regulatory perspective the "Evolution" image is business-as-usual. The image builds upon the assumption that 5G will be compliant with the rules and regulations for e-communications as currently being proposed in the new Electronic Communications Code. (EC, 2016b). For a listing and discussion of specific regulatory actions reference is made to the underlying research report Lemstra, Cave & Bourreau (2017).

4.2. *The "Revolution" image*

The "Revolution" image represents a clear break with the trends that can be observed from the previous generations of mobile communication. In this image the future of 5G is determined by the new business opportunities that virtualization of communication networks provides. This includes in particular shaping service portfolios to the needs of particular (vertical) industries or economic sectors by specialised providers, operating as virtual mobile network operators (VMNOs). In the "Revolution" image the consumer market is one of the many vertical markets. The European leadership role is constituted in the role of advanced industry services, which allow the particular industries to take a leadership role in their markets and thereby contribute to economic development in the EU at large.

4.2.1. *The "Revolution" outcome*

This section describes the anticipated outcome of the stylized image of the future in hindsight. While in the "Evolution" image the supply side forces were the main drivers, in the "Revolution" image the demand side forces were the key drivers.

In the "Revolution" image the 5G future was and is characterized by a multitude of service providers (Virtual Mobile Network Operators – VMNOs) that have as core strategic asset the relationship with their customers and deep knowledge of their business

[22] One can argue that the GSMA as successor of the MoU could provide this kind of coordination, albeit European leadership would have to come from the regional interest group for Europe, which may be difficult to realize as the GSMA represents the interests of mobile operators globally.

[23] Across Europe the process has been completed by May 2016. Source: GSMA response to RSPG consultation. While spectrum bands may have been made technology neutral some aspects, such as the channel width, may have to be aligned with a particular generation of technology. This may involve adaptation of regulatory conditions.

operations and communication needs. They all have strong capabilities in translating these needs through application programming into dedicated virtual network service sets, which are real-time enabled by the network infrastructure asset base of mobile and fixed communication network providers (MNOs and FNOs). They are able to bundle and provide these communications needs in conjunction with other needs for services, such as cloud computing.

4.2.1.1. Expanded service provider base. These service operators (VMNOs) evolved from IT/CT departments of the firms in the vertical industries, from specialized providers of ICT services to these vertical industries, from the service divisions of mobile operators (MNOs and MVNOs) and from start-ups that recognized the new opportunities for developing applications. The image reflects the digital transformation process that was taking place across all industries and economic sectors. For the firms the appeal was the ability to establish a direct customer relationship, irrespective of any intermediaries in the communication supply chain, being able to tailor this relationship in competition with other firms across geographical borders and having full control of its shape, content and timing.

4.2.1.2. Leadership through services. The European Commission with the support of the Parliament and Council recognized the opportunity for leadership in 5G in serving industry verticals to boost economic growth and productivity across all sectors of the economy. It recognized that the development of mobile communications infrastructure had evolved beyond regional leadership and that 5G had become truly global. Hence, the logical next step for Europe was to assume leadership in the use of the global 5G infrastructure, i.e., in the provision of (business) services sets tailored to particular industries and economic sectors. It thereby focused on globally leading industries. This 'move up the value chain' towards services and through differentiation made strategic sense as virtualization was leading to commoditization at the network equipment level and loss of market share typically to suppliers from China.[24]

4.2.1.3. Change in industry mindset. Shifting the mobile communication industry momentum from leaders in consumer markets to leaders in services markets for vertical industries required, in the terms of some industry observers, a mindset change in the strategic vision of the actors involved. It resulted in a new prevailing industry logic. Virtualization provided the technological opportunity, but active policy support and restraint in regulation were essential to ensure it led to the desired future outcome. The new services providers became the new virtual mobile network operators (VMNOs), as virtualization allowed the slicing of network resources, as if each service provider did run its own mobile network or networks.

4.2.1.4. An innovation project. The transition to the new industry configuration was a major innovation project. Tailoring services to specific requirements of a particular industry took a lot of time and effort in terms of service concept development followed by business model development. This required major investments from both the communications industry as well as the particular vertical industry involved. While the prospects were largely recognized, success was not guaranteed as often other parties, such as regulators, had to be brought onboard and needed to be convinced of the merits of the projects.

