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Connectivity for a Competitive Digital Single Market - Towards a European Gigabit Society

{COM(2016) 587 final}

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1. Introduction

This Staff Working Document accompanies the Communication "Connectivity for a Competitive Digital Single Market – Towards a European Gigabit Society". The purpose of this document is to provide the background information which underpins the Commission's choice of new proposed long term strategic objectives for 2025 to focus on Europe's connectivity needs beyond 2020.

1.1 Growing demand for connectivity

The creation of a connected Digital Single Market is one of the top priorities of the European Commission. One of the three pillars of the European Commission's Digital Single Market Strategy of May 2015 aims to create the right environment and conditions for the deployment of very high-capacity networks. Both the European Parliament[1] and the European Council[2] have recently emphasized the need for more Internet connectivity.

The prerequisite to achieve a fully functional Digital Single Market is to ensure access to ubiquitous, very high-capacity fixed and mobile infrastructures. The increase in data consumption and usages (see section 2.2) and the process of aggregation and convergence between wireless and fixed networks will require the provision of very high-capacity (VHC) networks[3] ever closer to the end-user.

This is particularly relevant in view of Europe's competitive position in the Global Digital Economy. Gigabit connectivity is already a reality in countries such as Japan and South Korea, and is translating into increasing usage of video and high bandwidth applications. Bandwidth usage in Korea has historically been considerably higher than in Europe. It now also seems that Japan, which initially had limited bandwidth usage despite high fibre coverage, is starting to take off and would overtake Europe according to forecasts from IDATE[4]. In mid-2015, VHC networks represented around 70% of total fixed broadband in Japan and South Korea. Comparing the dynamics of investment into high capacity networks it can be concluded that South Korea and Japan have already entered into the Gigabit era, and China and Russia are also pursuing network rollout at a similar level of ambition. In comparison, by mid-2015, in the EU NGA networks represented 9% of the total fixed broadband subscriptions and e.g. Fibre to the Premises (FTTP) coverage was 20.8%, although in some Member States, such as Estonia, Portugal, Spain and Sweden, deployment was taking place at a much more significant scale.

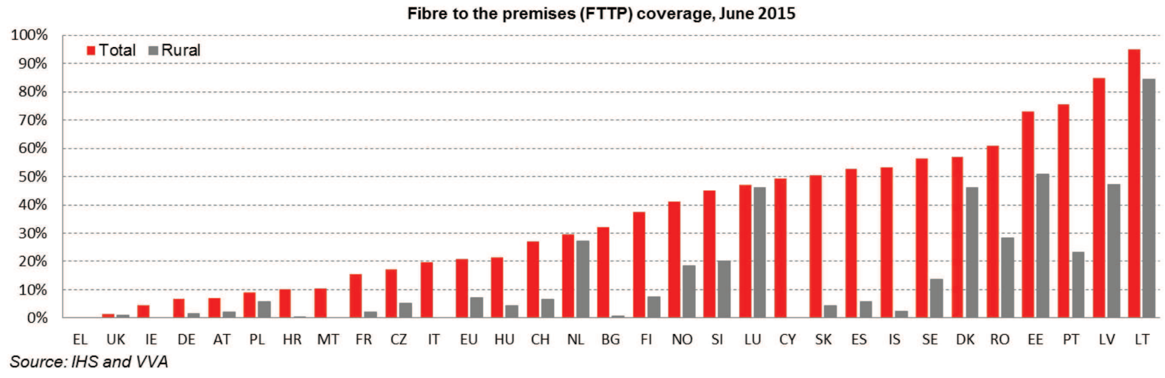
1 European Parliament Resolution of 19 January 2016 on Towards a Digital Single Market Act (2015/2147(INI))

2 Conclusions of the European Council meeting of 28 June 2016 (EUCO 26/16).

3 "Very high-capacity network" means an electronic communications network which either consists wholly of optical fibre elements at least up to the distribution point at the serving location or which is capable of delivering under usual peak-time conditions similar network performance in terms of available down- and uplink bandwidth, resilience, error-related parameters, and latency and its variation. Network performance can be considered similar regardless of whether the end-user experience varies due to the inherently different characteristics of the medium by which the network ultimately connects with the network termination point.

4 See Study on "Regulatory, in particular access, regimes for network investment models in Europe", by WIK Consult, Deloitte and IDATE; SMART 2015/0002.

Figure 1: VHC coverage in the European Union, June 2015



When considering the growing capacity needs in terms of network infrastructures, there is a need to take into account how new devices are enabling the development of new applications (e.g. smartphones) and affecting customer bandwidth requirements (e.g. larger screens and higher resolution). In addition, a single connection/subscription often serves simultaneously multiple users, in particular for households with children, SMEs and organisations like schools and libraries, further increasing the need to ensure speed and quality of experience.

The widespread adoption of cloud services[5], the number of connected devices (IoT) and the booming Machine-to-Machine (M2M) industry[6] is also contributing to further increase the traffic load on communications networks, including mobile networks[7].

In particular the growing use of smartphones and tablets increases the traffic per wireless access point (Wi-Fi and/or 4G/LTE base stations) and will require increasingly smaller cells to deliver the planned 5G connectivity performance. The volume of data that will transit through future 5G small cells will reach several gigabits per second (Gbps) and be further aggregated into multi-Gbps traffic streams.

This requires appropriate high capacity backhaul communications, which will mostly be fibre-based links, making 5G a complement but not a replacement to fixed VHC networks in areas with such a dense concentration of connected devices and users. In addition, developments in 5G are likely to lead to massively improved fixed wireless (as opposed to cellular wireless) solutions.

1.2 The user's perspectives

The results[8] of the public consultation launched last year by the European Commission on the need for Internet speed and quality beyond 2020 show the perception of respondents – mostly individual and business users – that important improvement in connectivity features is needed

[5] Communication from the Commission on a European Cloud Initiative-Building a competitive data and knowledge economy in Europe, COM(2016) 178 final.
[6] Communication from the Commission on Digitising European Industry. Reaping the full benefits of a Digital Single Market COM(2016) 180 final.
[7] Commission Staff Working Document Europe's Digital Progress Report 2016, SWD(2016) 187 final.
[8] Full synopsis of the results available at https://ec.europa.eu/digital-single-market/en/news/full-synopsis-report-public-consultation-needs-internet-speed-and-quality-beyond-2020

for the future. The public consultation was addressed to all types of users in all sectors. Some 1550 respondents from across Europe contributed to the public consultation, of which around 85% as individuals and 15% as (public or private) organisations. In particular, the results of the public consultation show the following main trends:

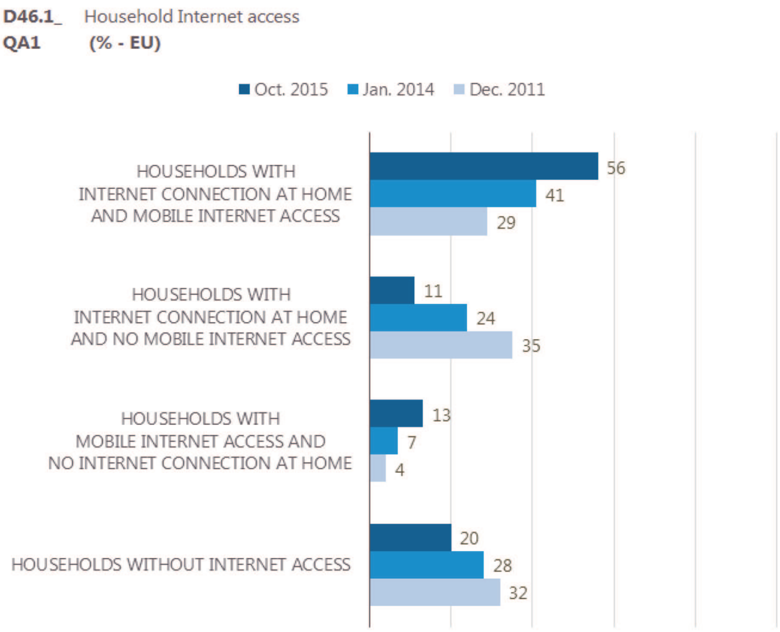
- Good connectivity is seen as a **necessary condition to achieve the Digital Single Market, for citizens, for the industry, for businesses** (whatever their size and sector of the economy), **for schools, for research and innovation centres**, as well as – more generally - for competitiveness, jobs and growth. Inadequate connectivity is considered as a risk or a high risk for around three quarters of the respondents – affecting in particular employment, cohesion, education and learning, research and data driven activities, consumer welfare, and accessibility.
- While **respondents pointed to download speed as the most important feature** of fixed connectivity today, **other connectivity features will gain significant importance** in the future - notably upload speed, reliability and uninterrupted access.
- Contributors have a **low trust that future connectivity would spontaneously emerge** at a level of quality and speed that would fulfil their needs: more than half declared themselves sceptical.
- Among the respondents who are pessimistic or very pessimistic about the fulfilment of their future fixed and/or mobile connectivity needs in 2025, close to **90% think that measures by public authorities are needed to promote investment in and take-up of connectivity networks and services** in line with (or even beyond) identified future needs.

The results of a representative Eurobarometer survey[9], carried out in the 28 Member States of the European Union between 17 and 26 October 2015, confirm that when subscribing to an Internet connection, respondents are increasingly likely to consider quality criteria. They are important criteria for 70% of customers, which makes them the second most important. In terms of trend, quality criteria are those that gained most in importance compared with 2014: e.g. +7 points for maximum download or upload speed, +6 points for maximum amount of data downloaded or uploaded.

Figure 2 summarises the main trends as far as households' Internet access is concerned.

[9] 27,822 EU citizens from different social and demographic categories interviewed face-to-face at home in their native language

Figure 2: Percentage of households with fixed and/or mobile Internet access in EU



Base: All respondents (n = 27822)

These trends underline the growing needs for Internet connectivity for all the sectors of the European economy and show that expanding individual usage aggregates into quickly growing demand for VHC fixed and mobile broadband infrastructures that can underpin the Digital Single Market. When considering these trends in Europe, it should further be emphasised that future needs should in particular take into account current practices of today's "digital natives" (below 25 years old) since they will increasingly influence mainstream data consumption patterns as this generation grows in demographic terms and becomes part of tomorrow's workforce.

In addition, the availability of higher capacity connectivity networks in itself drives the development of innovative and value-adding services: failing such favourable conditions, providers have to adapt their services or launch them elsewhere. Updating and enhancing existing network infrastructures to meet this anticipated growing demand for higher capacity will however require significant additional investments.

2. State of play

2.1 Current state of connectivity in Europe

Today virtually all EU citizens have access to basic broadband networks[10] (97% have access to fixed broadband connections according to the DESI index 2016[11]) and increasing numbers

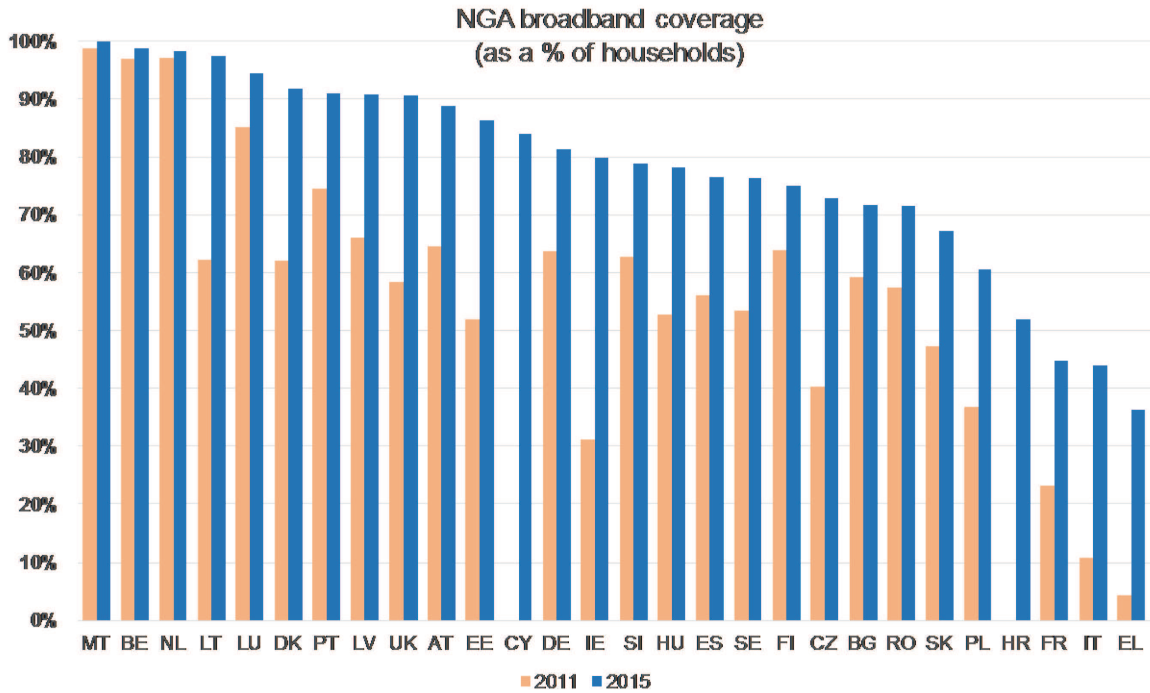
[10] At a download speed of at least 2Mbps at end-user level.

of citizens and businesses have access to networks allowing at least 30 Mbps download speed: 70.9% have general coverage at Next Generation Access (NGA) connectivity level[12] in the EU, according to DESI 2016.

However, only some countries, such as Malta, Lithuania, Belgium and the Netherlands, already enjoy nearly comprehensive coverage of NGA networks; in most of those cases, this is probably due to the competitive impulse provided by cable networks, which can be upgraded at relatively low cost to NGA levels of connectivity[13]. Elsewhere, NGA coverage has been slow to develop – notably in countries that lacked extensive cable in their legacy networks (Italy or Greece being examples).

However, the roll-out of NGA networks has improved significantly since the DAE objectives were adopted in 2010. As shown in Figure 3, some Member States in particular have been able to leap frog others in increasing network capacity.

Figure 3: 30Mbps and more (NGA) coverage of households per Member State (2011 vs 2015)



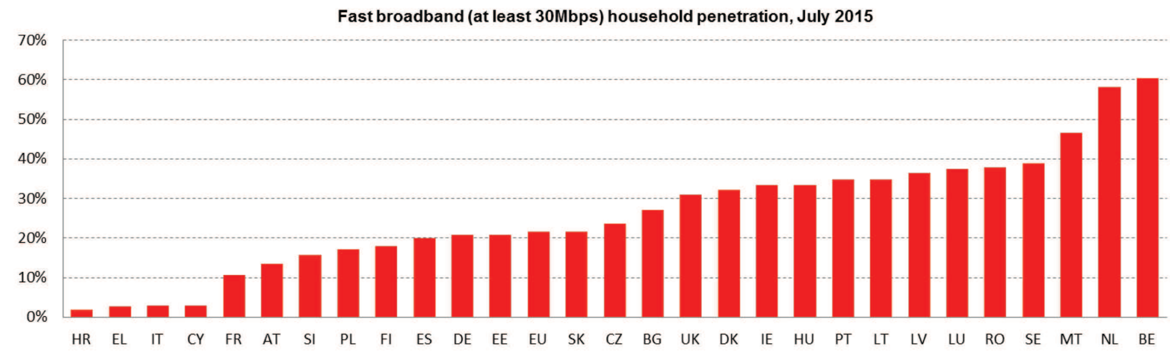
[11] The Digital Economy and Society Index (DESI) is a composite index developed by the European Commission (DG CNECT) to assess the development of EU countries towards a digital economy and society. It aggregates a set of relevant indicators structured around 5 dimensions: Connectivity, Human Capital, Use of Internet, Integration of Digital Technology and Digital Public Services. For more information about the DESI please refer to http://ec.europa.eu/digital-agenda/en/digital-agenda-scoreboard

[12] NGA broadband coverage/availability (as a % of households) with Next Generation Access including the following technologies: FTTH, FTTB, Cable DOCSIS 3.0, VDSL and other superfast broadband allowing at least 30 Mbps download).

[13] Several studies highlight the role played by cable networks in stimulating NGA deployments including SMART 2015/0002, WIK-Consult (2015) for Ofcom 'Competition and Investment: analysing the drivers of superfast broadband', and the EP (2013) study 'Entertainment X.0 to boost broadband deployment'.

Yet there are still substantial differences between Member States[14] in terms of take-up of high speed (NGA) broadband subscriptions.

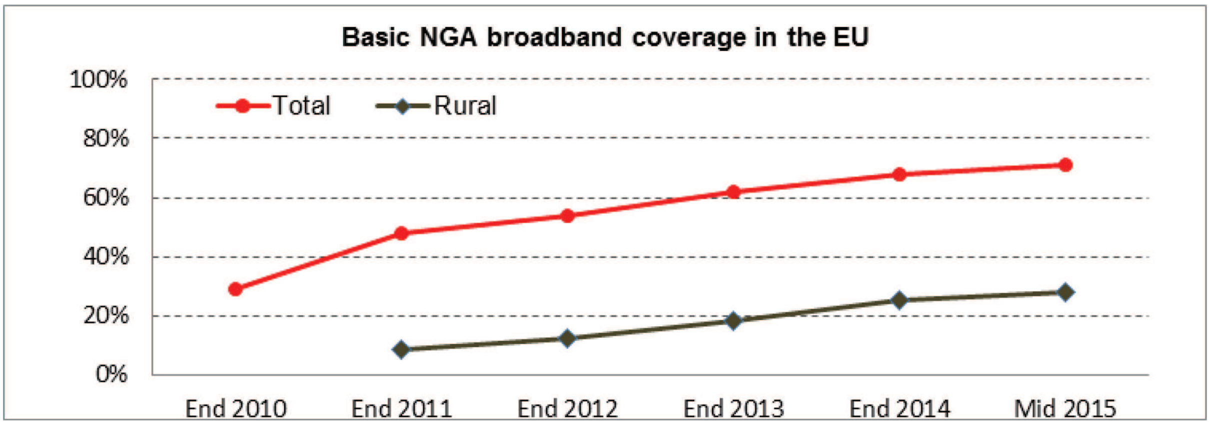
Figure 4: fast broadband (at least 30 Mbps) household penetration, July 2015.



Source: Communications Committee

In addition, the connectivity challenge in rural areas remains acute, with patchy basic NGA coverage exemplified by 28% fixed line coverage and 36% mobile 4G household coverage (both coverages being partially overlapping).

