Centre on Regulation in Europe
Improving network industries regulation

Towards the successful deployment of 5G in Europe:

What are the necessary policy and regulatory conditions?

Project report

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Table of Contents

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Executive Summary

Historical regularity suggests that approximately every 10 years a new generation of mobile communications technology is introduced. The next generation – 5G – is expected to be introduced around 2020. Each new generation represents a complex interplay between interdependent stakeholders, including infrastructure equipment manufacturers, device makers, operators, and end-users, as well as regulators and policy makers at national, regional and global level. This is a high-stakes game requiring deep investments which can only be successful if well coordinated, and when supply and demand can be aligned.

European policy makers have a keen interest in the success of the next generation because ubiquitous and high capacity electronic communication infrastructure is recognised as a cornerstone of economic development and productivity growth. The second generation, GSM, was a big success. It reached its peak in deployment in 2015 with 3.83 billion subscribers served through over 700 operators in 219 countries and territories.

With 5G rapidly shaping up in the R&D and standardisation environment, what are the lessons to be learned from 1G through 4G that should be taken into account to ensure a successful development and deployment of 5G in Europe? What does 5G have in common with previous generations and where is it different? What are the implications? Moreover, is the path towards the future predetermined by the previous generations, by a prevailing industry structure, or are there alternative routes? Is there possibly a fork in the road ahead that requires special attention from policy makers and regulators, as it may lead to different futures? When there are different futures with different outcomes, is one more desirable than the other? In sum, what would be the policy and regulatory framework required to enable the success of 5G in Europe?

To respond to these questions, this report identifies first, on the basis of an assessment of the previous generations of mobile communication technologies and against the backdrop of European leadership in the development and deployment of GSM, the **policy and regulatory lessons** to be drawn from the latter's success.

Secondly, it provides a **description of 5G**, the **performance objectives that have been assigned to it, the latter's architecture and key features; the report then compares those features with previous generations**.

Thirdly, it describes **two stylised,** extreme **images of possible futures of 5G**, 'Evolution' and 'Revolution'. Those images represent two different sets of outcomes that are enabled by two different sets of policies and regulatory interventions. They constitute a fork in the road that policy makers and regulators will have to navigate in the years to come.

It should be emphasised that the latter do not aim to represent the complexity of how the actual future may unfold, nor should they be considered as scenarios, such as those initiated by

Shell in the eighties. They are merely intended to **stimulate the debate on the policy and regulatory conditions** for the successful deployment of 5G in Europe.

Fourthly, the report **describes the policy and regulatory framework that would be required to enable each of these images**.

'**Evolution**' follows the pattern of previous generations and current trends. '**Revolution**' represents a clear break with these trends. It exploits the opportunities of standardised application programming interfaces (APIs) for service creation, being enabled by network virtualisation as an architectural foundation of 5G. These open APIs allow the market entry of a multitude of virtual mobile network operators (VMNOs). VMNOs are dedicated to serve particular industry verticals or economic sectors with tailored feature sets and tailored qualities of services.

In 'Evolution', the regularities and trends that can be observed from the previous generations of mobile communication, i.e. 1G through 4G, are considered as the main determinants of the 5G future. A key assumption in this image is that the core business of the mobile operators continues to be serving the mass market of consumers.

'Revolution' reflects the shift to a layered model with multiple specialised providers at each layer. At the lower layer are the passive infrastructure facilities providers. At the next layer up are the network operators – the owners of radio frequency licenses and of active infrastructure facilities. These mobile network operators are the wholesale providers of a range of connectivity services with various grades of quality to the virtual mobile network operators (VMNOs) at the top layer.

These VMNOs can be compared to the MVNOs of earlier generations, serving specific market segments and leveraging a particular brand. However, they are different as VMNOs have full control of a virtual slice of the network infrastructure to deliver services with differentiated quality levels. In 'Revolution', the number of VMNOs is very large. In principle, each firm that wishes to extend its reach to end-users through a mobile service can do so as a VMNO using its own brand and applying bundling with other business services. As firms compete for end-users, they are expected to compete for providing the best virtual mobile services as well. This results in a very dynamic wholesale market. This is a market that unlocks a higher willingness to pay, which, through differentiation of network services, will flow through to incentivise 5G network investments.

The policy and regulatory actions that enable 'Evolution' build on the new Electronic Communications Code and the 5G Action Plan. They are also related to the topics of, amongst others, trading in radio spectrum usage rights, coverage obligations, indoor access, network sharing, net neutrality and minimum requirements for public protection and disaster relief.

The policy and regulatory actions that enable 'Revolution' also build on the new Electronic Communications Code and the 5G Action Plan. However, they also involve a 5G Action Plan focused on the European-wide use of open APIs. The transition to the new industry configuration is recognised as a major innovation project requiring restraint in terms of regulation. Regulatory action is based on intervention only in case of market failure, e.g. in areas such as retail market access, open and common APIs and national roaming. Special action is required for net neutrality, liberalisation of SIM usage and use of multiple VMNOs on a single device.

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1 Introduction

Historical regularity suggests that approximately every 10 years a new generation of mobile communications technology is introduced. The sequence started with 1G in 1981 and the latest generation, 4G, was introduced in 2009. Hence, the next generation – 5G – is expected to be introduced around 2020. Each new generation represents a complex interplay between interdependent stakeholders, including infrastructure equipment manufacturers, device makers, operators, and end-users, as well as regulators and policy makers at national, regional and global level. The interplay concerns the allocation and assignment of new radio frequency bands, the development of a new standard, the development of new network equipment, the investment in new infrastructure build-out, the launch of new devices and the uptake by end-users. This is a high-stakes game requiring deep investments which can only be successful if well-coordinated, and when supply and demand can be aligned.

European policy makers have a keen interest in the success of the next generation because ubiquitous and high-capacity electronic communication infrastructure is recognised as a cornerstone of economic development and productivity growth. Moreover, at the European level, electronic communications has become a strategic element in the creation of the single internal market. Following the success of the second generation – GSM – the question of European leadership in the development and deployment of cellular communications is being raised with each successive generation.

The benchmark for European leadership in mobile communications is GSM, a second generation technology introduced in 1991, which reached its peak in deployment in 2015 with 3.83 billion subscribers served through over 700 operators in 219 countries and territories. This is phenomenal achievement, especially when recognising that the nearest competing 2G technology – CDMA – reached its peak with 374 million subscribers also in 2015. This represents a factor 10 difference. However, in Europe the next generation 3G – UMTS is generally considered as less successful, having had a slow start in deployment compared to a much faster uptake of 3G in the USA and Asia. Nonetheless, from a consumer welfare perspective, 3G and 4G can be considered as quite successful, considering the price levels and the data rates provided.

Therefore, with 5G rapidly shaping up in the R&D and standardisation environment, what are the lessons to be learned from 1G through 4G that should be taken into account with the introduction of 5G in Europe? What are the policy and regulatory lessons to be applied for a successful deployment of 5G in Europe? What does 5G have in common with previous generations and where is it different? What are the implications? Moreover, is the path towards the future predetermined by the previous generations, by a prevailing industry structure, or are there alternatives routes? Is there possibly a fork in the road ahead that requires special attention from policy makers and regulators, as it may lead to different futures?[1] When there are different futures with different outcomes, is one future more desirable than the other?

To respond to these questions, this research report provides first an assessment of the previous generations of mobile communication technologies and derives the policy and regulatory lessons against the backdrop of European leadership in GSM. Secondly, it provides a description of 5G, the performance objectives that have been set, its architecture and key features and compares this with previous generations. Thirdly, it describes two possible stylised images for the future of 5G, an 'evolution' image and a 'revolution' image. These two images represent two extremes to capture the widest range of possible 5G futures. These images are deliberately chosen to represent extremes, as it is not the intention to try to predict the most likely future of 5G. Furthermore, these images of the future do not aim to represent the complexity of how the actual future may unfold, nor should they be considered as scenarios, such as those initiated by Shell in the eighties. They are aimed at stimulating the debate on the best set of policy and regulatory conditions for the successful development and deployment of 5G in Europe.

The 'evolution' image follows the pattern of previous generations and current trends. The 'revolution' image represents a clear break with the trends as it exploits the opportunities of open access APIs being enabled by network virtualisation as an architectural foundation of 5G. These open APIs allow the market entry of a multitude of virtual mobile network operators. VMNOs dedicated to serve particular industry verticals or economic sectors with tailored feature sets and tailored qualities of services. These VMNOs may originate from the industries they serve, such as internal ICT departments extending their reach to customers, from services firms specialised in and dedicated to a particular industry, from incumbent[2] operators diversifying beyond the mass market of consumers and from start-ups.

These two stylised images reflect two different futures of 5G, two extremes. They yield two different sets of outcomes that are enabled by two different sets of policies and regulatory interventions. They constitute a fork in the road that policy makers and regulators will have to navigate in 2017.

This research report is structured as follows: in Section 2 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 the next generation, i.e. 5G. Section 3 describes the architecture and features of 5G, with special attention to virtualisation. The demand side expectations are also captured in this section. Section 4 introduces the two stylised images of the future of 5G. Section 5 describes the 'Evolution' image using the Porter/Wheelen industry structure dimensions and includes a sketch of the anticipated industry outcome. This outcome is compared with the GSM success factors identified in Section 2. In Section 6, the

[1] The metaphorical 'fork in the road' does not suggest there are only two futures.

[2] The term 'incumbent' is used to denote mobile network and service operators as they exist at the time or in the time period as referenced. The term does not typically include mobile virtual network operators.

policy and regulatory actions are derived that would enable the 'Evolution' image. Section 7 describes the 'Revolution' image and the anticipated outcome, while Section 8 captures the policy and regulatory actions that would be required to enable the image. Section 9 provides as a summary an overview of the pros and cons of the two stylised images. As background information, Annex A provides a short brief on the characteristics of the mobile communications business. Annex B provides the list of abbreviations and acronyms. Annex C presents a timeline of major developments in mobile communications. Annex D explores the 5G related radio frequency management challenges and Annex E addresses net neutrality in the context of managed services.

2 The leadership role

In describing the European leadership in mobile communications typically, reference is made to the global success of GSM, a second generation technology introduced in 1991, which reached its peak in deployment in 2015 with 3.83 billion subscribers through over 700 operators in 219 countries and territories. This is phenomenal achievement, especially when recognising that the nearest competing technology – CDMA – reached its peak at 374 million subscribers also in 2015. This represents a factor 10 difference.

However, the next generation 3G – UMTS – is generally being considered as less successful, having had a slow start in deployment compared to a much more rapid uptake in the USA and Asia. Nonetheless, from a consumer welfare perspective, 3G can be considered as quite successful, considering the price levels and the additional functionality provided.

For an appreciation of the differences a comparison is made between 2G and 3G based on the 'roadmap to market' and the 'leadership role' as identified for GSM by Hillebrand[3] (see Table 1 and Table 2 below).

Table 1: The road map to market: 2G and 3G compared

Legend: Action similar to 2G
Different action compared to 2G, but conducive
No similar action

2G – GSM	3G – UMTS
The top plane – political level to generate the political will to make an agreement on GSM happen:	
Agreement between the French and German Heads of State of November 1984 and the commitment of the UK in 1986	No similar political level engagement by Member States
Opening up of a new range of frequencies	Similar action with 24% more bandwidth being allocated
Linking the release of new spectrum to the market with a new technology	Similar action through auctions; freeing up previous allocations by introducing technology neutral assignments
EC Directive to reserve the frequency bands for the GSM technology	The EC Directive on a timely assignment process; no threat of alternative standards being considered for deployment; large installed base of

[3] Source: Hillebrand (2002).

2G – GSM	3G – UMTS
	2G/2.5G
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	Timely assignment of licenses including major markets; deployment delays due to economic setback in the aftermath of the telecom/internet bubble
Competitive pressure was required to drive volume	Highly competitive market; being depressed in the aftermath of the telecom/internet bubble
Use of a common standard allowing for new revenues from international roaming at almost zero incremental costs	No change in market structure, no new gains in moving to the next generation
The third plane – the technical standardisation effort	
Focusing the R&D efforts of the supply industry	Preceded by EU R&D program, standardisation process in ETSI; participants changed from only European to becoming global in 3GPP
Providing mediation between buyers and suppliers of networks	Similar situation; buyers and suppliers changed from predominant European to become global
The fourth plane – the industrialisation by the supply industry	
To be able to recognise the market and its size to have the confidence for the deep investments required	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
Semi-conductor industry to be pulled behind the equipment manufacturers	The semi-conductor industry is aligned, but impacted by the telecom industry set back

Source: Authors

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

Legend: Action similar to 2G
Different action compared to 2G, but conducive
No similar action

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

Source: Authors

As Ungerer observed,[4] the deployment of GSM and DCS1800 systems in Europe was unique because it coincided with the de-monopolisation and introduction of competition in mobile communications. The early accelerated mass deployment of GSM was mainly due to new entrants. 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.

[4] Source: Private conversation in the context of this project.

From 1993 to 1996, a number of procedures were undertaken under EU competition law to force fair terms for new entrants in several countries, including Italy, Spain and Ireland. This culminated in the Mobile competition directive issued in 1996, which also mandated the issuing of the DCS1800 licenses with the deadline of 1 January 1998 – coinciding with the date on which the European telecommunications market was to be liberalised.

In 1998 there was a debate in the Commission on whether the licensing of 3G should again be mandated under competition law or under the sector-specific internal market regulation. Competition law would have given a much more direct enforcement role to the Commission in overviewing and coordinating licensing and auctions. In the end, the decision was taken in favour of the internal market approach on which the electronic communications regulatory framework is based.

With 3G auctions construed to maximise proceeds for the national budget and the auctions coinciding with the Internet bubble, meant that investment resources were mainly spent on licenses. New entrants were no longer the main drivers and deployment was mainly with incumbents and GSM entrants of the nineties. All spent large amounts on the 3G licenses to secure their 2G position, not for the rapid deployment of 3G. All of this led to a slow deployment and the loss of the European position in digital mobile.

It should also be noted that the context has changed significantly between the launch of 2G and the launch of 3G, and further into the 4G era: (1) the market has been fully liberalised and has become highly competitive; (2) the position of European equipment manufacturers and mobile operators has changed as the industry has become global; (3) the role of nation states has changed as part of the liberalisation process and as part of the European Union project; (4) 2G was instrumental in establishing the mass consumer market, while 3G and 4G are largely representing replacement markets for voice and enhancement markets for data; and (5) the role of the device market has become much more important, the choice of smartphone and related applications platform have become leading in the decision making process of consumers.

As Fejióo et al. pointed out, during the earlier mobile generations a 'virtuous circle' of investment, innovation and adoption of services had been in play. With the introduction of 4G, this cycle appears to be broken, being replaced by a cycle that runs in the opposite direction. Now, the innovation and adoption of services require investments from mobile operators although these will not necessarily lead to an increase in operators' revenues.[5]

Hence, actions that were identified as having been crucial to the leadership role in GSM have to be reinterpreted in the current context of 5G.

[5] Source: Chapter on Spain by Feijóo, Gómez-Barroso, Coomote and Ramos in "The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda" by Lemstra & Melody (2015).

2.1 Regularities in next generation mobile communication: 1G through 4G

Notwithstanding the differences between the generations, many actions are part of a recurring pattern, a pattern typical for the introduction of a new generation of mobile technology. For Europe, these events and actions – generally called attributes – have been captured in Table 3 for the generations 1G through 4G. The column 5G has been added to capture those attributes as they could be observed to date.[6]

It should be noted that GSM not only represented a major growth phenomenon, it also established the foundational elements in the cellular communications business that are still valid today in Europe, such as calling party pays, international roaming and mutual recognition of terminal devices. In Table 3, these have been denoted as 'established routine' (est. rout.).

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	Televerket + Nordic Incumbent operators	1970	UK+FR incumbent operators	1981	Govt. representatives in FAMOUS	1991	3GPP study into LTE LTE-Advanced	2004 2012	EC FP7 METIS initiative; ITU WP 5D	2011 2011
Research into next generation requirements and technology	Televerket + Nordic Incumbent operators		FT + DT, incumbent operators	1984	RACE 1 RACE 2 ACTS	1985 1990 1995			METIS 5GPPP METIS-II	2012 2013 2015
R&D collaboration agreements									EU – South Korea w/ Japan w/ China w/ Brazil	2014 2015 2015 2016
Global set of requirements for the next generation					ITU IMT-2000	1999	ITU IMT-Advanced	2008	ITU IMT for 2020 and beyond	2012
Global allocation of mobile bands	ITU		ITU-WARC	1979	ITU-WRC	2000	ITU-WRC		ITU-WRC targets 400 MHz; ITU WRC to specify	2015 2019
Allocation of additional	CEPT		CEPT	1982	CEPT		CEPT		CEPT proposal	2015

[6] See also Annex A for a high level description of the cellular communications business and Annex C for a timeline of major events in the communications industry.

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
spectrum									24.5-27.5 31.8-33.4 40.5-43.5 GHz; decision	2017
Regional harmonisation of spectrum for dedicated standard			EC Directive	1987	Est. rout.		Est. rout.		EC 5G Action Plan	2017
Newly allocated band(s) (MHz)	450		GSM 900 GMS-R 890 GSM450		2100		800 2100 2600 3400-3800 700		24.5-27.5 31.8-33.4 40.5-43.5 60 GHz	
Amount of spectrum allocated (MHz)			GSM 2x25 DCS 1x75 GSM-R 2x 4	1982 1993 2006	155 MHz		60 120 190 400 60		Tbd in WRC2019	
Assignment method	Assignment		Assignment; Beauty contest		Auction; Beauty contest		Auction			
Political endorsement			Quadripartite agreement EC Directive on use of 900 MHz	1986 1987	3G Green Paper, intro 2000 Endorse-ment UMTS Forum	1993 1995			EC Directive on 700 MHz	
SDO and start standardisation	NMT: Televerket and Nordic operators	1975	CEPT (<1989); ETSI(>1989) 3GPP (>1999) EC-GSM-IoT	Dec 1982 2015	ETSI 3GPP	1996 1999	3GPP MTC	2013	3GPP RAN	2015
Participants in SDO WGs	CEPT: Operators		CEPT: Operators; ETSI: Operators, manufact-s, academic inst.		Operators, manufacturers, academic inst.		Operators, manufact-s, academic inst.		Operators, manufact-s, academic inst.	
Country of origin participants in SDO WGs[7]	Europe		GSM900: Europe; GSM1900:		Europe + USA Europe + Japan		Global		Global	

[7] In this dimension, it is important to recognise the deployment of GSM in countries outside Europe and hence the inclusion of actors from these countries in the standardisation efforts.

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
			USA		Global					
Determination basic parameters			CEPT GSM#13	1987	UMTS Task Force input to ETSI, final by ETSI	1996 1997 1998				
Selection of radio interface				1987		1998			Above 24 GHz	Expect. 2018
Decision on the core network	Not applicable		Replace 1G circuit switched core		Retain 2G circuit and packet switched core		Replace 3G core by packet switched core; slicing		New radio interface; core to be replaced; virtualisa-tion	
First release specification			For tendering; for roll-out	1988 1990	First release R99; For service offering	1999 2000 Mar	3GPP Release 8	2008	EC Action Plan target 3GPP R14 target R15 target R16	2019 2017 2019 2020
Entity for commercial & operational coordination			MoU Association	1987	UMTS Forum GSMA	1996	GSMA		GSMA MGMN	
Coordination of introduction; target date			Operators through GSM MoU; 1991	1987	EC Directive on licensing process with execution < Jan 2000	1999			EC 5G Action Plan Early intro Large scale	2018 2020
First spectrum assignment(s)					Finland	1999 Mar	France 700 MHz Germany 700			
Last spectrum assignment(s)					Denmark	2001 Sept				

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
First commercial service	NMT450 TACS	1981 1985	GSM900 DCS1800 PCS1900[8] GSM800[5]	1992 1993 Sept 1995 Nov 2002	WCDMA UMTS	2001 2002	Norway and Sweden	2009		
Availability terminals	Nokia Ericsson		Handhelds	1992	PCMCIA Handsets	2001 2002				
Mutual recognition			Through type approvals		RTTE Directive	1999	est. rout.		Est. rout.	
First roaming agreement			Telecom Finland + Vodafone-UK	June 1992	est. rout.		Est. rout.		Est. rout.	
First million(s) users	1 mln 10 mln 100 mln		1 mln 10 mln 100 mln	1993 1995 1998	1 mln 100 mln 1000 mln	2003 2006 2012	1 mln 100 mln 1000 mln	2010 2013 2015	1 mln 100 mln 1000 mln	
First non-EU operator			Australia	1993	est. rout.		Est. rout.		Est. rout.	
First major upgrade specification/ services (x.5G)			Packet data (GPRS) Enhancement	1998 2000	IMS High-speed packet access HSDPA HSUPA	2001 2005 2007	Release 10 LTE-Advanced	2011		
Peak deployment	NMT	1996	GSM CDMA[9]	2015 2015						
First retirement	Telia Finland	Dec 2002	Macau	June 2015						
Last retirement		2010 ?		2030 ?						

Source: Authors.

[8] Related to deployments outside Europe.
[9] CDMA added for comparison purposes.

2.2 Interpretation of the regularities and trends leading to 5G

The four subsequent generations of mobile network technology show a clear pattern in terms of succession: every 10 years, a new generation is introduced.[10] The developments to date with respect to 5G are at large aligned with these regularities. Hence, we may expect 5G to be introduced around 2020.

The initiative for a next generation typically emerges at the time a previous generation is being introduced in the field, i.e. some 11-10 years before the launch date. In 1G and 2G these initiatives originated with the mobile operators, at that time the government-owned national telecom monopolies. These initiative included R&D into the next generation by the incumbent players. With the introduction of competition, starting with the deployment of 2G and being fully established when 3G was introduced, the emphasis had shifted to pre-competitive R&D programs initiated and sponsored by the European Union with participation of equipment manufacturers, operators and academic research centres. During the 3G era, the operators typically reoriented their R&D activities towards service provision, while leaving network-related R&D to the equipment vendors. The 5G-oriented research within the EU funded FP7 and Horizon 2020 programs aligns with this trend, in terms of timing, content and industry participation. The strategic collaboration agreements on 5G R&D made by the EU with Japan, Korea, China and Brazil are consistent with 5G to become a global standard, with 3GPP as the standardisation platform. A platform that was established based on European initiative recognising the extended geographical scope of the standardisation efforts, largely as a result of the global deployment of GSM.

At the time of a next generation initiative, the allocation of new frequencies is also made by the CEPT, in line with agreements made at the global level within ITU-R.[11] For the first three generations, new radio frequency bands were typically found at higher frequencies, which provided for higher data rates. This nicely coincided with the need for increasing data rates per user. With increasing mobile use, the pressure for more spectrum mounted and through the transition from analogue to digital broadcasting, lower frequency bands were becoming available, e.g. the 800 MHz band as part of 4G. The plans for 5G are in line with this trend, i.e., high-end extensions are foreseen in bands between 24 GHz and 83 GHz,[12] as well as a low-end re-allocation of the 700 MHz band.[13]

However, the linkage between next generation and new spectrum assignments appears to have become weaker. On the one hand, auctions are organised at the national level as and when new

[10] Note that 4G – LTE was ahead of 'schedule' with close to 2 years, apparently to stay ahead of WiMAX, which had become an IMT2000 family member.
[11] At certain instances the ITU-R has been leading, at other times the CEPT proposed an allocation scheme to the WRC.
[12] See for details https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0014PDFE.pdf
[13] In a number of countries the 700 MHz band is made available earlier for use by LTE. See also Annex D.

or re-allocated spectrum becomes available and, on the other hand, spectrum is now assigned on a technology-neutral basis, i.e. next generation equipment may be deployed in bands originally assigned for previous generations.[14] This trend started with 4G and also applies to 5G.

The prominent coordinating role of operators in the introduction of 2G, in terms of timing and functionality, has moved to the background in 3G and 4G. On the one hand, the competitive market is expected to drive the introduction process – and coordination could be interpreted as collusion – and, on the other hand, the operational aspects of a next generation are now addressed by the GSMA, the institutional successor of the Memorandum of Understanding between operators in the 2G era.

At the time of 1G and 2G, the introduction of a new generation required deep investments in the roll-out of new infrastructure replacing the previous generation. With the deployment of a packet-overlay network in the form of GPRS, an inter-generational upgrade was introduced: 2.5G. With 3G, the investment in a new radio access and new core equipment became separated in time: first, a new radio was introduced (Wide band CDMA), which was made interoperable with the existing 2G circuit switching and 2.5G packet switching core. As part of 3.5G the packet capabilities were upgraded towards HSPA. In 4G, the circuit core was abandoned and the packet core was further enhanced. Still in 4G, a new modulation technique was applied on the radio access (OFDMA), requiring upgrades of base stations and handsets, while earlier generations remained backward compatible with existing evolved core network. LTE-Advanced, which is providing higher data rates based on carrier aggregation, represents the inter-generational upgrade to 4.5G. The envisioned evolution towards 5G includes adding a new radio access in the frequency bands above 24 GHz to be compatible with the existing evolved packet core (EPC). The plans also project the introduction of virtualisation (Software Defined Networks and Network Function Virtualisation), which means a further move of functionality into software and the application of bulk-standard Ethernet switches and computing resources. This is expected to be a gradual process, starting with new interfaces being added to existing network equipment.