Policy makers and regulators needed to be convinced of the expected future outcome to justify their restraint in terms of regulation, as the industry was moving to a new competitive configuration with a multitude of VMNOs served by a relatively small number of MNOs. It appeared that the concerns about further consolidation at the wholesale level were more than offset by the end-user benefits from vibrant competition at the retail level, made possible through service differentiation.

4.2.1.5. Common 5G standard. At the time of 2G an endorsement by the European Commission of the GSM project and reserving the allocated frequency band for the implementation of the GSM standard were critical conditions that assured the harmonized implementation of GSM across Europe. In the 5G era such mandates were not required as the industry was and still is aligned, no alternative standards were in a position to threaten the focus of the efforts on the development of 5G.[25]

A concern in such a setting is that choices otherwise available to end-users in the market are made in a standard development organization typically dominated by suppliers. Historical developments suggest that end-users when they organize their interests can be properly represented in the standards making process, as shown by the inclusion of features for the rail transport sector in the GSM specification and features for the PPDR sector in subsequent LTE releases.

Early signs of business-critical users becoming organized and being recognized as part of the TCCA (TETRA Critical Communications Association) community representing the PPDR interests suggested that the market actors were organizing their interests. In other industries government support appeared to be required for the actors to coordinate their interests to become reflected in the standard.[26]

4.2.1.6. Common set of open APIs. With the virtualization of the 5G architecture a new 'north-bound' interface became available allowing services to be tailored using applications programming interfaces (APIs). As 5G functionality became available through subsequent releases the associated APIs also became available over time. These APIs being closely related to the functionalities defined in the subsequent releases of the 5G standard became an integral part of the standard.

[24] The debate within government circles whether for national security reasons the national communications infrastructure could depend solely on equipment from non-European equipment vendors remains ongoing. The accusations addressed to Chinese manufacturers are being offset by the revelations on US government actions being revealed through WikiLeaks.

[25] One could argue that an extended life of 4G is a threat to 5G deployment. Given the different context compared to the 2G era, the transition to 5G is largely the decision of independent market actors, with the governments in a facilitating role.

[26] Note that with the support of the services set required for PPDR a much broader set of features is made available for business critical use.

The timely availability of a common set of APIs implemented across the networks of multiple MNOs was and still is essential for the ecosystem of VMNOs to flourish. With the changed mindset of industry actors came the recognition of this crucial requirement, which was implemented as part of the 3GPP efforts and subsequently made available by MNOs to VMNOs as 5G technology was introduced in the network. The second Action Plan initiated by the European Commission appeared to have been crucial to build the necessary industry momentum, in particular the trust of VMNOs in the openness and timely availability of the APIs, which can be considered a bottleneck resource of strategic importance.

To invoke the appropriate behavior by market actors with respect to the timely availability and openness of the APIs, the European Commission informed the industry that a mandate could be issued to ETSI for the development of a standard set of APIs if market development deemed such an action as being warranted. Also the industry was informed of the potential use of European regulation on the implementation of these common APIs by all mobile operators if this was not achieved on a voluntary basis. In this way the European Commission recognized the innovative aspect in the development of APIs and its gradual implementation, at the same time it unequivocally communicated the intended end goal of this development.

To ensure service compatibility across networks an entity was established by the industry that could test and approve new applications for compatibility with the standard and its APIs, much like the model of the Wi-Fi Alliance. Again, the European Commission had indicated that ETSI would be mandated if the industry would fail to set up such an entity.

4.2.1.7. Coverage and fallback. Considering the importance of PPDR type services being available to all citizens everywhere at any time, industry actors agreed to enter into good-faith private contracting to implement the equivalent of national roaming. Based on the new mindset it was clear that this approach was more attractive than awaiting a regulatory obligation to be enforced. As a consequence, these contracts also allowed optimal service provision to vertical markets irrespective of location. Thereby it facilitated market entry of VMNOs while incentivizing MNO investments.