Figure 5: NGA broadband coverage in EU



Source: IHS and VVA

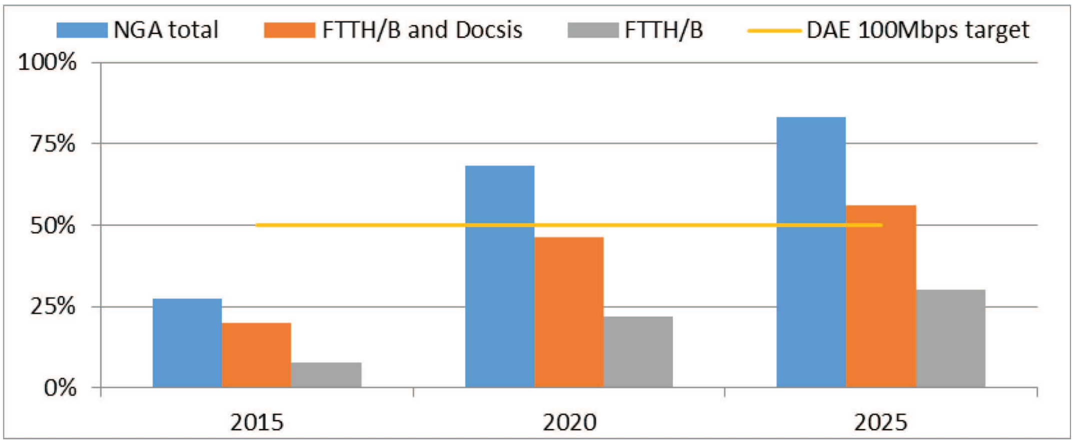
A key development driving the increase of network capacity is that legacy telephone and cable (coaxial) networks, including the copper 'local loops', are in the process of being upgraded to improve their broadband performance.

In many countries, including the UK or Germany, a large part of the NGA coverage beyond the cable footprint has been achieved through only partial upgrades of the legacy copper loop (FTTC), rather than through full VHC upgrades (e.g. FTTH/B). As investigated in the Study,

[14] For instance according to the Digital Economy and Society Index, updated in July 2015, 22 % of European homes subscribed to broadband access of at least 30 Mbps but this represented only 1% of households in Hungary and 60% in Belgium. Similarly, subscriptions to broadband access of at least 100 Mbps reached on average 11% in the EU, but less than 1% in Croatia, Cyprus, Greece, and Italy (where networks capable of such speeds are largely absent) while it exceeded 40% in Latvia, Romania and Sweden.

"Regulatory, in particular access regimes for network investment models in Europe"[15], the former approach is most unlikely to be sufficient to cope with data consumption under the most ambitious scenario forecast. As a result, the current state of broadband connectivity in Europe and the actual trends in its modernisation will not fulfil the growing needs for Internet speed and quality beyond 2020.

Figure 6: Projections of NGA penetration by technology 2015 – 2025 (% of households, EU28)

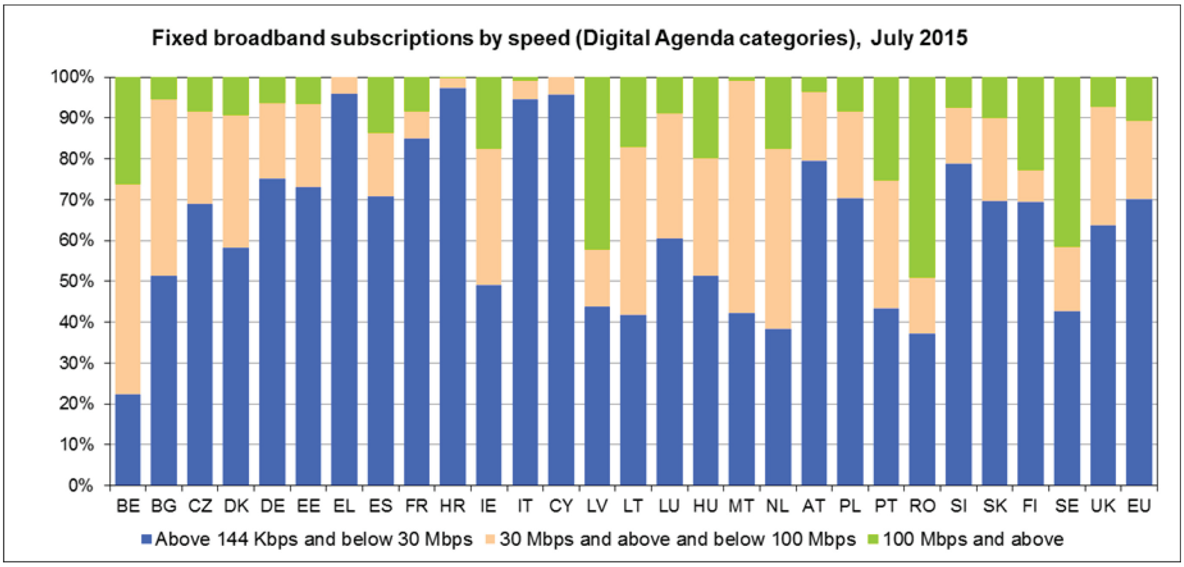


Despite some technological progress[16], today not all NGA networks can deliver 100 Mbps. This remains an important challenge for the achievement of the 2020 DAE objective for 100 Mbps subscriptions of one European household in two: it will require both a wide availability and affordable offers to increase demand for connectivity of at least 100 Mbps by 2020.

[15] See Study by WIK-IDATE-Deloitte;"*Regulatory, in particular Access regimes for network investment and business models in Europe*"; SMART 2015/0002.

[16] In July 2010, only 0.5% of lines in the EU had average speeds at or above 100 Mbps. By mid-2015, an estimated 11% of fixed broadband subscriptions in the EU were able to provide at least 100 Mbps.

Figure 7: Fixed broadband subscriptions in EU by speed



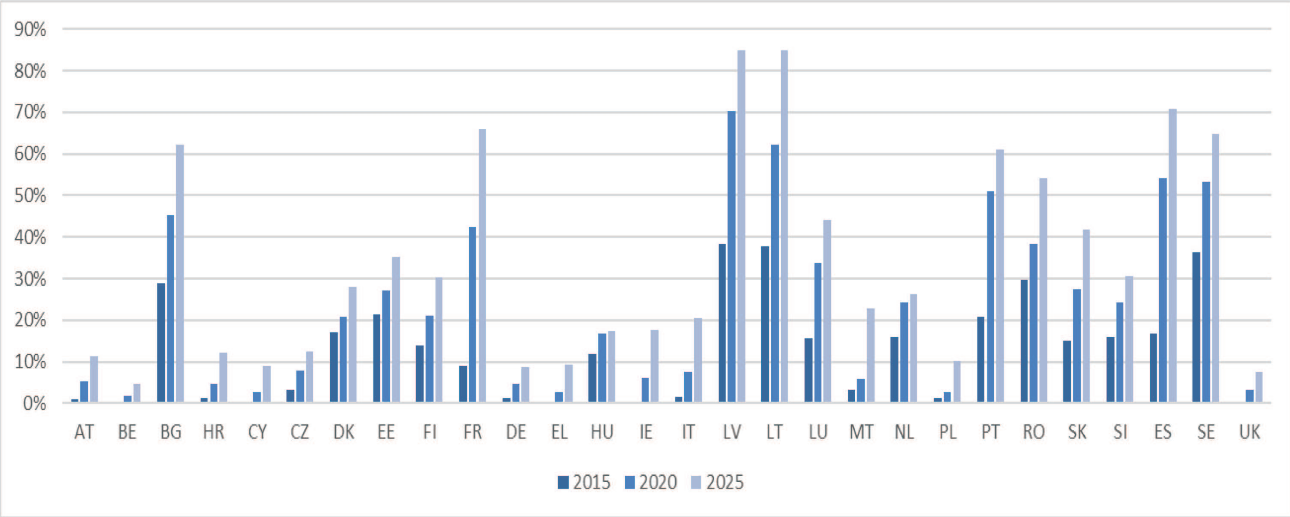
Take-up projections of NGA in a 5-10 year timeframe vary, and show significant differences across countries and connectivity parameters.

For example, based on announcements from operators, Government subsidy initiatives and trends in demand, IDATE has projected that overall NGA take-up will surpass the 50% mark by 2020 in the EU on average. However, it is notable that a high proportion of take-up is projected to be on the basis of FTTC technologies which may not in all cases meet the 100Mbit/s quality of service objective. When such technologies are excluded from the calculations, take-up is projected to be around 45% of households in 2020, falling short of the DAE objective. Besides, gaps between countries are expected to persist, with a significant proportion of countries expected to lag behind the DAE take-up objective, even if all technologies are considered.

As far as FTTH/B is concerned, projections by experts[17] suggest that only 20% of households would be subscribing to an FTTH offer by 2020 leading to a take-up of 31% by 2025. Due to different levels in the projected coverage of FTTH, take-up is also expected to vary widely by country, with high take-up in several Eastern European countries as well as in Portugal, Sweden, Spain and to a lesser extent France, contrasting with low take-up in several countries including the UK, Germany, Italy and Poland (See Figure 8).

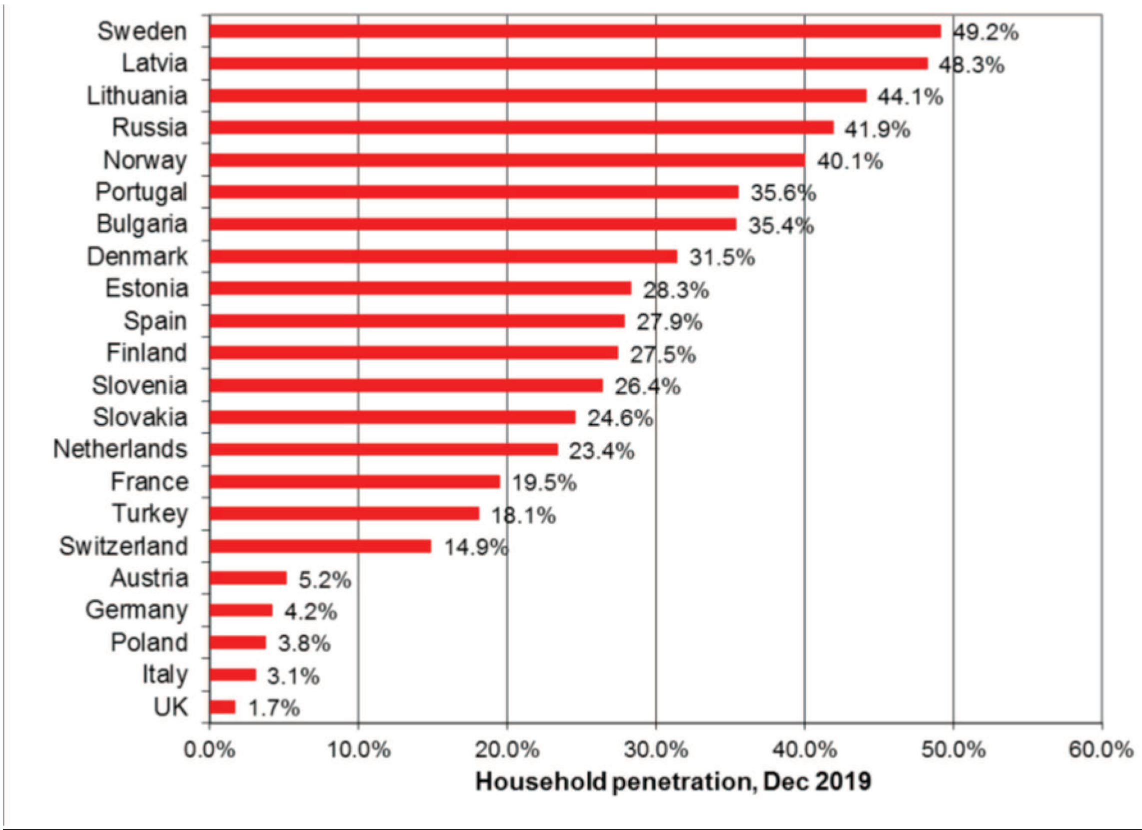
[17] See Study *WIK-IDATE-Deloitte: "Regulatory, in particular access regime"* ; SMART 2015/0002

Figure 8: Projections for FTTH/B penetration by country (% of total households, 2015-2025) IDATE



Projections by 2019 from other sources such as Heavy Reading[18] (see Figure 9), also suggest low take-up levels in the UK, Italy, Poland and Germany.

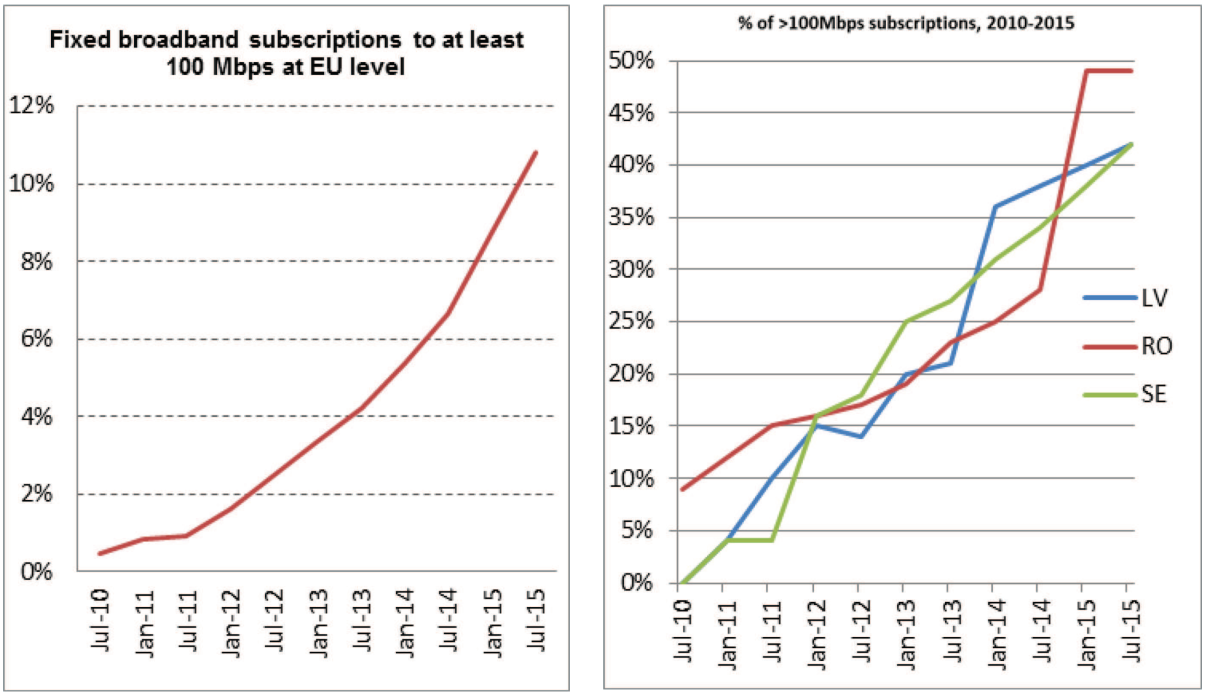
Figure 9: Projections for household take-up of FTTH/B in December 2019 (Heavy Reading)



[18] http://www.ftthcouncil.eu/documents/Webinars/2015/Webinar_14April2015.pdf

Closer analysis of the developments reveals a trend that, as business and household services and applications depending on high quality connection are becoming more popular, subscriptions to 100 Mbps or more are growing sharply, albeit from a low base. Especially pronounced in the Member States which already have the highest 100 Mbps subscription rate, this suggests both important emulation effects on demand and increasing supply of attractive services which exploit such higher capacity connectivity – the so-called next generation applications. Figure 10 shows how dramatically the take-up rate of connections offering at least 100 Mbps is progressing in countries where VHC networks are widely available.

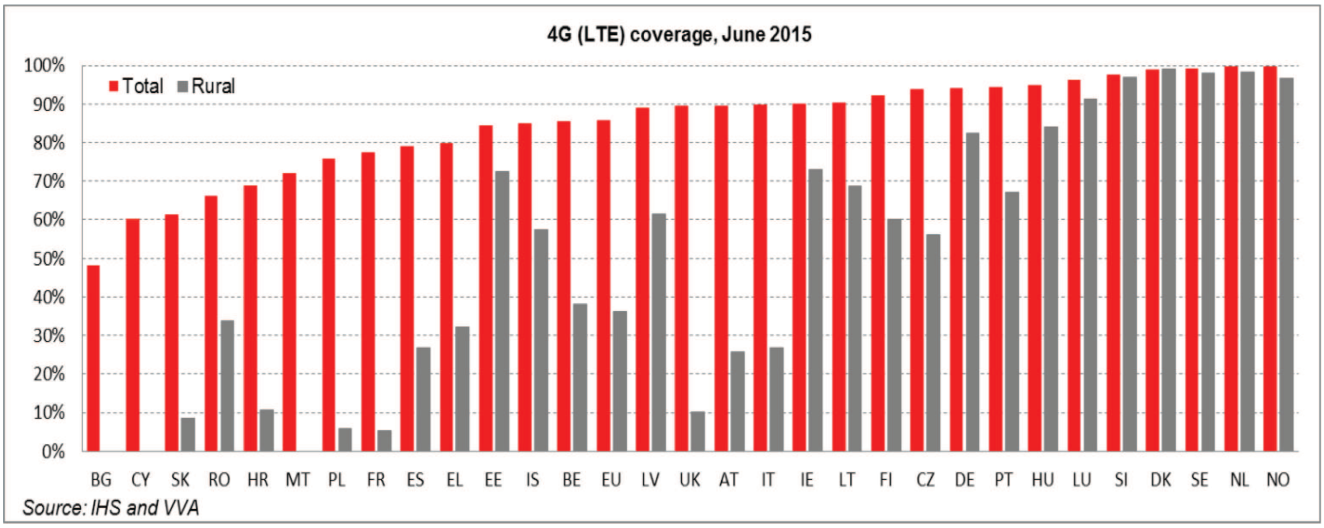
Figure 10: Increase in subscriptions offering at least 100 Mbps connectivity in EU and in selected countries (fixed broadband)



Source: Communications Committee

Concerning mobile connectivity, the deployment of 4G has continued to increase sharply after a very slow start in many Member States and is now available from at least one operator to 86% of homes; however, some Member States lag significantly behind this average, and even in the better-served countries, away from population centres mobile data coverage continues to be subject to very significant gaps, including along major transport routes.

Figure 11: LTE household coverage by at least one operator in EU countries



Source: IHS and VVA

In addition, connectivity in Europe is still overwhelmingly asymmetric, while uplink speeds are increasingly important for services such as cloud computing.

2.2 A growing need for connectivity

The number of Internet users, devices and applications continues to grow and will generate more and more traffic over the core networks, creating greater need for connectivity.

Mobile data traffic in Western Europe is expected to grow six fold from 2015 to 2020[19]. The European Parliament report "*Reforming EU telecoms rules to create a Digital Union*" (2016)[20] points out a "*tremendous expected increase of mobile data traffic in Europe - from 0.98 Exabytes per month in 2015 to 7.23 Exabytes per month*" by 2020.