Evolution of handsets

The replacement model of 1G by 2G implied the need for new devices. With the allocation of additional GSM bands (1800 and 1900 MHz), followed the introduction of multiband radios allowing for interoperability within a single generation across multiple frequency bands. With more bands being allocated and assigned over time, the support of multiple bands by handset providers in line with the national band plans has become a critical issue. Handset roll-out plans are being optimised based on device market size and market priorities as perceived by handset

[14] 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.

vendors.[15] Furthermore, handset functionality extends well beyond mobile network functionality and the launch of new devices is increasingly driven by smartphone vendors, with typically a new release every 1-2 years.[16] In certain markets, the 3.5 GHz band has been assigned but has remained unused, lacking appropriate terminal devices.[17] Also, the use of carrier aggregation as part of 4G is subject to terminal-network compatibility. In the evolution towards 5G, this is expected to remain an issue of concern, suggesting the necessity for further coordination of frequency plans by national administrations.

Evolution of the core network based on standards

Over the generations, the scope of mobile communication standards has evolved from being national, through being regional to becoming global. That process has been strongly influenced by the regional and subsequently global success of GSM. With GSM deployed in all regions, it brought together the interests of operators across the globe in relation to the next generation standard to be deployed. With 3G being designed to be compatible with the previous generations, three regional standards resulted. 4G *in casu* LTE and LTE-Advanced have been conceived as global standards and are now accepted and deployed as such. 5G will become the next global standard for mobile communications. Based on its experience with 3G and 4G, the 3GPP as standard development organisation is set to create the 5G specifications.

Evolution towards verticals

While oriented towards the mass market of consumers, GSM has evolved to support a first public sector vertical market: GSM-R serving European railway operators, for which a separate frequency band had been allocated in Europe. The GSM-R functionality has become part of the general GSM specification, such that the functionality was available to address other similar niche markets. A second public sector vertical is being accommodated as part of 4G release 13 through 15: the public protection and disaster relief (PPDR) sector, which includes the police, fire brigade and ambulance services. In Europe, the PPDR sector was previously served through a dedicated system called TETRA, operating in a dedicated 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 a viable option.

[15] This has for instance led to the Apple iPhone 5 at release not being compatible with the assigned 4G frequencies in Belgium. Source: Van der Wee, Verbrugge & Laroy (2015).
[16] See Annex C for the introduction dates of Apple iPhone releases as example.
[17] See for instance gsacom.com on the limited availability of LTE devices in band 42/43.

3 5G architecture and features[18]

5G represents a next step in the technological evolution of mobile communications networks: 1G was dedicated to telephony. 2G started as capacity expansion for telephony, to which a packet-switched overlay network (GPRS) was later added to provide access to the Internet. 3G was designed for voice and high-speed data communication (implemented through resp. circuit switching and packet switching). High demand for Internet access accelerated the transition to the next generation of mobile technology – 4G – also known as Long-Term Evolution (LTE), which is packet-switched only.[19] The upgrade to LTE Advanced, introducing data rate enhancement through carrier aggregation, was first introduced in 2013. It provides a peak cell capacity of 1.2 Gbit/s.

3.1 5G requirements

In 2012, the METIS research project, one of many projects dedicated to the development of 5G within the EU co-funded FP7 and Horizon 2020 research programs, set out the design targets for 5G as follows:

1000 times higher overall capacity	10-100 times more devices
10 to 100 times higher end-user data rates	5 times lower latency
10 times longer battery life	

The 1000-fold capacity increase is foreseen to be achieved through 3 simultaneous approaches: network densification, providing 50x improvement; the use of more spectrum, including higher frequencies, such as mm Wave (e.g. 24 and 60-80 GHz), providing 10x improvement; and realising an increase in spectral efficiency, providing 2x improvement.[20]

In addition to the EU research initiatives, a 5G public-private partnership, called the 5G-PPP, has been formed. It brings together research institutes, operators and vendors, and was endorsed by the European Commission. A 5G Infrastructure Association was also founded and has formulated a vision on 5G including (much similar) high-level requirements (5G Infrastructure Association, 2015).[21].

[18] This Section draws on the research first reported in “Imagine 2025” published as Appendix 2 to the CERRE report “An integrated regulatory framework for digital networks and services” (De Streel & Larouche, 2016).
[19] In the context of LTE telephony, services are provided through Voice-over-LTE (VoLTE) or a fall-back to 3G or 2G, so-called Circuit Switched Fall-back (CSFB) until VoLTE is made available.
[20] This compares well with a doubling of aggregate network capacity every 3 years over the last 30 years (Rysavy Research, 2015).
[21] For an overview of global 5G initiatives, see the report by 4G Americas (2014a).

According to the Association *5G Vision*'s statement, the 5G design is aimed at:

- bringing together the various radio access technologies (e.g. GSM, UMTS, LTE, Wi-Fi and satellite) to provide the end-users with seamless handovers;
- to provide a multitenant environment for various users groups (mobile operators, broadcasters, public safety and disaster relief, providers of cellular service for the railways); thereby
- paving the way for virtual pan-European operators, relying on national infrastructures.

The performance objectives formulated are:

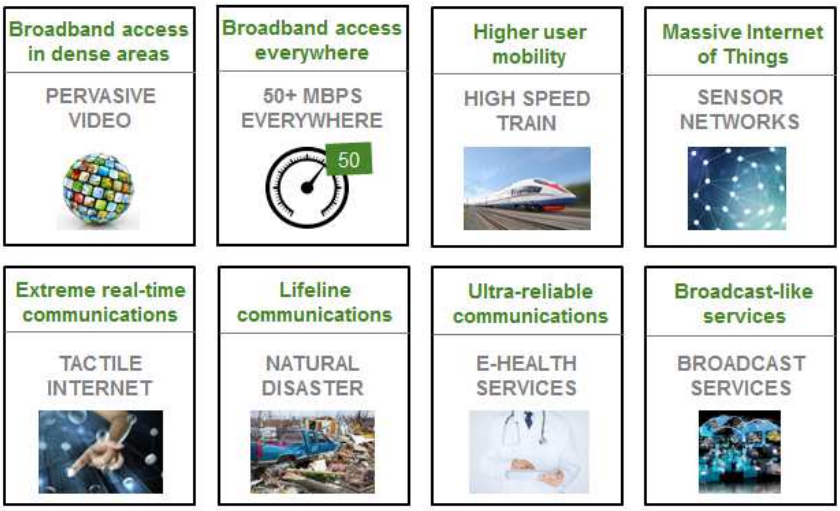
- radically higher wireless area capacity (1000x relative to 2010);
- much lower round-trip delays (latency <1 ms);
- very high dependability to enable (business/mission) critical applications; combined with
- a far lower energy consumption, to enable support of very low energy devices, such as sensors;
- reduced service creation time, from 90 hours to 90 minutes; and
- a reduction in the exposure to electromagnetic radiation.

In terms of operational capabilities, 5G is considered to provide:

connectivity for over 20 billion human oriented terminals	connectivity for over 1 trillion IoT terminals
guaranteed user rates of over 50 Mbit/s	with aggregate service reliability better than 99.999%
communication for ground transport at speeds of 500 km/hour	an accuracy of outdoor terminal location less than 1 meter

The 5G infrastructure is expected to provide network solutions for so-called vertical markets, such as automotive, energy, food and agriculture, city management, government, healthcare, manufacturing, public transport, etc. Figure 1 links the capabilities to the use cases.

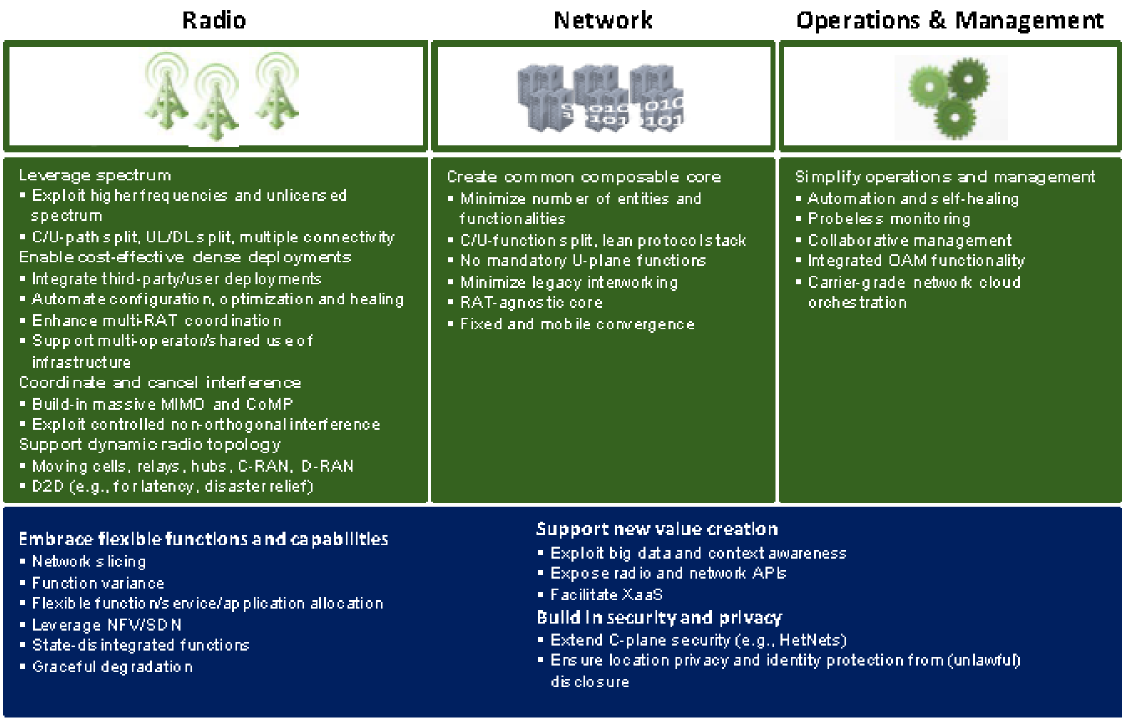
Figure 1: 5G use case families and related examples



Source: NGMN Alliance (2015).

Next to functional requirements related to data rates, latency, number of devices, etc. a set of design principles have been formulated by the Next Generation Mobile Network Alliance on behalf of its members. These design principles reflect the operational requirements of the mobile network operators (see Figure 2).

Figure 2 : 5G design principles

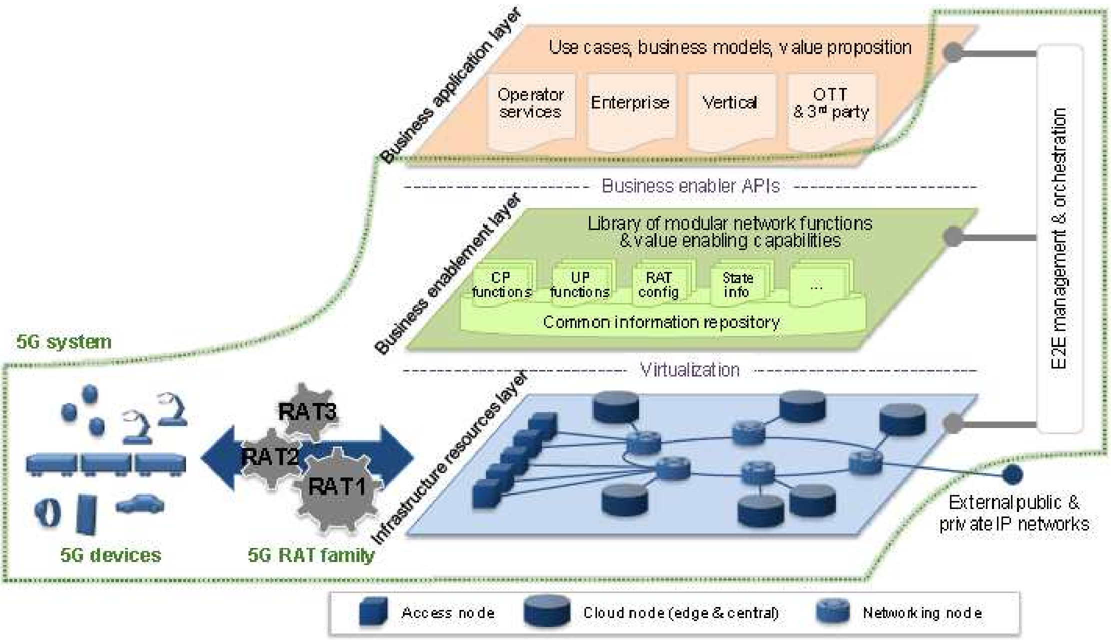


Source: NGMN Alliance (2015).

3.2 5G architecture and virtualisation

The overall 5G architecture as foreseen by the NGMN is reflected in Figure 3. It reflects the layered structure including virtualisation and the use of APIs.

Figure 3: 5G architecture



Source: NGMN Alliance (2015).

The major new technological development affecting 5G is network virtualisation and the use of application programming interfaces (APIs). Network virtualisation refers to implementing the functions of the communications infrastructure in software running on commercial 'off-the-shelf' computing equipment, essentially Ethernet switches linked by optical fibers being centrally controlled by software. This follows the virtualisation of data centres and the use of a modified version of the Internet protocol adapted towards centralised network control. More specifically, 5G will be implemented based on software-defined networking (SDN) and network function virtualisation (NFV), mobile edge computing (MEC) and fog computing (FC), in essence an architecture based on "cloud" computing, linking together a diverse set of resources for transport, routing, storage and processing, including (user) resources at the edge of the network. Moreover, it supports the development of new services through application programming interfaces.[22]

[22] Sources: Patel et al. (2014); 5G Infrastructure Association (2015). For small scale application and experimentation with virtual networks see for instance the PhD by Strijkers (2014). For information on SDN in general, see Göransson & Black (2014) and Stallings (2016).

Virtualisation already started in the fixed network with AT&T being in the lead and Verizon a close follower. AT&T described the motivation to move towards network function virtualisation (NFV) as follows: “AT&T’s network is comprised of a large and increasing variety of proprietary hardware appliances. To launch a new network service often requires adding yet another variety, and 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. Moreover, hardware-based appliances rapidly reach end-of-life, requiring much of the procure-design-integrate-deploy cycle to be repeated with little or no revenue benefit. Additionally, hardware lifecycles are becoming shorter as technology and service innovation accelerates, and this can inhibit the expeditious roll out of new revenue earning network services and constrain innovation in an increasingly network-centric connected world. NFV aims to address these problems by evolving standard IT 29 virtualisation technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage that can be located in data centres, network PoPs or on customer premises. This involves the implementation of network functions in software, called Virtual Network Functions (VNFs), that can run on a range of general purpose hardware, and that can be moved to, or instantiated in, various locations in the network as required, without the need for installation of new equipment.”[23] AT&T senior management announced as target 75% of the network to be virtualised by 2020.

The compelling reasons for applying virtualisation 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.

The European Telecommunications Standards Institute (ETSI) has standardised the framework, including interfaces and reference architectures for virtualisation (see Figure 4 showing the ETSI framework, in which virtualised network functions – VNFs – are the nodes or applications by which operators build services). Other standards and industry groups involved include 3GPP, The Open Network Foundation, OpenStack, Open Daylight, and OPNFV.[24]

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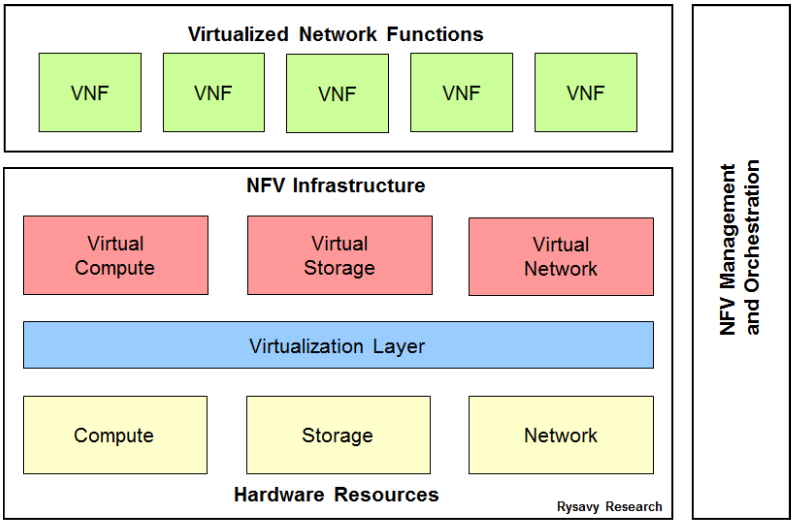
[23] AT&T (2013).
[24] 4G Americas (2014b).

Figure 4: ETSI ISG network virtualisation framework



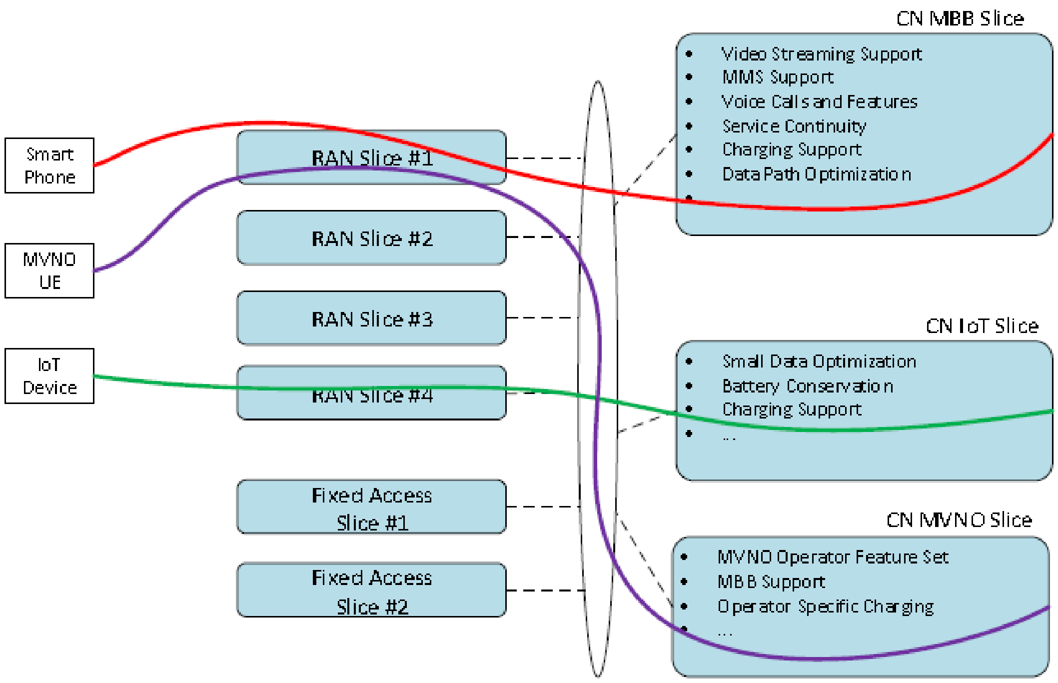
Source: Rysavy Research (2015).

The core network, consisting of fewer nodes, provides an easier starting point for virtualisation. Although more complex, virtualisation of the RAN is expected to provide the greatest network efficiency gains, particularly for small-cell deployments.[25]

Virtualisation and the decoupling between radio access technologies (RATs) and 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 in terms of data processing in the core network can be combined and supported by one integrated mobile network. For an illustration see the 'paring' of RATs with CN slices in Figure 5.

[25] For an insightful description of virtualisation in particular network slicing, see the 5G Americas White Paper "Network Slicing for 5G networks and services." Source: www.5gamericas.org/files/3214/7975/0104/5G_Americas_Network_Slicing_11.21_Final.pdf Retrieved: 2016-11-21.

Figure 5: Network slice examples

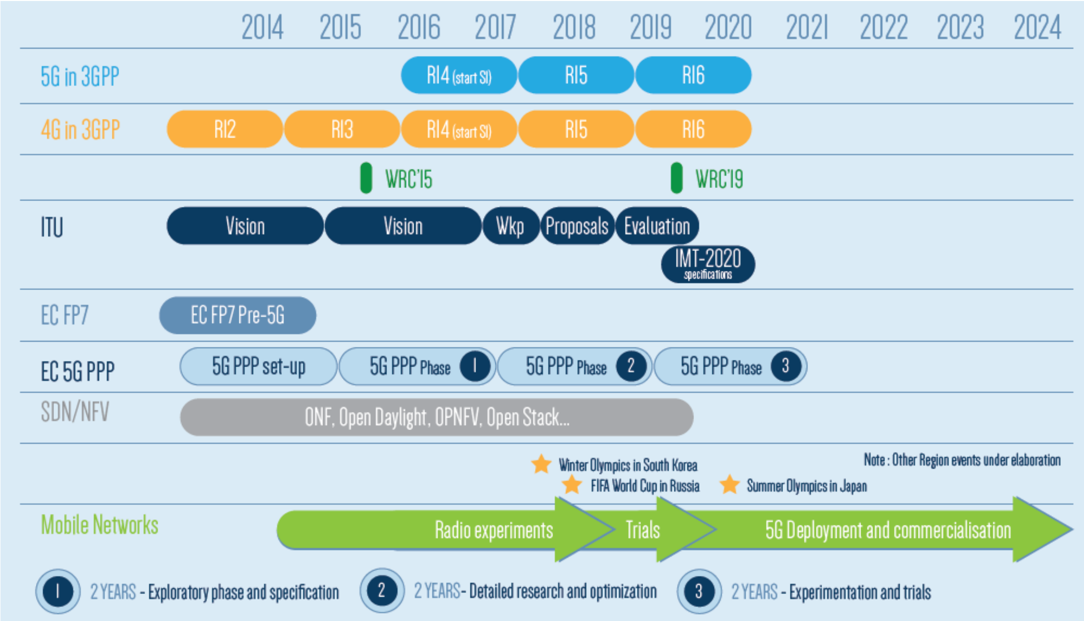


Source: 5G Americas (2016).

3.3 5G roadmap

The high level roadmap for the various 5G related activities is reflected in Figure 6. Note that the functionality foreseen for 5G will become available over time in a series of releases of the specifications.

Figure 5: 5G roadmap, 2014-2024



Source: 5G Infrastructure Association (2015).

3.4 The demand-side perspective

This section provides the demand-side perspective of 5G, largely as an extension of the current trends.

3.4.1 The market for connections and devices

Figure 6 provides Cisco's forecast for growth and penetration of global consumer mobile services towards 2019 (Cisco, 2015b).

Figure 6: Forecast global mobile consumer services, 2019

Source: Cisco VNI Mobile, 2015(Cisco, 2007).

Note that all but one of the services shown are applications which use the mobile infrastructure to obtain access to the Internet. Only MMS is an integrated service, which is shown with a negative growth rate. Moreover, mobile telephony and SMS as distinct services have disappeared from the radar screen, having become part of mobile social networking.

Using Cisco's VNI 2016 projections, the mobile communications landscape will have the following features by the time 5G is introduced, i.e. 2020:

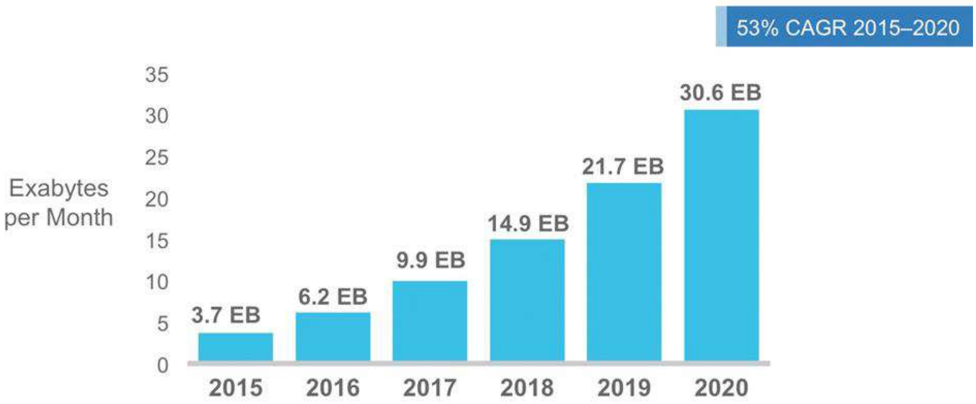
- Global mobile data traffic will increase nearly eightfold between 2015 and 2020. Mobile data traffic will grow at a compound annual growth rate (CAGR) of 53 percent from 2015 to 2020, reaching 30.6 exabytes[26] per month by 2020.
- By 2020, there will be 1.5 mobile devices per capita. There will be 11.6 billion mobile-connected devices by 2020, including M2M modules—exceeding the world's projected population at that time (7.8 billion).
- Mobile network connection data rates will increase more than threefold by 2020. The average mobile network connection speed (2.0 Mbit/s in 2015) will reach nearly 6.5 Mbit/s by 2020.
- By 2020, 4G will represent 40.5 percent of connections and 72 percent of total traffic. By 2020, a 4G connection will generate 3.3 times more traffic on average than a non-4G connection.
- By 2020, more than 60 percent of all devices connected to the mobile network will be "smart" devices. The vast majority of mobile data traffic (98 percent) will originate from these smart devices by 2020, up from 89 percent in 2015.
- By 2020, 66 percent of all global mobile devices will be capable of connecting to an IPv6 mobile network. There will be 7.6 billion Ipv6-capable devices by 2020.