4.2.1.8. Outcomes. Through these actions a Europe-wide communications platform was created. A platform void of geographical borders and a platform, being software based, with low barriers to entry. It allowed parties with deep knowledge of the (existing, new and emerging) digital business models of a particular industry to effectively enable these models by providing the necessary electronic communication services, without the need to invest in infrastructure assets. For the network infrastructure providers (MNOs), these service providers (VMNOs) represented a new wholesale market segment with high willingness to pay, derived from the bundles of ICT business services being provided.

In terms of the number of mobile users the new market extended well beyond the size of the mass market of consumers as it included IoT and IoE. It now covers both mass market communications and ultra-reliable low latency machine type communications.

4.2.2. Policy and regulatory actions enabling the "Revolution" image

This section describes in summary form how the outcome of the "Revolution" image can be enabled through policy and regulatory action. It provides a forward looking perspective.

In enabling the "Revolution" image the European Union demonstrates its leadership not only in the development of a next generation of mobile communications but in changing the trajectory of the mobile industry by embracing the opportunities that virtualization provides.

4.2.2.1. Policy formation and implementation. The European Commission with the support of the Parliament and Council recognized the opportunity for leadership in 5G in serving industry verticals to boost economic growth and productivity across all sectors of the economy. It recognized that the development of mobile communications infrastructure had evolved beyond regional leadership and that 5G had become truly global. Hence, the logical next step for Europe to take is to assume leadership in the use of the global 5G infrastructure, i.e., in the provision of (business) services sets tailored to particular industries and economic sectors. This is made an integral part of the overall Industry 4.0 vision and implementation.

The transition to the new industry configuration is recognized as a major innovation project. Tailoring services to specific requirements of a particular industry will take a lot of time and effort in terms of service concept development followed by business model development. Major investments will be required from both the communications industry as well as the particular vertical industry involved.

While the prospects are largely recognized, success is not guaranteed as progress often involves other parties, such as industry specific regulators, which have to be brought onboard and need to be convinced of the merits of the projects. Moreover, in many industries the governments at local, regional and national level are required to invest in unison with the industry. This is recognized and calls for specific coordination efforts by industry across all actors involved.

Based on assessments of the future outcomes, policy makers and regulators become convinced of the expected future outcome, which justifies their restraint in terms of regulation, as the industry is moving to a new competitive configuration with a multitude of VMNOs served by a relatively small number of MNOs.

The concerns about further consolidation at the wholesale level are considered to be more than offset by the end-user benefits from vibrant competition at the retail level, which is made possible through services differentiation.

Policy makers and regulators are coming to grips with a new technical feature: the 'north-bound' interface hiding the lower level architecture functionality while allowing services to be tailored using APIs. The timely availability of a common set of APIs implemented across the networks of multiple MNOs is recognized as essential for the ecosystem of VMNOs to flourish. It is also recognized that 5G

Table 4
Main differences between the "Evolution" and the "Revolution" image.