In addition, these high levels of anticipated mobile data traffic are still expected to fall well below projected traffic to fixed locations, given that already in 2012 the cellular mobile data traffic was identified as "*only the tip of a much larger iceberg"* if one takes account of the data used via Wi-Fi access points[21].According to Cisco, the overall IP traffic is expected to grow to 194 Exabytes per month by 2020, up from 72.5 Exabytes per month in 2015, *i.e.* a compound annual growth rate (CAGR) of 22 percent[22].

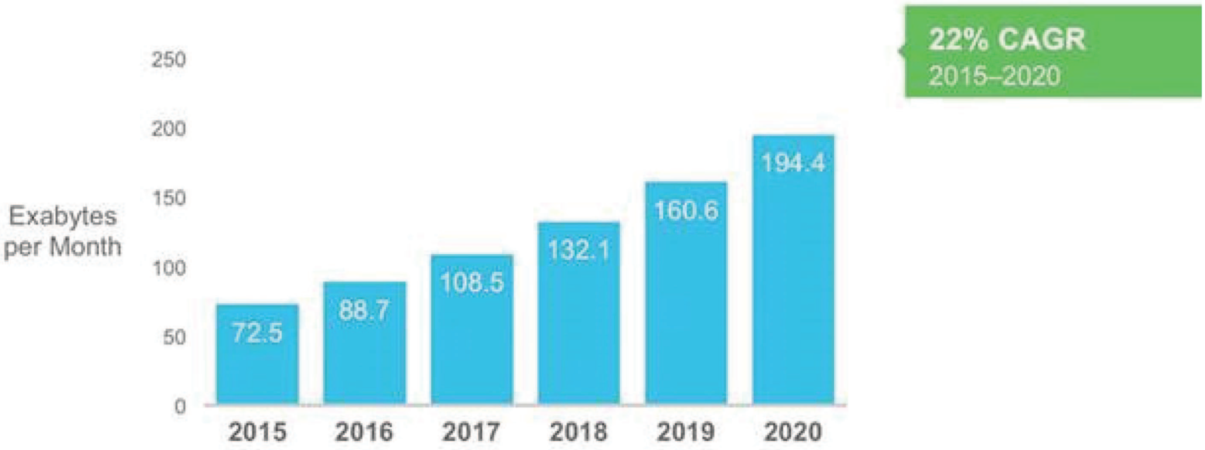
[19] Commission Staff Working Document Europe's Digital Progress Report 2016, SWD(2016) 187 final.

[20] ISBN: 978-92-823-8882-2

[21] Study on Impact of traffic off-loading and related technological trends on the demand for wireless broadband spectrum (SMART 2012/0015).

[22] Source: CISCO VNI index, see: http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html

Figure 12: IP Traffic volumes 2015-2020



Source: Cisco VNI Global IP Traffic Forecast, 2015–2020

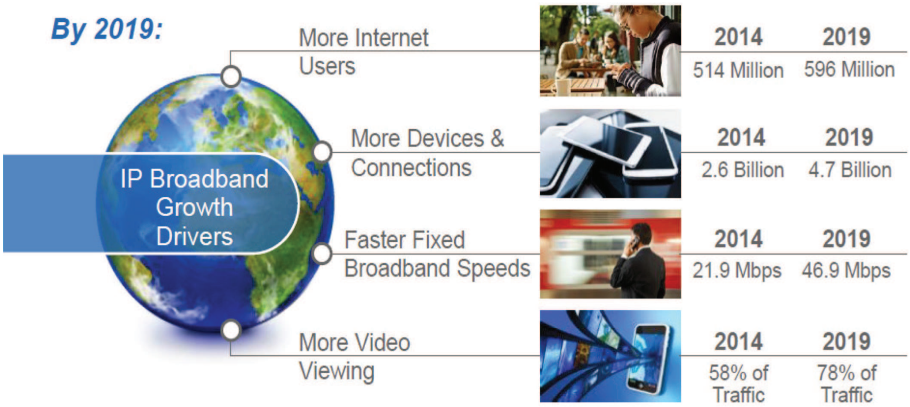
IP traffic growth is explained by the increase in the number of users but also by the substantial growth of IP traffic per capita over the past decade. Globally, monthly IP traffic is expected to reach 25 GB per capita by 2020, up from 10 GB per capita in 2015[23].

Business Internet traffic is estimated to grow 2.6-fold from 2015 to 2020, a compound annual growth rate of 21% and, in 2020, it will reach 27.9 Exabytes per month. In particular, as businesses and consumers exchange their data with the cloud, this will also lead to a modified demand pattern for upload traffic. Hence, while most of the traffic will still be in download, demand for upload will increase, as well as the need for lower latency (i.e. higher responsiveness) for applications such as cloud computing, connected driving and e-health.

This capacity demand is fuelled by the desire of users to enjoy better quality online services including online video and cloud applications, as well as enabling multi-screen viewing, which is becoming increasingly prevalent in European households. Projections by Deloitte[24] see very high capacity connections as a requirement to meet the aggregate demand from dozens of connected devices in a home. This is becoming the norm in European households where several users consume bandwidth from several devices at once. Deloitte further notes that "*demand for connectivity has evolved symbiotically: as faster speeds have become available, the range of applications supported has increased and the viable number of devices per person has steadily risen*."

[23] Cisco, The Zettabyte Era: Trends and Analysis, June 2016.
[24] Deloitte Technology, Media and Telecommunications Predictions 2016.

Figure 13: Europe IP Traffic and Service Adoption Drivers

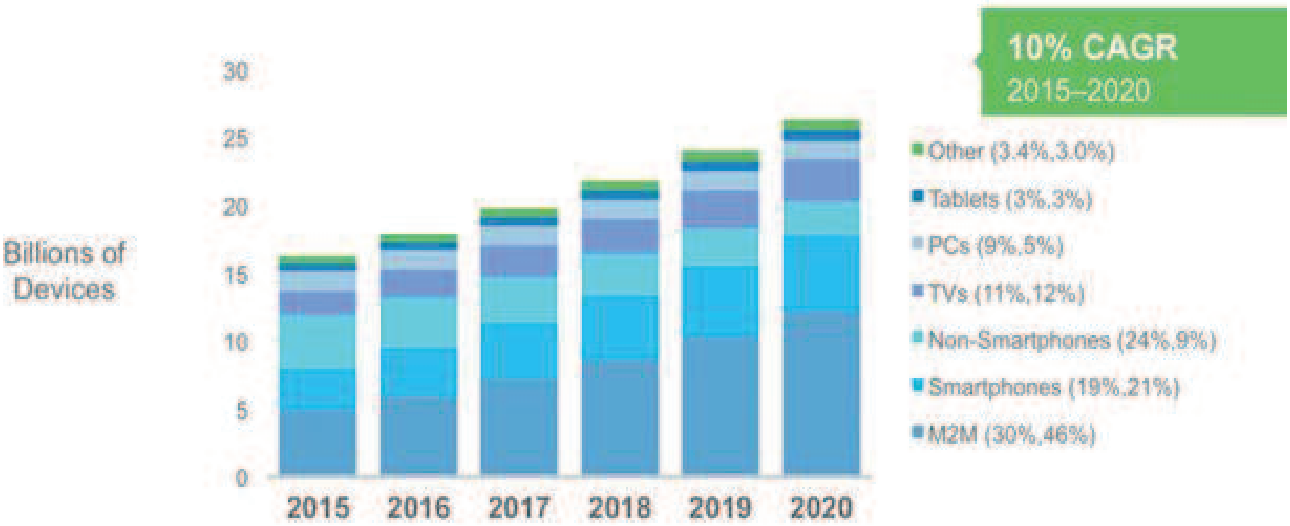


Source: Cisco VNI Global IP Traffic forecast 2014-2019 – Europe includes Western Europe + CEE, excluding Russia

These trends increase the demand for capacity and other quality of service characteristics of digital networks. There is an emerging consensus among industry players and investors that in the medium and long run, fixed and mobile networks converge: for instance, it is expected that 5G connectivity providers will rely on (nearly) ubiquitous VHC network infrastructures coming very close to users' premises (i.e. to the building, to the small cell), to support their business.

As mentioned above, this booming global traffic is the product of the increase in connected activity at the level of individual users (both the growing number of end users and, to an ever greater extent, the increase in data traffic per end user). Globally, the average number of devices and connections per household and Business place is also growing due to M2M applications, such as smart meters, video surveillance, healthcare monitoring, transportation, and package or asset tracking. By 2020, M2M connections will represent 46 percent of the total devices and connections, according to Cisco.

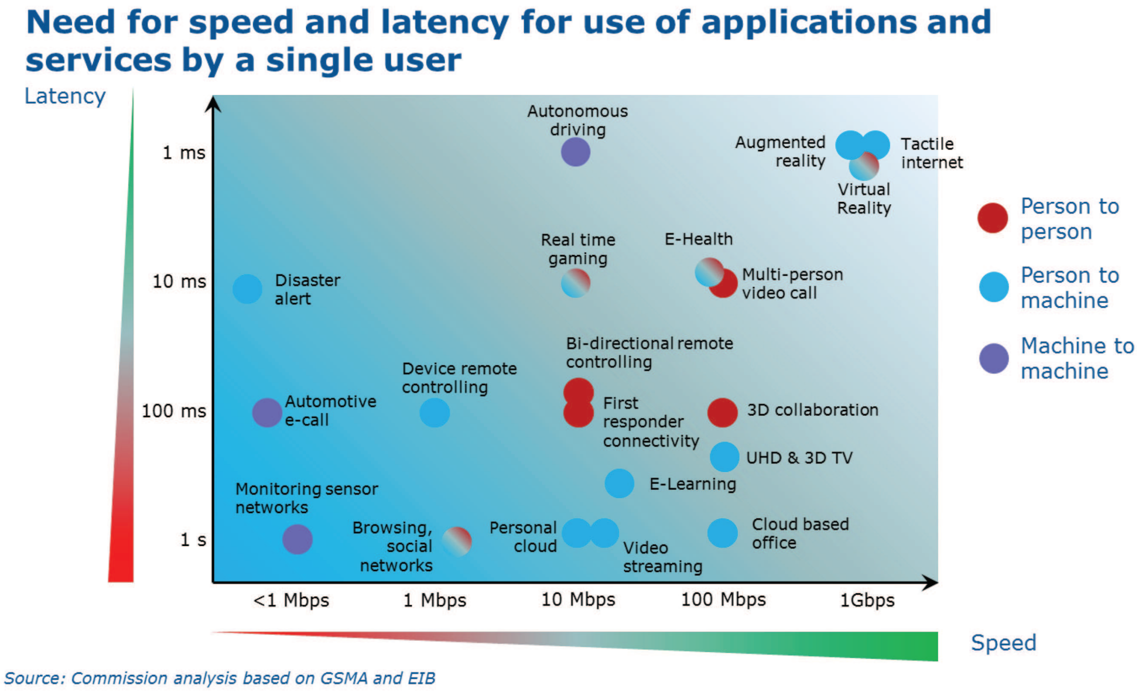
Figure 14: Traffic evolution by the type of devices 2015-2020



Source: Cisco VNI Global IP Traffic Forecast, 2015–2020

New and innovative (so-called "next-generation") applications requiring low latency, high Internet access speed - often bi-directional - and other improved connectivity parameters are emerging and will reinforce the demand for better connectivity.

Figure 15: Applications' bandwidth and latency requirements



Next generation TV is likely to be a significant driver of bandwidth demand for households in the coming years. However, it is not the only driver. Bandwidth may also increasingly be needed and used for business purposes, both in business premises and in the home office. For a complete picture therefore, it is helpful to take into account a range of applications (in addition to TV) and to understand how bandwidth requirements may vary for different types of users including businesses.

Table 1: Application categories with their capacity and quality requirements 2025

Application category	Downstream (Mbit/s)	Upstream (Mbit/s)	Packet loss	Latency
Basic Internet	≈20	≈16	0	0
Homeoffice/VPN	≈250	≈250	+	+
Cloud Computing	≈250	≈250	+	++
Media and Entertainment HD/3D	≈150	≈30	++	+
Media and Entertainment Ultra-HD, 4k-TV, 3D, ...	≈300	≈60	++	+
Communication	≈8	≈8	++	+
Videocommunication (HD)	≈25	≈25	++	++
Gaming	≈300	≈150	++	++
E-Health	≈50	≈50	++	+
E-Home/E-Facility	≈50	≈50	0	0
Mobile Services / Wifi-Offloading	≈15	≈12	0	0

0 = No specific importance
\+ = High importance
++ = Very high importance

Source: WIK-IDATE-Deloitte; Regulatory, in particular access, regimes for network investment models in Europe, SMART 2015/0002

Further examples of current applications with particular quality requirements are presented in table 2.

Table 2: Quality requirements of applications

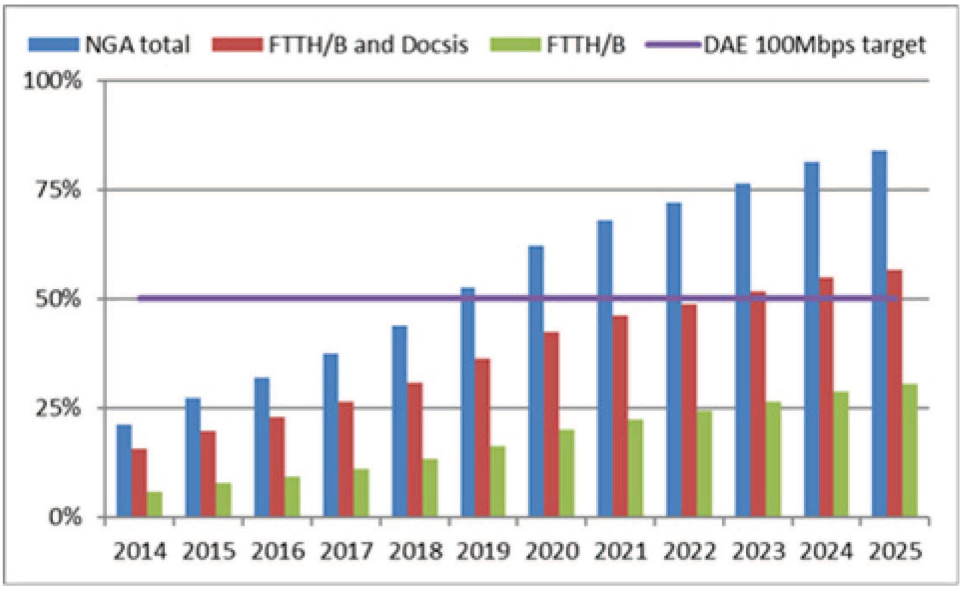
		High Security	High Capacity	High Reliability	High Ubiquity	High Connections Density	High Download Speed	High Upload Speed	High Peak data rate	Symmetry	Low Latency	Low Jitter	Low Packet Loss
real-time applications	Video, 3D video, UHD screens		■	■			■					■	
	Education / e-Learning			■			■	■		■	■	■	
	IoT & M2M	■		■	■	■						■	
	Audio / Music											■	
	Gaming		■				■	■		■		■	
	e-Commerce				■							■	
	IP Telephony											■	
	HD telepresence						■	■				■	
mission critical applications	e-Banking	■		■	■						■		■
	Health Services	■		■	■		■	■		■	■	■	■
	Self-driving car	■		■	■	■					■	■	■
	Security / CCTV	■		■							■	■	■
	e-Government	■		■					■				■
massive communications	Smart City	■	■	■	■	■			■				
	Industry automation	■		■			■	■	■	■			■
	Augmented Reality		■				■	■	■	■			
	Big Data	■	■	■			■						
	Work and play in the cloud	■	■				■	■	■	■			
	Gigabytes in a second		■				■		■				
basic applications	Email				■								■
	Social Networking				■								■
	Smart Home / Building												
	Location-Based Services				■								
	Videoconferencing												
	Browsing												■

Source: European Commission

2.3 Baseline analysis: from today to 2020 and beyond

In terms of supply of NGA in commercially viable areas, forecasts from IDATE based on market intelligence (see Figure 16) suggest that upgrades to NGA and VHC networks will continue, but at a relatively gradual pace. The reasons are notably uncertainties in the market regarding the rate of pick-up (demand in subscriptions), the materialization of new services and applications, the durability of intermediate technical solutions based on legacy copper infrastructures, arguably underpinned by strategic profit-maximizing considerations which can favour delaying such a transition at the operator level, even at the cost of beneficial externalities for society as a whole.

Figure 16: - Projected take-up of NGA by technology (to 2025)



Source: WIK-IDATE-Deloitte; Regulatory, in particular access, regimes for network investment models in Europe SMART 2015/0002

IDATE projections above suggest that by 2020, even under very optimistic assumptions (assuming FTTC/VDSL delivers 100Mbit/s in practice[25]), around 16 countries may miss the DAE objective of 50% households taking up at least a 100 Mbps connection, and within the 16 affected countries the objective may be missed by around 25m households. In reality other advanced hybrid copper-based solutions may deliver the required speed provided the local loop is sufficiently short[26]. Countries with limited competition between legacy networks (copper lines / coaxial cables), such as Italy and Greece, are included amongst those considered likely to miss the objectives (though there has been a fairly recent spurt in activity in Italy), while incountries which have been characterised by strong FTTC coverage could

[25] If FTTC/VDSL is excluded (as this technology is less likely than the other technologies considered to be offered at speeds of 100Mbps and above), then only between 42% and 45% of all households in Europe would subscribe to 100 Mbps-capable networks in 2020.

[26] See figure 26 in Technological developments' Annex.

fail to meet objectives under the stricter assumption that FTTC technologies may not in all cases meet the 100Mbit/s objective[27].

This pace of development may be sufficient to meet the needs of some users, but is likely to limit the potential for more demanding users, including small business and home office users and may not be sufficient to enable Europe to fully benefit from a connected economy and society. As explained in more detail in Chapter I of the Study "*Support for the preparation of the impact assessment accompanying the review of the regulatory framework for e-communications*", SMART 2015/0005, the demand for data is booming and the scenarios considered are mostly rather conservative.

Rural NGA deployments vary across the EU and within Member-States, as shown in various case studies. If the current varying practices remain, the current status of uneven rural deployment is likely to persist, resulting in patchy access in rural communities to broadband capable of reaping the benefits from the social and economic integration that digitisation may bring. This process is likely to have repercussions on public finances, especially if accompanied by ageing population. Challenge areas could in theory be addressed through public subsidies, but these are by no means sufficient.

2.4 The gap between bandwidth demand and network capacity deployed

In Asia, affordable very high capacity (Gigabit) connectivity has already been available as a consumer service in Japan[28], Singapore and Korea for some years. In 2014, Korea's SK Telecom announced trials of 10 Gbps[29] and the Korean National Broadband Plan (Ultra Broadband Convergence Network[30]), already launched a 1 Gbps objective in 2010.