[26] Exabytes: 1 EB = 1000^6 bytes = 10^{18} bytes = 1000 petabytes = 1million terabytes = 1billion gigabytes.

- By 2020, 75 percent of the world's mobile data traffic will be video. Mobile video will increase 11-fold between 2015 and 2020.
- The amount of mobile data traffic generated by tablets by 2020 (2.6 exabytes per month) will be 7.6 times higher than in 2015, a CAGR of 50 percent.
- The average smartphone will generate 4.4 GB of traffic per month by 2020, nearly a fivefold increase over the 2015 average of 929 MB per month. By 2020, aggregate smartphone traffic will be 8.8 times greater than it is today, with a CAGR of 54 percent.
- Currently, more than half of all traffic from mobile-connected devices (almost 3.9 exabytes) is offloaded to the fixed network by means of Wi-Fi devices and femtocells each month. Without Wi-Fi and femtocell offload, total mobile data traffic would grow at a CAGR of 55 percent between 2015 and 2020, instead of the projected CAGR of 53 percent.
- The Middle East and Africa will have the strongest mobile data traffic growth of any region with a 71-percent CAGR. This region will be followed by Asia Pacific at 54 percent and Central and Eastern Europe at 52 percent.

See also Figure 8 for the projected mobile traffic growth.

Figure 6: Forecast of global mobile traffic growth, 2015-2020

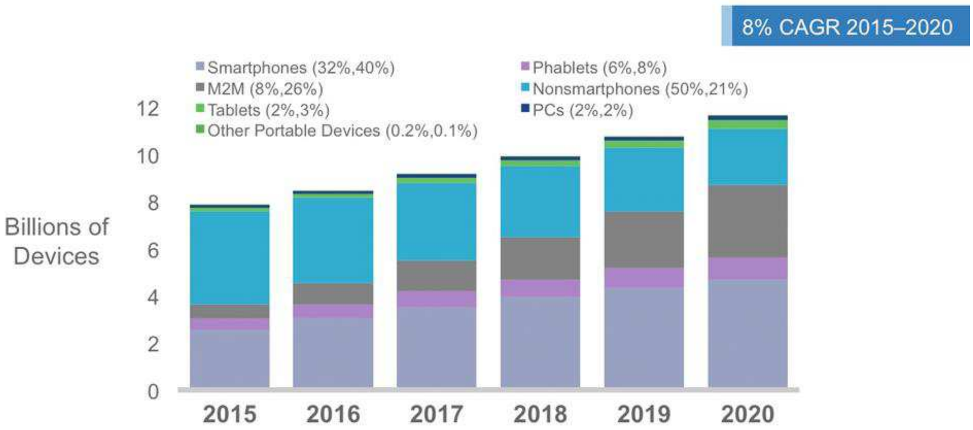


Source: Cisco VNI Mobile, 2016.

In this projection, Western Europe accounts for 9% of the total volume in 2020 and Central and Eastern Europe for 14%.

Figure 7 shows the projection for connections and devices towards 2020.

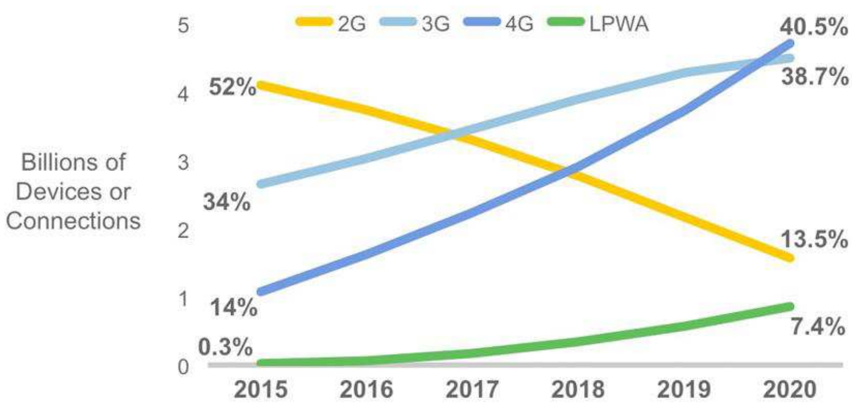
Figure 7: Global growth of mobile devices and connections, 2015-2020



Source: Cisco VNI Mobile, 2016.

Figure 8 reflects the distribution of devices/connections by technology 2G-4G and LPWA. The percentages refer to the device/connection share of the total.[27]

Figure 8: Global mobile devices and connections by technology, 2015-2020



Source: Cisco VNI Mobile, 2016.

3.4.2 The IoT market

Following the major transition from car-borne phones to handsets, the next major expansion of the addressable market is the Internet-of-Things (IoT), or the interconnection of uniquely identifiable embedded computing-like devices using the Internet. IoT requires: (1) the transition

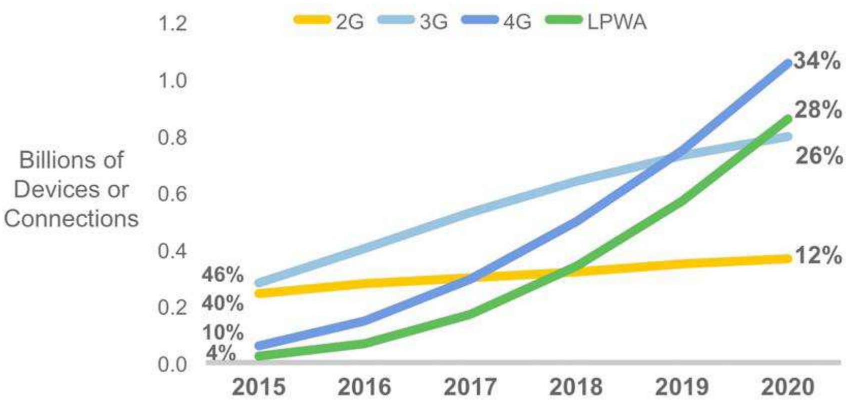
[27] LPWA: Low power wireless access, mainly used for connections in the context of IoT.

to IPv6, which has a much larger address space of up to 3.4×10^{38}; (2) high as well as very low data rates; and (3) very low energy consumption.

IoT includes the earlier form of machine-to-machine (M2M) communication, which originated in the field of industrial instrumentation. The ubiquitous use of the Internet facilitates M2M communication and expands its range of applications. Previously, this was also denoted as telematics. Meanwhile, many mobile operators have created business departments dedicated to providing M2M services. As an example, a number of energy utility companies have outsourced the collection of smart-meter data to communication providers. At least one of the utility companies has acquired a radio spectrum license to set up a network to collect metering data over the air.[28]

The lowest-cost devices enabling M2M communications today are GPRS modems, which may become obsolete as operators decommission their GSM systems. HSPA is also used for M2M communications. Furthermore, LTE has been optimised to efficiently communicate small bursts of information, making it well suited for M2M. Low-cost LTE modem options included in 3GPP releases 10 through 13, reduced costs, improved the communications range, and extended battery life (Rysavy Research, 2015). Figure 9 reflects the forecasted use of mobile technologies for M2M.

Figure 9: Global mobile M2M connections by technology, 2015-2020



Source: Cisco VNI Mobile, 2016.

5G is set to serve the two different segments of the IoT market: (1) the market of massive machine-type communications (mMTC), related to smart cities, smart infrastructures and objects (sensors and actuators); and (2) the market for ultra-reliable and low-latency machine-type communication (uMTC), related to autonomous vehicle control, smart electricity grids and factory cell automation.[29]

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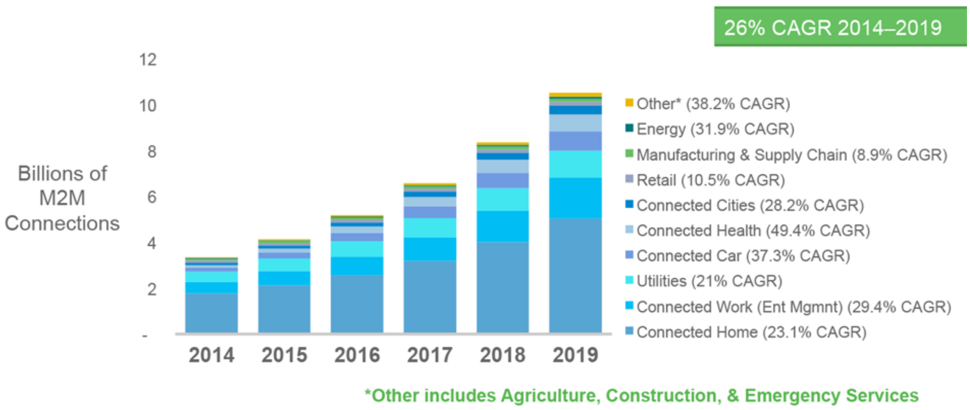
[28] Alliander in the Netherlands acquired a license in the 450 MHz band to deploy CDMA450.
[29] Osseiran, Monserrat & Marsch (2016).

IoT is considered to include a very wide range of applications such as: environmental monitoring; energy management; remote health monitoring and notification; building and home automation; smart vehicles; and more. Contributing to the growing adoption of Internet-of-Everything (IoE) are wearable devices. Wearable devices have the capability to connect and communicate to the network either directly through embedded cellular connectivity or through another device (primarily a smartphone) using Wi-Fi, Bluetooth, or another technology. These devices come in various shapes and forms, ranging from smart watches, smart glasses, heads-up displays (HUDs), health and fitness trackers, health monitors, wearable scanners and navigation devices, smart clothing, etc. The growth in these devices has been fuelled by enhancements in technology making the devices light enough to be worn. These advances are being combined with fashion to match personal styles, especially in the consumer electronics segment, along with network improvements and the growth of applications, such as location-based services and augmented reality.[30]

According to Cisco´s 2015 VNI projection, M2M connections will grow to over 10 billion worldwide by 2019, with 4.6 Petabytes of traffic per month. See Figure 10 for the growth rates and a breakdown by industry vertical (Cisco, 2015a). In the 2016 outlook, the forecast is lowered significantly based on a lower take up in the early years: globally, M2M connections will grow from 604 million in 2015 to 3.1 billion by 2020, a 38-percent CAGR.

Figure 10: Forecast global M2M connections by industry vertical, 2014-2019



Source: Cisco, VNI Mobile 2015.

[30] Cisco (2016).

4 The two stylised images of the 5G future

It has been said that 'forecasting the future is best done in hindsight'. Nonetheless, exploring what the future might bring remains of critical importance in successfully managing a business. As the policy enterprise has in common with the business enterprise the need to explore the future to devise successful policies, we present two contrasting stylised images for the 2020-2025 horizon. These two images represent two extremes to capture the widest range of possible 5G futures. These images of the future neither aim at representing the complexity of how the actual future may unfold, nor should be considered as scenarios, such as those initiated by Shell in the eighties.

To avoid any doubt on the purpose of the images, we are not suggesting that either one of these represents the most likely future outcome. The future may evolve as a mixture of these two in a pattern which varies over time and place, or may be different from what is described. The two images have been developed to highlight the range of 5G challenges which are likely to be faced, and thus focus attention on the key short and medium term choices concerning policy and regulation which have to be made to assure the successful development and deployment of 5G in Europe.

4.1 'Evolution' and 'Revolution'

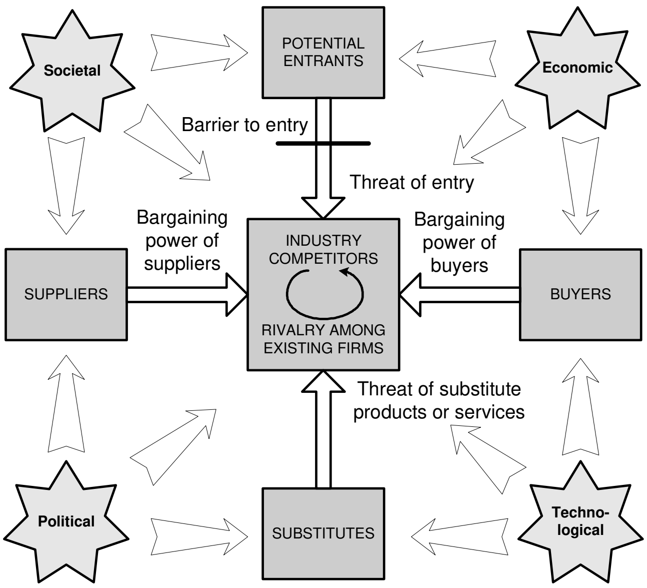
The stylised images are called 'Evolution' and 'Revolution'. They represent respectively a continuation of the development path of mobile communications as it can be derived from the development of the previous generations, i.e. 1G through 4G, and a break with past developments made possible through technological developments, i.e. the virtualisation 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 service providers, and on the other a market that is driven by a wide range of firms specialised in serving the requirements of different (vertical) industries through applications running on open access network infrastructures, providing seamless service on a regional basis.

The two images are informed by research into, on the one hand, the development of 1G through 4G – in particular an investigation into regularities and trends that can be observed – and on the other hand, the relatively recent experience with the development and deployment of virtualisation in data centres and the steps taken by AT&T and Verizon to virtualise their telecom infrastructures.

4.2 The industry structure

To describe the 5G communication services industry structure and environment under the two stylised images, use is made of the framing provided by Porter and Wheelen, i.e. a combination of the Five Forces framework and the SEPT framework respectively, to which the environmental dimension is added[31] (see Figure 11).

Figure 11: Framework for industry analysis (Porter-Wheelen)



Source: Author, based on Porter (1980) and Wheelen & Hunger (1983).

The SEPT dimensions provide a sketch of the broader socio-economic context in which the more detailed 'Evolution' and 'Revolution' images are positioned.

[31] It is acknowledged that the Porter framework provides a static view of the industry and needs to be used in a comparative static mode to capture dynamic aspects. In the context of the image development its main purpose is to structure the information and act as a check to assure all relevant dimensions are addressed. Sources: Porter (1980) and Wheelen & Hunger (1983).

5 The 'Evolution' image

In the 'Evolution' image? the regularities and trends that can be observed from the previous generations of mobile communication, i.e. 1G through 4G, are considered as the main determinants of the 5G future. The incumbent operators consider spectrum holdings, the active parts of the network and customer relationships as their core strategic assets – while passive infrastructure (e.g. towers) are sold and leased back, and maintenance is increasingly outsourced to third parties. It provides opportunities for vertical integration of networks and services and thereby differentiation from the so-called Over-the-Top service providers. The incumbent operators deploy new technologies to defend and strengthen their position vis-à-vis the competitors and in developing the relationship with their customers. A key assumption in this image is that the core business of the mobile operators continues to be serving the mass market of consumers.

5.1 Anticipated outcome – attractiveness of the outcome[32]

This section describes the anticipated outcome of the future image in hindsight.

In the 'Evolution' image – described in Section 5.2 – 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 remain small. Hence, the incumbents have a strong incentive to optimise past investments and to be prudent with new investments. The business case has become more challenging with each new generation, as the investment costs per subscriber increased while per subscriber revenues remained flat. See Figure 12.[33]

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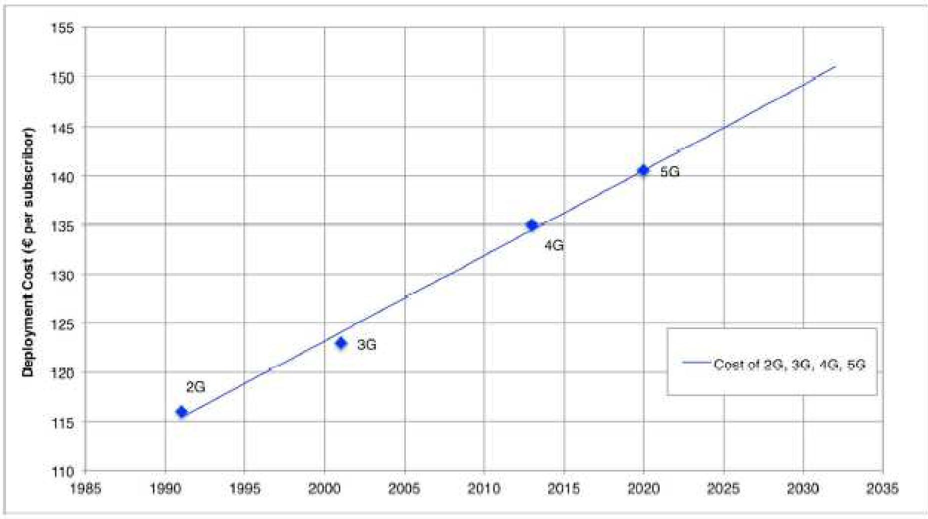
[32] In this Section we compare the outcome of the image of the 5G future with the GSM success factors derived in Section 2.

[33] Source: SMART 2014/0008 Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe. Final report prepared by Tech4i^2, Realwireless, Trinity College Dublin and InterDigital. (2016). Doi: 10.2759/56657.

Figure 12. Estimated per subscriber costs of next generation mobile technologies, 1990 - 2025



Source: SMART2014/0008 (2016)

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.[34] This provides 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 can serve the demand for higher data rates in an incremental way, particular in high density city areas, as and when demand is 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. However, 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.

The market of IoT provided opportunities for growth, but this market is highly diverse and served by competing technologies operating in unlicensed bands, such as LoRa. These

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

alternative technologies were designed for IoT from the outset, with long range and low power as design objectives. These systems appeared to be more effective than scaled-down versions of high-capacity cellular systems. Hence, they provide effective competition in city-wide areas. Moreover, early IoT deployments were served by LTE and even GSM (GPRS) through functional upgrades of these systems. Thus, IoT as the growth driver for 5G was already shared with many other wireless technologies. Moreover, it was and is up to the incumbents when to migrate from earlier generations to 5G, which led to dilution in terms of 5G adoption.

With a well-functioning competitive market, and in line with the policies for 3G and 4G, a light-handed policy was applied with respect to the introduction of 5G, including an Action Plan aimed at early experimentation and harmonised introduction. At the time of GSM, 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 has 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 have remained without results, in part due to the 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.[35]

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

Given the regularity of successive generations, the equipment suppliers are accustomed to the ten year cycle in terms of R&D investment, industrialisation and deployment. There is a strong incentive to keep the market momentum, which translated in early technology trials with operators and showcasing of the new technology at major events, such as the Olympic Games. The same applied for the semi-conductor industry.

In summary, the attributes that played an important role in the introduction of GSM were by and large present and relevant to the introduction of 5G, however, they point to an evolutionary rather than an revolutionary trajectory; the dynamics of 5G being more akin to 4G than to 2G.

5.2 Industry structure in the 'Evolution' image

The socio-economic dimensions that are part of the Porter-Wheelen framework, are provided to fill out the broader context in which the development of electronic communications takes place,

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[35] Note that the 1G market was largely a business market.

to obtain an internally consistent description of the future image. As the socio-economic dimension is not the focus of the image, only some highlights are provided.

5.2.1 Societal

In the 'Evolution' image, social media continue to play an important role in society. People continue to allow the gathering of behavioural data for the provision of personalised services, such as targeted marketing and location based services, as well as 'freebies', such as free services and applications. Concerns remain about privacy and data protection, with breaks and leaks being a recurring phenomenon.

The inappropriate use of the Internet, such as cyber-bullying and similar practices, continues. Bona fide as well as mala fide business models benefit from improved Internet services. Cybercrime and cyber-attacks have become a feature of modern society.

5.2.2 Economic

Economic development is lacklustre as one crisis follows another, a result of global and regional issues not being resolved, such as the war against ISIS moving from one country to the other in the Middle East and Northern Africa. The countries remain instable and cannot provide the proper economic conditions for their population. Hence, the refugee problem remains.

The trust in the financial system outside the sector remains weak; interest rates remain low. Alternative ways for executing financial transactions are being pursued, disintermediating traditional banks. There is no cause for an economic upswing. Governments fail to boost economic growth, despite low capital costs. GDP growth is modest; income distribution remains largely the same. Discretionary spending of households is constrained; consumers expect to receive more for less.

5.2.3 Political and Regulatory

Less money and fewer jobs, at least in terms of the perception, lowers solidarity and encourages nationalism. A lack of a compelling future vision, failing a sense of urgency and a need for politicians to survive in the next elections leads to populism. The European project is unable to inspire, to transcend the national level, despite the necessity of scale to survive in an increasingly global business world. The issues emerge largely at the perimeter of the region, in those countries where the administrative and political infrastructure is relatively weak and unable to cope with the demands imposed on them. The gap between regional, national and local governments is widening. The lack of turning agreements and promises at regional level into reality on the local level further erodes political credibility and fuels unrest.

China is the world's single largest market. It benefits from this domestic scale, from political willpower, including constancy in purpose of their industrial policy, and from people wanting and recognising opportunities to improve their economic conditions.

The importance of broadband for economic development is well recognised in Europe. The Digital Agenda for 2020 includes technological as well as societal development goals. Mobile communications is recognised as the preferred means to provide service in deep rural areas. The European Commission has an urge to deliver results, while it is by and large dependent on the liberalised market to deliver those results. Shifting support from one industry to another, e.g. from agriculture to ICTs, is extremely difficult. The compelling economic logic does not go down well with those affected and they are able to block change through political action at the ground level. Captured by the past, Europe is unable to embrace the future.

5.2.4 Technological

While mass production had been outsourced to low wage countries, high tech engineering skills allow the retention of high-tech production in Europe. New technologies, such as 3D printing, now allow the expansion of the industrial base and a reduction in outsourcing.

The regional, and later global, success of GSM has allowed Europe to become the initiator of the global standardisation efforts for mobile communications through the 3rd Generation Partnership Project. 3GPP continues to be the core platform for 4G and 5G standards work.

The technological underpinning of standards work by pre-competitive research programs by industry, and co-funded by the European Union, continues to enforce the European contribution and position, from 3G through 4G into 5G.

While European manufacturers have benefited from the GSM success, and US manufacturers, in particular Qualcomm, from the use of CDMA as radio technology in 3G, they all have incurred a set-back in the aftermath of the telecom/internet bubble. At the same time, Chinese manufacturers have benefited from the economic catch-up in their home market, providing them with opportunities to expand abroad. Participation in 5G is truly global and recognised by the European Commission through strategic R&D collaboration agreements with South Korea, Japan, China and Brazil.

The major technological development affecting 5G is network virtualisation. Network virtualisation refers to implementing the functions of the communications infrastructure in software running on commercial 'off-the-shelf' computing equipment, essentially Ethernet switches linked by optical fibers being centrally controlled by software. This follows the virtualisation of data centres and the use of a modified version of the Internet protocol adapted towards centralised network control. More specifically, 5G is implemented based on software-defined networking (SDN) and network function virtualisation (NFV), mobile edge computing (MEC) and fog computing (FC). In essence, this is an architecture based on "cloud" computing, linking together a diverse set of resources for transport, routing, storage and processing, including (user) resources at the edge of the network. Moreover, it supports the development of new services through application programming interfaces (APIs).[36] SDN and NFV constitute an entirely new way of building and managing networks and takes many years to complete. The first step has been the addition of the appropriate interfaces to existing network functions.

5.2.5 Environmental

Increasing concerns regarding climate change puts pressure on all stakeholders to shift to sustainable sources of energy and to reduce energy consumption. The energy footprint of ICTs has become an increasing concern with increasing usage. Equipment suppliers have pledged to reduce energy consumption with the introduction of next generation equipment.

Health concerns related to the use of radio frequencies continue and increase with the proliferation of base stations in support of increasing mobile usage and demands for higher data rates.

5.2.6 Rivalry

Since the liberalisation of the mobile communications services market the rivalry has been intense, the number of players growing from 2 to 4-5 in most EU member states. With each round of radio spectrum auctions governments aim to keep the barrier to entry low, as they observed consolidation of the industry between auctions. This typically implied set-asides for entrants and/ or spectrum caps for incumbents.

Competition on price has led to a level that is sustainable, all major parties understanding the economics of the business. Start-ups operating in the resale part of the market regularly drop prices to gain customers. As they become (too) successful, they are acquired by one of the incumbents. This has become a recurring feature of the industry.

As mobile communication is all about 'getting the signal out of the air into the ground' access to fixed backhaul infrastructure is of key importance. Also in providing a full service offering to business users the combination of mobile and fixed services is essential. Mobile operators in 'pure play' mode have over time built or acquired positions in fixed. The convergence of fixed and mobile has become a competitive game of the integrated operators.

In the competitive game alternative wireless technologies, such as Wi-Fi, are a curse and a blessing. On the one hand the technology is a substitute and on the other a complement, as it provides for traffic offload, improving the economics of the cellular business. Fixed (only) network providers offer Wi-Fi access to increase their ability to capture traffic onto their networks away from mobile operators. With license assisted access (LAA) cellular operators control the interworking with Wi-Fi and can make use of the license-exempt frequencies to improve overall network performance. In this mode 'true Wi-Fi users' have voiced concerns whether MNOs are a fair neighbour in the sharing of the license-exempt space.

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[36] Sources: Patel et al. (2014); 5G Infrastructure Association (2015).

With the IoT market having opened up, the deployment of dedicated networks such as LoRa provide a similar challenge, as substitute and as a way to address IoT specific communication profiles ahead of 5G. With lower frequencies available (700 MHz band), and providing deeper penetration and longer range, keeping multiple types of networks in the air is becoming less attractive. Rolling over LoRa customers onto a 5G network, when fully deployed, is the strategy followed by most incumbents.