Attributes	"Evolution" image	"Revolution" image
Mobile communications industry		
Main characterization	Business as usual; focus mass consumer market; serving business needs are incremental	Exploring and exploiting new business opportunities offered by unlocking vertical industries; consumer market as another vertical that allows for differentiation
Use of 5G virtualization	Internally focused, improving operational efficiency	Externally focused, enabling vibrant retail market through VMNOs
Use of APIs	Internally focused, improving operational efficiency and reducing equipment costs	Universally deployed and open, enabling EU-wide markets; improving operational efficiency and reducing equipment costs
Effect on industry dynamics	Low, determined by the low number of MNOs in each member state and their (limited) capacity to exploit the 5G capabilities	High, through the introduction of virtualization and open APIs, with a multitude of VMNOs creating a vibrant retail market
Effect on industry structure	MNOs continue as the infrastructure operators and service providers	MNOs remain as the infrastructure operators and assume key role as wholesalers (few); VMNOS are the new retailers (many)
Effect on competition	No market entry at MNO level anticipated given maximization of level of competition achieved	No market entry at MNO level, but large scale entry at retail level by multitude of VMNOs
Effect on infrastructure investment	No change; constrained due to depressed margins; consumers expect more for the same price in a highly competitive environment	Ability and willingness to invest improved by unlocking new markets and as result of flow through of higher margins from higher valued, differentiated and bundled services
Services	More of the same, but better	Tailored to the specific needs of industry verticals; packaged with IT components
Service development	MNOs in the lead; focus on a few standardized services aimed at mass consumer market	VMNOs in the lead; virtualization and open APIs enable tailoring to a variety of end-user needs
Responsiveness	No change; MNOs bottleneck in translation of diverse end-user service needs	High as VMNOs leverage insights into operation of vertical industries
Other industries and economic sectors:		
Effect on other economic sectors	Gradual move to serve business users in addition to consumers, constrained by limited resources within MNOs; small positive economic effect	Enables and facilitates digital transformation in all economic sectors; improving efficiency and unlocking new business opportunities; stimulating productivity improvement resulting in economic growth
EU and Member State policy:		
Policy implications	Continuation of current level of policy engagement	Need to discuss industrial policy change to enable the image to be realized Need to inform industry of the industrial policy objectives and measures
Policy actions	Business as usual; 5G Action Plan	Need for additional 5G Action Plan to facilitate market development based on open APIs Need to remove uncertainty; to inform and facilitate market development Assure deployment of 5G standard across EU with open APIs
EU and Member State regulation:		
Regulatory implications	No change in regulatory practice	Need to update market analysis to reflect new market dynamics and structure Less concern with low number of MNOs or regarding consolidation of MNOs in the presence of highly dynamic retail market Need to investigate cross-overs with regulation of verticals
Regulatory actions	No change in regulatory actions	Need to enable entry of VMNOs using MVNO experience Need to apply regulatory constraint to enable innovation by MNOs/VMNOs Need to enable collaboration for national coverage and fallback Need to revisit net neutrality regulation

functionality will become available through subsequent releases and thus the associated APIs will also become available over time. As these APIs are closely related to the functionalities defined in the 5G standard, there is basic trust among policy makers and regulators in an appropriate outcome.

Nonetheless, APIs are recognized as a potential bottleneck resource of strategic importance, as their openness and timely availability are of crucial importance to build the industry momentum. To invoke the appropriate behavior by market actors with respect to the timely availability and openness of the APIs, the European Commission informs the industry that a mandate could be issued to ETSI for the development of a standard set of APIs if market development deemed such an action as being warranted.

4.2.2.2. Policy actions. In addition to the Action Plan described in Section 4.1.2. A '5G Action Plan II' is launched in September 2018, with an emphasis on enabling the vertical markets through network virtualization. To assure a fast and broad deployment of tailored services as soon as a virtualized 5G is being deployed, the Action Plan focuses on a series of workshops for prospective service providers (VMNOs) organized across the Union. The workshops are led by ETSI experts in close collaboration with the industry. Through the workshops the API toolkit is introduced and participants are made familiar with the process of service creation, including the validation process. Parallel sessions are organized by industry verticals where 'supply' can meet 'demand'. Operators present their experience with network slicing as part of LTE, while industry representatives discuss how they are applying digital transformation using ICTs in general and mobile communications in particular. They explain how 4G contributed to the transformation process. At these sessions the start-ups financially supported through Action Plan I demonstrate their new service offerings.

4.2.2.3. Regulatory actions. From a regulatory perspective the "Revolution" image builds upon the assumption that 5G will be compliant with the rules and regulations for e-communications as currently being proposed in the new Electronic Communications Code. (EC, 2016b). The major regulatory differences that the image invokes have been highlighted in Section 4.2.1 For a listing of the specific regulatory actions reference is made to the underlying research report Lemstra, Cave & Bourreau (2017).

4.3. Inputs to the debate

To inform the policy debate, Table 4 captures the main differences between the "Evolution" and the "Revolution" image.

As there are different stakeholders, there are likely different perspectives on the most desirable future of 5G. To further stimulate the debate on the future of 5G, the perceived pros and cons of the two images are summarized below using the perspectives of five different groups of actors:

a) European policy makers and regulators, electronic communications specific;
b) incumbent mobile operators;
c) potential mobile market entrants;
d) industry verticals as end-users; and
e) consumers as end-users.