In the US, very high capacity (Gigabit) connectivity is also available to households and small businesses, notably in the cities served by Google Fibre,[31] and recent reports suggest that AT&T is responding to the competitive challenge with more widespread urban Gigabit deployments of its own[32].

[27] For additional deployment forecasts see, SMART 2015/0002.
[28] KDDI launches Gbps service 2008 http://www.japantoday.com/category/technology/view/kddi-to-launch-1gbps-fiber-optic-service-in-oct
[29] SK Telecom showcases 10Gbps service http://www.businesskorea.co.kr/english/news/ict/6789-100x-faster-internet-sk-broadband-offer-10-gbps-internet
[30]UNESCAP http://www.unescap.org/sites/default/files/4.1%20Korean%20Broadband%20Policies%20and%20Recommendations.pdf
[31] https://fiber.google.com/cities/kansascity/plans/
[32] See for example http://www.latinpost.com/articles/101338/20151210/google-fiber-vs-att-gigapower-likely-to-win-gigabit-race-thanks-to-google.htm

Figure 17: Percentage of FTTB connections on total subscriptions (OECD)

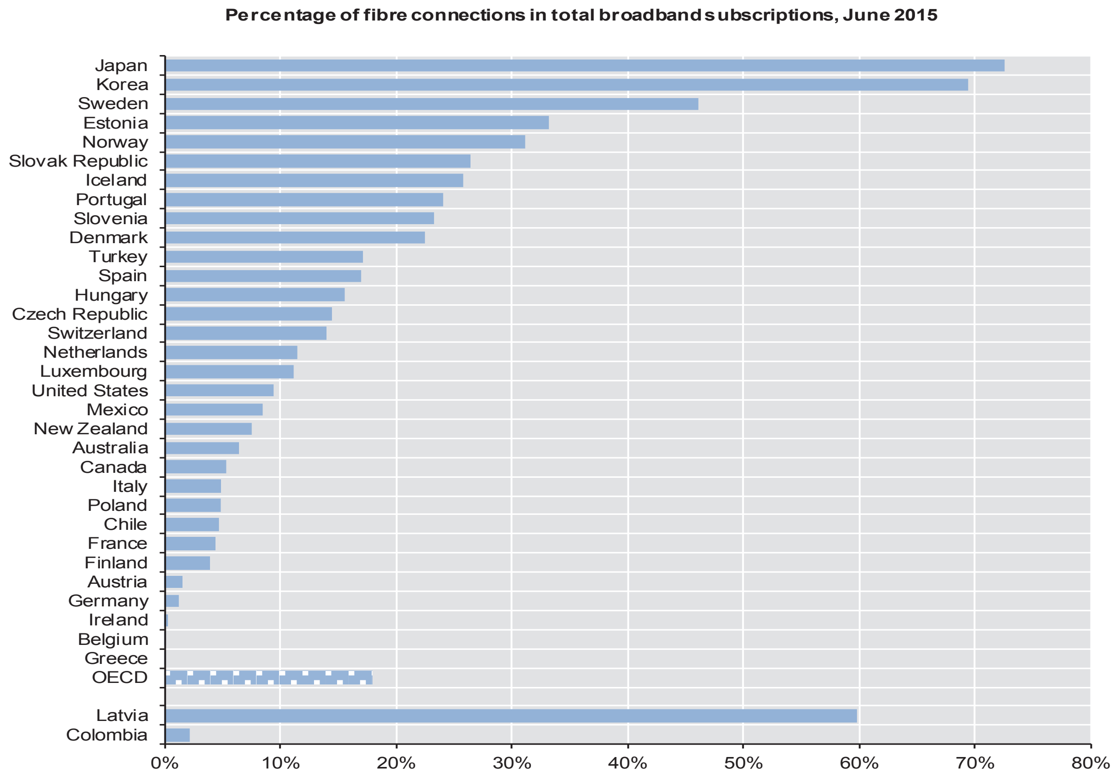


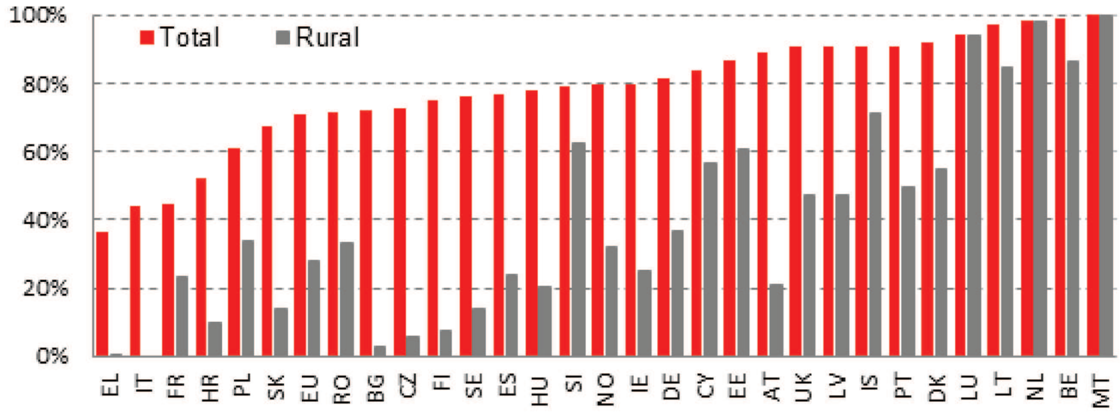
Figure 17 illustrates the state of transition from copper to fibre inside and outside of the EU. In the European Union, some Member States, such as Latvia, Sweden or Estonia already compare well with Japan on a range of NGA metrics (although Swedish fixed rural coverage remains relatively limited),.

Several other EU countries, including Portugal, Spain, France, Romania, which benefit from an expanding FTTH/B footprint, albeit at different pace of deployment, may become Europe's leading countries for VHC connectivity in the years to come[33]. However, large European countries which have so far been experiencing limited or incremental NGA deployment may lag behind European and global leaders on VHC broadband.

Although the picture does not take into account the effect of cable subscriptions, it gives an idea of the different pace of this transition. Furthermore, rural NGA coverage has been increasing slowly in several countries such as Germany, France, Italy, Austria and Finland, increasing the risk of a growing urban and rural digital divide as can be seen in Figure 18.

[33] See the Study "Support for the preparation of the impact assessment accompanying the review of the regulatory framework for e-communications", SMART 2015/0005 and, Study SMART 2015/0002

Figure 18: – Next generation access (FTTP34, VDSL and DOCSIS 3.0 cable) coverage, June 2015



Source: *IHS and VVA* - Digital Scoreboard – Connectivity section[35]

The size of the gap between gradually upgraded network infrastructures and the exponentially growing usage depends on several factors, such as (1) whether future demand can be met through incremental upgrades of existing copper and coaxial (cable) networks or only through FTTH/B; and (2) the extent to which future wireless technologies (5G) will be able to rely on fixed networks for backhaul and other data transmission needs.

The size of Europe's bandwidth challenge can be seen most vividly by comparing where we are today with what would be needed to benefit from all aspects of a connected society in 2025. For instance, Prof. Brett Frischmann observed that current demand expressed by end-users may fail to reflect the innovation potential in the market, which could be unlocked through more performant infrastructure[36].

According to the Samknows Survey, average download speeds achieved in Europe in 2014 were 24Mbit/s.[37] If investment in NGA technologies continues at its current levels, IDATE has projected that average download speeds would reach around 185Mbps by 2025,[38] while upload speeds would reach around 84Mbps. Based on trends in video and cloud usage under the 'status quo', IDATE has also estimated that bandwidth use in the EU may expand from 62GB per line per month in 2025 to 303GB per line.[39] This may seem a significant improvement for households used to experiencing restricted bandwidths,[40] but may not be

[34] FTTP – fibre to the premises – includes fibre to the home and fibre to the building projects. The term premises includes residential houses, as well as apartment houses. See annex for further reference on the technologies..

[35] Source: https://ec.europa.eu/digital-single-market/en/download-scoreboard-reports

[36] See the Expert Panel conducted under SMART 2015/005 –Annex 13 for more details.

[37] Page 115 Samknows for EC Oct 2014 Quality of Broadband Services in the EU.

[38] In the context of SMART 2015/0002, IDATE/WIK/Deloitte forecast a likely uptake of NGA by technology to 2025 and based speeds and speed growth per technology on the basis of Samknows data. According to Akamai speed measurements, average speeds have been increasing by 16% per annum across a range of geographies. Extending this projection would result in speeds of around 150 Mbps in 2025.

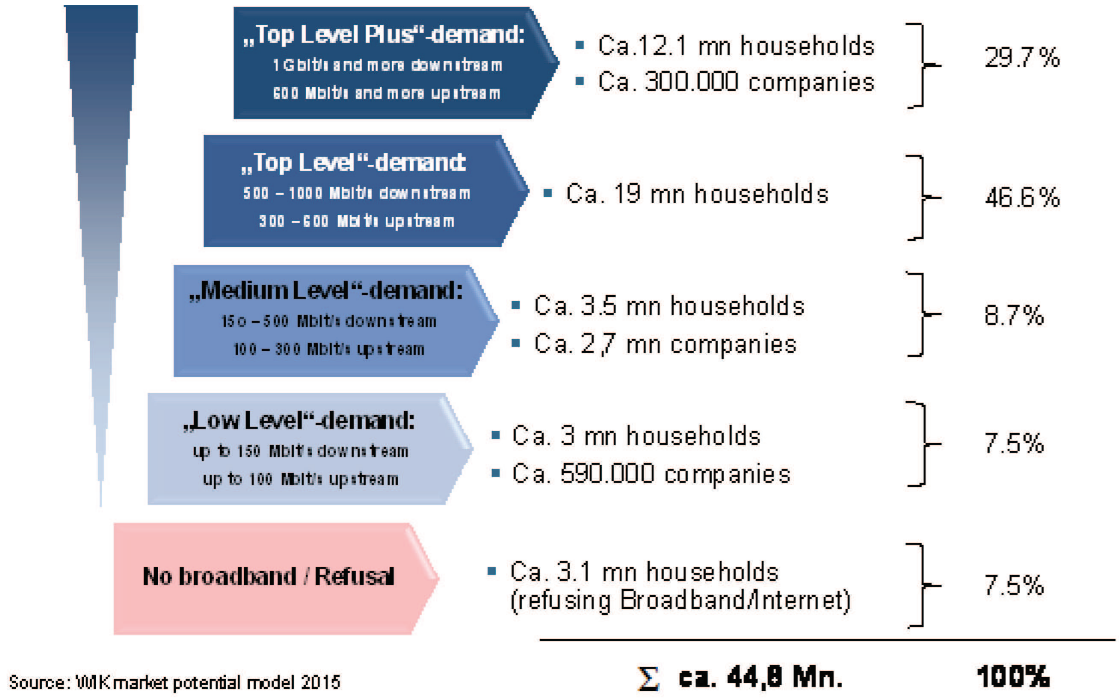
[39] See Study SMART 2015/0002

[40] Many Internet users are already experiencing challenges with the bandwidth they have available. Almost four in ten respondents to the Eurobarometer survey of 2014 noted that they had experienced difficulties accessing online content or applications as a result of insufficient speed of download capacities.

enough to enable home and business users to benefit from future technological and service innovations.

If bandwidth needs are calculated on the basis of what might be required to run certain applications, a case study of the German market providing a forecast for 2025 suggests that an average user might require 150-500Mbit/s downstream with more than 100Mbit/s up, while high-end users including those running small or home offices might require 1Gbit/s in download and more than 600 Mbps in upload (see SMART 2015/0005). This bandwidth would be used not only for multi-screen ultra HD video, but also for applications such as cloud and e-health as well as for teleworking and small business needs.

Figure 19: - Model of market potential – Germany 2025



As shown in Figure 19, data rates required by the most demanding users could reach 1 Gbps or more on the downstream link by 2025, while a significant proportion of households and offices could demand download speeds of 500-1000Mbit/s and 300-600Mbit/s upstream by 2025. This scenario therefore sets the upper bounds for potential users (including many business users) demands in the medium term, while it is worth noting that even a less ambitious scenario will need the VHC rollout to reach far deeper into most of the present networks. In addition, it has to be assumed that middle- and larger sized enterprises in the digital economy will have much greater simultaneous up- and download needs.

There is evidence suggesting that in the telecom sector **demand responds to supply**, and that limited download and upload speeds may limit the types of usage and applications that might otherwise emerge.

- Data from the UK regulator Ofcom for example suggests that download bandwidth consumption for NGA (FTTC and FTTP) networks was around two times higher than bandwidth consumption for non-NGA networks, with significantly higher use of upload capacity.

- This evidence of higher usage being associated with the availability of NGA is supported by the case of Palaiseau in France, which has been the subject of a pilot trial for the switch-over of Orange copper customers to FTTH networks: it was observed that the average Internet traffic of Orange's broadband customers was multiplied by a factor of three. Importantly, this trial also resulted in fibre clients' usage of upload bandwidth being increased 8 times[41].
- In Sweden, following an early boost by the central government, one out of every two municipalities is involved in VHC to the business and VHC to the home deployments. This has led to very high take-up: as of July 2015, 68% of the broadband connections in Sweden are NGA, achieved predominantly through FTTH and FTTB connections. Where FTTH is widespread, extending VHC to base stations is far more feasible and efficient. This is well illustrated by the example of 4G in Stockholm where the world's first 4G deployment took place helped by the virtually 100% VHC coverage.[42]

Although all technologies are likely to continue to improve, the gradual replacement of the medium over which connectivity is provided appears inevitable. Leveraging the speed of light, fibre has an efficiency range for delivering high quality, symmetrical connections of dozens of kilometres as against 250 meters for the most promising copper developments.

While existing copper-based infrastructure has the advantage of wide territorial reach in most of the Union, continuous reliance on this infrastructure in all but the very outer reaches of the network (e.g. within multi-dwelling buildings) may limit the availability – and possible take-up - of applications which demand the highest quality of connectivity, retarding developments necessary for the digitalisation of European industry, access to cost-reducing cloud services for SMEs and spontaneous, game-based skill development for the new generation.

Europe's gaps in high speed broadband connectivity are likely to have a significant impact on productivity and growth: econometric analysis conducted by WIK-Consult/Ecorys, VVA[43] suggests that broadband speed is positively correlated with Total Factor Productivity across a range of industrial sectors, while external studies have also identified positive economic effects from Gigabit technologies.[44] There is also evidence that a persisting digital divide between countries and regions of Europe may affect migration, employment and social inclusion.[45]

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[41] http://www.fibre-systems.com/news/story/orange-plans-full-fibre-coverage-9-french-cities-2016

[42] Source: Vodafone's call for the Gigabit Society, Dec. 2015

[43] Study supporting the Impact Assessment for the Review of the Framework for electronic communications.

[44] A Study by Analysis Group found that 14 broadband communities which benefited from gigabit connectivity enjoyed approximately $1.4 billion in additional GDP when gigabit broadband became widely available (Early Evidence Suggests Gigabit Broadband Drives GDP, David Sosa 2015, http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/gigabit_broadband_sosa.pdf). Forzati and Mattsson (2013) estimate the benefit of fibre installation in Stockholm by Stokab at 16 billion SEK.

[45] For example, Forzati and Mattsson (2012) found that a 10% increase in the proportion of the population living within 353 metres from a fibre connected premise corresponds to a positive change in the population after three years. Xiong (2013) also found that a higher fibre penetration of 10% at workplaces and 13% at residential places in a municipality in 2007 lead to a 0.17% improved population evolution between 2007 and 2010.

In line with literature pointing out that an increase of 10 percentage points in standard broadband penetration could contribute between 0.25% to 1.38% to GDP growth[46], a small, but expanding body of literature highlights how the effects of faster broadband through VHC connectivity could boost growth further and offer a new lease of life to rural communities[47],

3. Cost and benefits of very high capacity connectivity

3.1 Costing the networks for a Gigabit Society

3.1.1 Costing the gap and the financial endowment of current initiatives

Some studies have tried to estimate the NGA broadband gap in Europe and to provide estimates about the cost to fill it. The best known of these studies is probably the one performed by the European Investment Bank in 2011. The study considers four scenarios for broadband deployment in Europe. The most **ambitious scenario foresees FTTH/B** roll-out throughout Europe and the gap was estimated at €221 billion[48].

The same scenario of 100% FTTH/B coverage was analysed by Analysys Mason in a study for DG CONNECT in 2012[49]. The amount foreseen is similar (€250 billion, for deployment of FTTP-only, across Europe). The amount is reduced to €154 billion in case of high duct re-use. Analysys Mason also estimated the costs associated to a 100% FTTC deployment which are in the area of €50 billion. In case of high duct re-use, the cost would go down to €31 billion.

Studies suggest that the costs are justified by the benefits. Analysys Mason's study[50] showed that the bigger is the intervention, the higher is the consumer surplus.

[46] Among others: Crandall, R., Lehr, W., and Litan, R. (2007), The Effects of Broadband Deployment on Output and Employment: A Cross-sectional Analysis of U.S. Data, *Issues in Economic Policy*, 6; Czernich, N., Falck, O., Kretschmer T., and Woessman, L. (2011), Broadband infrastructure and economic growth, *Economic Journal*, 121(552); Koutroumpis, P. (2009). The Economic Impact of Broadband on Growth: A Simultaneous Approach, *Telecommunications Policy*, 33; Qiang, C. Z., and Rossotto, C. M. (2009), Economic Impacts of Broadband, In *Information and Communications for Development 2009: Extending Reach and Increasing Impact*, 35–50.Washington, DC: World Bank.

[47] See Study SMART 005/2015

[48] http://www.eib.europa.eu/attachments/efs/eibpapers/eibpapers_2011_v16_n02_en.pdf

[49] Analysys Mason, The socio-economic impact of bandwidth (2013).

[50] ibidem

Table 3: NGA investments and associated benefits under three scenarios

Scenario	Total NGA investment (EUR billion)	Input-output benefits (EUR billion)	Jobs created (million)	Consumer surplus benefits (EUR billion)
Do nothing	76.4	181.2	1.35	26.5
Modest intervention	102.5	270.4	1.98	28.6
Major intervention	211.2	569.4	3.94	31.9

Figure 2: Cumulative benefits of high-speed broadband in the EU27 countries, by scenario 2012–20
[Source: Tech4i2, 2012]

Source: Analysys Mason 2013 Study on the Socio-economic impact of bandwidth

An internal estimate carried out by DG CONNECT in 2014 on the basis of the Analysys Mason study of 2013 showed that Europe needed an additional €34 billion in investment to reach the objective of 100% coverage at 30 Mbps, and an additional €92 billion to credibly enable reaching the 50% take-up objective at 100 Mbps[51]. These figures already take account of the amount that the private sector could be expected to invest[52] and would leave part of the network below the performance levels required to serve a Gigabit society if substantial copper-based parts of the networks (e.g. beyond the cabinets) were to be durably maintained thereafter.