With IoT, the embedded SIM has become a standard feature and over-the-air updates of SIMs a necessity, to allow the switching of mobile provider by IoT network operators. This is enabled by regulation that expanded the definition of MNOs to include IoT network operators for the purpose of assigning network codes.[37]

The attempt by (fixed) communications providers to integrate unique or exclusive content into their service offerings has been effective on the national market for the established mainstream customers. The (successive) younger generation(s), however, is much more interested in streaming video at the time and place they consider convenient. They are accustomed to finding their information on the Internet and highly value services like Netflix, providing full flexibility in terms of consumption.

The cost reduction that 5G provides, in capex and opex, over earlier generations of mobile technology has accelerated the transition from earlier generations to 5G, including early IoT users being served by GPRS. This applies to all mobile incumbents and has not significantly changed the competitive landscape.

However, the way 5G allows service to be tailored to the needs of business users through virtualisation changed the playing field. While initially the traditional providers of mobile network equipment were concerned by potentially being disintermediated by agile software providers and low cost computing platform providers, their knowledge of network service operations – in part obtained through extensive outsourcing of operations by network providers – now proves to be a major asset in keeping a critical position in the value chain. They have changed the business focus from telecom equipment functionality to telecom services software functionality. Their participation in standards work on 3G, 4G and 5G gave them a head start over outsiders in terms of service creation. And, as most of the incumbent operators had outsourced their R&D many years ago to the equipment vendors, incumbents are now in need of a knowledgeable partner to safeguard their position as service provider to an increasingly diverse customer base.

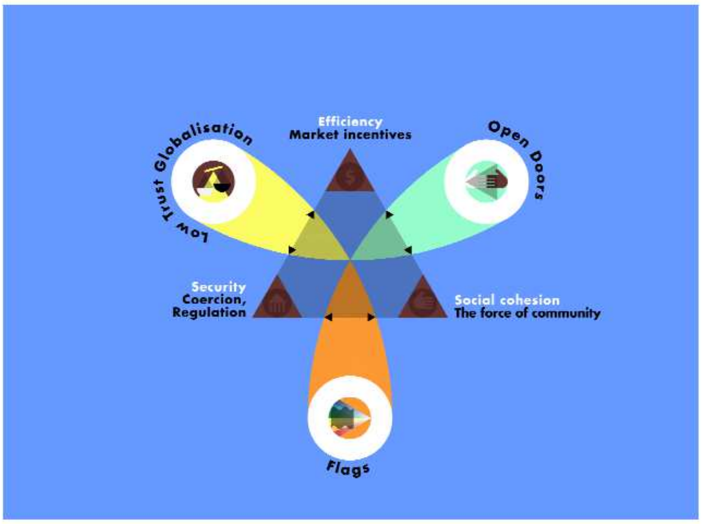
As service creation has become a competitive differentiator for the business market, incumbents have aligned with a preferred vendor, thereby creating a vertical integration of the industry. The major incumbents have aligned with the major software services providers through contractual arrangements that discourage the software service provider from serving

[37] See the proposed new Electronic Communications Code.

other competing communications providers in the same country at the same time. This strengthened the position of the major incumbents while disenfranchising the smaller players.

The ability of the major incumbent to provide governments with the most reliable network to support the needs for public protection and disaster relief consolidated the position of the major incumbent. In the context of increasing threats from cyber-crime and cyber-warfare, national governments want to ensure a dependable network that is difficult to hack and to take-over. This reflects the notion of 'national flag-carriers' as described in the Shell scenarios for 2025, see Figure 13.[38]

Figure 13. Shell global scenarios to 2025



Source: Shell (2005)

5G provides for standard application programming interfaces. However, the way these interfaces are used to create services and applications is flexible. This allows incumbent operators, in collaboration with their software service providers, to create a unique service set, in effect a closed applications environment. In that way, they create an environment that is impossible for over-the-top service providers to (re-)create. As a result, the incumbents are able to escape the race to the bottom as pure data transport providers, and to 'return' to being communications services business, in particular of mission and business critical services. However, this is a services business that is much smaller in numbers compared to the mass market of consumers. It is also very competitive, as business users have stronger negotiation positions than individual consumers, but it confers differentiation based on network assets, in part 'protected' by serving the government through the same network. For the consumer, market differentiation has been attempted but proven to be difficult to achieve. In this market

[38] Sources: Shell (2005, 2007).

segment, the communications operators are by and large data transport providers, with the OTT providers filling in the services layer.

5.2.7 Barriers to entry

With each radio spectrum auction, governments aim to keep the barrier to entry low, as they observed consolidation of the industry in between auctions. This implies the use of set-asides for entrants and/or spectrum caps for incumbents. Considering the deep investment required for participation in the communication network and services business, the entries that have been observed in recent auction rounds have been related to fixed-only operators obtaining access rights to the use of the radio frequency spectrum. As this process is largely complete, no new entry is likely to occur, the economic climate not being conducive for forays by incumbents into neighbouring or other geographical markets, as had occurred after market liberalisation and during the euphoric period in the late 1990s.

While the 5G technological development led to a lower cost-base and hence to a lower barrier to entry, vertical integration between incumbent and main suppliers has hindered entry. Nonetheless, for specialised firms focusing on niche business markets, entry is feasible based on interconnection regulation, which remained essential in the oligopolistic market. As the past has shown, strong regulatory oversight is essential to prevent incumbents from using non-price competition to hinder entry.

5.2.8 Substitutes

On the application and services level, OTT service providers have effectively provided substitutes for plain voice communication, for texting and to a large extent for broadcasting. By 2020 the battle with the incumbents is over, regulation having been re-designed based on technology-neutrality and the new rules are affecting all players alike where it concerns services that are deemed of public interest, such as access to emergency services.

Partial substitutes for national mobile communications networks, including 5G, are local-area networking technologies, such as Wi-Fi, Bluetooth Low Energy, and ZigBee, and city wide-area wireless technologies in support of IoT, such as: LoRaWAN, Sigfox, OnRamp Wireless, and Weightless. These networks can also be seen as micro access networks to efficiently funnel traffic to and from the national cellular network. In this perspective they are complements to mobile communication networks.

In the past, private networking needs of governments and private business have been served by dedicated wireless technologies, such as GSM-R for railways and TETRA networks for the police, fire brigade and ambulance services. TETRA was also used for business critical communications at airports, and the oil and gas industry. Furthermore, Private-GSM has been made available on the fringes of the GSM bands to serve business critical needs. With the need for higher data rates and having relatively small economies of scale, users have migrated to LTE as the technology platform of choice, but with retaining dedicated spectrum assignments. With software defined networking as part of 5G, and already preceded by network slicing as part of 4G, different needs in terms of services and quality of service are provided simultaneously through a single 5G network fabric. This alleviates the need for dedicated spectrum assignments in the 5G era. Nonetheless, not all current users were willing to accept the 5G promise made by operators and insisted on the continuation of dedicated spectrum assignments. In relation to the Porter-Wheelen framework, to the mobile incumbents this represents a form of substitute.

5.2.9 Buyers and buyer power

Individual consumers do not constitute strong buying power; however, collectively they can shift preferences and determine the success or failure of products and services. Over time, the selection criteria have shifted from mobile operator focused, to smart devices and device platforms as leading criteria in the selection of the next smartphone and the next subscription offer. As such, the relational distance between mobile operator and mobile user has become larger. The announcement of the next iPhone is more significant than the announcement of the next generation of mobile communication. Upgrades of smart devices is more frequent, typically once every one to two years, compared to major network upgrades every 10 years and a major interim upgrade after 5 years. With interim network upgrades and operators providing regular customer upgrades, a next generation has become a marketing item rather than a network item.

Business users typically have stronger buying power. This market segment is highly competitive, as buyers are able to negotiate low prices for volume contracts. The group of business buyers has become much more diverse with the deployment of IoT. In terms of numbers of users, the IoT market is attractive, however, the amount of data to be transported is in general very limited, and the willingness to pay is low. With a network infrastructure in place, this business is largely incremental and therefore attractive to pursue. The government as user of the 'public' network represents a different class of users. They are very demanding in terms of coverage and service quality, in particular reliability under demanding circumstances. This requires investment in higher network resilience. On the other hand, the government accepts a premium price for premium service levels. A similar argument applies for those business users that require mobile/wireless communication for business critical processes.

5.2.10 Suppliers and supplier power

There has always been a close collaboration between network equipment providers and network operators. That collaboration is typically reflected in long-term supply agreements, although the major operators typically have more than one major supplier.

Over time, the dependence on suppliers has increased as incumbents have outsourced their R&D to varying degrees. Nonetheless, China-based suppliers, which are benefitting from the large economies of scale of their home market, have been successful in prying open the communications markets in Europe, taking share from the incumbent suppliers.

With virtualisation of the network infrastructure, network operators (MNOs) use bulk standard Ethernet switches, servers and storage, thereby benefiting from the economies of scale that were realised in the IT industry.

With virtualisation of the network infrastructure, the traditional supplier-buyer relationship has seen a revival, with the lead European suppliers providing first-to-market tailored services. For the supply of equipment, such as Ethernet switches and data centre services, the operators have turned to general IT companies for supply.[39]

Telecom equipment providers retain their position in the supply of transmission specific equipment, the optical fibre cable systems and in the supply of radio base stations. The latter is, however, also becoming more and more subject to virtualisation, through ‘front-haul’, whereby the radio signal is transported from base stations through fibre to a centralised node for software-based signal processing.[40]

The importance of smart devices in the decision making process of consumers has conferred supplier power on the device manufacturers, as illustrated by the exclusive deal of Apple with AT&T at the launch of the iPhone.[41] Such deals are, however, of a temporary nature. More critical in recent years has become the band plan that is supported by the smart device manufacturers.

5.2.11 Market structure in the ‘Evolution’ image

The market structure under the ‘Evolution’ image reflects the market structure prevailing under the 4G regime: an oligopolistic market controlled by typically two to four major incumbent network and service operators in each national market. Some of these operators have a footprint in a number of national markets. In those markets where MVNOs had been well established under the 2G/3G/4G regimes, they are able to continue their role in the 5G era.

Mobile incumbents have included in their portfolio offerings of Wi-Fi and alternative technologies optimised for specific applications, such as LoRaWAN in support of IoT. These technologies address the needs of specific market segments and are deployed by the incumbents at marginal cost, through the use of existing tower/cell site infrastructure and backhaul. In this way, incumbents can and have migrated users to 5G as and when this became economically attractive, through upscaling or geographical extension of services.

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[39] This reflects the succession of technology cycles each having their own leading suppliers, the giants in voice being replaced by Internet start-ups, growing into Internet giants, being replaced by agile software providers making use of bulk standard IT equipment.

[40] It should be noted that the pooling of baseband processing in a cloud-RAN can, but does not necessarily, use virtualisation techniques. Separating the radio function from baseband processing typically requires transporting digitised radio signals across high data rate (multi-Gbit/s) fibre connections.

[41] The other side of this story is that Apple needed a mobile operator for the successful launch of the iPhone. Source: http://www.forbes.com/sites/petercohan/2013/09/10/project-vogue-inside-apples-iphone-deal-with-att/#2245d81148ae. Retrieved : 2016-09-26.

Next to the leading mobile network operators, niche players are actively exploiting alternative technologies optimised for specific applications, such as IoT. This includes operators at municipal level, which operate IoT networks based on e.g. ZigBee or LoRaWAN.

Virtualisation, and the ability to provide tailored service sets with distinct quality of service levels, has allowed incumbents to provide attractive value-added offerings to business users. This has also attracted SMEs, which used to procure consumer-rate service, as business rate services were undifferentiated and too expensive in the past. The large market for consumers, with relatively low prices, remains satisfied with best-effort services provided over the open internet. They are the key market segment for the OTT service providers.

Some of the OTT service providers have evolved to provide managed services to specific market segments. This has led to an increasing importance of the wholesale market for the incumbents, as OTT providers have not seen economic benefits from investing in their own infrastructure facilities, other than mobile edge computing in the form of data centres, caching facilities, cloud-based processing, etc.

6 Policy and regulatory actions enabling the 'Evolution' image

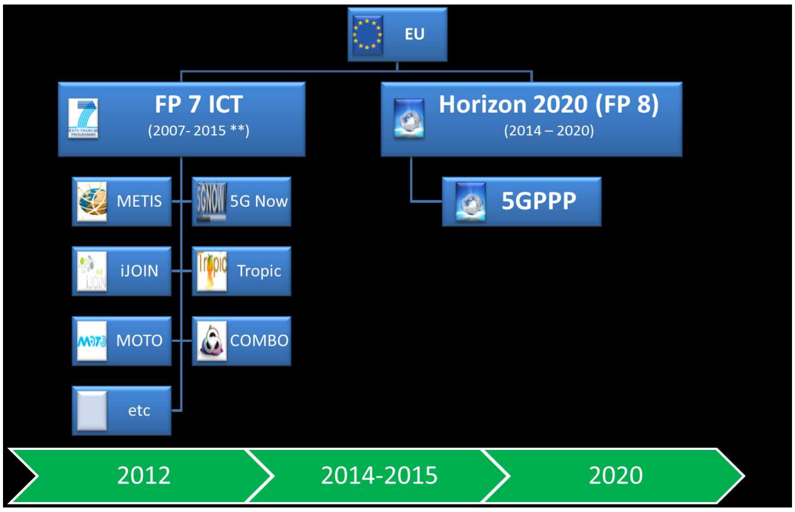
This section describes how the outcome of the 'Evolution' image can be enabled through policy and regulatory action. It provides a forward looking perspective.

In enabling the 'Evolution' image, the European Union demonstrates its leadership in the development of a next generation of mobile communications.

Through GSM, nationally fragmented mobile communications markets were united into a European regional effort. However, the ultimate result of its global deployment was a process of global alignment along a common specification. Through the transition from ETSI to 3GPP, a global platform was established for the specification of the next generation of mobile communications, starting with UMTS. With the global adoption of LTE, the need for 3GPP2 covering the USA-based 3G specification work had ceased to exist and 3GPP had become the *de facto* global platform for 5G specification efforts.

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 European industry is broadly recognised. See also Figure 14.

Figure 14. 5G related European research programs, 2012-2020



Source: 4G Americas (2014a)

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

As the success of GSM is directly related to opening-up the mass market of consumers, for 5G the new addressable market is that of enabling the Internet-of-Things. In principle, this market for connecting devices is many times the size of the market for connecting human beings. However, this market is already being addressed by existing technologies, all the way back to an extension of GSM to support extended coverage for IoT. 5G is expected to support, on the one hand, a mass market for machine type communications and, on the other, very low latency applications in support of what is being called the Tactical Internet.

6.1 Policy action – the 5G Action Plan

Another factor 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[42], as was the case with GSM, coordination is pursued by the European Commission through the development of the '5G Action Plan' launched on 14 September 2016, as a partnership between the Commission, Member States and industry.[43] This plan recognises 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 in terms of: (1) a common timetable for the introduction of 5G, including preliminary trials, pre-commercial trials and large scale introduction; (2) development of national roadmaps by the Member States; (3) allocation of (pioneer and full set of) radio spectrum bands for 5G applications; (4) development of national roadmaps for the deployment of 5G, including coordination of fibre and cell deployments and best administrative practices for cell deployments; (5) ensuring timely availability of 5G standard, with support for a wide range of connectivity scenarios; (6) detailed roadmaps for the implementation of advance trials and plans for technological experiments involving industrial sectors; (7) encouragement for national governments to use 5G for the PPDR services; and (8) arranging a venture financing facility for start-ups using the opportunity for customised communications services as part of the 5G architecture.

Broadly, the 5G Action Plan fits the recurring pattern by addressing the actions required for a coordinated introduction of 5G in Europe. As it is 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 emphasises the role of early trials to assure a timely general roll-out of 5G. Additionally, it calls upon all Member States to engage in the timely roll-out, together with industry stakeholders, including the development of national 5G deployment roadmaps as part of national broadband plans. The latter is in line with the Digital Agenda implementation

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[42] 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 realise as the GSMA represents the interests of mobile operators globally.

[43] 5G for Europe: An Action Plan. Sources: COM(2016) 588 final ; SWD(2016) 306 final. Retrieved from: https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan?utm_source=twitter&utm_medium=social&utm_campaign=5G. Retrieved: 2016-09-26.

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.[44]

To the extent 5G follows the trend of using higher frequencies for increasing data rates with every next generation, the 5G Action Plan is in line with the generic pattern. This pattern is based on the premise that a next generation has a lower cost base, which allows higher data rates to be offered to the mass consumer market at roughly the same price. For the higher frequencies, 24 GHz and higher, a new radio interface will have to be developed, implying new radio base station equipment and new terminal devices. For a successful deployment of 5G in these bands, it is not only essential that Member States coordinate the release of the appropriate spectrum bands, but that those bands are as much as possible globally harmonised to create economies of scale for equipment and device providers. The higher frequency ranges provide more options and hence imply a risk of fragmentation.[45] In this respect it should be noted that the FCC has adopted a new ruling on 14 July 2016. In addition, South Korea has already selected bands for early 5G deployment. In terms of availability of equipment and devices in the selected bands, it is worth noting that companies such as Huawei, Intel, Qualcomm and Samsung have responded to the RSPG consultation, but that input from others (e.g. Apple and Google) is missing.[46]

This suggests the European Union is not leading in terms of being the first in 5G deployment; however, it can be a ‘fast follower’. However, for Europe to be credible in the perspective of global stakeholders it requires as a minimum that the major member states markets are fully aligned, including Germany, France and Italy. Moreover, the participation of the UK, as it is part of ITU Region 1, will help the European cause.

In terms of regional harmonisation, the 5G Action Plan does not explicitly touch upon the important role of the CEPT in coordinating radio spectrum allocation for Region 1, which extends well beyond the European Union.

An aspect that needs further elaboration are the Actions related to the identification of so-called pioneer spectrum bands for the initial launch of 5G services in advance of the WRC-19, and a full set of spectrum bands for initial commercial deployment which will become available only after the WRC-19. This is in the light of 4G services continuing next to 5G services. Moreover, early auctions of the 700 MHz band, such as in France and Germany, makes this band available for 4G-LTE use and hence pre-empts the harmonisation as part of the spectrum for 5G.

[44] This aspect is elaborated as part of the ‘Revolution’ image. See Section 7.

[45] An important indicator for such coordination is the current situation around the 3.5 GHz band, which has been harmonised in Europe for mobile use. However, there is no uptake at this point in time.

[46] A typical case was the iPhone initially not supporting operation in the 800 MHz band for LTE (TNO, 2014).

Also the fact that spectrum assignments have been made technology neutral[47] suggests that it is up to the incumbent operators to decide when and in which bands currently assigned to them, they wish to transition to 5G.

6.2 Regulatory actions

From a regulatory perspective, the 'Evolution' 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.[48]

Nonetheless, the 'Evolution' image raises issues important for consideration within the policy and regulatory domain. Next to regulatory considerations, coordination issues may also hinder the successful introduction of 5G. Policy, regulatory and coordination instruments are available to facilitate the proper development of the market, and they play an important role at the regional as well as the national level. Furthermore, high transaction costs also impact the optimal operation of the market. Note that the 5G Action Plan builds upon coordination rather than regulation as part of its contribution to a successful introduction of 5G.

The issues that the 'Evolution' image raises in relation to regulation, coordination and transaction costs which need to be addressed and resolved to enable the image are listed below:

- ***Market access***: The new frequencies to be allocated and assigned as part of 5G are in the range above 6 GHz, in particularly in the bands above 24 GHz. These frequencies are intended for densification of the mobile network with pico and femto cells, including use within end-user premises. As such the new bands do not provide an opportunity for general entry into the mobile communications market, as that requires frequencies below 1 GHz for coverage and above 1 GHz for supporting high data rates. Below 1 GHz bands have been made available as part of the Digital Dividend II, in particular the 700 MHz band. This band is in most countries auctioned well ahead of the introduction of 5G, as an extension of the frequency ranges available for 4G. While this constitutes an opportunity for entry, it cannot be directly linked to creating success with 5G.
  A new window of opportunity for entry would occur with licenses expiring and being reissued. In relation to GSM licenses, however, this has already occurred in most EU member states well ahead of the introduction of 5G. With the new proposed Code, the license duration is being increased from typically 15-17 years to 25 years. This effectively rules out the expiry event as an entry opportunity.[49]

[47] 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.
[48] COM(2016) 590 final. Proposal for a Directive of the European Parliament and of the Council establishing the European Electronic Communications Code.
[49] See also Annex D.

- ***Vertical integration***: The interdependency between incumbent mobile operators and network software providers that leads to a tying of the two stakeholders may disturb the level playing field, re-enforcing the position of the major incumbents to the detriment of smaller players. Combined with closed sets of APIs, this reduces the degree of effective competition in the market.
- ***Dedicated spectrum assignments***: Starting with 2G, dedicated spectrum bands have been assigned to particular user groups, such as the railways – GSM-R. In addition, the public protection and disaster relief sector (police, fire brigade, ambulance) have been users of dedicated spectrum as part of TETRA. In the transition to broadband, these users have aligned their interests with those of the mass market users to achieve economies of scale on the equipment side. This has occurred as part of 4G – LTE, where dedicated assignments have typically been retained. However, 5G allows network resources to be allocated to specific user groups based on different requirements in terms of quality of service. This would obviate the need for dedicated spectrum. Nonetheless, not all current users are willing (as yet) to accept the 5G promise made by operators and insist on the continuation of dedicated spectrum assignments. Closing the gap between (perceptions of) demand and supply with respect to this issue will improve the more efficient use of the radio spectrum.
- ***Network sharing***: To reduce investments and stimulate roll-out, network sharing has been promoted. Sharing varies from simple passive sharing of ducts and masts to more integrated schemes of active sharing all the way up to the sharing of core infrastructure. Different degrees of network sharing impact competition to different degrees. As the success of 5G depends on a quick roll-out for availability but also on attractive prices for high adoption, any regulatory uncertainties regarding sharing should be removed *ex ante*.
- ***Technology neutrality***: By the time of 5G introduction, all existing radio spectrum assignments will have been made technology neutral. This allows existing bands allocated for mobile use to be used by different technologies, essentially to be determined by the license owner.[50] This in principle allows optimisation of business operations across multiple generations. It could extend the life time of existing generations, but also allow for an accelerated deployment of 5G, if the business case is more compelling. In principle, it allows existing radio interfaces at the lower frequencies to be used with a new 5G core and a new 5G radio access at higher frequencies to be added to the existing 4G core. This flexibility adds to the complexity of coordinated introduction of new 5G functionality, in particular any considerations on backward compatibility.

[50] While spectrum bands 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 require adaptation of regulatory conditions.

- ***Trading, secondary market***: It has been argued that trading in radio spectrum usage rights has been less than anticipated when the scheme was introduced. Some trading has occurred directly after an auction took place. Most of the licenses that change ownership did so as part of an acquisition.[51] With 5G, the pressure on efficient radio spectrum usage increases further. Measures to make the market more 'liquid' are worth pursuing, such as: maintaining a register of license holdings; keeping a data base of market prices; providing a trading platform where demand and supply can meet to explore the possibilities of trades.
- ***Spectrum sharing***: With a limited range of radio spectrum being available and the demand for its use growing unabated, spectrum sharing is a means to improve efficient use. Current practice suggests that sharing is more easily accomplished among users that are alike, e.g. among government users or among private sector users.[52] Such sharing is not necessarily part of the DNA of the parties involved and typically requires mediation and can benefit from a platform for knowledge sharing.[53]
- ***Coverage obligations***: In markets with a high degree of competition, coverage obligations may be dropped. However, in underserved areas, in particular in areas with little or no fixed network coverage, mobile coverage obligations may be required to fulfil public interest objectives.
- ***Indoor access***: To avoid distortion of competition, indoor access through distributed antenna systems and/or through a neutral host may be required through regulation, if parties cannot agree on a commercial arrangement.
- ***Open Internet***: 5G is considered to serve the specific needs of vertical industries in terms of quality of service, including: availability; reliability; data rates; and latency. The regulation on net neutrality (Open Internet) having come into force as of April 2016 is suggested to provide "…certainty for internet access providers and providers of content and applications to offer specialised services with specific quality requirements, including necessary safeguards to ensure the open internet is not negatively affected by the provision of these services. Specialised services cannot be a substitute to internet access services; they can only be provided if there is sufficient network capacity to provide them in addition to any internet access service and must not be to the detriment of the availability or general quality of internet access services for end-users."[54] The way 5G is being positioned may not contradict these rules but considering the special case of PPDR, including priority override, does suggest circumstances where national (security) interests can take precedence over the net neutrality rule. Potential

[51] Mobile infrastructure devoid of an appropriate license has very little value, hence, the typical trade of fixed assets in combination with a license.
[52] For an example of sharing in the area of critical and professional use of 4G see "Hub One", a case of sharing at the French airport Charles de Gaulle. (Olszanski et al., 2014)
[53] See the recommendations in "From spectrum management to spectrum governance" Anker (2017).
[54] Source: https://ec.europa.eu/digital-single-market/en/open-internet-net-neutrality. Retrieved : 2016-10-03. See also Annex E on "5G and Net Neutrality".

conflicts resulting from other applications with differentiation in the quality of service should be clarified upfront to prevent unnecessary uncertainties hindering the broad uptake of 5G. Special attention should be given to member states that have implemented more stringent net neutrality regulation, such as The Netherlands.