The role these actors can play in shaping European leadership with 5G is identified and elaborated. Note that the presentation of the pros and cons is not aimed to be exhaustive.

4.3.1. European policy makers and regulators

The "Evolution" image is expected to emerge as a result of keeping the status quo, i.e., business as usual. The image builds on the current Electronic Communication Code as the regulatory framework. In this image, with no fundamental changes in the industry structure, the Code enables the 5G deployment. The current practice of industry oversight continuous. Concerns regarding consolidation of MNOs remain. Special regulatory attention is drawn to in-house and rural coverage. In the context of net neutrality regulation, serving PPDR can be considered as an enhanced service and hence as an exception as defined in the net neutrality rules. However, to avoid that the net neutrality ruling becomes a constraint in the development of services to industry verticals revisiting the net neutrality rules will be necessary.[27]

Enabling the "Revolution" image calls for a much more pro-active policy and regulatory stance at national and regional level, by the national governments and the European Commission. Such a stance would fit a pro-active industry policy aimed at economic growth in the EU.

The unlocking of the industry verticals requires enabling VMNOs in support of each industry vertical. VMNOs are likely to emerge as national level policy-led initiatives, to grow into regional initiatives. To assure that these business development efforts in the mobile communications market can be successful, policy support and regulatory restraint are required.

Given the differences in the uptake of MVNOs across member states, different attitudes may be expected from incumbents with respect to enabling VMNOs. Policy guidance may be required to create a well-functioning wholesale market. Moreover, a level playing field is required to allow the industry insights accumulated by, e.g., the in-house ICT service providers to be leveraged in the new role of an VMNO.

Hence, close market monitoring at the national level will be required and intervention if market failure occurs. The first market failure is likely to be a lack of information on how 5G may enable vertical industries. Providing information and organizing workshops on the use of the open APIs are possible remedies in this case (see 5G Action Plan II as part of the "Revolution" image). In first instance the national governments will become a market facilitator, a market maker. Regulatory intervention is considered as a means of last resort, if all else fails. While the EC has the possibility to issue mandates to force developments in a particular direction collaboration with the mobile sector is expected to provide better results.

The use of standard and open APIs across the EU enables borderless end-user services to be provided. This is enabled through a common standard for 5G, however, the standard does not enforce openness of the APIs. When the befit of deploying open APIs is not recognized by the incumbents, policy action will be required. Through enabling a vibrant market for VMNOs, the concerns regarding consolidation at the MNO level are reduced.

4.3.2. Incumbent mobile operators

In the "Evolution" image business is as usual. As the mass market of consumers remains as the core business, the margin pressure is expected to continue. With the ability to provide services with differentiated quality levels, MNOs will be able to compete more effectively with OTT service providers, which will need to use the best effort based last mile.

[27] For a discussion on net neutrality in relation to 5G see Frias & Pérez Martínez (2017).

A higher willingness to pay for business services is expected. To open-up the additional revenue streams investments are required for market development. The degree to which the vertical markets are developed is essentially constrained by the ability of the incumbent operators to address these new markets.

In the "Revolution" image the market development is expected to go faster and to be more broad as MNOs through a wholesale offering and the use of open APIs enable VMNOs as new players to expand the size of the market. Players who are likely to be vertical industry insiders. An increase in VMNOs at the retail level is expected to lead to increased wholesale revenues for the MNOs. It is expected that a broader market and higher willingness to pay will more than offset a loss of potential retail revenues as a result of enabling VMNOs.

At first instance, the market is expected to develop based on good faith negotiation between MNOs as wholesale providers and VMNOs as retail providers. Hence, in a market-driven environment the MNOs hold the key to the "Revolution" image to become reality. Based on the experience obtained with broadening and deepening the market though MVNOs, it is expected that the private market actors will enable a well-functioning market place for VMNOs.[28] This will pre-empt regulatory intervention. However, undue use of SMP through price or non-price competition will likely invoke regulatory intervention. The use of standard and open APIs across the EU enables borderless end-user services to be provided.