The **financial resources available** at the European level are certainly not sufficient to meet the challenge presented above and need to be focused on mobilising more private and national public investments. The allocation of **European Structural and Investment Funds** (ESIF) for high speed broadband networks experienced a sharp increase from €2.7 billion in 2007-2013 to around €6 billion for 2014-2020 (about €5.1 billion ERDF and an estimated €0.9 billion EAFRD)[53]. Most of this investment is expected to be made in the form of grants. However, the Communication on the Investment Plan for Europe called for a doubling in the use of financial instruments under ESIF[54], including an indicative target of 10% of support in the field of ICT. Overall, with the leverage effect of ERDF and EAFRD on public (national

[51] Based on a 75% coverage assumption.

[52] According to the Digital Agenda Scoreboard, telecom (including fixed, integrated and mobile-only) CAPEX in Europe was € 43 billion in 2013. CAPEX figures remained relatively stable over the 2011-2014 years despite the fact that in the same period NGA coverage increased from 29% to 68%. In 2014, Mobile CAPEX spending represented 59% of total spending. However, this CAPEX is not only directed at modernising the network, so the part which is spent on increasing coverage in the coming years might be subject to the operators' strategic priorities being it, among others, network expansion, modernization or cost optimization. On top of it, operator expenses depend on the evolution of the market trends and the investment climate.

[53] An estimate as the Commission cannot differentiate between allocations foreseen in EAFRD for ICT and Broadband as this type of information is not requested by the regulation. However, additional information is requested and will be provided in the context of monitoring activities (in particular, monitoring will be done for "N° of operations", "Population benefiting from new or improved IT infrastructure" differentiating here between "Broadband" and "Other than broadband"). See for more information the *ICT Monitoring Tool* : http://s3platform.jrc.ec.europa.eu/ict-monitoring

[54] See COM(2014) 903 final, p.10

and/or regional co-funding) and private co-funding, it is expected €9-10 billion will be invested in broadband during the 2014-2020 programing period, with the target to provide high speed connectivity to an additional 14.6 million households and make 33% of rural population benefit from new or improved ICT services or infrastructures.[55]

The Connecting Europe Facility (CEF) in the digital area is endowed with a limited budget of €150 million to support deployment of state-of-the-art broadband infrastructure, based on the provision of financial instruments via the European Investment Bank (EIB). The broadband component of CEF is expected to mobilise around €1 billion[56].

Finally, the European Fund for Strategic Investment (EFSI) does not have sectorial earmarking, hence it is difficult to anticipate how much broadband infrastructure investment will be facilitated by it.

Analysys Mason's most recent study for the European Commission (SMART 2015/0068) "Costing the new potential connectivity needs" analysed 6 scenarios, the outcomes of which and the necessary investments are presented in table 4.

Table 4: Description of costing scenarios with their price tags in the recent Analysys Mason study

Gigabit connectivity for socioeconomic drivers			
Scenario A	Most important e-health, e-education and e-government players as well as medium sized SMEs[57]	486 thousand medium sized SMEs (50-249 employees), 210 thousand local authority buildings, 110 thousand hospital and doctor's surgeries; 210 thousand primary and secondary schools; half of the existing s SMEs, hospitals and secondary school is assumed to have already a leased line connection	€46 billion
Scenario D	All big and small socioeconomics drivers such as teleworkers, professionals, small and micro enterprises and most important cultural sites	All from scenario A plus: 31.5 million small and microenterprises, 10 million teleworkers and freelancers 265 thousand libraries, museums, and sites of cultural interest 134 thousand post offices and police stations	€149 billion
Ubiquitous mobility[58]			
Scenario F1	Railways	Currently 75% covered	€5.2 billion
Scenario F2	Railways and motorways	Currently 75% covered	€6.7 billion

[55] https://cohesiondata.ec.europa.eu/themes/2

[56] Under the pilot phase of the Europe 2020 Project Bond Initiative, the EIB and the Commission closed in July 2014 the first deal on a broadband project bond (in France – Axione is the beneficiary). The leverage factor foreseen for the broadband part of CEF is around 7 times, so it is expected to mobilise around €1 billion. This leverage was exceeded by the Axione deal which had a leverage factor of 14 times.

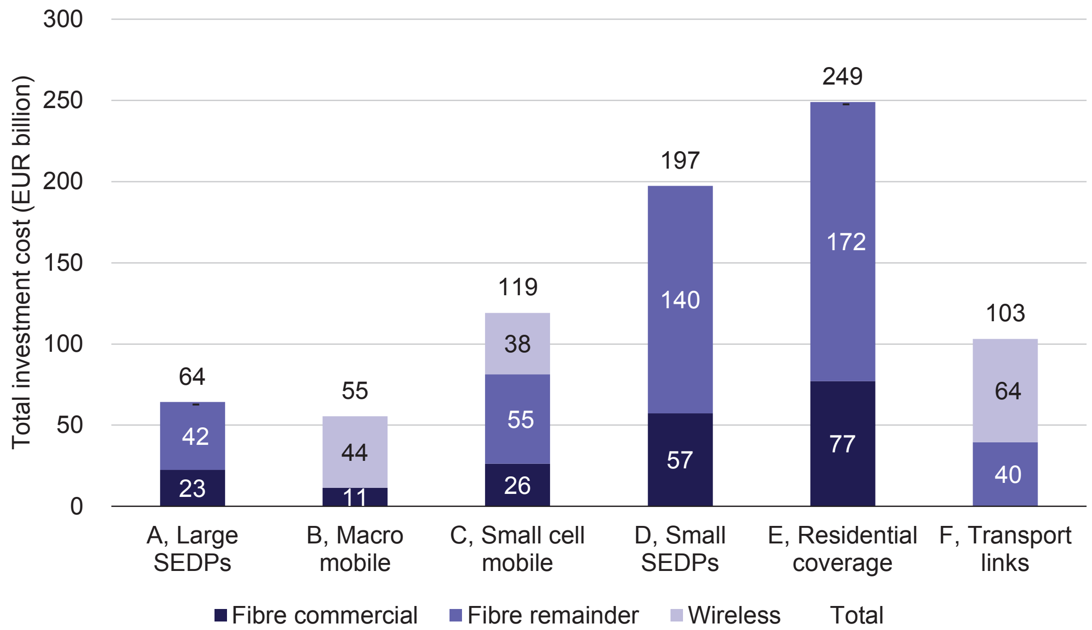
[57] For medium SMEs, hospitals and secondary schools only half are supposed to need connection as the other half are assumed to be using leased lines.

[58] For the Scenario F all the calculations are based on the price per length of the transport corridor calculated by reference to the amount of connected base stations required.

Scenario F3	Railways, motorways and state roads	Railways, motorways (75% coverage), state roads (50% coverage)	€28 billion
Scenario F4	Railways, motorways, state and provincial roads	Railways, motorways (75% coverage), state and provincial roads (50% coverage)	€103 billion
Improved connectivity for rural areas			
Scenario B	Residential coverage for all the population with wireless connectivity above 100 Mbps (macro cells)	Base station radius: 4km; active equipment cost €20 000 per site for interim upgrade and EUR40 000 per site for full upgrade	€79 billion
Scenario C	Residential coverage for all the population with 1 Gbps wireless connectivity (micro cells)	Base station radius: 200 m; active equipment cost €1000 per cell	€143 billion
Scenario E	Residential coverage for all the population with 1 Gbps fixed connectivity	1Gbps access available to all residential customers; 81% of them are assumed to take up services	€183 billion

Figure 20 shows the total standalone costs for each of the above-mentioned scenarios.

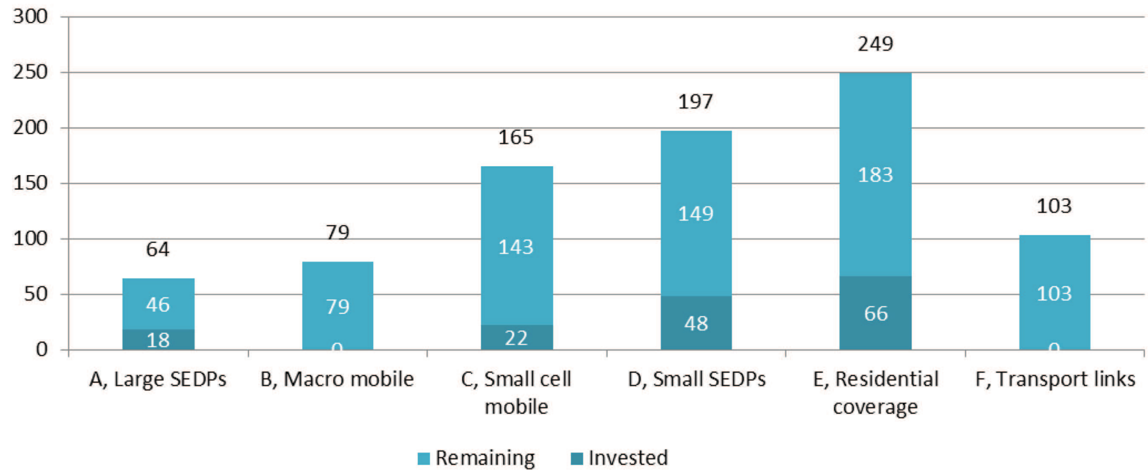
Figure 20: Summary of the scenarios: Total costs split by technology and commercial viability).



For scenarios B and C costs reflect 95% population coverage. Source: Analysys Mason, 2016

Despite the investments already undertaken, there is still a long way to go to complete any of the scenarios as to date at most roughly 25% of the total sum has been invested, as shown in Figure 21.

Figure 21: Summary of the scenarios: Investment already undertaken.



For scenarios B and C costs for 100% coverage. Source: Analysys Mason, 2016

3.1.2 The trajectory of private infrastructure investments

The Commission estimates, on the basis of trends throughout the decade to date, an annual investment by operators of €40 billion that should reach a cumulative investment of €360 billion by 2025. This baseline estimate is based on the projected overall capex for the period, based on continuation of most recent observable trends, and corrected on the basis of assumptions on non-network-related capital expenditure (e.g. terminal equipment such as routers /set-top boxes).

This calculation is in line with the growing interest from the private telecom sector in investing in the network. In November 2014, 10 CEOs of the main telecom and manufacturing companies committed to invest €150 billion in CAPEX in Europe over five years, to play a major role in the Commission's agenda for investment, growth and employment[59].

This estimate also takes into account that a share of the investment required will be common to all proposed options and that certain synergies can be expected. For instance backhaul high-speed networks can be used across scenarios, and high–speed Internet access to socioeconomic drivers resulting in fibre deepening diminishes also the cost of connecting households in the same area. The exact amount of the spending saved through synergies depends on the scenarios selected and increases with the amount of investment.

[59] "Make the Net Work" initiative of Alcatel-Lucent, Deutsch Telekom, Ericsson, Liberty Global, Orange, Telecom Italia, Telefónica, Telenor, TeliaSonera, Vodafone.

3.2 The importance of defining objectives for broadband

In 2010 the Digital Agenda for Europe (DAE) defined objectives for connectivity by 2020: it introduced objectives of universal availability at 30 Mbps to ensure territorial cohesion in Europe and a penetration objective of 100 Mbps (subscription by at least 50% of European households) to anticipate future competitiveness needs.

These objectives have progressively become a reference for public policy. In retrospect, the DAE objectives represented a sea change for European digital policy. Despite a lot of early scepticism, in particular from the private sector, the 2010 objectives succeeded in formulating the level of ambition and providing direction, consolidating first public and then increasingly private investment plans around the path towards 2020. The objectives were taken up as a reference point under the rules and guidelines in both the European Structural and Investment Funds and the Connecting Europe Facility (CEF Broadband), as well as under the Broadband State Aid guidelines.

Private sector investment plans are often adjusted to the objectives as well, and the expressed research and innovation ambition with regard to improvement of current technologies often refers to DAE objectives. At national level, setting objectives has become the cornerstone of broadband deployment public policy. Every Member State has today established broadband targets but also, on this basis and as shown in a recent study commissioned by the European Commission on National Broadband Plans in the EU[60], adopted or planned a set of funding and regulatory measures aiming at reaching them.

The impact of objectives, in terms of setting direction and a European common approach based on common minimum standards, is well reflected in the overview of the NGN plans adopted by Member States. Many Member States have indeed aligned their national or regional NGN plans to the DAE speed categories.

[60] AteneKom: National Broadband Plans in the EU -28 Smart 2014/007.

Figure 22: Overview of the degree of alignment of NBP with DAE objectives: Map

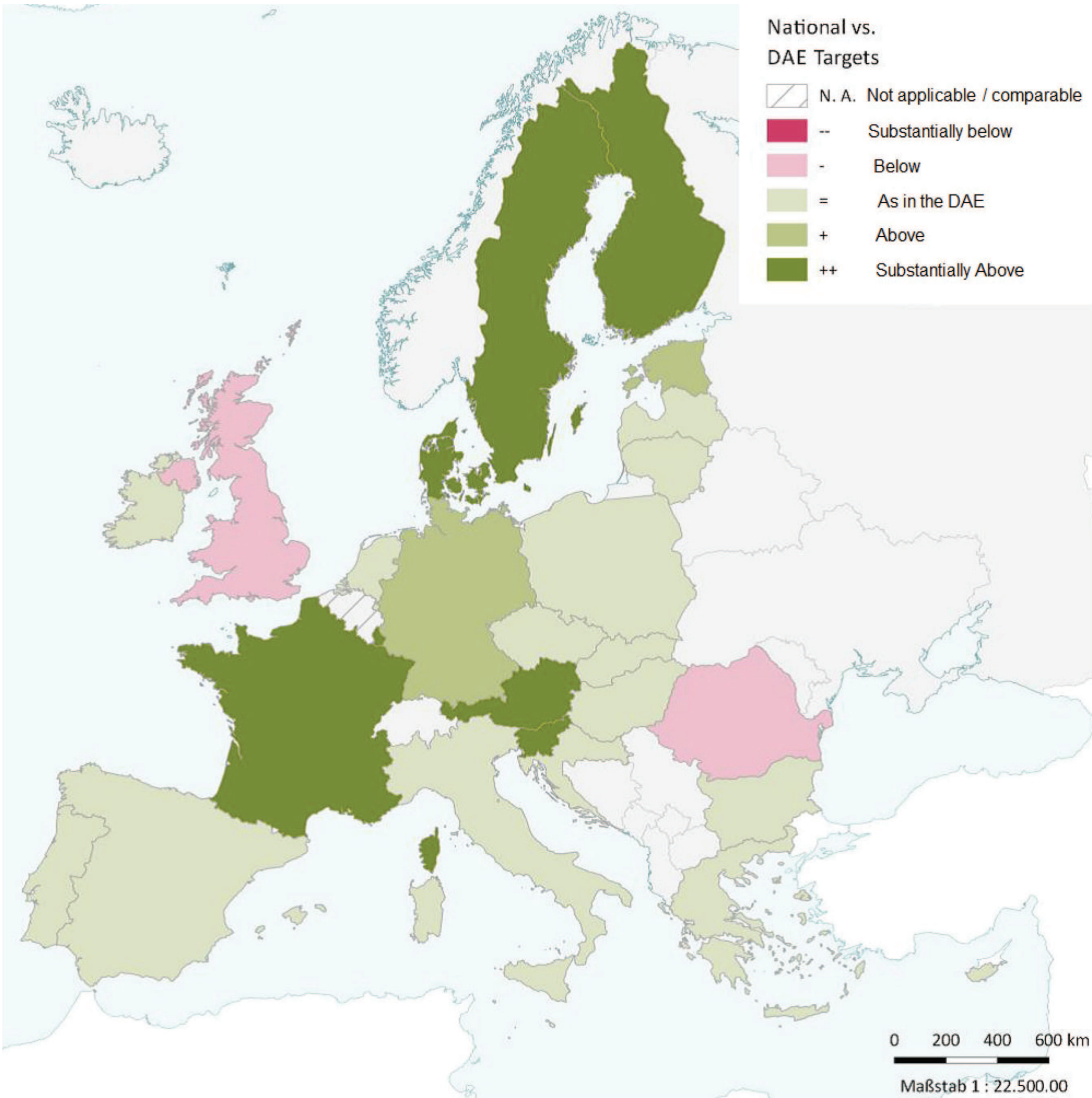


Figure 23: Overview of the degree of alignment of NBP with DAE objectives: Table

Member State	NBP-objectives	National vs Coverage objective	National vs take up objective
Austria	99% coverage with 100 Mbps by 2020	++	N.A.
Belgium	50% connections with 1 Gbps by 2020	N.A.	++
Bulgaria	100% coverage with 30 Mbps by 2020 50% of households and 80% of businesses subscribing > 100 Mbps by 2020	=	+
Croatia	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by 2020	=	=
Cyprus	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by 2020	=	=
Czech Republic	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 MBps service by 2020	=	=
Denmark	100% coverage with 100 Mbps download and 30 Mbps upload by 2020	++	N.A.
Estonia	100% coverage with 30 Mbps by 2020 60% coverage with 100 Mbps by 2020	+	+
Finland	99% of all permanent residences and offices should be located within 2km of an optic fibre network or cable network that enables connections of 100 Mbps	N.A	N.A.
France	100%coverage with 100 Mbps by 2022	++	N.A.
Greece	100% coverage with 30 Mbps by 2020 50% coverage with 100 Mbps by 2020	=	=
Germany	100% coverage with 50 Mbps by 2018	+	N.A.
Hungary	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by 2020	=	=
Ireland	100% coverage with 30Mbps by 2020 50% HH penetration with 100Mbps service by 2020	=	=
Italy	100% coverage with 30 Mbps by 2020 85% HH coverage to reach 50% penetration of 100 Mbps services by 2020	=	=
Latvia	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by 2020	=	=
Lithuania	100% coverage with 30 Mbps by 2020 50% coverage with 100 Mbps by 2020	=	=
Luxembourg	100% coverage with 1 Gbps by 2020	++	N.A.
Malta	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by 2020	=	=
Netherlands	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by	=	=

	2020		
Poland	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by 2020	=	=
Portugal	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by 2020	=	=
Romania	80% coverage with 30 Mbps by 2020 45% HH penetration with 100 Mbps service by 2020	-	-
Slovakia	100% coverage with 30 Mbps by 2020.	=	N.A.
Slovenia	96% coverage with 100 Mbps 4% coverage 30 Mbps by 2020.	++	N.A.
Spain	100% coverage with 30 Mbps by 2020 50% HH penetration with 100 Mbps service by 2020	=	=
Sweden	90% coverage with 100 Mbps by 2020	++	N.A.
United Kingdom	95% coverage with superfast broadband by 2017	-	N.A.