- ***Serving vertical industries – rules and regulations***: With software defined networking as part of 5G, and already preceded by network slicing a part of 4G, different needs in terms of services and quality of service can be provided simultaneously through a single 5G network fabric. This enables serving the needs of specific industry verticals and facilitating their digital business models. As a consequence, industry specific regulations and electronic communications regulations become close twins. A successful deployment of 5G being based on serving verticals[55] suggests the need for mutual understanding of regulations, in terms of purpose and content. This includes the potential impact on data protection and privacy. In addition, liabilities crossing traditional boundaries is an aspect that requires attention from regulators on both sides.
- ***Serving PPDR as an industry vertical – minimum requirement***: The way ICTs are used in society makes the electronic communications infrastructure a 'critical infrastructure'. If we add to this the use of the 5G network to provide PPDR services, the question may be raised whether a minimum quality of service should be set; which the infrastructure must be able to provide under a specific set of circumstances. If so, will this requirement just be a matter of properly engineering the network or are there implications for the architectural design of 5G? Will this minimum requirement be offered as part of the competitive market, or is regulatory intervention required?
- ***User data***: In serving vertical industries, and enabled by virtualisation, one may expect to see the extensive use of user data in shaping services provided by mobile operators. Current rules make a distinction between network operators and OTT service operators in terms of user data. This represents an uneven playing field and a barrier to the development of 5G as foreseen in the 'Evolution' image. Efforts towards regulatory alignment are considered necessary.
- ***Data protection and privacy***: The Internet-of-Things is expected to encode 50 to 100 trillion objects globally and to be able to follow these objects. Human beings in urban environments are expected to be individually surrounded by 1000–5000 traceable objects. This raises new issues around privacy and security, as well as of autonomy and control.[56]

[55] Consider for instance electronically mediated autonomous driving and remote surgery.
[56] Source: Höller et al. (2014).

7 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 virtualisation 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 this image, the consumer market is 'just' another vertical. 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 market – typically operating globally.

Enabling the vertical industries constituted major innovation efforts on the part of communication network operators, the specialised providers and their (prospective) industry clients, often requiring alignment between two regulated industries, e.g. transportation and communications, health care and communications. In many cases this required joint investment, which included investments by governments, e.g. in the ICT infrastructure alongside roads.

For 5G to become successful in this endeavour, policy support and regulatory restraint were essential, as the electronic communications industry was the subject of reshaping towards a much more vibrant level of competition at the retail level. This competition was based on differentiation in communication services and bundling with business services. This resulted in a higher willingness to pay from business users. This in turn provided the financial incentives for investments in 5G at the network level.

7.1 Anticipated outcome – attractiveness of the outcome

This section describes the anticipated outcome of the image of the future in hindsight.

While in the 'Evolution' image the supply side forces are the main drivers, in the 'Revolution' image the demand side forces are the key drivers – see the detailed description in Section 7.2.

In recent mobile generations, demand was shaped by mass market consumers wishing to have increasingly higher data rate Internet access, which was essentially being provided at a flat price. Premium services such as telephony and SMS were replaced by over-the-top applications, which came for free. Hence, with increasing infrastructure costs, see Figure 12, the business case for the next generation of mobile infrastructure became more and more challenging.

In the 'Revolution' image new value-added demand from vertical industries drives the need for new mobile communications services. These communication services are part of a bundle of business services and hence lead to a higher willingness to pay.

The 5G architecture allowed the tailoring of services, in terms of feature sets and qualities of services. This in turn allowed the creation of virtual mobile networks for specific user groups, for specific industry verticals and for government sectors.

Within 4G-LTE, the first steps in this direction had been taken by allowing 'network slicing'. This allowed the UK government to procure the services for police, fire brigade and ambulance (formally the public protection and disaster relieve services – PPDR) from BT-EE as-a-service, rather than having to roll-out and operate a dedicated PPDR network.[57]

PPDR constituted a new market segment for mobile operators, with high quality demands but also a willingness to pay for high quality and high availability. Once the network was made fit for purpose to serve PPDR as a very demanding customer, it was ready to serve other mission critical and business critical users.

For PPDR users, the virtualisation of 5G allowed them to outsource while remaining in control. Through 5G they got the best of both worlds: service provision and operation under own control, i.e. the upside but not the downside of owning a network. This was, and still is, a very attractive prospect for other users of mission and business critical services.

Moreover, it allowed better utilisation of the radio frequency spectrum as the need for dedicated assignments disappeared. It is also attractive economically, as sharing of the infrastructure allows better utilisation and thus higher margins.

Next to mission critical services, there are many industries with business critical service needs. Some had adopted TETRA for private use, such as airports, ports and the oil and gas industry. However, in the past other industries and firms could not be served properly, when their needs did not fit one of the two models available.

With 5G this has changed. Service sets can be tailored to a variety of needs. Moreover, through virtualisation of the mobile infrastructure the vertical industries can manage these service sets themselves, as virtual mobile network operators, if they wish. In that way, they are in full control of the customer relationship, as well as the supplier relationship, using their own branding.[58] In that way they created an all-encompassing experience, exploiting digital transformation to the full extent.[59]

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[57] Note that in Europe, PPDR services have traditionally been provided by a dedicated network using a dedicated spectrum band – TETRA. TETRA had to a large extent been based on GSM. The sector organised in the TCCA (TETRA Critical Communications Association) has concluded that the only affordable and feasible way of making the transition from narrowband to broadband is through the use of commercial systems, starting with LTE. For this reason specific features are implemented in Release 13 through 15 for the PPDR community. In continental Europe, the PPDR community wants to continue the use of dedicated spectrum band, while the UK government had decided to go one step further.

[58] In, for instance, the automotive industry the brand and branding is extremely important. In certain cases intangible assets have grown to half of corporate valuations. More generally, according to Interbrand, the value of the top-30 global brands accounted for about 25% of their market capitalisation. (Diehlman & Häcker, 2013)

[59] A simple but telling example is 'Volvo On Call', typical for the top-end brands in Europe. While the e-call legislation was under discussion, Volvo introduced an equivalent service to its customers in 2012, not only providing the safety service but establishing an opportunity for direct interaction with its customers and its products as they are being used. With Volvo On Call their products are on-line, thereby complementing and enhancing the service provided by the car dealers. With 5G, Volvo can further tailor the service to its needs, adding value-added functionality and away

Through the adoption of a single set of application programming interfaces (APIs) as part of the 5G deployment across Europe, the tailoring of services is 'borderless'. It means that vertical industries can provide the same customer experience across the whole of the Union, provided the industry specific rules were also aligned across the Union as part of the enabling efforts.

In the example of autonomous and assisted driving it meant that, for instance, rules on distances between trucks when platooning have been harmonised. For the health sector, it meant that new apps, once approved by the medical profession, could be introduced by the ICT departments with the required availability and reliability levels. In that way they are an integral part of the health care service under their responsibility while provided beyond hospital walls. This improved healthcare service levels while at the same time reducing costs. As it concerns an integrated service, it is treated in the same way in terms of insurance, allowing remote services to be financed through health care plans. This provided a clear (professional) separation from health related services offered over-the-top (OTT). For start-ups, it provided an innovation path to move from the 'open' to the 'controlled' environment, if so desired.

In this way 5G provided an alternative value-added service channel in competition with OTT offerings. While the market for OTTs was, and still is, open and unconstrained, managed services provided the end-users with certainty, and as there are multiple Virtual MNOs (VMNOs) they were also provided with choice. With the possibility of VMNOs being branded at the firm level (just like MVNOs today) market entry in 5G is at the retail level, with inter-firm level competition being extended into VMNO level competition, which translates into a highly dynamic wholesale market.

5G also offers a solution to a long-standing investment problem as a result of benefits being accrued in one sector while another sector carries the burden of investment, the pricing mechanism alone not being able to solve the problem. The typical example of this is private sector infrastructure investments in support of government sector beneficiaries, such as those related to e-Health, e-Government and e-Education. In the 5G model VMNOs operate as retailers procuring managed wholesale services from infrastructure providers, while remaining in control of the service offering to end-users. This allows value differentiation and value transfer along the supply chain, whereby OTT service providers make use of the 'best effort' part of the Internet while VMNOs use the managed part.

Note that the necessary harmonisation within the vertical industries had to be realised by the actors in the particular vertical industry themselves, as only they have the necessary in-depth knowledge. Hence, the introduction of 5G provided an unique opportunity for further EU level harmonisation to realise the internal single market. It also meant that the successful deployment of 5G was dependent on the successful harmonisation. The good news was that these efforts were already underway in all industries and economic sectors in the Union. The

from standard subscriptions and fees. See also the case description in "Leading Digital" by Westerman, Bonnet & McAfee (2014).

introduction of 5G provided an additional impetus. Moreover, it allowed the different Directorates of the Union to pull together in a joint effort towards the achievement of the Single Market. All of this was executed as part and parcel of an overarching vision on the digital transformation of European industries, i.e. in a Union-wide effort to enable Industry 4.0.

By providing vertical industries the opportunity to seamlessly extend their internal ICT capabilities to include relationships with customers and suppliers under their own brand, and by providing full service control over these relationships and the value added business services offered, firms in the vertical industry had strong incentives to remove any remaining barriers. Those industries that had a strong cross-border dimension, and which had the highest interests in using 5G tailored services, were in the forefront of the harmonisation efforts.

It should be noted that the harmonisation efforts were not trivial and industry stakeholders did not come together automatically. The service proposition of 5G was new and (business) end-users had no experience with diversification of electronic communication services. How could they give credibility to what equipment vendors and operators were telling them? Operators on the other hand were complaining that business users were not articulating their demands properly, i.e. in terms of the new realities. Specific efforts by governments to 'close the gap' between the parties were required, typically supported by academic experts as 'neutral thirds'. This was organised by industry vertical and led to the formation of special interest groups (SIGs) that continued to serve the interests of the business users.[60]

Opening up the mobile services sector to VMNOs provided the necessary broad base for 5G adoption across industry verticals, with different VMNOs leading the efforts in different industries. The alternative of having only incumbent MNOs involved would have restrained the development for three reasons: (1) the incumbents lacked the deep industry sector insights required to tailor the service sets to individual industries or even the individual firms; (2) they would have been unable or unwilling to achieve the necessary harmonisation within each vertical (due to the wrong positioning, limited resources and lack of specific expertise required); and (3) they would not have been able to achieve all this across multiple industries simultaneously and as fast.

7.2 Outline of the 'Revolution' image

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

[60] These 'gap closing' efforts were modelled after early experience obtained by the Ministry of Economic Affairs in the Netherlands. The Ministry organised a series of stakeholder meetings to shape the new strategic agenda for its radio spectrum policy. Here the gap identified related to the capabilities of LTE and LTE/Advanced. Gap closing efforts emerged from e.g. the ICT department of Schiphol Airport and from the Cognitive Radio Platform NL, which facilitated sessions dedicated to the electronic communication needs of academic medical centres.

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 services needs such as cloud computing.

Expanded service provider base

These service operators (VMNOs) evolved from IT/CT departments of the firms in the vertical industries, from specialised providers of ICT services to these vertical industries, from the service divisions of operators and from start-ups that recognised the new opportunities for developing applications. The image reflects the digital transformation process that is taking place across industries and economic sectors. The appeal for firms is the ability to establish a direct customer relationship, irrespective of any intermediaries in the 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.

Leadership through services

The European Commission, with the support of the Parliament and Council, recognised the opportunity for leadership in 5G in serving industry verticals to boost economic growth and productivity across all sectors of the economy. It recognised 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 makes strategic sense as virtualisation would lead to commoditisation at the network equipment level and loss of market share, typically to suppliers from China.[61]

Change in industry mind-set

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 mind-set change in the strategic vision of the actors involved. It resulted in a new prevailing industry logic. Virtualisation provided the technological opportunity, but active policy support and restraint in regulation were essential to ensure it led to the desired future outcome.

The success of the application platforms of Apple and Google served as an example and benchmark. The controlled model of Apple was more attractive, as it provides the opportunity

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[61] The debate within government circles as to 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 offset by the revelations on US government actions being revealed through WikiLeaks.

for control over quality, considered as essential for critical infrastructures. The example also showed the ability of fast scaling being critical for achieving European leadership. The new services providers became the new virtual mobile network operators (VMNOs), as virtualisation allowed the slicing of network resources, as if each service provider ran its own mobile network or networks.

An innovation project supported by policy and enabled by regulatory restraint

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 recognised, success was not guaranteed as often other parties, such as regulators, had to be brought on-board 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 was more than offset by the end-user benefits from vibrant competition at the retail level, made possible through services differentiation.

Note that these innovation efforts first took place at a national level by industry, and upon success became more widely applied. Interested actors orchestrated their interests across borders to further build momentum and impact, increasingly Europe-wide. Use was made of institutions that in earlier times had represented broader interests, but had for various reasons become less prominent, such as INTUG and its national members. Furthermore, industry interest groups evolved to embrace electronic communications as their field of interest.

Common 5G standard

At the time of 2G – GSM, a mandate from the European Commission to ETSI for the development of the 2G standard, and a mandate to the telecom operators for the implementation of this standard were required to assure harmonised implementation of GSM across Europe. In the 5G era, these mandates were not required as the industry was and is aligned; no alternative standards were in a position to threaten the focus of the efforts on the development of 5G.[62]

A concern in such a setting is that choices otherwise available to end-users in the market are made in a standards development organisation typically dominated by suppliers. Historical

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[62] 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.

developments suggest that end-users, when they organise 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 organised and being recognised as part of the TCCA community representing the PPDR interests suggested that the market actors were organising their interests.[63] In other industries, government support appeared to be required for the actors to coordinate their interests to become reflected in the standard.[64]

In 3GPP, due consideration was given to the expectations of the new 5G standard. Reflecting the concerns articulated by AT&T: "Traditionally, carriers interested in a new architecture would gather with their suppliers and start a new standardisation activity in one or several SDOs, often calling the work Next Generation Network or NGN. The standards body would gather requirements from interested parties, work out backwards compatibility, and negotiate an outcome that was mutually acceptable and described the end-to-end system as an optimised and tightly coupled whole. This process was [is] lengthy and expensive, diminished a carrier's ability to navigate their own technology transitions, and often created entities that fail to serve the interests of the companies that fund them. This is not to say that standardisation is no longer valuable, but rather that the goals of standards activities are better targeted toward smaller, re-usable components that can be composed and recomposed into various systems and architectures."[65]

Common set of open APIs

With the virtualisation 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 are closely related to the functionalities defined in the 5G standard and became an integral part of the standard.

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 mind-set 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

[63] TCCA: TETRA Critical Communications Association.

[64] 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.

[65] Source: AT&T (2013).

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.[66]

To invoke the appropriate behaviour 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. In addition, the industry was informed about 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 recognised the innovative aspect in the development of APIs and its gradual implementation, while at the same time it unequivocally communicated the intended end goal of this development.

To ensure service compatibility across networks, an entity that could test and approve new applications for compatibility with the standard and its APIs was established by the industry, 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.

Coverage and fall-back

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 mind-set, it was clear that this approach was more attractive than awaiting a regulatory obligation to be enforced. These contracts also allowed optimal service provision to vertical markets irrespective of location. Thereby it facilitated market entry of VMNOs while incentivising MNO investments.

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 business services being provided.

The new market extended well beyond the size of the mass market of consumers: including IoT and IoE. It now covers both mass market communications and ultra-reliable low latency machine type communications.

[66] See also Section 8.1.1 on the Action Plans.

Creating a level playing field for the new service providers at the level of the common and open APIs was essential to kick-start the new services model. Earlier experience in the field of fixed infrastructures suggested that to avoid incumbent operators favouring their own services divisions regulation was deemed necessary, which in a number of cases led to functional separation.[67] The mobile sector, however, developed along different lines, being aligned around a common standard with infrastructure-based competition among multiple players from 2G onward. Nonetheless, the tendency towards consolidation of the sector was a concern for policy makers and regulators.

The reshaping of the mobile industry that 5G enabled, the innovation trajectory that was involved, and the perspective of a new and vibrant form of competition combined with incentives to invest as a result, convinced policy makers and regulators to assume a position of restraint, to allow the prospects of 5G to develop without undue constraints. For all stakeholders it was clear that the Electronic Communications Code that was in force allowed the regulators to intervene if and when deemed necessary.

The changed mind-set in the industry allowed the developments to take the right course. In hindsight, representatives of incumbents admitted that separating the management of the infrastructure business from the management of the services business was supported by business logic. The difficulty to compete with highly specialised service providers, being able to move at 'software speed', outweighed the value of a tightly integrated business model that constantly needed to resolve conflicting demands.

The earlier period of OTTs had also shown that it is extremely difficult for incumbents which are successful in one paradigm to switch on their own accord to another paradigm.[68] The Swedish experience – where one out of every two municipalities is in fibre networking – also contributed to the logic. Separation of network operations from service operations into independent businesses allowed each to optimise its own business model. In the end, the incumbent service provider (in this case TeliaSonera) did benefit from providing services without having the need to invest in infrastructure.

Given the industry transition set in motion with NGN and with most network providers operating fixed and mobile infrastructures, virtualisation had become applied across the total network asset base. Fixed–mobile convergence enabled by virtualisation was leading to fully interconnected and interoperable communications network platforms, seamlessly enabling a multitude of service providers addressing business and consumer needs across the region and beyond.

[67] Examples are BT – Ofcom in the UK; TP – UKE in Poland; Telecom Italia – AGCOM; TeliaSonera – PTS in Sweden; and O2 in the Czech Republic. Source: Lemstra (2016a).
[68] See for instance the analysis by Christensen in the "Innovators dilemma" (1997) and the extension by Rogers in "The digital transformation playbook" (2016).

7.3 Industry structure in the 'Revolution' image

The socio-economic dimensions as part of the Porter-Wheelen framework are provided to fill out the broader context in which the development of electronic communications took place to obtain an internally consistent image description. As the socio-economic dimension is not the focus of the image, only some highlights are provided.

7.3.1 Societal

In the 'Revolution' image, social media continue to play an important role in society. People continue to allow the gathering of behavioural data for the provision of personalised services, such as targeted marketing and location based services, as well as 'freebies', such as free services and applications. With digital transformation being applied across all industries and economic sectors, customer relationship management had become much more than targeted advertising. Individual usage of products and services are directly monitored by the providers and used for product and service improvements.

The digital transformation of industries and economic sectors has led to many traditional jobs with little value add being removed. For the younger generation the new opportunities provided for new jobs, but unemployment amongst the older generations increased. This created a strain on the provision of a minimal level of subsistence.

Concerns remain about privacy and data protection, with breaks and leaks being a recurring phenomenon. The inappropriate use of the Internet, such as stalking, cyber-bullying and similar practices, continued. Bona fide as well as mala fide business models are benefitting from improved Internet services. Cybercrime and cyber-attacks have become a feature of modern society.

7.3.2 Economic

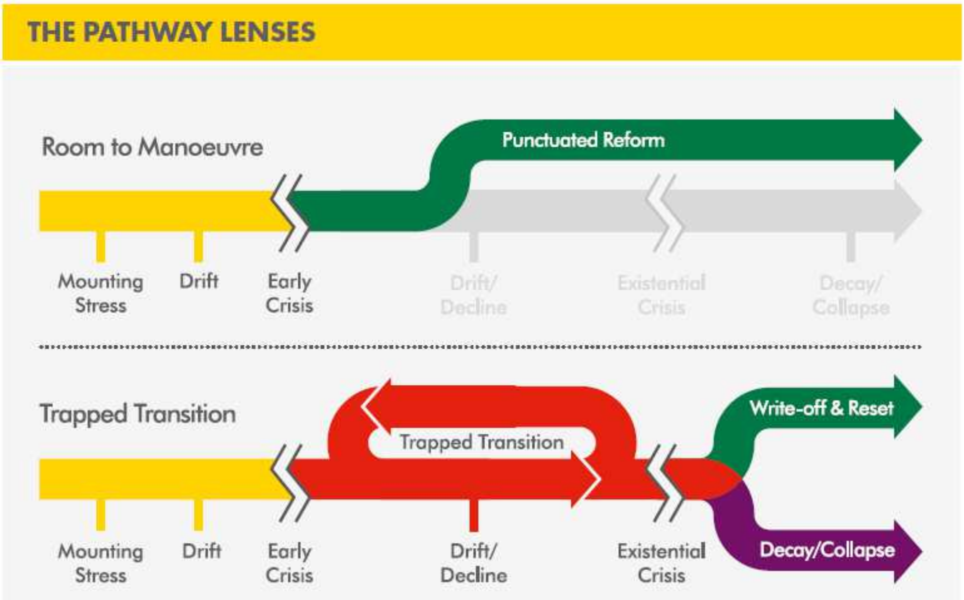
The digital transformation of the economy led to productivity improvement and economic growth across the European Union. It enabled the financial support of the weaker economies bordering the Union in the South, leading to a significant reduction in the inflow of economic refugees.

Digital financial solutions (fintech/blockchain) provided alternatives for the traditional financial system in linking supply and demand at much lower costs. Through timely adaptation of regulation, regional and national governments enabled economic growth. Average GDP growth remained modest, as income distribution became more skewed. Discretionary spending of households improved, but the spending pattern shifted in line with an ageing population.

7.3.3 Political and Regulatory

A compelling future vision, based on a re-invigorated industrial policy at the European Union level, enabled a punctuated reform based on digital transformation of the economy at large. It provided an escape from the trapped transition that hindered economic progress in the preceding decade. See Figure 15.[69]

Figure 15. Shell scenarios: Pathway lenses



Source: Shell (2013).

The importance of broadband for economic development is well recognised in Europe. The Gigabit Society vision captured the goals for 2025. Mobile communications was recognised as the preferred means to provide service in deep rural areas. Through the re-invigorated industrial policies of the European Union, the liberalised markets were able to deliver on the policy goals. Europe had been able to embrace the future.

China is the world's single largest market and influences developments elsewhere. It benefits from this domestic scale, from political willpower, including constancy in purpose of their industrial policy, and from people wanting and recognising opportunities to improve their economic conditions. Growth in average income had become more moderate as resources are being spent on improving the environment.

7.3.4 Technological

While mass production had been outsourced to low wage countries, high tech engineering skills have allowed the retention of high-tech production in Europe. Digital transformation combined

[69] Source: Shell (2013).

with new technologies, such as 3D printing, allowed the re-invention of the industrial sector and allowed it to again become the main source of added value in Europe.

The regional, and later global, success of GSM had allowed Europe to become the *de facto* host of the global standardisation efforts for mobile communications through the 3rd Generation Partnership Project. 3GPP continued to be the core platform for 4G and 5G standards work.

The technological underpinning of standards work by pre-competitive research programs, run by industry and co-funded by the European Union, continued to enforce the European contribution and position, from 3G through 4G into 5G.

Participation in the development and standardisation of 5G is truly global and recognised by the European Commission through strategic R&D collaboration agreements with South Korea, Japan, China and Brazil.

Network virtualisation, as the major technological development affecting 5G, was embraced by the European Commission in a reform of the electronic communications sector, which in turn enabled the punctuated reform of the Union at large.

The European Telecommunications Standards Institute (ETSI), already involved in network virtualisation since 2012, has become pivotal in the 5G standardisation contributions in the field of open access APIs and the certification of services and applications for seamless operation across the European Union. As designated European partner in 3GPP, ETSI contributed its work on virtualisation as input for the 5G specification.

7.3.5 Environmental

Increasing concerns regarding climate change put pressure on all stakeholders to shift to sustainable sources of energy and to reduce energy consumption. The energy footprint of ICTs had become an increasing concern with increasing usage. Equipment suppliers pledged to reduce energy consumption with the introduction of the next generation of equipment, in line with the need to serve the IoT at much lower power levels to extend battery life.

Health concerns related to the use of radio frequencies continued and increased with the proliferation of base stations in support of increasing mobile usage and demands for higher data rates. Higher spectrum efficiency through beam steering, increased spectrum sharing and dynamic power management of base stations have mitigated the issues and prevented escalation of the issue.

7.3.6 Rivalry

The opening up of the industry to a multitude of virtual mobile network operators (VMNOs) serving the interests of particular industry verticals, government entities and end-users led to vibrant competition at the retail level. Through service differentiation, it resulted in a healthy level of rivalry between a small number of firms operating on the network level (MNOs) in attracting VMNOs as their wholesale clients.

At the network level, the core assets of the firms are twofold: (1) the infrastructure assets in terms of transmission and switching equipment, servers and software platforms; and (2) the radio spectrum licenses. Network operators compete for business from service providers for which they act as hosting provider, i.e. as providers of virtual network slices with a particular quality of service profile. They act as 'single point of sales' and where necessary contract (virtual) resources from other network providers, e.g. to complement coverage or certain aspects of the quality of service profile.

At the network level the trend towards consolidation continued. In the competition for contracts with service providers coverage and scale play an important role. Through acquisitions, the need and the costs for subcontracting was reduced or even avoided.

At the services level the core assets are also twofold: (1) the customer relationships and the deep understanding of the customer business model and how this can be supported by tailored services; and (2) the applications services platforms (edge computing) that complement the resources of the network providers in delivering business services to the end-users.

Incumbent service providers were by and large able to retain their relationship with the mass market consumers by extending the Internet access services with (unique) content services. The rivalry remained intense, as new service providers continued to segment the consumer market to improve value appropriation, in particular in the SME market. Moreover, OTT providers ventured into becoming service providers, to be able to offer services with a guaranteed quality level.