4.3.3. *Potential mobile market entrants*

In the "Evolution" image the market entry barrier remains high, as only the acquisition of radio spectrum usage rights provides entry for full control of service differentiation (MNO level entry), while the market entry barrier as MVNO remains the same.

In the "Revolution" image the market barrier is lowered at retail level through VMNOs. The scope for service differentiation by VMNOs is equivalent to that of the service division of MNOs. As there are many potential entrants a vibrant retail market may develop. Market players now active as OTT operators may become VMNOs to extend their services portfolio with managed services.

4.3.4. *Industry verticals*

In the "Evolution" image it is up to the MNOs to determine when and how a particular vertical industry or firm will be enabled. The way the verticals will be served and can benefit from technological developments in the mobile sector is constrained by the (limited) capabilities of the MNOs.

In the "Revolution" image the new role of VMNOs allows firms within a particular vertical industry to extend the digital transformation process of their business to include end-users, products and services. As an VMNO these firms can decide how to tailor the mobile communication services they wish to provide and how to combine these with other IT and/or business services under their own brand. This allows product/service differentiation on industry/firm level to include mobile communication services to end-users, products, services and devices (as part of the Internet-of-Things).

As part of the "Revolution" image, internal ICT departments are enabled to extend their service provision beyond the physical firm boundaries. The use of standard and open APIs across the EU enables borderless end-user services to be provided. In this image vertical industries are able to fully leverage the possibilities that the combination of CT and IT is offering.

4.3.5. *Consumers*

In the "Evolution" image the mass consumer market is considered to be central stage. Competition will continue and incumbents will provide end-users with higher data rates at rather constant prices.

In the "Revolution" image the consumer market is another 'vertical' with services specifically tailored to its needs. This image recognizes that the so-called mass consumer market is not homogeneous and VMNOs have the ability to segment the market along the dimensions of service needs, qualities and price. This will benefit the end-users. Their individual or collective buyer power is not expected to steer the developments within the sector.

5. Conclusions and recommendations

The aim of the research discussed in this paper was to provide a follow-up on the call by politicians for a leadership role of the EU in the development and deployment of 5G. To assess how such a role may be realized a historical analysis has been conducted to identify the conditions that have shaped the success of 2G-GSM. The conditions identified have been used to subsequently assess the less successful developments with 3G and 4G in Europe to frame the conditions for success with 5G. It appears that the basic conditions that have enabled success in the past, i.e., the harmonized use of a particular radio frequency band, the development of an open standard, the agreement on operational procedures and the availability and mutual recognition of terminal devices, are fulfilled today. However, the conditions that have built market momentum, i.e., opening of a new market, operators coordinating the launch of the new generation of technology, the creation of an EU-wide market, the introduction of competition, and reserving the harmonized spectrum for the designated standard are not applicable anymore or only to a much lesser degree. Nonetheless, a leadership role with 5G is considered feasible. Next to fulfilling the basic conditions, it hinges on how the features embedded in the architecture of 5G are used and how the use cases of 5G are enabled.

5G is different from its predecessor 4G-LTE in its aim to serve a wide range of industry verticals, such as automotive, public transport,

[28] Note that the Mobile Green Paper by the European Commission published in 1994 already identified the importance of independent service providers. Moreover, the first licenses in the UK were based on wholesale only and aimed at the development of a highly dynamic retail market of resellers. (CEC, 1994; Higham, 1994).

media and entertainment, financial services, energy utilities, manufacturing, health and public safety. The requirements of these industries are much different from those of the mass consumer market, the main stay of the previous generations, and they are very diverse. To meet these requirements, 5G is being designed for very low latency applications, very high travelling speeds of its users, high accuracy in terms of determining user location, much higher data rates and lower energy consumption, while serving an order of magnitude more end-users, in particular devices as part of the Internet-of-Things and of Industry 4.0. Use cases of 5G require particular combinations of these features. To accommodate these diverse requirements within one architecture, Software Defined Networking and Network Function Virtualization are the architectural cornerstones of 5G. To provide service sets according to specific needs, APIs are implemented to allow customization. Virtualization and the use of APIs are identified as the key conditions for 5G market momentum to build and be maintained. The EU leadership with 5G hinges on releasing the capabilities embedded in its architecture, to allow vertical industries to tailor services to their needs and to reap the benefits of enhanced productivity and improved competitiveness.