Source: National Broadband Plans in the EU -28 Smart 2014/007; AteneKom

3.3

4. Strategic objectives for 2025

4.1 The importance of setting realistic political guiding objectives

The Europe 2020 Strategy[61] set five ambitious objectives - on employment, innovation, education, social inclusion and climate/energy - to be reached by 2020. Each Member State has adopted its own national targets in each of these areas, underpinned by concrete actions at EU and national levels.

Political objectives – also sometimes called targets - are recognised as a clear signal of priorities to be achieved and as a way of influencing decision-making – by both public and private players – on a continuous and homogeneous basis. By themselves they cannot resolve the challenges related to achieving them; additional instruments – policy, funding and legislation, have to be used so that they are fully effective. Well defined objectives can nonetheless have an early effect on private investor decision making if there is a clear public policy commitment to achieve them, by mobilising public support through available instruments, and avoiding public policy interventions which would be counter-effective.

An increasing number of EU Member States is already focusing on new objectives beyond those set in the Europe 2020 Strategy, notably with a view to providing businesses and the public sector with Gigabit connectivity. In Bulgaria, structural funds help connecting community centres. In Poland, all schools will be connected with at least 100 Mbps, and some bigger ones even with 1 Gbps by 2017. Similarly, in Ireland, 750 schools have been connected with 100 Mbps in 2014 and the program is continuing.

Outside the EU, in South Korea, the Giga Korea project has the ultimate goal of building a digital information distribution infrastructure for a Gbps fixed-line and mobile connection network covering all people by 2020[62]. The US have the ambition that every American community should have affordable access to at least 1 Gbps broadband service to anchor institutions such as schools, hospitals and government buildings by 2020. Russia plans to make 100 Mbps available to 80% of Russian residents by 2018.

Against this background the European Commission has identified 3 strategic objectives for 2025 that will complement those set up for 2020:

1. Gigabit connectivity for all main socio-economic drivers such as schools, transport hubs and main providers of public services[63] as well as digitally intensive enterprises.
2. All urban areas[64] and all major terrestrial transport paths[65] to have uninterrupted 5G coverage.

[61] Communication from the Commission EUROPE 2020; A strategy for smart, sustainable and inclusive growth, COM(2010) 2020 final

[62] Electronics and Telecommunications Research Institute (ETRI) President Kim Heung-nam; http://newsworld.co.kr/detail.htm?no=436,

[63] Covering: e.g. primary and secondary schools, train stations, ports and airports, local authority buildings, universities, research centres, doctors' surgeries, hospitals and stadiums.

[64] As per definition: http://ec.europa.eu/eurostat/statistics-explained/index.php/European_cities_%E2%80%93_the_EU-OECD_functional_urban_area_definition.

[65] Motorways, national roads and railways, in line with the definition of Trans-European Transport Networks.

As an Intermediate objective for 2020, 5G connectivity to be available as a fully-fledged commercial service in at least one major city in each Member State, building on commercial introduction in 2018.

3. All European households, rural or urban, to have access to Internet connectivity offering a downlink of at least 100 Mbps, upgradable to Gigabit speed.

4.2 Leveraging mutually reinforcing objectives and existing infrastructures

Demand developments (see section 2.2.) confirm the virtuous dynamic between availability and take-up of VHC broadband services. Given the very slow start of take-up for 100 Mbps services in Europe, the strategic objectives for 2025 need to a) maximise the number of Europeans who have access to VHC networks for a given cost as well as b) enable the most innovative and beneficial connected services to be used throughout the Digital Single Market.

The new strategic objectives proposed for 2025 are therefore mutually reinforcing, focusing on entities which are best placed to further stimulate the demand for and use of online services and applications and on encouraging synergies in network expansion. They all require the deployment of VHC networks.

The deployment of VHC fixed networks will also contribute to the backhaul needs for the upcoming dense 5G wireless network deployments as close as possible to the end-user, thus strengthening the convergence between mobile and fixed networks.

The new objectives for 2025 build on the DAE objectives, in particular on the 100 Mbps objective. Indeed, the efforts to reach the 100 Mbps DAE objective will contribute to the achievement of the objectives for 2025.

The new strategic objective to reach all European households with 100 Mbps builds on and reinforces the 100 Mbps DAE objective (50% of households having 100 Mbps subscriptions or higher). It is very likely that particularly rural area networks built to reach the 30 Mbps DAE objectives in 2020, will be able to deliver 100 Mbps in 2025, as it is economically advantageous for mobile operators to expand networks coverage into rural areas (e.g. by serving 5G base stations with the same backhaul).

In addition, reaching the DAE 100 Mbps take-up objective can only be done with far-reaching deployment of VHC networks. Reaching the first and second strategic objectives, can thus benefit from using such deployments, bearing in mind that at least 75-80% of the population has to be covered with such networks for at least 50% of European households to actually subscribe to 100 Mbps services.

4.3 Benefits of the strategic objectives for 2025

4.3.1 Gigabit connectivity for all main socio-economic drivers such as schools, transport hubs and main providers of public services as well as digitally intensive enterprises

This objective will optimise investment in VHC networks by connecting with priority socio-economic drivers, i.e. physical places or online hubs where people gather or which they visit to learn, to work and to access public services and where a single connection provides Internet to multiple users. Providing European socio-economic drivers with VHC connectivity by 2025 will have multiple benefits for the DSM, in particular by:

- Encouraging such institutions to subscribe to very high-capacity connectivity (Gigabit, symmetrical, low latency, etc.) that will enable the use of the best products, services and applications and to provide the best service to European citizens. This in turn, creates a market for such online services. The Commission estimates that almost 100 million pupils and students, more than 70 million workers as well as almost 2 million doctors and more than 2.5 million patients in hospitals across Europe will benefit directly[66].

- Contributing to and stimulating the extension of very high capacity networks and the densification of mobile coverage, including for 5G backhaul needs, would benefit from proximity of very high capacity interconnection and backhaul opportunities. This will in turn increase the chances for advanced users, including in particular small and micro businesses and home office users, to be served by VHC connections.

- Creating a spill-over effect on demand for better connectivity in the rest of the economy (business ecosystems) and in the population at large (households), since users who experience very high capacity networks are more likely to subscribe to such services when they become available[67]. Higher take-up will in turn improve the economic case for further investment, as the higher penetration of services results in more users sharing the same connection and the cost of the investment, leading to a decrease of the cost per user..

The Commission services have considered, on the basis of the findings of Study SMART 2015/0068[68], two main options for this strategic objective:

A. Providing all the significant socio-economic drivers (in particular schools, transport hubs digitally intensive enterprises, local authority buildings[69]) with Gigabit connectivity. According to the cost estimates, the investment needs would be approximately €46 billion.

B. Providing all the socio-economic drivers without exception (in particular, in addition to the significant socio-economic drivers: micro and small enterprises, libraries and museums) with Gigabit connectivity. According to estimates, the investment needs amount to €149 billion[70].

Option A has been chosen, primarily on cost-effectiveness grounds. By bringing Gigabit connectivity to e.g. over 200.000 schools, over 200.000 public authorities buildings and roughly half a million digitally intensive enterprises[71], it is already fully relevant to stimulate

[66] Estimate based on the findings of the Study "Costing the new potential connectivity needs" (Smart 2015/0068) by Analysys Mason.
[67] The socio-economic return on Stockholm municipality's Stokab investment in fibre infrastructure is estimated to be over 16 billion SEK (approx. €1.6 billion), almost three times the investment in 2013. See Figure 2.20 of the Annex in Study SMART 2015/0002.
[68] Study "Costing the new potential connectivity needs" (Smart 2015/0068) by Analysys Mason
[69] The full list includes primary schools, secondary schools, universities, local authority buildings, digitally intensive enterprises, hospitals, doctor's surgeries, research centres, business parks, airports and stadiums.
[70] The full list includes, in addition to the large socio-economic drivers: micro enterprises, small enterprises, post offices, police stations, libraries, community centres, home workers, farmers markets, museums and galleries.
[71] The number of digitally intensive enterprises has been estimated by the Commission by cross referencing the estimates from the study by Analysys Mason "Costing the new potential connectivity needs" (Smart 2015/0068) and the assumptions underpinning the analysis of Integration of Digital Technology by enterprises in the DESI Index.

the extension of further fixed and mobile networks and to create additional appetite for better connectivity.

It is also worth noting that these efforts will complement the growing investment in the digitalization of industry and other sectors. Digitized products and services generate approximately €110 billion of additional revenues per year for the European industry. It is estimated that by 2020, European industrial companies will invest €140 billion annually in industrial internet applications[72]. The European Commission Communication on "*Digitising European Industry - Reaping the full benefits of a Digital Single Market*"[73] proposes actions that are expected to mobilise close to €50 billion of public and private investment in the next 5 years, but which are largely dependent on underlying connectivity provision.

In this respect, ETNO has recently underlined[74] that digitization is important in all public service domains and should include: i) 100% EU schools and universities connected to at least 1Gbps by 2030, ii) 100% administrative procedures digitised by 2025 and iii) 100% IDs in the EU to be turned into electronic IDs or mobile IDs by 2025 (all the IDs in EU to be digitized and e-administration enabled).

4.3.2 High performance 5G connectivity: by 2020 a fully-fledged commercial service in at least one major city in each of the 28 Member States and by 2025 uninterrupted 5G coverage of all urban areas and major terrestrial transport paths

The 5G objective aims at addressing Europe's future competitiveness in wireless technology. 5G services will be crucial to cope with increasingly demanding connectivity. Media applications, professional-grade communications in various industrial and service sectors such as automotive, transport, manufacturing, health as well as next generation safety and emergency services will have to rely on a seamless, shared, fixed and wireless infrastructure which offers various pre-determined levels of reliability and quality of service tailored to specific business needs.

In Japan, 5G networks have received substantial policy attention, and there are objectives to introduce a system trial in Tokyo in 2017, with implementation in time for the 2020 Olympics and Paralympics. In Europe Teliasonera and Ericsson have already announced that they will launch 5G services in Stockholm and Tallinn in 2018. Building on this experience, a fully-fledged commercial service in at least one major city in each Member State by 2020 is a necessary but reasonable objective and a stepping stone in the process of wider deployment of 5G.

In addition, as part of the 5G connectivity objective, the Commission aims at achieving by 2025 a 5G coverage of major terrestrial transport paths (defined as motorways, national roads, and railways).

5G connectivity on railways is needed to address in the long term the train passengers connectivity needs on board. According to estimates, in order to provide railways with 5G connectivity investment needs exceed €5 billion.

[72] http://www.strategyand.pwc.com/media/file/Industry-4-0.pdf
[73] COM(2016) 180 final; 19 April 2016.
[74] "A new digital Union I What's in it for citizens with IoT and 5G", https://www.etno.eu/datas/publications/studies/Narrative_Final_2016.pdf

In addition, 5G coverage of road transport routes will be the basis for the development of innovative applications for connected cars. The Commission services have considered the following scenarios[75]:

A. Providing motorways with 5G connectivity. According to estimates, the investment needs would be €1.5 billion.

B. Providing motorways and national/state roads with 5G connectivity. The investment needs would be close to €23 billion.

C. Providing motorways, national/state roads and provincial roads with 5G connectivity. In this case the investment needs would amount to €98 billion.

Option B[76] has been chosen because it would allow an EU-wide infrastructure to be developed which is capable of supporting solutions delivering information and entertainment on board and the progressive evolution towards fully autonomous driving, including the delivery of security functions reducing dramatically road casualties in Europe. Option A is considered too restrictive to achieve these goals. As to Option C (including provincial roads), it seems at this stage too costly but could represent a natural future evolution.

4.3.3 All European households, rural or urban, to have access to Internet connectivity offering a download speed of at least 100 Mbps, upgradable to Gigabit speed.

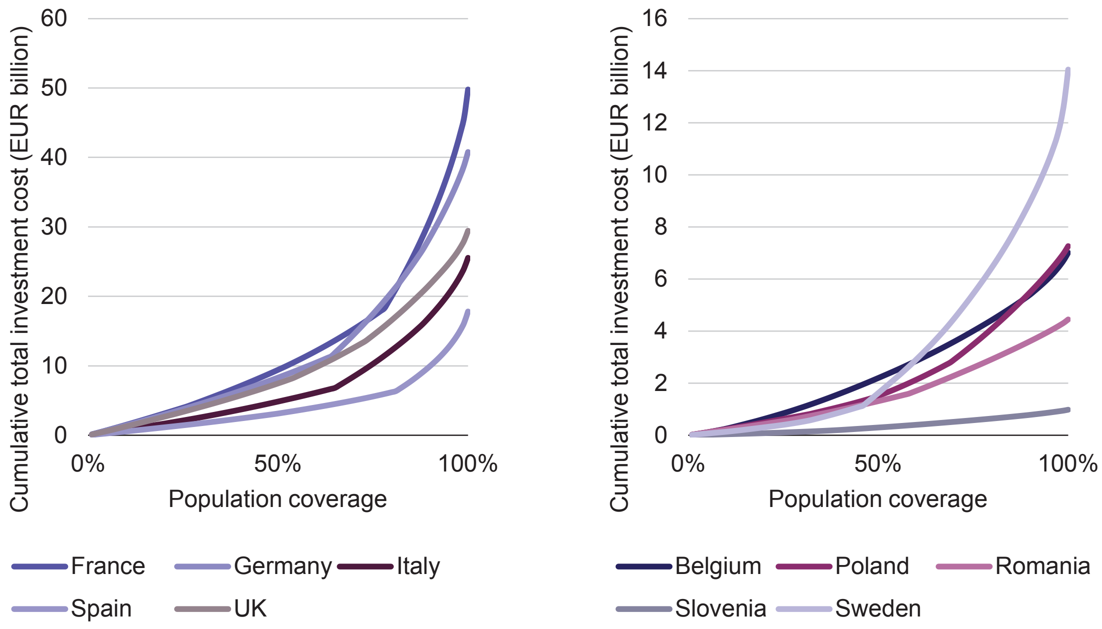
The challenge of comprehensive coverage objectives that concern all households lies in the last percentages of the population, those living in the most remote areas which are the most difficult and costly to reach. The lack of connectivity has an extremely high cost, not only by forgoing benefits of the digital single market, but also in terms of digital divide, depopulation, lack of cohesion etc.

Figure 24: Total cost (cumulative) of connecting countries with FTTP/H depending on the population covered per country (Analysys Mason[77])

[75] Based on the findings of the Study "Costing the new potential connectivity needs" (Smart 2015/0068) by Analysys Mason.

[76] Under this option, for terrestrial transport paths, and depending on the considered transport service, account will be taken of ongoing investments in C-ITS technologies while ensuring coordination with relevant stakeholders, Action 4 of the 5G Action Plan

[77] Study SMART 2015/0068, page 22.



This objective aims at making sure that no one is left behind in the digital world. It is to be seen against a wider ambition that there should be access to mobile data connectivity throughout the territory, in all places where people live, work, travel and gather.

In most rural and remote areas connectivity plays an essential role in rural development and agriculture, as well as in preventing digital divide, isolation and depopulation. It also enables remote or rural businesses to reduce the costs of commercial activities through video-conferencing, access to online administration, e-commerce, or data storage in the cloud. European households, rural or urban, will require a minimum level of fixed or mobile connectivity in 2025 much higher than it is today due to the growing needs for connectivity.

The investment needs for 100% household coverage of at least 100 Mbps will depend on the type(s) of infrastructure deployed. According to estimates[78]:

- The investment needs to provide 100% of the households with a (macro cell) wireless connectivity offering at least a download speed of 100 Mbps amount to €79 billion.
- The investment needs to provide 100% of the households with a (micro cell) wireless connectivity offering at least a download speed of 1 Gbps would cost €143 billion.
- The investment needs to provide 100% of the households with a fixed (FTTH) symmetrical Gigabit connectivity offering at least a download speed of 1 Gbps amount to €183 billion.

On the assumption that each type of infrastructure will account for an equal part of the future deployment (macro and micro cells for wireless and FTTH for fixed connectivity, mostly in urban areas), the investment needs for improved rural connectivity are estimated to amount to €127 billion; including €24 billion to cover the last 5% (around 11 million households) with wireless connectivity offering at least a download speed of 100 Mbps.

[78] Based on the findings of Study SMART 2015/0068.

4.4 The need to prioritise investments

The proposed additional objectives for 2025 are based on a focused approach choosing objectives that are designed to maximise societal and economic benefits relative to costs, but continue to ensure adequate connectivity even in rural areas and at the same time widen the approach to take into account the growing importance of the mobile/wireless dimension of broadband. This can unlock significant additional benefits, including for the equipment industry and for various "vertical" sectors (automotive, health, audiovisual) in which European leadership in the connected transformation is attainable.

The Commission services have therefore examined strategic needs and corresponding objectives of three types:

- for leader institutions, with significant user numbers and an important place in national and local economies and societies – the socio-economic drivers – which can be expected to have especially important connectivity needs;
- for wireless connectivity, by reference to the next (5G) technology generation;
- for universal coverage, including of rural households.

The Commission has sought expert advice to cost some specific scenarios for 2025 defined on the basis of the criteria described above. This includes the already mentioned study "Costing the new potential connectivity needs"[79]and has been complemented by further work by its own services.

The total estimated cost for the fulfilment of the three proposed objectives by 2025 is c. €515 billion. This entails an additional investment of €155 billion, to complement the investment of €360 billion that can already be expected in a "business as usual" or baseline scenario from telecommunications operators over the 2016 to 2025 period (see section 4.4).

In more detail, the individual amounts necessary to achieve the three objectives, not counting synergies between them, are estimated as follows, based on plausible assumptions about the proportion of underlying infrastructure needs that would in each area already be met by "business as usual" market activity (e.g. fibre along motorways):

- Gigabit connectivity for socio-economic drivers: Providing all main European socio-economic drivers with gigabit connectivity by 2025 will require an additional €46 billion investment on very high capacity fixed networks to connect primary and secondary schools, local authority buildings, digitally intensive enterprises, business parks, universities, research centres, doctors' surgeries, hospitals, stadiums, train stations, ports and airports. This will amount *on average* to an estimated maximum additional connectivity cost for each socio-economic driver institution of roughly €3500-4000 annually. In the case of a school of 20 classes with 25 students this would translate into an additional annual connectivity cost of €7-8 per student,[80].
- High performance 5G connectivity along main transport corridors including railways, motorways and national roads will require another €28 billion investment in mixed fix and wireless networks: €5.2 billion to connect railways, €1.5 billion to connect

[79] See Study SMART 2015/0068.

[80] The costs are estimated assuming 15 years return on investment period, 20% profitability margin for the operator and operational cost that are spread over all other users in a larger territory who will be served via the backhaul network that serves the relevant socio-economic driver institution (e.g. nearby households and businesses, etc.).

motorways, and €21 billion to connect national roads. In comparison with the scale of the automotive industry providing jobs for 12 million people and accounting for 4% of the EU's GDP (more than €400 billion) the investment is not huge and would be a logical step in the process of innovation of the transport sector.