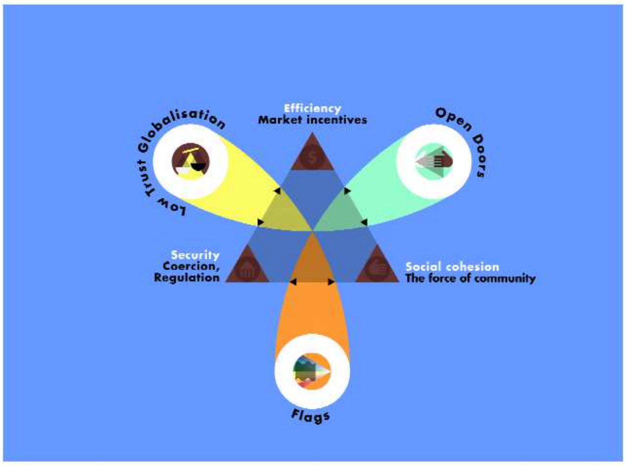
In the business market, positions built through early IoT service provision were challenged effectively by new service providers having their roots in the industries they served for many years. At the expiry of long term contracts, a significant level of churn could be observed.

In the fully virtualised network environment, Wi-Fi is just another radio access technology with a particular quality profile. As the resource is not encumbered with license fees, it is used wherever possible to reduce overall service costs. The same applies for LoRaWAN and other radio access protocols optimised for IoT using the unlicensed frequency bands. While these technologies are not part of the IMT2020 family, in practice they became integral parts of the virtualised mobile communication environment and were treated as such.

The cost reduction over earlier generations of mobile technology, in capex and opex terms, realised through the virtualisation of 5G, accelerated the transition from earlier generations to 5G. This applied to all network providers and did not significantly change the competitive landscape among MNOs.

The image of the future that virtualisation enabled, using APIs to open up the networks to a multitude of virtual service providers, resonates with the scenario of 'open doors', which links market incentives with the force of community, as described in the Shell scenarios for 2025, see Figure 16.[70]

Figure 16. Shell global scenarios to 2025 - Open doors



Source: Shell (2005)

7.3.7 Barriers to entry

Virtualisation and APIs lowered the barrier to entry for service providers to a level never experienced before. It resembled the lowering of the entry barrier to smart phone platforms through the Apple app store and later Google's Android Play Store.

For network providers, governments aimed to keep the barrier to entry low with each radio spectrum auction, as they observed consolidation of the industry between auctions. This implied the use of set-asides for entrants and/or spectrum caps for incumbents. Considering the deep investment required for participating in the communication network business, the entries that have been observed in recent auction rounds have been related to fixed-only operators obtaining access rights to the use of the radio frequency spectrum. As this process was largely complete before 5G was launched, no similar entry occurred or is likely to occur.

With an extension of the license period to 25 years, investment in license assets may be considered by financial institutions as more akin to real estate and hence allows for comparable financing schemes. In this respect, license assets and passive infrastructure assets have become more alike and so-called tower companies were contemplating forward integration into license ownership, and possibly ownership of optical fibre networks.[71]

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[70] Sources: Shell (2005, 2007).
[71] Source Feasey; personal conversation in the context of this project.

7.3.8 Substitutes

On the application and services level, OTT providers introduced substitutes for plain voice communication, for texting and to a large extent for broadcasting. By 2020, the battle with the incumbents was over, regulation having been re-designed based on technology-neutrality. The new rules were affecting all players alike, where it concerned services that were deemed of public interest, such as access to emergency services.

Partial substitutes for national mobile communications networks, including 5G, are local-area networking technologies, such as Wi-Fi, Bluetooth Low Energy, and ZigBee, and city wide-area wireless technologies in support of IoT, such as: LoRa, Sigfox, OnRamp Wireless, and Weightless. These networks can also be seen as micro access networks used to efficiently funnel traffic to and from the national cellular network. In this perspective, they functioned as complements to mobile communication networks and as virtualisation progressed they became integral parts of the wireless fabric.

In the past, private networking needs of governments and private business were served by dedicated wireless technologies, such as GSM-R for railways and TETRA networks for the police, fire brigade and ambulance services. TETRA was also used for business critical communications at airports, and the oil and gas industry. Furthermore, Private-GSM was made available in the fringes of the GSM bands to serve business critical needs. With the need for higher data rates and having relatively small economies of scale, users migrated to LTE as the technology platform of choice, but retaining dedicated spectrum assignments. With software defined networking as part of 5G, and already preceded by network slicing a part of 4G, different needs in terms of services and quality level can be provided simultaneously through a single 5G network fabric. This removed the need for dedicated spectrum assignments in the 5G era.

7.3.9 Buyers and buyer power

For service providers, individual consumers do not constitute strong buying power, however, collectively they can shift preferences and determine success or failure of products and services. Over time, the selection criteria shifted from mobile operator-focused to smart devices and device platforms as leading criteria in the selection of the next smartphone and the next subscription offer. As such, the relational distance between service provider and mobile user became larger. The announcement of the next iPhone is more significant than the announcement of the next generation of mobile communication. Upgrades of smart devices is more frequent, typically once every one to two years, compared to major network upgrades every 10 years and a major interim upgrade after 5 years. With interim network upgrades, and service providers offering regular customer upgrades, a next generation has become more of a marketing item.

Business users, represented through their dedicated service providers, typically have stronger buying power. This market segment was highly competitive, as service providers were able to negotiate low prices for volume contracts from network providers. The group of business service providers (VMNOs) has become much larger and more diverse through virtualisation and through the deployment of IoT. With communications having become bundled with other business services it has become an input to the production function of almost all businesses. As a result, the volume and value of business services have grown significantly. With VMNOs typically dedicated to a particular industry, this provided for increasing bargaining power in some industries, but fragmentation in others.

Service providers that serve the government as end-user represent a different market segment. In particular, the PPDR users are very demanding in terms of coverage and service quality, especially reliability under extreme circumstances. As such, they are similar to other business critical users, such as airports. Their demands require that network operators (MNOs) invest in higher levels of network resilience. On the other hand, these end-users accept a premium price for premium service levels.

7.3.10 Suppliers and supplier power

With virtualisation of the network infrastructure, network operators (MNOs) use bulk standard Ethernet switches, servers and storage, thereby benefiting from the economies of scale that were realised in the IT industry. The leading providers of the software layer(s) that enabled the virtualisation are the traditional network equipment suppliers, which have adapted their business model to the new reality of virtualised networks. With further standardisation on IP and softwarisation, their position was and is being challenged by the leading software providers in the data centre space, such as Amazon and Google.

Network equipment providers retained their position in the supply of transmission specific equipment, the optical fibre cable systems and in the supply of radio base stations. However, the latter also became increasingly subject to virtualisation. This happened through ‘front-haul’, whereby the radio signal is transported through fibre from base stations to a centralised node for software-based signal processing.

The importance of smart devices in the decision making process of consumers has conferred supplier power on device manufacturers, as illustrated by the exclusive deal of Apple with AT&T at the launch of the iPhone[72], although such deals are of a temporary nature. More critical in recent years has been the band plan that is supported by the smart device manufacturers.

[72] The other side of this story is that Apple needed a mobile operator for the successful launch of the iPhone. Source: http://www.forbes.com/sites/petercohan/2013/09/10/project-vogue-inside-apples-iphone-deal-with-att/#2245d81148ae. Retrieved : 2016-09-26.

7.3.11 Market structure in the 'Revolution' image[73]

The 'Revolution' image is also denoted as the "horizontal" image as it reflects the shift from a model with vertically integrated infrastructure and services providers to a layered model with multiple specialised providers at each layer. At the lower layer are the passive infrastructure facilities providers – the 'tower' companies and owners of ducts and other conduits. At the next layer up are the network operators (MNOs) – the owners of radio frequency licenses and of active infrastructure facilities, such as Ethernet routers, optical and microwave transmission equipment and radio base stations. These operators of the physical mobile network are the wholesale providers of a range of connectivity services with various grades of quality to the virtual mobile network operators (VMNOs) at the top layer. These VMNOs include the specialised service divisions of MNOs.

The VMNOs can be compared to the MVNOs of earlier generations, serving specific market segments and/or leveraging a particular brand. However, there is an important difference, in that they now are provided with the control of network capabilities equivalent to that of traditional MNOs. All this was enabled through network virtualisation. It looks like the model of service level competition on top of a common network, as applied in fibre optical networks.[74] However, it differs from this model as VMNOs have full control of a virtual slice (or slices) of the network infrastructure, which meets the requirements of the service offering and quality levels they wish to provide to their end-users. The number of VMNOs is very large, extending well beyond the largest range of MVNOs observed earlier in any country. In principle, each firm that wished to extend its reach to end-users through a mobile service could and can do so as a VMNO using its own brand and by bundling communications services with business services. As firms compete for end-users, they will compete for providing the best virtual mobile services as well. This resulted in a very dynamic wholesale market with differentiated services.

To allow VMNOs to reach their end-users irrespective of location, the MNOs agreed to make use of the same set of APIs to enable seamless (national/international) roaming.

Within this horizontal model, actors in each layer aim to optimise their market position. Passive infrastructure is typically an economically non-replicable asset. To the extent passive infrastructure of incumbent fixed operators had been opened up through regulation, this regulation stayed in force. This also applied to the sharing of towers, masts, etc. as local authorities wanted to minimise the number of permits for additional cell sites. This passive layer

[73] As stated in the introduction of Chapter 4, we are not suggesting that either one of the two images , Evolution and Revolution, represents the most likely future outcome. The future may evolve as a mixture of these two in a pattern which varies over time and place, or may be different from what is described. The two images have been developed to highlight the range of 5G challenges which are likely to be faced, and thus focus attention on the key short and medium term choices concerning policy and regulation which have to be made to assure the successful development and deployment of 5G in Europe

[74] See for instance the Case description of Sweden by Forzati and Mattson in "The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda" (2014).

is subject to consolidation. Combined with restrictions on growing the number of sites on the one hand and the costs of building new passive infrastructure on the other, regulatory oversight has intensified.

At the active network layer, the number of mobile network operators (MNOs) is essentially equal to the number of radio spectrum license holders. The oligopolistic market structure that existed during the 4G era has essentially remained. After the repurposing of the 700 MHz band, no new low-end spectrum has been actioned, hence, no new market entry opportunities were created. In the unlicensed bands, the number of specialised IoT operators increased. They essentially funnel wireless traffic to the fixed network operators and/or to mobile network operators. As such, these providers are, to a degree, in competition with the MNOs and to another degree complementary to their business. They interconnect on a specific network access slice optimised for their type of communication needs. See Figure 5.

The MNOs compete fiercely for the business of the VMNOs. The extent to which their network provides better coverage and higher capacity on the one hand, and offers flexibility and support in response to the demands of VMNOs on the other, determines their competitive position. Any weakness in coverage or other network resource constraints were compensated through private negotiations leading to national roaming agreements with their competitors.

Initiatives for further consolidation of MNOs have in most cases been unsuccessful, lacking the required approvals from the competition authority. Proposals allowing pooling of radio frequency assets by MNOs are being studied by the regulatory authorities. The proposal is attractive as it provides for a more efficient use of the radio frequency spectrum; However, it weakens the competitive game and is a step on the road towards a network utility.

As said, at the top layer the competition between VMNOs is fierce. The standardisation and common use of APIs has resulted in a level playing field. The market actors include: former service divisions of incumbents; the national police, fire brigade and ambulance services; extensions of ICT departments within firms; specialised service providers; as well as entries by Amazon, a division of Google, Facebook for Business; and a range of start-ups.

The high penetration of small cells with associated fibre backhaul has become synergistic with the provision of fibre to the home. With the flexibility of TWDM-PON[75] these different needs are now served over a common infrastructure.

The layered model has also shown itself to be investment-friendly, as the separation of passive and active network elements allowed financing to be tailored to the different technology life cycles.

[75] TWDM-PON: Time and Wave length Division Multiplexing – Passive Optical Network. See for a discussion Lemstra (2016b) “The digital economy.” Available at: http://ssrn.com/abstract=2809892.

8 Policy and regulatory actions enabling the ‘Revolution’ image

This section describes 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 virtualisation provides.

8.1 Policy formation and implementation

The European Commission, with the support of the Parliament and Council, recognised the opportunity for leadership in 5G in serving industry verticals to boost economic growth and productivity across all sectors of the economy. It recognised 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 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.

Shifting the mobile communication industry momentum from leaders in consumer markets to leaders in services markets for vertical industries is recognised as requiring a mind-set change in the strategic vision of all actors involved. It requires a new prevailing industry logic. Virtualisation provides the technological opportunity. Active policy support and restraint in regulation are recognised as essential to ensure it leads to the desired future outcome.

The transition to the new industry configuration is recognised 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 recognised, success is not guaranteed as progress often involves other parties, such as industry specific regulators, which have to be brought on-board and need to be convinced of the merits of the projects.

Moreover, in many industries the government at local, regional and national level is required to invest in unison with the industry. This called for specific coordination efforts by industry among 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 allowing services to be tailored using applications programming interfaces (APIs). The timely availability of a common set of APIs implemented across the networks of multiple MNOs is recognised as essential for the ecosystem of VMNOs to flourish. It is also recognised that 5G 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 recognised as a potential bottleneck resource of strategic importance, their openness and timely availability being crucial to build industry momentum. To encourage the appropriate behaviour 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 necessary.

In addition, the industry is informed on 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 recognises the innovative aspect in the development of APIs and its gradual implementation. At the same time, it unequivocally communicates the intended end goal of this development.

In the same spirit, to ensure service compatibility across networks the industry is encouraged to establish an entity that can test and approve new applications for compatibility with the 5G standard and its APIs, much like the model of the Wi-Fi Alliance. The European Commission indicates that ETSI would be mandated if the industry would fail to set up such an entity in a timely manner.

8.2 Policy actions

While the nationally fragmented mobile communications markets were united into a European regional effort through GSM, the ultimate result of its global deployment was a process of global alignment along a common specification. Through the transition from ETSI to 3GPP, a global platform was established for the specification of the next generation of mobile communications, starting with UMTS. With the global adoption of LTE, the need for 3GPP2 covering the USA-based 3G specification work had ceased to exist and 3GPP becomes the *de facto* global platform for 5G specification efforts.

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 recognised. See also Figure 14.

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

While the success of GSM was directly related to opening-up the mass market of consumers, for 5G the new addressable market is that of the vertical industries and the Internet-of-Things, which have a lot in common. The market for connecting devices is many times the size of the market for connecting human beings. This market is already being addressed by existing technologies, all the way back to an extension of GSM to support extended coverage for IoT. However, the versatility of 5G and the ability to tailor services to specific IoT markets is leading to a rapid upgrade of all past IoT service implementations to 5G. 5G supports, on the one hand, the mass market for machine type communications and, on the other hand, the market for very reliable, low latency applications, in support of what is being called the Tactical Internet.

8.2.1 5G Action Plans

Another factor that contributed to the success of GSM has been the alignment of the stakeholders towards a coordinated introduction. However, in a highly competitive market such coordination is not likely to occur through coordination among the mobile operators[76], as was the case with GSM. In the case of 5G the coordination is pursued by the European Commission through the development of the '5G Action Plan' launched on 14 September 2016, as a partnership between the Commission, Member States and industry.[77] This plan recognises the 'chicken and egg' problem associated with the introduction of a next generation of mobile communications and aims to reduce the uncertainties between the supply and demand side through adequate coordination in terms of: (1) a common timetable for the introduction of 5G, including preliminary trials, pre-commercial trials and large scale introduction; (2) development of national roadmaps by the Member States; (3) allocation of (pioneer and full set of) radio spectrum bands for 5G applications; (4) development of national roadmaps for the deployment of 5G, including coordination of fibre and cell deployments and best administrative practices for cell deployments; (5) ensure timely availability of 5G standard, with support for a wide range of connectivity scenarios; (6) detailed roadmaps for the implementation of advance trials and plans

[76] 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 realise as the GSMA represents the interests of mobile operators globally.

[77] 5G for Europe: An Action Plan. Sources: COM(2016) 588 final ; SWD(2016) 306 final. Retrieved from: https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan?utm_source=twitter&utm_medium=social&utm_campaign=5G. Retrieved: 2016-09-26.

for technological experiments involving industrial sectors; (7) encouragement for national governments to use 5G for the PPDR services; and (8) arranging a venture financing facility for start-ups using the opportunity for customised communications services a part of the 5G architecture.

A '5G Action Plan II' is launched in September 2018, with an emphasis on enabling the vertical markets through network virtualisation. To assure a fast and broad deployment of tailored services as soon as a virtualised 5G is deployed, the Action Plan focuses on a series of workshops for prospective service providers (VMNOs) organised 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 organised 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.

8.3 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.[78]

Nonetheless, the 'Revolution' image raises important issues for consideration within the regulatory domain in two ways: (1) issues related to the introduction of 5G as 'just another' generation of mobile technology; and (2) issues related to virtualisation and enabling the emergence of new virtual service providers (VMNOs). The issues under (1) are largely the same as those identified under the 'Evolution' image.

Next to regulation considerations, coordination issues also hindered the successful introduction of 5G as a mobile communications technology and as a virtualised platform for service provision. Policy, regulatory and coordination instruments are available to facilitate the proper development of the market, and they play an important role at the regional, as well as the national, level. Furthermore, high transaction costs also impact the optimal operation of the market and, in relation to virtualisation, a lack of information exists among a much wider group of stakeholders. Note that the 5G Action Plans build upon coordination rather than regulation as part of their contribution to a successful introduction of 5G and of virtualisation.

[78] COM(2016) 590 final. Proposal for a Directive of the European Parliament and of the Council establishing the European Electronic Communications Code.

The issues the 'Revolution' image raises in relation to regulation, coordination and transaction costs that need to be addressed and resolved are listed below. The items in common with the 'Evolution' image are underlined:

- ***Market access – network level***: The new frequencies to be allocated and assigned as part of 5G are in the range above 6 GHz, in particularly in the bands above 24 GHz. These frequencies are intended for densification of the mobile network with pico and femto cells, including use within end-user premises. As such, the new bands do not provide an opportunity for network entry into the mobile communications market, as that requires frequencies below 1 GHz for coverage and above 1 GHz for supporting high data rates. Below 1 GHz bands have been made available as part of the Digital Dividend II, in particular the 700 MHz band. In most countries, this band was auctioned well ahead of the introduction of 5G, as an extension of the frequency ranges available for 4G. While this constitutes an opportunity for entry, it cannot be directly linked to creating success with 5G.[79]
  A new window of opportunity for entry would occur with licenses expiring and being reissued. However, this has already occurred in most EU member states well ahead of the introduction of 5G. With the new proposed Code, the license duration is being increased from typically 15-17 years to 25 years. This effectively rules out the expiry event as a network entry opportunity.
- ***SMP at the network level***: With a highly competitive services market, the concentration of market power at the network level is considered to be less of an issue. In fact, concentration improves the efficiency of the resources, in particular in terms of scarce radio spectrum resources. Moreover, it is expected to improve the willingness to invest by network operators (MNOs), which is one of the public policy objectives. Nonetheless, national regulatory authorities should monitor developments closely and enforce price cap regulation when deemed necessary, in a way that a reasonable return on investments is guaranteed.
- ***Market access – service level*****:** Enabling a vibrant level of competition among VMNOs is a key attribute of the 'Revolution' image. This is, in the first instance, left to the forces of the market, with close monitoring by the government to be able to facilitate the development when and where necessary and to intervene when all else fails. It is expected that the lessons learned from the development of MVNOs will contribute to the development of VMNOs, starting with good-faith contracting between wholesale and retail providers, respectively MNOs and VMNOs. Any restrictions that applied to MVNOs in certain member states should be removed.
- ***Market access – 5G standard with open APIs:*** The availability of a 5G network standard with open access APIs is expected to result from the standardisation efforts in 3GPP. ETSI is expected to be a major contributing regional partner. In case these industry-led

[79] See also Annex D.

efforts do not provide the expected results, a Directive may be issued by the European Commission to ETSI.

- ***Market access – uniform deployment of the 5G standard:*** Given the universal adoption of LTE, it is expected that MNOs will apply the 5G standard and its releases uniformly across the EU. To safeguard such an outcome, the European Commission has, as a matter of last resort, the option to mandate such uniform deployment by operators within the Union.
- ***Market access – compatibility and interoperability of devices and applications with APIs:*** To assure the devices and applications developed by service providers or third parties meet minimum network quality standards and are compliant with the 5G standard including its APIs, the industry is expected to establish a certification facility/entity, which could be modelled after the certification process applied by the Wi-Fi Alliance. If such a facility/entity is not forthcoming in a timely manner or with the expected functionality, the European Commission has the option to issue a mandate to ETSI to establish such a facility/entity.
- ***SMP at the service level***: With the introduction of 5G the MNOs are expected to open up the wholesale business to support a multitude of VMNOs at the retail level. It is expected that the higher willingness to pay and the additional volume of business oriented VMNOs are attractive for NMOs to be served on the wholesale level. Hence, they are expected to engage in good-faith private negotiations. To resolve any potential use of SMP by network operators (former incumbents) in the service market, regulators have the option to enforce functional separation. As an instrument of last resort they have the option to apply structural separation.
- ***National roaming***: is made possible through private contracting among the MNOs. It is an essential requirement for the delivery of PPDR services and as a fall-back mechanism in case of network outages. If the desired results are not forthcoming through private contracting in a timely manner, the regulator can make national roaming mandatory, to assure that under all circumstances the best possible service is made available to the end-users, in particular for services of public interest such as public protection and disaster relieve.
- ***Role of MVNOs***: In some, but not in all, member states MVNOs played an important role in extending the market and in keeping the market competitive. The experience obtained (positive/negative – including the pricing of different service levels) will serve as lessons learned for the introduction of VMNOs in a virtualised 5G environment, including an obligation to make a wholesale offer available and to enter into good-faith contract negotiations.
- ***Liberalisation of SIM usage and support of multiple VMNOs on a single device***: Through the use of the subscriber identity module (SIM), a close link between the MNO network and the end-user device was established, which has served the industry well in terms of providing a highly secure 'connection'. To support customer switching, the use

of SIMs has been extended to MVNOs, and more recently to IoT network operators. The latter is enabling 'wholesale' switching of the installed base of sensors and actuators provided with embedded so-called eSIMs. eSIMs are programmable to provide more flexibility in the provisioning, as well as future switching, of provider. In the perspective of full virtualisation a single device, such as a smart phone, may support multiple service sets from different VMNOs. Consider for instance a body area network providing heartbeat data from a sensor through Bluetooth to the smart phone to be forwarded to a healthcare data centre – a service provided by VMNO1. This service set requires the use of the highest possible quality of service class available. At the same time, the smart phone may be linked to a car navigation provider at a lower quality of service class – a service provided by VMNO2. While the principle of multiple-SIMs is well known, what needs to be resolved is how different and possibly conflicting service/application requirements are being resolved by the radio layer mobility manager and the quality of service manager. This is a topic that crosses the boundary between regulation and standardisation.

- ***Dedicated spectrum assignments***: Starting with 2G, dedicated spectrum bands have been assigned to particular user groups, such as the railways – GSM-R. In addition, the public protection and disaster relief sector (police, fire brigade, ambulance) have been users of dedicated spectrum as part of TETRA. In the transition to broadband, these users have aligned their interests with those of the mass market users to achieve economies of scale on the equipment side. This has occurred as part of 4G – LTE, typically dedicated assignments have been retained. However, 5G allows network resources to be allocated to specific user groups based on different requirements in terms of quality of service. This obviates the need for dedicated spectrum assignments.
- ***Network sharing***: To reduce investments and stimulate roll-out, network sharing has been promoted. Sharing varies from simple passive sharing of ducts and masts to more integrated schemes of active sharing all the way up to the sharing of core infrastructure. Different degrees of network sharing impact competition to different degrees. As the success of 5G depends on a quick roll-out for availability, any regulatory uncertainties regarding sharing should be removed *ex ante*.
- ***Technology neutrality***: By the time of introduction of 5G, all existing radio spectrum assignments will have been made technology neutral. This allows existing bands allocated for mobile use to be used by different technologies, essentially to be determined by the license owner.[80] This, in principle, allows optimisation of business operations across multiple generations. It could extend the life time of existing generations, but also facilitate an accelerated deployment of 5G if the business case is more compelling. In principle, it allows existing radio interfaces at the lower frequencies

[80] While spectrum bands 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 require adaptation of regulatory conditions.

to be used with a new 5G core and a new 5G radio access at higher frequencies to be added. This flexibility adds to the complexity of coordinated introduction of new 5G functionality, in particular any considerations on backward compatibility

- ***Trading, secondary market***: It has been argued that trading in radio spectrum usage rights has been less than anticipated when the scheme was introduced. Some trading has been occurring directly after an auction took place. Most of the licenses that changed ownership did so as part of an acquisition. Sometimes a license was returned to the government following an acquisition for re-issuance, rather than being offered in the market.[81] With 5G, the pressure on efficient radio spectrum usage increases further. Measures to make the market more 'liquid' are worth pursuing, such as: maintaining a register of license holdings; keeping a data base of market prices; providing a trading platform where demand and supply can meet to explore the possibilities of trades.
- ***Spectrum sharing***: With a limited range of radio spectrum being available and the demand for its use growing unabated, spectrum sharing is a means to improve efficient use. Current practice suggests that sharing is more easily accomplished among users that are alike, e.g. among government users or among private sector users.[82] Such sharing is not necessarily part of the DNA of the parties involved and typically requires mediation. In addition, it can benefit from a platform for knowledge sharing.[83]
- ***Spectrum pooling***: From the regulatory perspective, the outlook presented by the 'Revolution' image assumes a continuation in the use of exclusive licenses for access to the radio frequency spectrum dedicated for mobile use. This is in order to ensure long-term investments in networks, and access to the radio spectrum. Nonetheless, full virtualisation would imply that the frequency assets are pooled among the owners. This would constitute the most extreme scenario in terms of spectrum sharing.
- ***Coverage obligations***: In markets with a high degree of competition, coverage obligations may be dropped. However, in underserved areas, in particular in areas with little or no fixed network coverage, mobile coverage obligations may be required to fulfil public interest objectives.
- ***Indoor access***: To avoid distortion of competition, indoor access through distributed antenna systems or a neutral host, may be required through regulation, if parties cannot agree on a commercial arrangement.
- ***Interworking***: To enable seamless operation of virtualised services across national and international network domains, standardised APIs are required. Moreover, the management methods must be uniform across all types of VNFs, services and vendors.