Opening-up the capabilities of 5G to vertical industries poses a dilemma. On the one hand, 5G provides incumbent mobile operators with an opportunity to improve operational efficiency and to grow revenues by serving vertical industries. On the other hand allowing market momentum to build requires the vertical industries to be served across the board and simultaneously. To serve the vertical industries effectively requires deep insights in the operation of each vertical and potentially of each (major) competing firm within these verticals. With the required knowledge residing within the verticals and with only a few incumbent mobile operators in each country, the current mobile market structure represents a major obstacle in the upscaling of 5G, and hence in enabling a leadership role with 5G within the EU.

The solution to resolving this dilemma can be found in the features that the 5G architecture provides, i.e., virtualization and the use of APIs. When the standardized APIs are opened up to third parties, the ICT-departments of firms within vertical industries can become virtual mobile network operators (VMNOs). With their inside knowledge they are best positioned to enable their firms to leverage 5G capabilities. As firms within vertical industries compete, a vibrant 5G retail market is expected to emerge. As verticals are enabled across the board mobile incumbents providing the 5G network capabilities will experience a vibrant wholesale market. Meeting the needs of vertical industries for bundles of communication and information technology services is expected to provide for a higher willingness to pay for higher valued services. This will feed the virtuous circle of demand and supply, allowing the 5G market momentum to build and be maintained.

The success of MVNOs in some countries suggest that incumbent CEOs and Chief Strategy Officers recognize that opening up the wholesale market and stimulating a retail market enlarges and deepens the market, which is in the benefit of both the retail and wholesale players. Given that 5G provides the opportunity to enable a vibrant retail market, while it may at the same time reduce the regulatory pressure for allowing more players in the wholesale market, an industry wide discussion seems to be warranted. This discussion could be facilitated by industry organizations such as ETNO and ECTA.

Historical evidence also shows that incumbents in well-established industries face the 'innovators dilemma'; switching to a new technological paradigm, a new business model appears to be counter to how business success is perceived and framed (Christensen, 1997; Rogers, 2016). The telecom industry falls in this category. Hence, for the leadership opportunity with 5G to become reality the industry may need some nudging. Given the envisioned European leadership role and the benefits accruing at the EU level, EU policy makers are in a key position to provide the necessary political and regulatory action. The benefits that 5G may bring to the EU at large warrant a discussion of the 5G leadership role within the European Commission, the European Parliament and the European Council, as well as within the regulatory fora such as the ERG and the IRG.

As member states are the custodians of the use of the radio frequency spectrum and as through the design of radio spectrum auction market entry is regulated, discussions on national level involving national stakeholders is equally important.

The innovative nature of the 'leadership project' suggests as a first step market facilitation rather than market regulation. The debate among the stakeholders can be facilitated and stimulated by using the two contrasting stylized images of the future provided in this paper. They inform the debate by providing the perceived pros and cons for each stakeholder group. The images are not prescriptive, they are intended to facilitate a debate resulting in a shared vision on the future of mobile communications in the European Union, a vision that maximizes the benefits from an opportunity that is offered only once every ten years.

As this paper explores future developments, it prompts future research into the development and implementation of 5G, and into the discussions that are expected to ensue. Further study into the role of open APIs is also recommended. Within 5G the use of open APIs are identified as critical to enabling the "Revolution" image. In Finland, open APIs are made a cornerstone of a new regulatory regime for public transport that opens up the market for platform–driven business models and the evolution towards Mobility-as-a-Service (MaaS).[29] Moreover, in the regulation of the financial industry open APIs are considered as a means to enable fintechs to participate and innovate the industry.[30]

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[29] Speech by the Minister of Transport and Communication Anne Berner at the Politico Summit "Connected Transport 2017" in Brussels on December 4, 2017.

[30] As proposed by the EBA in the context of the debate on the implementation of the PSD2 Directive. (FD, 2017).

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