- Improved connectivity in rural areas will require a €127 billion investment in a combination of fixed, wireless large and small cell-based networks:
    - The cost per user grows exponentially as the network reaches less and less populated areas, where the number of users sharing it is smaller. While the first 50% population coverage requires 20-25% of the total investment the last 5% are the most costly and difficult to connect. For this reason, the last 5% of households, roughly 11 million households, are assumed to be covered by macro cell infrastructure only (with very high capacity backhaul). Deployment of wireless connectivity offering the last 5% at least a download speed of 100 Mbps is estimated to cost over €24 billion. It is clear that this investment will require public intervention – public investment or publicly enabled investment.
    - For the other 95% of households, we expect a variety of approaches, between macro and micro cells for wireless and FTTH/B for fixed connectivity. On the assumption that each type of infrastructure will account for an equal part of the future deployment, the investment needs would amount to €103 billion,

The total of €201 billion, being the sum of all three options, does not take into consideration economies of scale and the synergies which could be used in combining more than one scenario. Based on the study by Analysys Mason we assume in particular that the re-use of the fibre networks rollout for reaching the first objective could produce up to € 46 billion savings in the third one. Therefore the final additional investment needed would be approximately € 155 billion.

Annex: Technological developments

I. Which technology?

Each year more and more fibre is being laid in Europe increasing the capacity, reliability and speed of the network. The deepening of the fibre (bringing it closer to the user) is taking place in a growing number of densely populated areas. However, the picture is not homogeneous. Even in more prosperous Member States, there are wide variations – attributable in part to differences in costs, in availability of duct infrastructure, in digital literacy and demand, but also no doubt to differences in commercial strategy – while some poorer Member States are leap-frogging.

A key question for policy-makers as well as investors is how will technological developments impact network performance and, in particular, i) whether future bandwidth requirements can be met through incremental upgrades of existing twisted pair copper and coax networks or require new investment notably in fibre networks reaching the user (FTTH/B); and ii) whether evolution of mobile technologies may enable some degree of substitution with fixed networks.

While in new greenfield deployments fibre will be the technology of choice, in the presence of a network constituted of twisted copper pairs, operators must decide whether to prolong the life of the existing network through new technologies, often replacing a limited part of the network with fibre, or roll out an entirely new fibre network.

Twisted copper pairs may be able to cope with downlink demand for video until 2024, when 8KTV (the current highest ultra-high definition television resolution in digital television and digital cinematography) will become available[81]. However the result is different in a demand scenario taking account of cloud and small business and home office usage where customers also have increased requirements for traffic symmetry (similar upload and download capabilities). In this scenario, very high capacity (VHC) technologies (G.Fast very close to the end user/FTTB, DOCSIS 3.1 and FTTH) would be needed at an earlier stage to meet the challenge.

In due course and as an alternative to the fixed last mile, it will be most likely possible to connect the customer with wireless high capacity networks, including wireless fixed links which focus on serving specific premises rather than supporting mobile use throughout an area. However, this will also require fibre connectivity to the base station, which will translate into a few hundred meters from the user depending on the spectrum availability.

This having been said, it should be noted that no data exists that would allow the estimation of future bandwidth needs of those sections of today's society that can be considered "digital natives " (below 25 years old) and which are driving data consumption already today.

Overall, fully or almost fully fibre-based networks are clearly in a better position to handle the challenges of improve connectivity parameters than their VDSL or cable competitors, although technological evolution such as the advent of DOCSIS 3.1 may alleviate several of

[81] See WIK-Deloitte-IDATE Study "Access regimes for network investment and business models in Europe" SMART 2015/0002

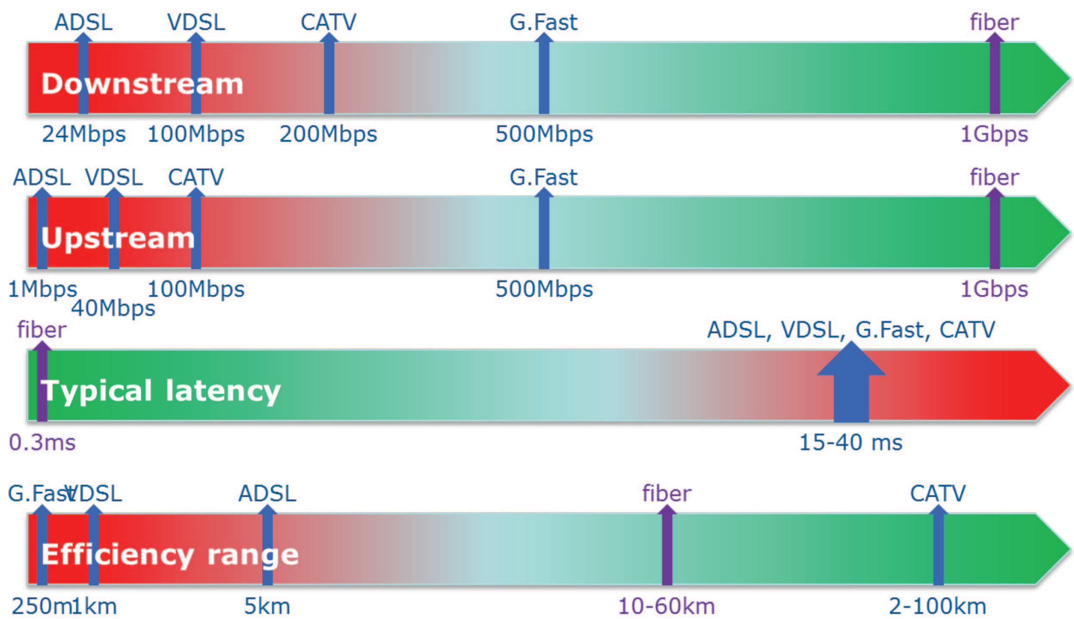
the latter's constraints, though probably not offering all the benefits and characteristics of fully fibre-based networks (see section IV below). It must also be acknowledged that the quality of a fully fibred network can also vary depending on design choices of the operator, including as regards active equipment. There is an emerging consensus among industry players and investors that, in the medium and long run, connectivity providers, both fixed and mobile, will have to rely on ubiquitous fibre infrastructures deployed very close to end-users' premises (buildings, wireless small cells) to support their business.

There are also differences of view as to what the timeline should be, which may be founded on genuinely different assessments as regards the pick-up in demand, the materialization of new services and applications, and the progress that can be made through intermediate technical solutions linked to legacy infrastructures – but can also be influenced by strategic considerations of operators who currently own such legacy infrastructures and may consider it to be profit-maximizing to delay such a transition, even at the cost of beneficial externalities for society as a whole.

II. What will technology deliver

The next figure illustrates that physical capabilities of the technologies or transmission media set barriers to certain applications – some of which derive directly from the laws of physics (the speed of light relative to the transmission of electrons). For example, the last arrow, showing the efficiency range for technologies, illustrates that the high-speed copper solutions give rapidly declining performance at more than 250 metres from the end-user, thus requiring fibre to be deployed to a drop point situated at that maximum distance from the end user premises to be effective.

Figure 25: Physical capabilities of the technologies or transmission media

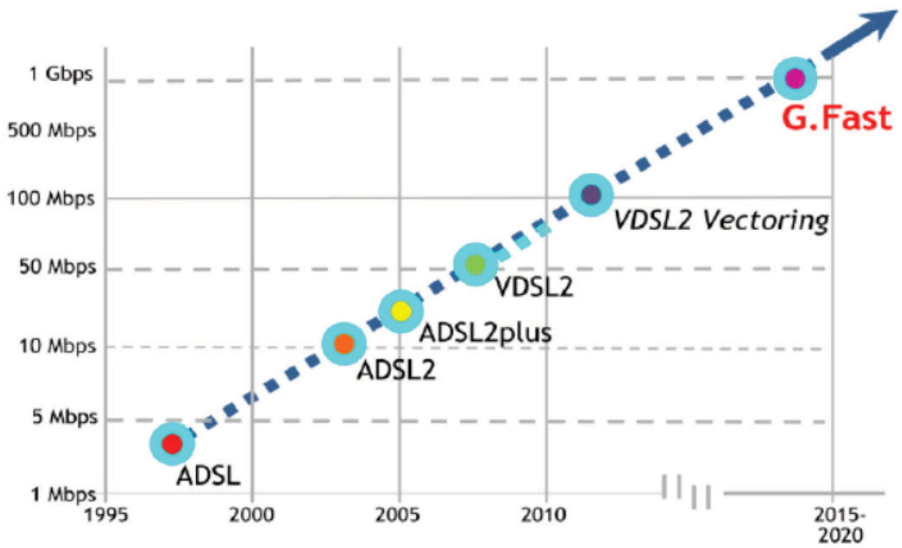


III. Copper based technologies

Twisted pair copper cables have been widely deployed in the past to provide telephony). In western European countries they have reached almost 100% of homes, although in central European countries the deployment has peaked at approx. 60% as mobile wireless access has filled the gaps.[82]

Internet access over twisted copper pairs has evolved over time. New technologies such as ADSL have made possible to provide higher data rates over copper networks. Figure 26 shows the progress in the theoretical data rates of the various DSL access technologies. It is notable that the introduction of VDSL2 vectoring is likely to raise download speed capabilities to 100 Mbps, while G.Fast could reach 1Gbps in a 2020 timeframe. However, the faster the DSL technology, the shorter is the distance from the drop point (where the fibre component of the network ends) to the customer that can still be covered on the basis of an upgraded copper network.

Figure 26: Evolution of DSL data rates, 1995-2020



wik CONSULT

Source: FttH Council Europe (2014). G.Fast. Brussels: FttH Council Europe

The practical consequence is that operators which are relying on improvements in copper technology to drive higher speeds must ultimately deploy fibre and locate associated active equipment ever closer to the customer[83].

[82] See Study "Access regimes for network investment and business models in Europe" SMART 2015/0002, Section 1.2.
[83] Ibidem, Section 5.1.

Figure 27: Copper access line use migration: Higher bandwidth over shorter sub-loops (source WIK)

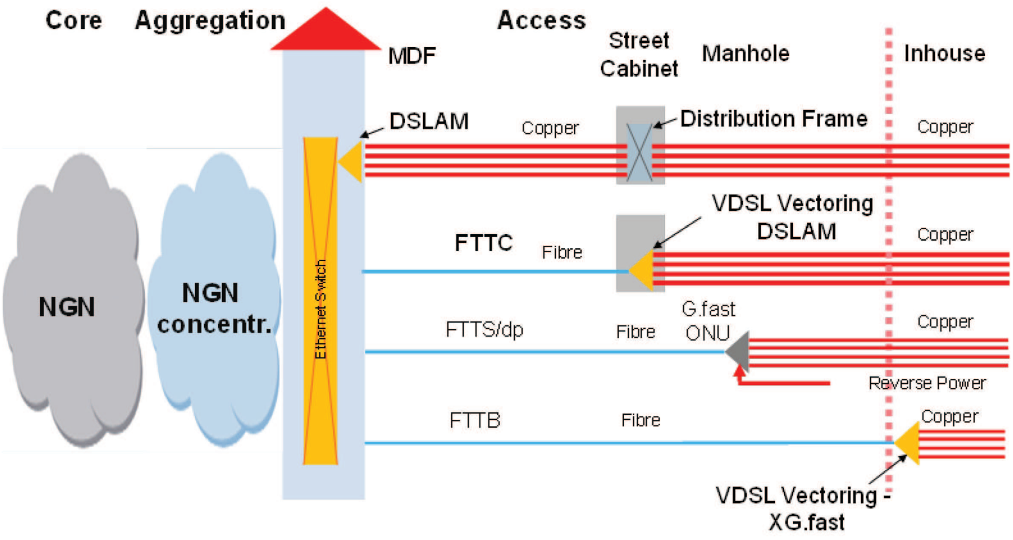
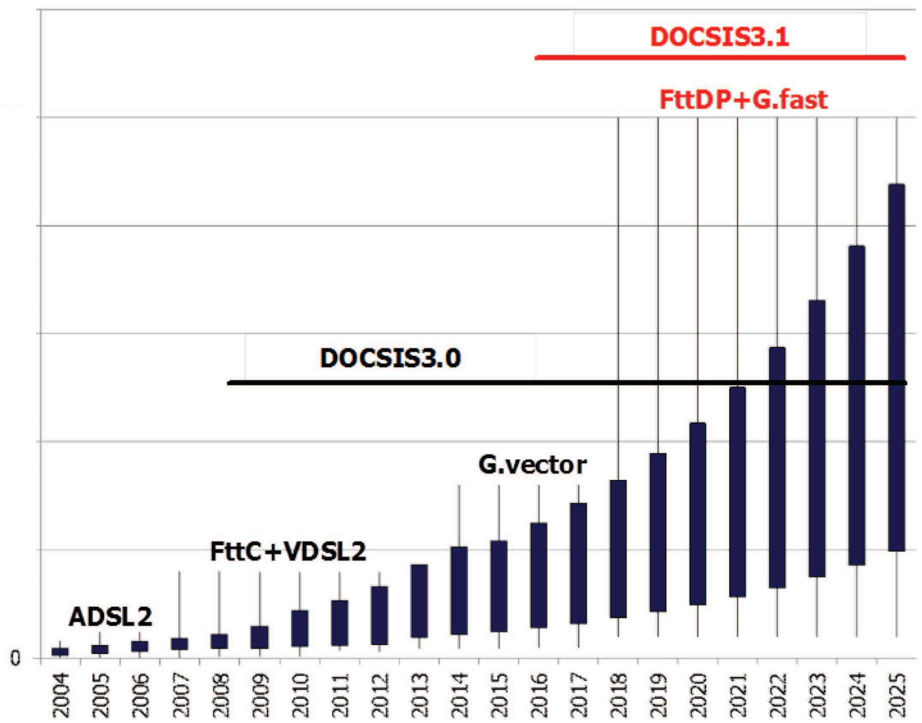


Figure 28 shows the historic technological developments and speed ranges in Belgium from Proximus and Telenet to the period 2015 and a forecast for subsequent years.[84]

[84] The forecast is based on the extrapolation of the 16% bandwidth growth rate observed over recent years as measured by Akamai, this being combined with the forecast on technological capabilities According to Akamai, the average connection speed is low because of: (1) parallel requests, whereby an average webpage generates 90 requests for content; i.e. involving relatively small files as many components make up a webpage; each session being too short to ramp up to maximum speed; and (2) IP address sharing, whereby multiple devices use an internet connection with an unique IP address, with simultaneous requests sharing the available bandwidth. The average peak connection speed reflects the highest connection speeds from each unique IP address. Thereby it is representative of internet connection capacity. It reflects larger files, such as software updates occurring late at night. Source: Akamai (2015). State of the Internet, 4Q-2014. Cambridge, MA.

Figure 28: The useful life of copper, 2025 perspective



Source: Wolter Lemstra

This scenario projects an average data rate of 50 Mbps and an average peak rate of approx. 220 Mbps downstream for the year 2025. The chart reflects the early and wide deployment of vectoring by Proximus. With many G.Fast trials underway and the first commercial deployments being announced, broad deployment of G.Fast could start in 2018. The predicted capacity of FttDP [85]+G.fast+G.vector on copper loops of 100 meters or less is given as at least 250 Mbps symmetrical. Under this scenario the useful life of twisted pair copper in the cable drop and in-house cable segment would be extended well beyond 2025. However, it should be noted that G.Fast requires the deployment of fibre very close to the end-user (FttDP), as well as continued OPEX heavy management of the energy and maintenance needs of active equipment at many points close to the edge of the network. It is thus not a costless solution.

While DOCSIS 3.0[86] could meet projected demand up to 2020, this scenario suggests an average peak connection rate in excess of 100 Mbps for 2020. However, within the next 5 years period Telenet will be in a position to upgrade from DOCSIS 3.0 to DOCSIS 3.1 and hence will be able to meet – and generate - growing demand under this scenario.[87]

[85] Fibre-to-the-Distribution-Point – i.e. somewhere between Fibre-to-the-Node (FTTN) and Fibre-to-the-Home (FTTH).
[86] Standard employed by many cable television operators to provide Internet access over their existing hybrid fibre-coaxial (HFC) infrastructure.
[87] See Study "Access regimes for network investment and business models in Europe" Smart 2015/0002, Section 1.2.

In conclusion, this case analysis suggests the possibility of an 'extended life' for copper-based access technologies towards the 2025 horizon, but only as the "last mile", which in practical terms means few hundred meters or less.

However, the above discussion concerns the demand on the downlink. Demand on the uplink has traditionally been much smaller than on the down link, but a shift towards more balanced use is expected as a result of an increase in the use of cloud services, social media and more business usage from the customer premises. G.Fast is said to support 250 Mbps symmetrical, while DOCSIS3.1 supports 10G/1G in a shared configuration and the ratios can be adapted to market demand. Hence, both technologies appear to have 'head room' on the uplink for a "business as usual" evolution.

In addition, beyond the traditional focus on speed, quality (in particular jitter and packet loss) as well as responsiveness (in particular latency) of the network are increasingly relevant. Figure 25 shows that while incremental upgrades of copper networks through technologies such as vectoring and G.Fast can deliver higher speeds in particular in short distances (e.g. G-fast up to 250m), fibre networks seem to be in a better position than copper-enhanced networks to handle challenges such as symmetry between up- and download, low latency, jitter and packet loss due to the physical parameters of the medium (e.g. electric vs optical signal).

IV. Optical fibre – a new generation of networks

In order to meet growing demand from the users, access with new technologies will be necessary and the most appropriate technology mix would be a combination of the fixed and wireless networks proving the most efficient mix at a reasonable price. Whatever technology is selected as the access to the customer in the final mile, the core network and backhaul will require optical fibre. Similarly, fibre deepening to a large degree is a prerequisite to all the other technologies, which deliver high connectivity.

Optical fibre-based transmission is probably the most robust high-throughput technology available today. It has seen wide deployment in long-distance networks following the liberalization in the late 1980s, in support of the growing needs from the booming Internet and mobile communication services.[88]

Apart from output fibre networks offer quite a few beneficial characteristics:

- **Low latency:** the ability to support instantaneous connections and transit data without almost any 'delay', measured in just Milliseconds over distances greater than 1000km, and only microseconds at distances in the 100's of KM
- **Availability:** these networks are inherently stable, offering extremely high availability
- **Security:** such networks, given the physical and often buried, nature of the cable, are harder to interfere with than wireless networks (or even 'radiating' copper based cables)

[88] See for a discussion of pan-European network deployments during the euphoric period and the consolidation in the aftermath of the crash Lemstra, W. (2006). Dissertation: The Internet bubble and the impact on the development path of the telecommunication sector. Department Technology, Policy and Management. Delft, the Netherlands: TU Delft.