[81] Mobile infrastructure devoid of an appropriate license has very little value, hence, the typical trade of assets in combination with a license.
[82] For an example of sharing in the area of critical and professional use of 4G see "Hub One", a case of sharing at the French airport Charles de Gaulle. (Olszanski et al., 2014)
[83] See the recommendations in "From spectrum management to spectrum governance" Anker (2017).

Furthermore, network function discovery must be uniform across all types of workloads and vendors' VNFs. This requires special attention in 3GPP and oversight by governments on the uniform implementation by the MNOs.

- ***Interoperability***: Resource management for a network slice may cross network operator domains and so requires cooperating resource management domains.
- ***Open Internet***: 5G is considered to serve the specific needs of vertical industries in terms of quality of service, including: availability; reliability; data rates; and latency. The Regulation on the net neutrality having come into force as of April 2016 is suggested to provide "…certainty for internet access providers and providers of content and applications to offer specialised services with specific quality requirements, including necessary safeguards to ensure the open internet is not negatively affected by the provision of these services. Specialised services cannot be a substitute to internet access; those services can only be provided if there is sufficient network capacity to provide them in addition to any internet access service and must not be to the detriment of the availability or general quality of internet access services for end-users."[84] The way 5G is being positioned may not contradict these rules considering the case of PPDR, which could be set as an exception under the rule. However, the 5G model hinges on services differentiation including different levels of quality of service. Network neutrality rules should be made conducive to the realisation of the 5G objectives. This issue should be clarified upfront to prevent unnecessary uncertainties hindering the broad uptake of 5G. Special attention should be given to Member States that have implemented more stringent net neutrality regulation, such as The Netherlands.
- ***Serving vertical industries – rules and regulations***: With software defined networking as part of 5G, and already preceded by network slicing a part of 4G, different needs in terms of services and quality of service can be provided simultaneously through a single 5G network fabric. This enables serving the needs of specific industry verticals and facilitating their digital business models. As a consequence, industry specific regulations and electronic communications regulations become close twins. A successful deployment of 5G being based on serving verticals[85], suggests the need for mutual understanding of regulations, in terms of purpose and content. This includes potential impacts on data protection and privacy. In addition, liabilities crossing traditional boundaries are an aspect that requires attention from industry and regulators on both sides.
- ***Harmonisation within vertical industries***: To enable European-wide services, the differences in regulatory requirements within a particular industry vertical across EU member states have to be resolved, to the extent it hinders seamless service provision.

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[84] Source: https://ec.europa.eu/digital-single-market/en/open-internet-net-neutrality. Retrieved : 2016-10-03. See also Annex E.

[85] Consider for instance electronically mediated autonomous driving and remote surgery.

- ***Serving PPDR as an industry vertical – minimum requirements***: The way ICTs are used in society makes the electronic communications infrastructure a 'critical infrastructure'. If we add to this the use of the 5G network to provide PPDR services, the question may be raised whether a minimum quality of service should be set, that the infrastructure must be able to provide under a specific set of circumstances. If so, will this requirement just be a matter of properly engineering the network or are their implications for the architectural design of 5G? Will this minimum requirement be offered as part of the competitive market, or is regulatory intervention required?
- ***User data***: In serving vertical industries, and enabled by virtualisation, one may expect to see the extensive use of user data in shaping services provided by mobile service providers. Current rules make a distinction between network operators and OTT service operators in terms of user data. Consideration should be given to the new role of VMNOs. Any potential barrier should be identified upfront and removed to facilitate the 5G deployment as envisioned.
- ***Data protection and privacy***: The Internet-of-Things is expected to encode 50 to 100 trillion objects globally and to be able to follow these objects. Human beings in urban environments are expected to be individually surrounded by 1000–5000 traceable objects. This raises new issues around privacy and security, as well as of autonomy and control.[86]

[86] Source: Höller et al. (2014).

9 Summary

In this Section, the perceived pros and cons of the two contrasting stylised images of the future of 5G are summarised. As there are different stakeholders, there are likely different perspectives on one and the same topic. Therefore, the pros and cons are presented using six different perspectives: (1) European policy, general industrial; (2) European policy and regulation, electronic communications; (3) incumbent mobile operators; (4) potential mobile market entrants; (5) industry verticals; and (6) consumers as end-users. Note that the presentation of the pros and cons is not meant to be exhaustive. Moreover, aspects which are related to the introduction of 5G, but where there are no differences between the two images, are not included.

European policy, general industrial and electronic communications

The stylised image that is considered to have the largest impact on economic development in Europe is the 'Revolution' image. The focus of this image is to unlock the potential of the vertical industries to extend their business services using the possibilities that virtualisation and open APIs as part of 5G are offering.

Through the offering of business service bundles, it is also the image that is expected to unlock a higher willingness to pay. This should benefit retail and wholesale mobile communication providers and improve the willingness to invest in 5G infrastructure.

The 'Revolution' image creates momentum by introducing virtual mobile network operators (VMNOs) on the retail level across all vertical industries simultaneously. This is achieved by leveraging industry expertise of in-house ICT service providers, specialised service providers, divisions of MNOs dedicated to verticals and start-ups. VMNOs may include current OTT providers who see opportunities to expand the current 'best effort' based business into offerings with defined levels of quality.

The 'Evolution' image, as it assumes the continuation of current trends, builds on the mass market of broadband consumers, which is complemented with service offerings to industry verticals. The new business markets are developed by the divisions of the MNOs dedicated to industry verticals.

In this image, with an emphasis on the mass market of broadband consumers, the margin pressure is expected to continue, which constrains abilities to invest in 5G infrastructure. However, the prospect of lower capital costs and lower operational expenditures for 5G, in comparison with 4G, has the ability to improve margins.

Policy makers may remain concerned about underinvestment in the sector.

European policy and regulation, electronic communications specific

The 'Evolution' 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 5G deployment. The current practice of industry oversight continues. 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 the net neutrality ruling becoming a constraint in the development of services to industry verticals, revisiting the net neutrality rules will be necessary.

The 'Revolution' image calls for a much more pro-active policy and regulatory stance. The unlocking of the industry verticals requires enabling VMNOs in support of each industry vertical. These VMNOs are likely to emerge as national level initiatives, and to grow into regional initiatives. To ensure that these business development efforts in the mobile communications market can be successful, policy support and regulatory restraint are required. In addition, a level playing field is required to allow the industry insights accumulated by, e.g. the in-house ICT service providers, to be leveraged. Hence, close market monitoring at the national level will be required, along with 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 organising workshops on the use of the open APIs are possible remedies in this case. In the 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.

The use of standard and open APIs across the EU enables borderless end-user services to be provided.

Through enabling a vibrant market for VMNOs, the concerns regarding consolidation at the MNO level are reduced.

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.

In the 'Revolution' image, a higher willingness to pay for business services is expected. To open-up the additional revenue streams, investments are required for market development.

In the 'Evolution' image, the degree to which the vertical markets are developed is essentially up to the incumbent operators.

In the 'Revolution' image, the market development is expected to go faster and to be more broad as MNOs enable MVNOs as new players. These are players who are likely to be 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 increased competition at the retail level.

In the first instance, the market is expected to develop based on good faith negotiation between MNOs as wholesale providers and VMNOs as retail providers. 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. 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.

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.

The image allows market players now active as OTT operators to become VMNOs, and to extend their services portfolio with managed services.

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.

In the 'Revolution' image, the new role of VMNOs allows firms within a particular vertical industry to extend their digital transformation process of the business to include end-users, products and services. As a VMNO, these firms can decide how to tailor the mobile communication services they wish to provide and how to combine these with other 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 firm's boundaries.

The use of standard and open APIs across the EU enables borderless end-user services to be provided.

Consumers

In the 'Evolution' image, the mass consumer market is considered to be central stage. In the 'Revolution' image the consumer market is another 'vertical' with services specifically tailored to its needs. This image recognises 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.

Annex A: Characteristics of the mobile communications business

The mobile communications business is an infrastructure business. The business is characterised by deep and long-term investments in a dense network of radio towers being linked with backhaul transmission equipment to centralised switching nodes and application servers, which in turn connect to fixed backbone networks.[87] This is complemented with investments in management, maintenance, billing and customer care systems, and with investments in licenses for the use of the radio frequency spectrum.

End-users, businesses and consumers, invest in the devices that make use of the infrastructure, predominantly smartphones and dongles. In some countries, the smartphones are pre-financed by the mobile operators to lower the barrier to adoption.

Over time, the usage has shifted from pure mobile telephony to providing access to the Internet for a wide range of services, including email access, search, voice, texting, music, video and social media.

In addition to the human user, there is an increasing number of so-called machine users, whereby wireless communication provides connectivity for sensors and actuator with some type of centralised processing unit. An example of early application of M2M is smart electricity metering. Today, M2M falls under the much broader term Internet-of-Things (IoT), which includes all things imaginable that can be interconnected using the Internet.

With typically 2-5 mobile network operators (MNOs) in each country and a range of mobile virtual network operators (MVNOs) in some countries, the mobile markets are largely competitive and for that reason do not present a major issue for regulators.

However, in Europe, where the calling-party-pays principle applies, the operators each have a monopoly on the terminating part of the calls to their subscribers and hence this market is regulated. Furthermore, international roaming tariffs have become subject of European Commission intervention.

Nonetheless, national governments have a prominent role in the services sector, as they control access to the market through the initial assignment of licenses to the use of the radio frequency spectrum. Today, licenses for mobile communication are or have been made tradable. However, at this point in time, the number of trades in licenses for mobile communications is rather low and transfers in ownership are typically taking place as part of mergers and acquisitions.

[87] Reference is made to terrestrial mobile communications, whereby our story line starts with the first generation of cellular mobile communications networks. Other forms of wireless communications offered either in competition with mobile or as complementary service include: broadcasting; satellite; private mobile radio (PMR); public use for public protection and disaster relief (police, ambulance, fire brigade - PPDR); microwave links; aeronautical; and short range devices (SRD), including Wi-Fi.

Sometimes, some reshuffling takes place following an auction held to assign the initial usage rights.

National governments coordinate the use of the radio frequency spectrum at the regional level; in Europe through the CEPT.[88] In the USA radio spectrum issues are addressed at the federal level through the Federal Communications Commission (FCC). At the global level, coordination takes place through the ITU Radiocommunication sector (ITU-R), which convenes the World Radio Conference (WRC) typically every 3-4 years. In ITU-R the allocation of radio spectrum bands to particular uses and use groups is determined. As already mentioned, the assignment of usage rights to particular users takes place at the national level.

In Europe, the Radio Spectrum Policy Group (RSPG) is a high-level advisory group that assists the European Commission in the development of radio spectrum policy.[89] Members of the RSPG are senior representatives of the Member States and official representative of the European Commission.

Through the 2002 Radio Spectrum Decision, the European Commission has created the possibility of imposing technical harmonisation measures. This decision created a legal framework for 'the harmonised availability and efficient use of radio spectrum in the European Union for the establishment and functioning of the internal market in Community policy areas, such as electronic communications, broadcasting and transport.' In the implementation of the Decision, the EC is assisted by the Radio Spectrum Committee (RSC). The EC can furthermore issue mandates to CEPT to advise on technical harmonisation measures. The implementation of these measures can be made mandatory for EU member states.[90]

In the USA, the National Telecommunications and Information Administration (NTIA), located within the Department of Commerce, is the Executive Branch agency that is principally responsible by law for advising the President on telecommunications and information policy issues, which includes radio spectrum policy.

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[88] CEPT: Conférence des Administrations Européennes des Postes et Télécommunications (European Conference of Postal and Telecommunications Administrations), cooperation of 48 European countries to regulate post, radio spectrum and communications networks. The early activities of CEPT concerned primarily tariff principles. Later, the activities expanded to include cooperation on commercial, operational, regulatory and technical standardisation issues. Following the liberalisation of the sector, CEPT became a body for coordination among policy makers. Within CEPT, the European Radio Committee (ERC) was set up to address all radiocommunciations related matters. The prime objective was to develop European harmonisation measures for the allocation and the use of radio frequencies. The ERC seeks consensus between administrations for the development of decisions and recommendations, which are non-binding. The role of the ERC has been recognised by the European Commission in 1990 and the support reiterated in a 1992 Council Resolution. Sources: Anker, Lemstra & Hayes (2010) and http://www.cept.org/ Retrieved: 2016-07-04.

[89] The RSPG was established under Commission Decision 2002/622/EC, which was one of the Commission's initiatives following the adoption of the Radio Spectrum Decision 676/2002/EC. The remit of the RSPG has been extended as a result of the adoption of the new telecom regulatory framework in 2009 (Commission Decision 2009/978/EU of 16 December 2009 amending the Decision establishing the RSPG). According to the new remit, the RSPG can now also be requested by the European Parliament and/or the European Council.

[90] Decision 676/2002/EC of the European Parliament and of the Council of 7 March 2002 on a regulatory framework for radio spectrum policy in the European Community (Radio Spectrum Decision)'. Official Journal. L 108, 1-6.

All in all, the national and regional governments are important actors in mobile communication markets.

The industry furthermore coordinates through standardisation bodies such as ETSI, ANSI and the IEEE.[91] Standardisation efforts are primarily aimed at realising compatibility among equipment from different providers and realising interconnection and interoperability among networks owned by different operators. In the context of mobile communications, the standardisation efforts have grown beyond defining an interface to become a systems specification. Standardisation plays an essential role in achieving economies of scale.

The interests of industry actors are channelled through organisations such as GSMA, which started its life by combining the interest of the mobile network operators (MNOs) in the coordinated roll-out of GSM in Europe.[92] In the USA, the telecom industry interests are represented through the Telecommunication Industry Association (TIA), the specific interests of the cellular operators in the CTIA, and the governmental users of radio spectrum through the NTIA.[93]

Next generation mobile communications

While technological progress in the sector is continuous and network capacity is added incrementally as demands grow, the infrastructural nature of the business forces major technological changes to be introduced as a 'next generation' network upgrade, which typically coincides with an increase in network system capacity, enabled by governments opening up a new frequency band. This typically requires new radios to be deployed in the radio base stations and in the terminal devices.[94] The major roll-out of new infrastructure equipment, together with new terminal devices, constitutes a next generation of mobile communications. A next generation also adds new functionality and thereby new end-user services. In practice, three generations of mobile equipment are in service: one being phased out, one in full use and one being introduced.

[91] ANSI: American National Standards Institute; ETSI: European Telecommunication Standards Institute; IEEE: Institute of Electrical and Electronic Engineers.
[92] The general interests of (fixed) telecom operators is represented by ETNO, the European Telecommunications Network Operators' Association.
[93] GSMA: GSM Association; CTIA: The Wireless Association, originally known as the Cellular Telephone Industries Association.
[94] The term 'base station' was introduced in the context of 2G. With 3G, the term 'Node-A' was introduced.

Annex B: Abbreviations and acronyms

Acronym:	**Meaning:**	**Remarks:**
3D	Three Dimensional	
1G	First generation mobile (cellular) communication	E.g. NMT450: Provides telephony
2G	Second generation mobile (cellular) communications systems	E.g. GSM: Provides telephony and low data rate services, based on circuit switching
2.5G	Intermediate upgrade of 2G	Incl. GPRS: Provides packet data services
3G	Third generation mobile (cellular) communication	E.g. UMTS: Provides voice and broadband data communication services
3.5G	Stepping stone from 3G to 4G	E.g. $HSPA^+$
3GPP	3G Partnership Project	Industry standards group
4G	Fourth generation mobile (cellular) communication	Also denoted as LTE. All-IP based; incl. VoLTE
5G	Fifth generation mobile (cellular) communication	All-IP based; includes SDN and NFV
5GPPP	5G Public Private Partnership	
AMPS	Advanced Mobile Phone System	USA
ANSI	American National Standards Institute	
API	Application Programming Interface	
ARPA	Advanced Research Projects Agency	USA
CAGR	Cumulative Average Growth Rate	
capex	capital expenditures	
CDMA	Code Division Multiple Access	CDMA-450: operating in 450 MHz band
CEPT	Conférence des Administrations Européennes des Postes et Télécommunications	Association of European Postal and Telecommunications Administrations (PTTs)
CN	Core Network	
CP	Control Plane	
CSFB	Circuit Switched Fall-back	
CT	Communication Technology	
CTIA	Cellular Telephone Industries Association	Now denoted as the Wireless Association
D2D	Device to Device	
DCS	Digital Communications System	DCS1800: operating in 1800 MHz band
DT	Deutsche Telekom	
DTI	Department of Trade and Industry	UK government entity

Acronym:	**Meaning:**	**Remarks:**
EB	Exabyte	
EC	European Commission	
EDGE	Enhanced Data rate for GSM Evolution	
Ent Mgmnt	Enterprise Management	
EPC	Evolved Packet Core	
ERC	European Radio Committee	
Est. rout	Established routine	
ETSI	European Telecommunication Standards Institute	
EU	European Union	
FC	Fog Computing	
FCC	Federal Communications Commission	US national regulatory authority
FNO	Fixed Network Operator	
FP7	7th Framework Programme	7th Framework Programme for Research and Technological Development in the EU
FR	France	
FT	France Telecom	
GHz	Giga Herz	
GPRS	General Packet Radio Service	
GSM	Groupe Spéciale Mobile, later to be known as Global System for Mobile Communications	Working party of CEPT; GSM-900: operating in the 900 MHz band; GSM-1800: operating in the 1800 MHz band
GSMA	GSM Association	
GSM-R	GSM-Rail	
HDMI	High-Definition Multimedia Interface	
HSDPA	High Speed Downlink Packet Access	
HSPA	High Speed Packet Access	$HSPA^+$ upgrade of HSPA
HSUPA	High Speed Uplink Packet Access	
HTML	Hyper Text Mark-up Language	
HUD	Heads-up Display	
ICT	Information and Communication Technology	
IEEE	Institute of Electrical and Electronic Engineers	
IETF	Internet Engineering Task Force	

Acronym:	**Meaning:**	**Remarks:**
IMT	International Mobile Telecommunications	
IMS	International Mobile System	
IoE	Internet of Everything	
IoT	Internet of Things	
IP	Internet Protocol	IPv6: IP version 6
ISG	Industry Standards Group	
ISOC	Internet Society	
IT	Information Technology	
ITU	International Telecommunications Union	Part of the United Nations organisation
ITU-R	ITU-Radiocommunication Sector	
LAN	Local Area Network	
LAA	License Assisted Access	
LPWA	Low Power Wireless Access	
LTE	Long Term Evolution	As related to cellular communication, also denoted as 4G, fourth generation; LTE Advanced upgrade of LTE
M2M	Machine to Machine	
MB	Mega Bytes	
MBB	Mobile Broad Band	
MBPS	Mega Bit Per Second	
MEC	Mobile Edge Computing	
METIS		Research project dedicated to the development of 5G within the EU co-funded FP7 and Horizon 2020
MHz	Mega Hertz	Unit of frequency; 1 Hz is once cycle per second
Mln	million	
MMS	Multi Media Services	
MNO	Mobile Network Operator	
MoU	Memorandum of Understanding	
MSN	Microsoft Network	
MTC	Machine Type Communication	
mMTC	Massive MTC	
MVNO	Mobile Virtual Network Operator	
NFV	Network Function Virtualisation	

Acronym:	**Meaning:**	**Remarks:**
NGN	Next Generation Network	
NGMN	Next Generation Mobile Network	Mobile operator alliance
NMT	Nordic Mobile Telephone system	NMT-450: operating in the 450 MHz band
NTIA	National Telecommunications and Information Administration	US government entity
OAM	Operations Administration Management	
OECD	Organisation for Economic Cooperation and Development	
OFDMA	Orthogonal Frequency Division Multiple Access	
opex	operational expenditures	
OTT	Over the Top (services)	
PC	Personal Computer	
PCS	Personal Communication System	
PMR	Private Mobile Radio	
PoP/POP	Point of Presence	
PPDR	Public Protection and Disaster Relief	
QoS	Quality of Service	
R99	Release 99	
R&D	Research and Development	
RACE	Research and Development in Advanced Communications Technologies for Europe	
RAN	Radio Access Network	
RAT	Radio Access Technology	
RSC	Radio Spectrum Committee	
RSPG	Radio Spectrum Policy Group	EU entity
RTV	Radio and Television	
RTTE	Radio Termination and Terminal Equipment	
SDN	Software Defined Network	
SEPT	Societal, Economical, Political and Technological	Dimensions of the Wheelen & Hunger model
SIM	Subscriber Identity Module	eSIM: embedded SIM
SME	Small and Medium size Enterprise	
SMP	Significant Market Power	

Acronym:	**Meaning:**	**Remarks:**
SMS	Short Message Service	
SRD	Short Range Device	
TACS	Total Access Communication System	
TCCA	TETRA Critical Communications Association	
TDMA	Time Division Multiplexed Access	
TETRA	Terrestrial Trunked Radio	
TCP	Transmission Control Protocol	
TIA	Telecommunication Industry Association	
UE	User Equipment	
UHF	Ultra-High Frequency	
UK	United Kingdom	
uMTC	ultra-reliable low latency MTC	
UMTS	Universal Mobile Telephony Service	Also denoted as 3G, third generation mobile communication
UP	User data Plane	
USA	United States of America	
VMNO	Virtual Mobile Network Operator	
VNF	Virtual Network Function	
VoLTE	Voice over LTE	
VoIP/VOIP	Voice over IP	
w/	with	
WAP	Wireless Application Protocol	
WARC	World Administrative Radio Conference	
WCDMA	Wideband CDMA	
Wi-Fi	Certification mark for interoperability between IEEE 802.11 conformant devices	
WiMAX	Worldwide Interoperability for Microwave Access	
WP	Working Party	
WRC	World Radio Conference	
WWW	World Wide Web	
XaaS	Anything as a Service	

Annex C: Timeline of major mobile communication events[95]

Note: the entries under the heading "Communication-Technology Event" are selected on the basis of their relationship to the developments in cellular communications. The information on the developments in the other categories has been retained to provide the reader with a broader context.

Date:	Internet Event:	Information-Technology Event:	Communication-Technology Event:	Social-Political Event:
1946		First general purpose computer ENIAC by Mauchly and Eckert	AT&T introduces first mobile telephone system in St. Louis	
1947			Invention of the transistor at Bell Labs by Bardeen, Brattain & Shockley	Organisation for European Economic Cooperation established
			Introduction of cellular concept by Ring at Bell Labs	
1962			AT&T demonstrates UHF cellular system in Murray Hill	
1970	ALOHAnet, the first radio-based packet network developed at the University of Hawaii, funded by ARPA	University of California Irvine Ring, first LAN by Farber	FCC sets aside 75 MHz of spectrum for cellular systems	
1971	Email invented by Tomlinson at Bolt Beranek and Newman (BBN)	Invention of microprocessor by Hoff at Intel	AT&T, RCA and Motorola file proposals at FCC to use 800 MHz band for cellular	
1975	Ethernet created by Metcalfe (based on 1973 PhD)	Founding of Microsoft by Gates and Allen	Illinois Bell applies at FCC for permission to build Chicago cellular AMPS development system	

[95] Hillebrand (2002); Lemstra (2006 and subsequent updates); Cox (2014).

Date:	Internet Event:	Information-Technology Event:	Communication-Technology Event:	Social-Political Event:
1979	USENET (newsgroups) introduction by Truscott, Ellis and Bellovin based on UUCP	Demonstration of VisiCalc by Bricklin & Frankston	NTT launches first cellular system	European Monetary System (EMS) established
1981	BITNET introduction based on IBM RJE	Launch of IBM PC	First (successful) cellular system in service, NMT450 in Saudi Arabia	Reagan President of the US
1982	Email exchange between ARPA and other computer networks	Compact Disc introduced	FCC starts acceptance of applications for 1st round cellular licenses, based on comparative hearings	
	Eunet formed for email and Usenet services	First portable computer, designed by Moggridge	CEPT initiates GSM project	
1983	Voice Funnel, early VoIP	Bulletin boards on PC networks	Ameritech Mobile Communications launches first cellular system in Chicago	
			FCC introduces lottery to award cellular licenses in 2nd round	
1984	Internet named	Point&Click interface developed by Xerox	EC endorses GSM project	
1986			NMT 900 placed in service in the Nordic area	
			Qualcomm files patent for use of CDMA in cellular	
1987	UUNet established as not-for-profit company	IBM introduces Video Graphics Array 640x480 (VGA) on IBM PS/2 computers	EU Green Paper on a Common Market for Telecom	October stock market crash
1988			Establishment of ETSI	
1989	IETF established	Stallman establishes Free Software foundation, starts project to develop free version of UNIX	TIA selects TDMA as digital cellular standard	Fall of the Berlin Wall

Date:	Internet Event:	Information-Technology Event:	Communication-Technology Event:	Social-Political Event:
1989	PSINet established to provide TCP/IP network services to businesses		First CDMA field trial by PacTel Cellular	
	Cisco implements support site for software downloads and upgrades		GSM standards work moved to ETSI	
1990	HTML and WWW by Berners-Lee at CERN		TIA approves IS-54 standard (TDMA)	
1991	www released by CERN “the web is born”	Kodak introduces first digital single-lens reflex camera	July 1, first GSM call made by Telenokia and Siemens in Finland	Gulf war
1992	ISOC formed		GSM-900 launched	
			Introduction of prepaid mobile service, Mexico	
			Dec. 3 first SMS message sent by Papworth	
1993	Introduction of Mosaic browser at the NCSA by Andreesen	Microsoft initiates project Marvel, to become the precursor of MSN	Australia deploys GSM, first outside Europe	Clinton President of the USA
			TIA adopts CDMA standard (IS-95A)	
1994	Introduction Netscape Navigator	McCool creates Apache web server software as open source at University of Illinois/NCSA	FCC licenses PCS or 1900 MHz GSM	EU Maastricht Treaty
1995	Start of Amazon.com	Sony Playstation introduced	First GSM 1900 network operational in the USA	WTO assumes implementation of GATT
1995	Yahoo! Incorporated	Dell introduces on-line configuration of PCs	Sprint PCS adopts CDMA technology	
1997	Netflix founded by Hastings and Randolph		EU Decision on licensing of 3G spectrum	Greenspan’s irrational exuberance speech

Date:	Internet Event:	Information-Technology Event:	Communication-Technology Event:	Social-Political Event:
1998	Google established by Brin and Page	Dept. of Justice vs Microsoft for tying the Internet browser to the operating system	EU Jan. 1 target date for opening telecom markets to full competition	
			TIA endorses cdma2000 as 3G solution for ITU	
			First 3GPP meeting held	
1999	NetAid webcast		Introduction of GPRS	Repeal of the Glass-Steagall Act
	Falling develops Napster for sharing music files		Launch of i-mode by NTT-DoCoMo in Japan	US State Court rules domain names are property that may be garnished
	Cyworld introduced in Korea		Nokia introduces first WAP enabled mobile phone	
			Ericsson and Qualcomm reach cross licensing agreement	
2000	Friis and Zennström establish KaZaA	First Bluetooth consumer product introduced	First UMTS auction in the UK	EU govts agree on Lisbon Agenda
			SK Telecom (Korea) launches first 3G CDMA2000 1X commercial service	
2001	SETI@Home launched		3GPP standard for All-IP network Release 5 issued (Release 2000)	9-11 terrorist attack
2002			GSM800 introduced	
			First cdma2000 network in service	
2002			First Multimedia messaging service launched	
2003			Frist EDGE network in service	

Date:	Internet Event:	Information-Technology Event:	Communication-Technology Event:	Social-Political Event:
2005			First HSDPA network in service	
2007	Google acquires DoubleClick for $3.1 bln	Waze founded by Levine and Shinar	Launch iPhone by Apple	EC investigation into Microsoft for leveraging SMP in OS into web browsers
2008	Launch Apple App Store		Apple announces iPhone3	
	Airbnb founded		3GPP releases standard for 4G (Release 8)	
			Android 1.0 OS launched by Google	
2009	WhatsApp founded by Acton and Koum	HDMI 1.4 specification released for 4k 24 f/s	3GPP Release 9	
			First HSPA+ network in service	
			First LTE network launched	
2010	Instagram developed by Kevin Systrom and Mike Krieger	Apple announces iPad using cellular of Wi-Fi for Internet access		EC opens investigation into Google for preferences of its own services in search results
2011	Microsoft acquires Skype from eBay for $18.5 bln	Lionbridge and IBM partnership offers Geofluent online instant chat translator	Apple announces iPhone 4S with Siri voice recognition	
	Google acquires Motorola Mobility for $12.5 bln	Apple introduces iPad2	3GPP release 10	
2012	Facebook acquires Instagram for US$1 bln	Apple introduces iPad Mini	Apple announces iPhone5	
			3GPP Release 11	
2013	Apple announces iCloud	Apple introduces iPAd Air and iPad Mini 2	Nokia sells devices business and licenses patents to Microsoft	
			Apple announces iPhone 5c and 5s	

Date:	Internet Event:	Information-Technology Event:	Communication-Technology Event:	Social-Political Event:
2014	Facebook acquires WhatsApp for $22 bln	Apple introduces iPad Air 2 and iPad Mini 3	Apple announces iPhone 6 and 6Plus	EC strategic R&D collaboration agreement with South Korea
			3GPP Release 12	
2015				EC strategic R&D collaboration agreement with Japan
				EC strategic R&D collaboration agreement with China
2016	Verizon to acquire Yahoo for $4.8 bln	EMC acquired by Dell and taken private	Apple announces iPhone 7	EC strategic R&D collaboration agreement with Brazil
			AT&T to acquire Time Warner valued at $85.4 bln	EC releases 5G Action Plan
			3GPP Release 13	
2017	IPO Snapchat at US$24 bln		3GPP Release 14	

Annex D: 5G and its spectrum requirements - an overview[96]

By Martin Cave & William Webb

The spectrum world is now focused on 5G, which is requiring more imaginative thought than its predecessor generations. The main body of this report is devoted to outlining two options – an evolutionary and a revolutionary one – of the development of 5G. Clearly, which of these broad options eventuates (or whether what we see is a combination of them in different regions) will have profound impact on the need for spectrum. We use the term "5G" here to include both evolutionary and revolutionary approaches since the need for spectrum is likely to be similar regardless.

Given these uncertainties, it is more fruitful to discuss the types of innovation in spectrum management which is likely to be required to meet the expected demand for spectrum, rather than discuss particular bands – although these more granular decisions are being widely debated within the 5G community and individual firms, verticals and countries are vigorously expressing and promoting their own preferences.

Regarding 5G, WRC 15 agreed to study 11 bands for possible identification. There are eight bands with an existing mobile allocation:

- 24.25 GHz - 27.5 GHz
- 37 - 40.5 GHz
- three bands in 40 GHz
- 50.4 - 52.6 GHz
- 66 - 76 GHz
- 81 - 86 GHz

and three bands with no existing mobile allocation:

- 31.8 - 33.4 GHz
- 40.5 - 42.5 GHz
- 47 - 47.2 GHz

The results of these studies will be discussed at WRC-19.

In addition, the US regulator, the FCC has stated an intention to open up additional frequency in the 28 GHz band, at 27.5 - 28.35 GHz, and certain other unlicensed bands.

[96] This annex draws on some material published in the Antitrust Chronicle, November 2016.

This and other announcements and interventions may be part of strategies pursued by individual firms (equipment manufacturers and operators), verticals and countries jockeying for position in the development of 5G.[97]

The choice of high-frequency bands is an interesting development. So-called millimetre wave spectrum has the characteristic that the range of any base station using it is small – which makes the construction of the network expensive, and possibly beyond the capacity of less sparsely populated areas to support commercial operations.

It is also the case that 5G differs from previous cellular generations in both its breadth and its uncertainty. In the past a new generation has broadly been faster than the previous one, with specific frequency bands designated near-globally to support it. There is not the space here for a detailed discussion of the arguments around 5G's role, but broadly it is expected that it will be faster than 4G, provide greater capacity especially in urban areas, provide support for the Internet of Things (IoT), integrate better with other systems such as Wi-Fi, and potentially enable new services via extremely fast links. Equally, some have noted that with mobile network operators (MNOs) seeing declining profitability and end-users generally not paying more for faster services, the business case for many of these is unclear and it is possible that 5G may just end up being the continued evolution of 4G. Robust competition between MNOs is seen by many regulators as a way to ensure rapid deployment of 5G services, but the costs of delivering multiple 5G networks are driving operators to consider cooperative models.

Achieving all of these aims requires a range of different bands of spectrum but the uncertainty means that timing and modes of access need to be flexible. At a high level, current modes of spectrum access for 5G being discussed include:

"Classic" access to harmonised bands agreed world-wide. The preferred approach is for regulators to clear the bands then auction them with exclusive licenses to the mobile operators. The key focus of the 5G community is the 700 MHz and 3.4-4.2 GHz bands but others are also discussed. However, these bands are not available worldwide – for example the USA has already auctioned 700 MHz and is enabling unlicensed access to 3.5 GHz.

Access to bands below 6 GHz on a license shared[98] basis. Operators consider that they will need substantial spectrum below 6 GHz to provide capacity and relatively high data rates. Attention has focussed on the 4 GHz band but this is used globally by a range of other services such as air-

[97] The views of the various protagonists are presented, together with a great deal of other information, in Dugie Standeford, Martin Sims and Dr Jonathan Watson, "The 4G and 5G spectrum Guide", Policytracker, October 2016.

[98] Licence shared access (LSA) involves maintaining the primary radio link to the mobile in licensed spectrum but opportunistically using shared spectrum for additional downlink bandwidth, enabling faster download and more capacity. Sharing is normally limited to a small number of users who reach appropriate agreement with the licence holder and may require database access.

traffic control and fixed links. It seems unlikely that it can be cleared and auctioned within the timescales desired in all countries and so approaches to sharing with incumbents, with an agreed priority of access, are being investigated.

***Use of unlicensed spectrum as an additional resource*.** Even with all these bands some fear that there will be insufficient spectrum and that making use of the unlicensed bands at 5 GHz may be necessary. These bands are widely used for Wi-Fi, raising fears of interference. Various approaches where the MNOs might opportunistically use the bands for additional downloading have been proposed.

***Access to high-frequency bands for new business cases*.** The ultra-fast solutions will require use of very high frequency bands likely above 20 GHz. With their short-range propagation, and with the uncertainty of the timing and success of 5G solutions, shared access may be suitable.

5G and shared access

From the discussion above, it is clear that only a small part of 5G spectrum will be found through classical “clear and auction”. Much of the rest will come from some form of shared access. Here, we provide an overview of sharing, show which elements are relevant to 5G and consider whether sharing can foster competition.

Primitive forms of spectrum sharing among alternative uses or users have been in place from the beginning of spectrum use. For example, spectrum can be shared temporally or geographically via a conventional licensing process. So-called spectrum commons have also existed for a long period. Here, users of very low powered devices (which are unlikely to interfere with one another) can transmit without a licence provided that they obey specified power limits.

However, it is now apparent that a more efficient way of sharing the spectrum in a wider class of environments is via ‘dynamic’ spectrum sharing, which allows one user opportunistic access to spectrum not being used by another user. The structure we follow in this section is set out in the simple table below which has two dimensions – whether access is restricted and whether interference is controlled in any way once access has been granted.

	Unrestricted access	**Restricted access**
No interference control	Commons	Classical sharing
Controlled interference	Database-controlled access	Collaborative working with incumbent

We can see how these apply to 5G in the modified table below.

	Unrestricted access	Restricted access
No interference control	(1) Cellular use of unlicensed bands at 5 GHz	(2) Sharing with incumbents in high-frequency bands
Controlled interference	(3) Not used (but some non-5G projects still active in places)	(4) Working with air traffic control and others at 4 GHz

We discuss each of these below.

Case (1) – access to 5 GHz bands. The 5 GHz band is classic "spectrum commons", with no licenses granted[99] and access allowed to technologies that meet general rules on power levels and politeness. In principle, as long as the variant of 5G proposed for this band meets such requirements there should be little debate as to whether to allow it. However, a case of "too big to fail" has developed which causes regulators and others to pause for thought. The band is currently almost exclusively used by Wi-Fi. If the 5 GHz band was to become congested due to 5G using the band this might cause significant consumer detriment.

This issue raises interesting questions as to whether regulators should recognise unlicensed applications that have become successful and offer them some degree of protection. It would intuitively appear that this is both appropriate and hard to avoid, but it sets precedents that may lead to mismatched expectations in the future. It also shows that the value derived from unlicensed bands is substantial – perhaps greater than that derived from licensed bands on a per MHz basis. This implies a much greater focus on regulation of unlicensed spectrum moving forward, including more efforts to identify additional bands for unlicensed usage and to monitor and manage existing bands. Such efforts would be most effective on a global basis.

Case (2) –sharing with incumbents in high frequency bands. In these bands the existing licence holders are often satellite users and fixed links. Both are static, with directional antenna and in many cases tend to be outside of urban areas. Given that the best bands for 5G are not yet determined, and the extent of deployment and business model for 5G ultra-fast solutions very unclear, then clearing these users appears premature. Instead, 5G could work around them. Where sharing has been proposed, regulators tend towards geographical exclusions zones around existing users.

The biggest challenge with this approach is the tendency for exclusion zones to become excessively large once a worst-case modelling exercise is performed. This can be resolved by making greater use of measurements to determine interference rather than predictions and adding some incentive on the incumbents to share as widely as possible.

Case (3) – TV white space and similar. In this case, unlicensed access is allowed into licensed bands when interference can be carefully controlled, typically through the use of a database

[99] With the exception of some radar use in some countries which unlicensed users have to detect and work around.

that unlicensed devices have to query prior to transmission. This was the concept behind TV white space, which garnered much interest around 2010. However, interest has faded partly because it has proven hard to get regulatory approval in all but a handful of countries, partly because the TV spectrum has progressively shrunk as bands have been identified at 800 MHz then 700 MHz for cellular, and partly because alternative approaches have been found for applications such as IoT that were proposed for TV white space.

Case (4) – Collaborative access in 4 GHz bands. Collaborative access has been proposed where (1) clearance of bands looks problematic and likely to take overly long and (2) the incumbents do not have uses that can be readily geographically ring-fenced. In these situations, operators see collaborative access as a "next-best" approach where they negotiate with the licence holder(s) as to how they can best gain access.

There is still much to be worked out with collaborative access, especially where it is the regulator that assigns the shared rights, as might be the case where the incumbent is a Governmental user such as defence. Here the form of the licence, the number of licences granted, and the auction approach adopted still require attention. It may be that 5G will be a valuable first deployment that will pave the way for more widespread usage. Incumbents may prefer to share with only one other player, or with a subset of MNOs. This could reduce competition but the grounds for regulatory intervention in such cases appear weak.

Conclusions

The discussions to date suggest the following lessons from the embryonic process of spectrum management for 5G:

1. ***It would be helpful to move to a position where (almost) all licenses are shared.*** The case of 5G has shown that much of its access will be shared. Sharing has been assisted by the development of new real time technologies for dynamic spectrum sharing which allow multiple users to coexist. It is time for these possibilities to be reflected more fully in rights of access to spectrum by the replacement of exclusive licences by arrangements which allow access to multiple users, possibly on a hierarchical basis which gives some users priority over others. The result to be expected is much greater flexibility in use of spectrum and lower prices of access to it. This could be accomplished by a process of progressively replacing exclusive licences with less restrictive alternatives, introduced in ways which manage the associated risks. We recommend in the future a brisk increase in the number of licences recast in this way, even if in practice some of these will continue to be exclusive.

2. ***We should reconsider ways to derive technical sharing criteria.*** History has shown that sharing calculations are almost always excessively cautious leading to much spectrum being unused. Changing licence conditions towards the amount of interference that a user is allowed to generate, measuring actual interference rather than modelling it, specifying the minimum performance levels expected of receivers, and utilising real-time databases to modify transmitter powers when interference does occur will allow for very substantial improvements in efficiency as well as providing the tools for a range of novel approaches to sharing.

Annex E: 5G and net neutrality

By Marc Bourreau

Net neutrality is a general principle that all types of data traffic should be treated equally, with no discrimination with respect to the type of content, service or application, or the identity of the transmitter. In the United States, it was put in force in April 2015 with the Federal Communications Commission (FCC)'s final rule on the Open Internet.[100] In the European Union, the 2015 Open Internet Regulation[101] also states that "providers of internet access services shall treat all traffic equally, when providing internet access services, without discrimination, restriction or interference, and irrespective of the sender and receiver, the content accessed or distributed, the applications or services used or provided, or the terminal equipment used."

Net neutrality has generated heated policy debates over the last years, both in the US and in the EU. A general argument in favour of net neutrality is that in the absence of it, innovation in services would be severely hampered. By contrast, critics of net neutrality, and in particular network carriers, argue that differentiated treatment of traffic would allow them to manage their networks more efficiently, and enhance their incentives to invest in new broadband infrastructures.

The economics literature has shown that net neutrality involves economic trade-offs, and that neither very strict net neutrality rules nor a complete absence of any rule is likely to be desirable from a social point of view.[102]

The question we wish to address in this annex is what could be the impact of strict net neutrality rules on the deployment of 5G, and whether some adaptation of these rules is warranted. As a first step, we discuss the arguments in favour of the differentiation of net neutrality rules for fixed and mobile networks. We then highlight specificities of 5G – consistent with both the evolutionary and revolutionary images envisioned in this report – that may be in contradiction with strict net neutrality rules.

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[100] Federal Communications Commission, "Protecting and Promoting the Open Internet - A Rule by the Federal Communications Commission on 04/13/2015". https://www.federalregister.gov/documents/2015/04/13/2015-07841/protecting-and-promoting-the-open-internet

[101] Regulation (EU) 2015/2120 of the European Parliament and of the Council of 25 November 2015 laying down measures concerning open internet access and amending Directive 2002/22/EC on universal service and users' rights relating to electronic communications networks and services and Regulation (EU) No 531/2012 on roaming on public mobile communications networks within the Union, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2120&from=EN

[102] For a recent survey of the economics literature on net neutrality, see Greenstein, S., Peitz, M., and Valletti, T. (2016): "Net Neutrality: A Fast Lane to Understanding the Trade-offs," *Journal of Economic Perspectives*, 30(2), 127-150.

Different rules for fixed and mobile networks?

In its 2010 Order on net neutrality, the FCC introduced less strict net neutrality rules for mobile networks than for fixed network,[103] though it later abandoned this idea of differentiated treatment of the two network technologies in the next versions of the rules.

Different arguments may support a differentiation of net neutrality rules for fixed and mobile networks, which pertain to differences in market structures and capacity constraints.

First, in most countries mobile markets are typically more competitive than fixed markets. It has been argued in policy debates that strong competition may discipline Internet service providers, and remove the need for net neutrality regulations. However, the economics literature on net neutrality suggests that the potential problems that may arise in the absence of net neutrality rules – e.g., the strategic degradation of the quality of the best-effort lane – do not necessarily vanish when the retail market is competitive.[104]

A second argument in favour of lifting net neutrality regulation for mobile networks is that capacity constraints are stronger for mobile than for fixed networks.[105] For example, this was one justification for the differentiation of rules between fixed and mobile in the FCC 2010 Order.

Though this sounds intuitive, recent research by Choi, Jeon and Kim (2015) suggests that the relation between capacity constraints and the desirability of net neutrality is more complex, when one takes into account not only innovation at the core (i.e., capacity investments by network operators) but also innovation at the edge (i.e. investments in quality of service by large content providers).[106] These authors show that when capacity constraints are limited, allowing for paid prioritisation (a departure from net neutrality) boosts investments in quality of service by major content providers; for example, they start using compression technologies or content delivery networks intensively. This is because the returns on such investments by large content providers are higher when fast lanes are available than when the network is neutral. However, these major content providers then use capacity to such an extent as to elevate congestion for other (smaller) content providers.

To sum up, though the trade-offs involved with net neutrality may be different for fixed and mobile networks due to differences in capacity constraints in particular, there seems to be no clear-cut case for differentiating net neutrality rules for the two network technologies.

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[103] See Maxwell, W. and Brenner, D. (2012): "Confronting the FCC Net Neutrality Order with European Regulatory Principles," *Journal of Regulation*, June.

[104] See, for example, Bourreau, M., Kourandi, F., and Valletti, T. (2015): "Net Neutrality with Competing Internet Platforms," *Journal of Industrial Economics*, 63(1), 30-73.

[105] More specifically, mobile operators may be constrained both by their network capacity and their spectrum capacity. See Alexiadis, P., 2016, "EU Net Neutrality and the Mobile Sector: The Need for Competition Law Standards".

[106] See Choi, J.P., Jeon, D.-S., and Kim, B.-C. (2015): "Net neutrality, network capacity, and innovation at the edges."

5G: a game changer for net neutrality?

The 5G technology, as it is envisioned today, has however some specificities that may conflict with strict net neutrality rules.

a. Surge in traffic loads

First, with 5G, capacity problems may become more acute due to increased traffic (because of an increased demand for data, the increase in the number of connected devices, etc.), raising greater challenges for network management.

b. Very strong heterogeneity between service providers

The revolutionary image outlined in this report views 5G as an infrastructure (or a "general-purpose technology") for a wide range of services – the so-called "verticals" (e.g., connected cars, e-health services, smart grid controls, etc.). Each of these services will have different requirements in terms of traffic management, with respect to latency, speed, or energy consumption. For example, Internet of Things (IoT) applications may combine low energy consumption with low data rates for sensors, require very low latency for autonomous driving, or use video streaming applications at high speed, etc.

A strict application of net neutrality rules may make it difficult for service providers and mobile network operators to deploy lanes with specific technical characteristics. In this spirit, the 5G Manifesto[107] of European telcos claims that the development of 5G services requires flexible management of network resources by network operators. Yoo (2016) also argues that, though net neutrality may be optimal when services are relatively homogenous, this may no longer be the case when they are heterogeneous.[108]

Another argument in favour of providing network operators with some flexibility in terms of traffic management or prioritisation of traffic is that for these different 5G verticals to succeed, a phase of experimentation will probably be needed. The different players involved (mobile operators, service providers, etc.) will have to test different technical and economic options, something that strict net neutrality rules may make more complex and costly.

One should also note that with 5G, the service providers' needs in terms of quality of service seem more "horizontally" than "vertically" differentiated. In other words, 5G verticals require the deployment of lanes of different nature, rather than a combination of slow and fast lanes.

c. Bypass

If strict net neutrality rules make it impossible for network operators to offer traffic lanes with specific characteristics (in terms of latency, speed, etc.), new alternative operators may enter

[107] http://ec.europa.eu/newsroom/dae/document.cfm?action=display&doc_id=16579
[108] Yoo, C. (2016): "Network neutrality in an increasingly diverse world".

and deploy specific networks to meet this demand. We already observe this trend for the Internet of Things, with the deployment of alternative networks, such as Sigfox network.

On the downside, such bypass may lead to inefficient duplication of infrastructures. It may also undermine the business case of 5G network operators, reducing their incentives to deploy their new networks. On the other hand, since separate network operators would manage the general (best-effort) and specific lanes, the incentives to manage traffic in an anti-competitive way (e.g. by throttling traffic on the best-effort lane) would be mitigated.

d. Network sharing

Though it is already common today in the mobile market (with MVNOs, roaming agreements, etc.), network sharing may become much more widely used with 5G. As outlined in this report, the 5G technology introduces the idea of "network slicing", with Software Defined Networks (SDNs) and Network Function Virtualisation (NFV). With these technologies, separate networks can be hosted on the same physical infrastructure. At the extreme, one single network infrastructure could be deployed and shared between different providers.

Strict net neutrality regulations could make network-slicing techniques difficult to implement. A second problem is that with little flexibility in traffic management, the infrastructure owner may find it difficult to implement an efficient utilisation of the resource by its different users. The shared resource can indeed be viewed as a "common" used by different parties, and some governance of the resource (i.e. traffic management) may be necessary to avoid users to over utilise the resource, to the detriment of the others.

Conclusions

It seems to us that the most extensive view of 5G, which corresponds to the "revolutionary" image in this report, conflicts with a very strict application of net neutrality rules. Under this extensive view, 5G is an infrastructure, which can support a large variety of services or applications, with varying needs in terms of quality of service. To make this image a possibility, some flexibility should be provided to the network operators, both in terms of traffic management and contractual terms with service providers. Very strict net neutrality regulations, which would forbid any form of traffic management, would clearly endanger this image.

The question is whether the Open Internet rules in the EU provide enough flexibility to mobile operators. These rules indeed allow the development of specialised services, and it seems to correspond well to 5G.[109] A number of conditions should, however, be met to offer specialised services. In particular, specialised services can be offered only when the network capacity is sufficient such that the quality of the other services is not degraded. On top of that, the BEREC Guidelines indicate that the NRA should investigate whether the specialised services meet the

[109] For example, footnote 26 page 25 of BEREC Guidelines states that "network-slicing in 5G networks may be used to deliver specialised services".

requirements for the delivery of such services. For example,[110] "the “specific level of quality” should be specified, and it should be demonstrated that this specific level of quality cannot be assured over the IAS and that the QoS requirements are objectively necessary to ensure one or more key features of the application." These guidelines seem to call for a very precise monitoring of specialised services, which could make the development of specific lanes for 5G verticals or network slicing complex and costly for operators.

[110] See BEREC Guidelines, paragraph 108.

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