- **Packet loss & low jitter:** near zero packet loss and variance in packet delay, i.e. "smooth signals"
- **Distance agnostic:** grade of service is essentially the same almost regardless of distance
- **Dynamic symmetry:** such networks can be configured to allow flexibility in assigning upload and download throughput for each connection, depending on the use case
- **Low maintenance:** fibre is inherently reliable, hence little maintenance is needed
- **Future proof:** transmitting equipment can be easily replaced and raw medium is future proof
- **No radio frequency interference:** signals travelling over fibre are not subject to radio frequency interference versus copper which is susceptible.

Figure 29: What is throughput? – measured as "time to download"*

Digital item (examples)	Typical size	Legacy network	FTTH network
Average Kindle eBook	2.6 megabyte	1 second	50 ms
CT scan (sent across hospitals)	2 gigabyte	14 minutes	40 seconds
Virtual reality game	5 gigabyte	34 minutes	1.7 minutes
Blu-ray movie	25 gigabyte	2.8 hours	8 minutes
Galaxy S7 storage	32 gigabyte	3.6 hours	11 minutes
4K movie	100 gigabyte	11 hours	33 minutes
Hard disc of a PC	240 gigabyte	27 hours	1.3 hours
Medium sized corporate server restore	6 terabytes	28 days	33 hours
Human genome (uncompressed)	7 terabytes	33 days	39 hours

** Today's actual effective download speeds illustrated a 20Mbps for a typical European 'legacy network' (usually ADSL2+ type) and 0.4Gbps for FTTH network*

Source: Creating a Gigabit Society; Arthur D. Little for Vodafone[89]

a. Fibre-to-the-Business

As business users have higher demand than consumers and are typically located in business districts or business parks, the business case for providing a new network technology by digging up the streets has largely been positive. In many cases we can observe competing fibre-based services being offered to business users. This includes the incumbents, locally as well as from abroad, but also new entrant providers specializing in servicing the business community.

b. Fibre-to-the-Home

Two standards are prevailing in the market place in Europe: the GPON standard providing 2.5 Gbps downstream and 1.25 Gbps upstream, shared by a maximum of 64 users; and the XG-PON[90] providing 10 Gbps downstream and 2.5 Gbps upstream, i.e., a fourfold increase

[89]http://www.vodafone.com/content/dam/group/policy/downloads/Vodafone_Group_Call_for_the_Gigabit_SocietyFV.pdf
[90] Serving 128 customers per splitter.

compared to GPON. This latter arrangement provides a minimum of 78/19 Mbps per end-user, depending on how much capacity is made available per user and reflecting shared medium constraints in case of uniformly massive demand growth.

For point-to-point networks the 'Ethernet in the First Mile' (EFM) standard, used over single mode fibre, is defined for a span of nominal 10 km. State of the art technology is able to bridge higher distances up to 80 km.

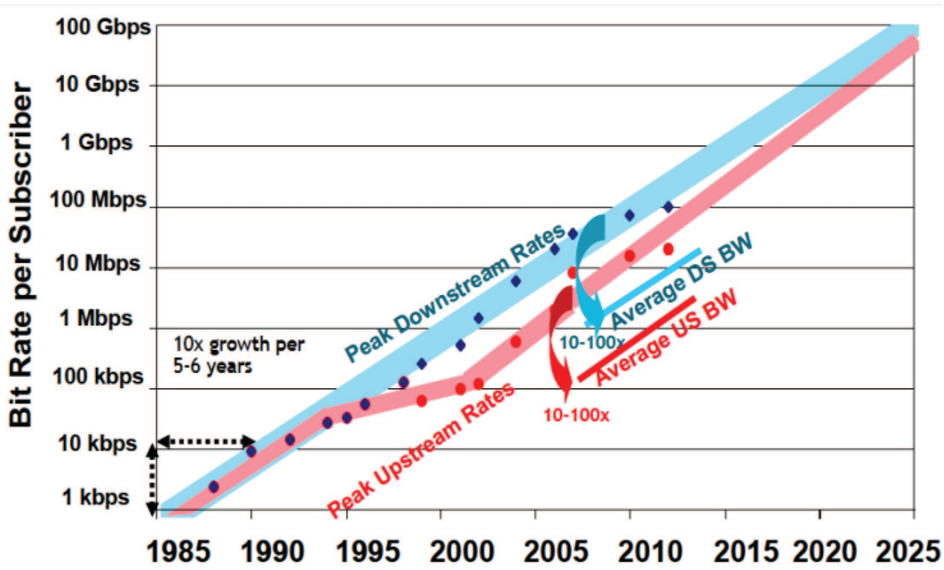
c. Outlook for the 2025 horizon

For the PON architectures, a further upgrade is foreseen under the name of NG-PON2 with a capacity of at least 40/10 Gbps (download/upload), for a minimum span of 20 km. Extensions to 80/20 Gbps and 60 km are being addressed. This standard makes use of four wavelengths and eight in the extended version. The minimum end-user data rates are 625/156 at a ratio of 1:64, respectively 312/78 Mbps at 1:256.

A combination of TDM-PON and TWDM-PON is also foreseen running at 100 Gbps reaching 100 km with a split ratio of 1:1024.

The evolution in user data rates using fibre is shown in figure 30.

Figure 30: Evolution of FttH data rates, 1995-2025



Source: FttH Council Europe (2014). FTTH Handbook: FTTH Council Europe

d. Investing in FTTH

While DSL and DOCSIS technologies have mostly been deployed as upgrades to legacy networks by historic incumbent and cable operators, FTTH is characterised by a more diverse investor-base.

In Sweden[91], which has a very low population density – 23 persons per square kilometre, municipalities have taken the lead in the deployment of open-access fibre networks, encouraged into that role by the central government.[92] The business case for these largely rural area deployments turns positive through a combination of factors: (1) the costs for procurement of communication services for the local government in all its facets turns from external to internal; (2) the community network provides lower cost bundled access for service providers; (3) at the same time providing for increased services competition; (4) the use of civil infrastructure owned by the municipality; (5) shared interest in the execution of the works; and (6) willingness of prospective subscribers to pay an upfront fee .

Commercial non-telecom infrastructure investors have also in some cases seen a profitable business case in building an FTTH access network in competition with the existing copper network(s). These cases are typically built around demand aggregation (i.e. activating projects in an area only when a minimum threshold of interested future subscribers has been passed), often in combination with payment of upfront fees by prospective end-users, and novel low-cost techniques of laying the fibres. These networks are often open-access, with competition on the services layer. A typical example is the case of Reggefiber in the Netherlands.[93]

The lack of broadband provision by traditional players in central Europe has led to grass-roots initiatives by local entrepreneurs in deploying fibre to provide Ethernet-based connectivity in apartment buildings and city neighbourhoods.[94] This has propelled some central European countries, for instance Latvia and Bulgaria, to the top of the broadband league tables in terms of peak connection data rates.

Higher deployment of FTTH can also be observed in circumstances where the costs of deployment are lower (for instance thanks to duct availability) and in countries with competitive pressure from alternative FTTH investors. Incumbents may also be expected to deploy FTTH in greenfield situations, as it provides for higher data rates, is more future proof and comes with lower operational costs.

e. Will fibre-based technologies be able to meet growing demand?

Fibre has been and still is the technology providing the highest possible data rates with the highest and most consistent quality of service. Since the early 2000s fibre-based Internet access has been offered at 50 Mbps and 100 Mbps symmetrical to residential customers and into the Gbps range to business customers. If demand grows the split ratio in fibre PON networks can be reduced. If demand would grow much further, wavelength division multiplexing (WDM) can be introduced which makes it possible to use multiple colours of

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[91] For a description of the Stockholm municipality fibre network Stokab, the role of housing corporations, initiatives in Swedish municipalities including rural communities and an example of regional coordination, see Section 1.3 of the Annex in Study SMART 2015/0002, see footnote 12.

[92] See Chapter 7 *Sweden* by Forzati and Mattson in Lemstra, W. & W. H. Melody (Eds). The dynamics of broadband markets in Europe: Realizing the 2020 Digital Agenda. Cambridge: Cambridge University Press.

[93] See Chapter 4 *The Netherlands* by Lemstra in Lemstra, W. & W.H. Melody (2015). "The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda". Cambridge University Press.

[94] See Chapter 15 *Latvia* by Virtmanis and Karnitis in Lemstra, W. & W.H. Melody (2015). "The dynamics of broadband markets in Europe – Realizing the 2020 Digital Agenda". Cambridge University Press.) As well as. Rood, H. (2010). Very high speed broadband deployment in Europe: The Netherlands and Bulgaria compared. Telecom Policy Research Conference, Arlington, VA: TPRC.

light to expand the capacity of a single (existing) fibre. This can be accomplished by an upgrade of the electronics at either end of the fibre.

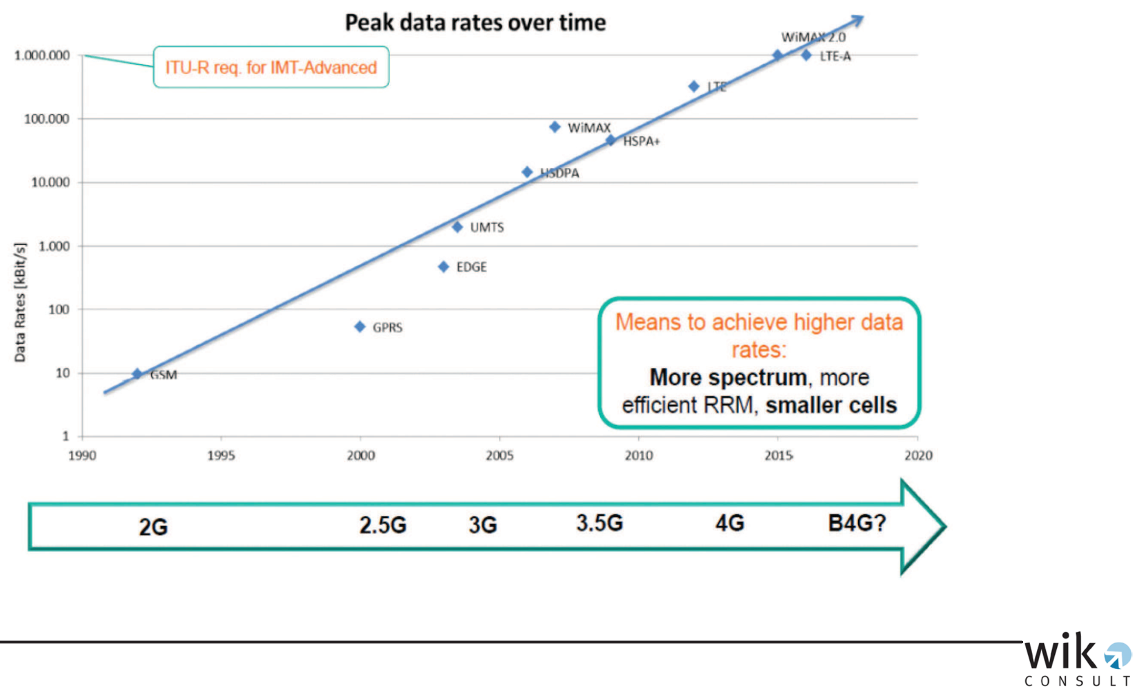
Recent technological developments suggest that a combination of time and wavelength division multiplexing (TWDM) can be deployed over passive optical networks (PONs) such that the (physical) point-to-multipoint architecture can be turned into a (logical) point-to-point architecture, combining the benefits of both architectures.

According to many sources[95] fibre can stay ahead of even the most optimistic forecasts in terms of end-user demand for at least next 25 years.

V. Wireless technological developments

Although Moore's Law does not directly apply to progress in performance of radio frequency chips[96], exponential growth is very clearly reflected at the systems level when performance is expressed in peak data rates, in particular as achieved in mobile communications, Figure 31 represents a data rate increase by a factor of approx. 1.8 every year. This is essentially the result of more capable digital signal processing. We may expect this trend to continue since the succession of generations of cellular mobile networks shows a high degree of regularity.

Figure 31: Peak data rates in mobile, 1990-2020



Source: Niemegeers, I. & S. Heemstra de Groot (2015). Cognitive Radio+ for 5G and beyond. Eindhoven: Technical University Eindhoven

[95] Research done by e.g. Ericsson, FTTH Council and ITU.

[96] As Golio observed: "*In digital systems, the fundamental unit of electrical design is the bit. Any bit will work as long as the difference between the '1'state and the '0' state can be distinguished as scaling reduces the size of devices, no fundamental change in electronic design is required. In contrast, the fundamental unit of RF/wireless systems design is the Watt. A specific amount of power is required from the transmitter in order to achieve link margin at the receiver the required power level is not nearly as scalable as the bit.*" Source: Golio, M. (2015). "Fifty years of Moore's Law." Proceedings of the IEEE *103*(10): 1932-1937.

Since data communication was introduced through GPRS the data rates have increased through different technologies. LTE Advanced was first introduced in 2013 and provides a peak cell capacity of 1.2 Gbps, which is shared among the users. The design vision for 5G aims for 1000 times higher overall capacity and for 10 to 100 times higher end-user data rates. This is expected to result in guaranteed user rates of over 50 Mbit/s. For more information on the future capabilities of 5G systems, please consult the Staff Working Document on "5G Global developments"[97] accompanying the Communication "5G for Europe: An Action Plan"[98].

Figure 32: Features of connectivity medium and technologies

Medium	Technologies	Down / upstream Rate[1]	Efficiency range[1]	Typical latency [5]	Shared medium for last mile?	Frequency bandwidth [6]	Infrastructure architecture	Suitability	Future of the technology
copper	Wired Broadband Technologies								
	ADSL, ADSL2, ADSL2+	24/1 Mbps	5 km	15-40 ms	no	0,0022 GHz	· internet access by transmitting digital data over the wires of a local telephone network copper line terminates at telephone exchange (ADSL) or street cabinet (VDSL) · Vectoring: Elimination of cross talks for higher bandwidths · G.Fast: Frequency increase up to 212 MHz to achieve higher bandwidth	· use of existing telephone infrastructure · fast to install · small efficiency range due to the line resistance of copper connection lines	· further speed and range improvements by enhancing and combining new DSL-based technologies (phantom mode, bonding, vectoring) · bridge technology towards complete fibre optic cable infrastructure
	VDSL, VDSL2, Vectoring	100 /40 Mbps	1 km	15-40 ms	no	0,017 GHz			
	G.Fast	500/500 Mbps	250 m	15-40 ms	no	0,212 GHz			
	CATV	200/100 Mbps [4]	2-100 km[2]	15-40 ms	yes	1 GHz	· coaxial cable in the streets and buildings; fibre at the feeder segments · network extensions to provide backward channel functionality	· use of existing cable television infrastructure · fast to install · high transmission rates	· Further implementation of new standards (DOCSIS 3.1) will allow to provide higher bandwidth to end-users
fibre	Optical Broadband Technologies								

[97] Commission Staff Working Document 5G Global Developments COM(2016)XXXX final.

[98] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2016) XXX final, 5G for Europe: An Action Plan.

	p2p	1/1 Gbps (and more)	10-60 km	0.3 ms (5 µs per km)	no	50000 GHz	· signal transmission via fibre · distribution of signals by electrically powered network equipment or unpowered optical splitters	· highest bandwidth capacities · high efficiency range · high investment costs · bandwidth depends on the transformation of the optical into electronic signals at the cabinet (FTTC), building (FTTB) or home (FTTH)	· next generation technology to meet future bandwidth demands
	p2mp				yes				
air	Wireless Broadband Technologies								
	LTE (Advanced)	100/30 (1000/30) Mbps (3)	3-6 km	5-10 ms	yes	0.1 GHz	· mobile devices send and receive radio signals with any number of cell site base stations fitted with microwave antennas · sites connected to a cabled communication network and switching system	· highly suitable for coverage of remote areas (esp. 700 and 800 MHz) · quickly and easily implementable · shared medium · limited frequencies	· commercial deployment of new standards with additional features (5G) and provision of more frequency spectrum blocks (490 - 700 MHz) · meets future needs of mobility and bandwidth accessing NGA-Services
	HSPA	42,2 / 5,76 Mbps	3 km	30-70 ms	yes	0.005 GHz			
	Satellite	20/6 Mbps	High	500-700 ms	yes	10 GHz		· highly suitable for coverage of remote areas · quickly and easily implementable · run time latency · asymmetrically	· 30 Mbps by 2020 based on next generation of high-throughput satellites
	Wi-Fi	300/300 Mbps	300 m	100 - 1000 ms	yes	0.005-0.160 GHz(7)		· inexpensive and proven · quickly and easily implementable · small efficiency range · shared medium	· increased use of hotspots at central places
	WiMAX	4/4 Mbps	60 km	50 ms	yes	0.01 GHz			· gets continually replaced by Wi-Fi and LTE

Glossary

- FTTB – fibre to the building. Used also for buildings inhabited by more than one tenant.
- FTTC – fibre to the cabinet. Fibre to a street cabinet close to the end-user.
- FTTH – fibre to the home. Typically used for residential homes.
- FTTP – fibre to the premise = FTTB + FTTH.
- High Capacity – capacity relates to the bandwidth of the connection and does not take into account the distance and the time necessary to establish connection.
- High Connections Density – is necessary when many devices try to connect with each other.
- High Download Speed – download speed is how fast one can pull data from others to you. It is measured in megabits per second (Mbps). The majority of online activity, like loading web pages or streaming videos, consists of downloads.
- High Peak data rate – peak data rate is the fastest data transfer rate for a device, typically available in short bursts during transfer activity, and not sustainable for long periods of time
- High Reliability – reliability is an attribute of any computer-related component (software, or hardware, or a network, for example) that consistently performs according to its specifications.
- High Security – secure connection is difficult to intercept and decode without the permission of the parties communicating, therefore the content is safe.
- High Ubiquity – ubiquity means being connected everywhere, anytime, on any device.
- High Upload Speed – upload speed is how fast one sends data from you to others. It is measured in megabits per second (Mbps). Uploading is necessary for sending files via email, or in using video-chat to talk to someone else online (since you have to send your video feed to them).
- Low Jitter – jitter is the deviation from true periodicity of a presumed periodic signal, often in relation to a reference clock source.
- Low Latency – latency is the delay between the sender and the receiver decoding it, this is mainly a function of the signals travel time, and processing time at any nodes the information traverses.
- Low Packet Loss – packet loss occurs when one or more packets of data travelling across a computer network fail to reach their destination.
- NGA – Next Generation Access with a minimum download speed of 30 Mbps.
- Symmetry – when download bandwidth is the same as upload bandwidth.
- VHC - Very high-capacity networks are networks with best-in-class performance in terms of speed (i.e. significantly above 100.