WIK-Consult • Final report

# The Benefits of Ultrafast Broadband Deployment

for Ofcom

by
WIK-Consult GmbH
Rhöndorfer Str. 68
53604 Bad Honnef
Germany

Authors:
Ilsa Godlovitch
Thomas Plueckebaum
Sonia Strube Martins
Tseveen Gantumur
Dieter Elixmann
Serpil Tas
Rene Arnold
Christian Wernick

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# 0 Executive summary

## 0.1 Background

The UK has made significant strides in deploying superfast broadband, defined as broadband offering download speeds of 30Mbit/s or more.[1] Customer surveys suggest that infrastructure in the UK is in general sufficient to meet the needs of the majority of customers and to serve society's interests in the short term.[2] However, it seems likely that demand could expand and new applications might emerge if there was additional investment in new fibre networks, driving wider availability and competition in ultrafast broadband services.[3] In this context, it is notable that, although more than a third of households have access to broadband technologies offering at least 300Mbit/s,[4] fewer UK homes have access to broadband based on Fibre-to-the-premise (FTTP) broadband than in other countries internationally. For example, UK coverage of FTTP was 3% in 2017, compared with an average of 24% across the EU for 2016.[5][6]

In order to keep the UK at the forefront of digital connectivity globally, Ofcom has highlighted[7] the need for more investment to "enable a step change in the speeds and technology available to consumers". Specifically, Ofcom is aiming to achieve greater coverage of 'ultrafast broadband', involving networks which offer downstream capacity of 300Mbit/s (with an upgrade path to 1 Gbit/s), and higher upload speeds than superfast broadband. Ofcom also considers it important for ultrafast networks to provide improvements in reliability and quality.[8]

1 Over 91% of UK properties can now receive superfast broadband, according to Ofcom's 2017 Connected Nations report https://www.ofcom.org.uk/__data/assets/pdf_file/0017/108512/connected-nations-fixed-broadband-2017.pdf

2 Data from the Ofcom Communications Market Review suggests that 82% of respondents were fairly or very satisfied with the speed of their broadband service in 2017.

3 For example, in the context of a study conducted for the European Commission by WIK in 2016 Regulatory, in particular access, regimes for network investment in Europe (SMART 2015/0002), WIK found evidence that bandwidth use increased (by 3x downstream, and 7x upload) when customers were switched from copper to FTTP services. This kind of evidence suggests that supply might contribute to increased demand

4 Ofcom 2017 Connected Nations Report

5 Study on broadband coverage in Europe 2016 https://ec.europa.eu/digital-single-market/en/news/study-broadband-coverage-europe-2016

6 Around 4% of households also currently have speeds of less than 10Mbit/s

7 Ofcom Digital Communications Review https://www.ofcom.org.uk/phones-telecoms-and-Internet/information-for-industry/policy/digital-comms-review/conclusions-strategic-review-digital-Communications

8 Broadband quality (as distinct from bandwidth) can be defined in terms of characteristics such as delay, jitter and packet loss. Availability (uptime) is also sometimes reported within Quality of Service (QoS) metrics.

## 0.2 Objectives of the study

In this study for Ofcom, we investigate to what extent consumers and small businesses, as well as the wider economy and society, might benefit from more widespread deployment of ultrafast broadband.[9]

The study assesses (i) applications that require ultrafast broadband, and how demand for bandwidth might evolve in the years to 2025; (ii) the evolution of network technologies and the degree to which they may meet evolving demand; and (iii) the direct and indirect benefits that might result from the more widespread deployment of ultrafast broadband in the UK.

The assessment of future demand is based on a market model developed by WIK which assesses bandwidth and quality requirements of different households based on the bandwidth requirements of current and upcoming applications and the usage patterns of different types of individual. The assessment of potential economic impacts has been based on an analysis of literature assessing the effects of FTTP and/or higher speed broadband in countries where it is prevalent. Our analysis has also been supported by case studies of advanced applications in various sectors including automotive, healthcare and education, and interviews with key users and suppliers of digital networks and applications.

The main findings are summarised below.

## 0.3 How will demand for bandwidth evolve towards 2025?

Demand for bandwidth today has largely been driven by the increasing importance of video. In 2016, the average UK consumer is estimated to have used 50 Gigabytes of Internet data.[10] Internet video accounted for 68% of that traffic.[11] Notwithstanding developments in compression technology, video traffic is expected to increase as the quality (definition) of video increases, for example from 4K to 8K,[12] and as broadband connections are increasingly used to deliver video to large-screen TVs.[13]

Consumer cloud traffic is also expected to grow significantly – and will add to demand for upstream connectivity. Gaming is a further growth sector.

9 In the analysis of benefits, we distinguish private benefits from public benefits, on the basis that although public benefits are important from a policy perspective, they may not be reflected in customers' willingness to pay and thereby operators' willingness to invest

10 Cisco VNI 2016-2021 forecast

11 Idem

12 8K refers to the current highest ultra high definition television resolution, 4230p.

13 The strong role of terrestrial and satellite television in the UK may limit the shift towards video over the Internet compared with other European countries in which these alternatives play a less significant role. However, the increasing prevalence of smart TVs is expected to support demand for high definition online video. The use of multiple devices to consume video in the household will also tend to increase bandwidth demand.

Looking forward, the main new developments which are expected to drive bandwidth demand are the 'tactile Internet' and 'immersive media'. Remote diagnostics and autonomous driving are examples of tactile applications which also require very low latency.[14] Virtual and augmented reality (which has applications in many spheres ranging from gaming through to education and healthcare) will also place significant demands on the quality of broadband connections.[15] As broadband in the home improves, these connections may become increasingly suitable for home working and small business use as well.

UK consumers are relatively advanced compared with consumers in other European countries as regards their use of multiple devices and applications such as cloud computing.[16] Based on WIK's modelling of expected demand for current and future consumer and business applications in the home,[17] we estimate that if they faced no technological or pricing constraints,[18] **around 40% of UK households may demand at least 1Gbit/s downstream and 600Mbit/s upstream by 2025**, with more than 40% having demand for at least 300Mbit/s symmetric.

Under a less aggressive scenario in which forecast bandwidth requirements for some services are reduced, and we assume there is no use of more advanced media such as 8K and virtual reality (VR) (except in the context of gaming), we estimate that **more than 50% of households would still require download speeds of at least 300Mbit/s by 2025 of which 8% would require Gigabit bandwidths**.

It should be noted that both estimates relate to households' ideal usage in an unconstrained environment, and do not seek to estimate customers' incremental willingness to pay for faster speeds.

14 See case studies in Chapter 3 based on interviews with Microsoft and Ericsson.

15 According to the UK games industry, the UK is estimated to have the largest and fastest growing VR hardware market in EMEA, growing at 76% CAGR in the next five years. See ukie (2017), UK Video Games Fact Sheet, https://ukie.org.uk/research

16 The UK has one of the highest percentages of cloud usage among Internet users in comparison with other European countries. In 2016 46% of Internet users used Internet storage space to save documents, pictures, music, video or other files. See Eurostat (2017), Use of Internet storage space for saving and sharing files, http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Use_of_Internet_storage_space_for_saving_and_sharing_files,_2014_(%25_of_individuals)3.png

17 WIK's model assesses demand based on the expected bandwidth requirements for a range of current and evolving applications alongside the usage of such within a household. The degree to which consumers' demand for bandwidth will evolve depend on how far they embrace applications such as gaming, home office applications, and newer technologies such as 8K, augmented and virtual reality, as well as the degree to which individuals in a household use several applications at the same time – noting that peak time demand sets a benchmark for network dimensioning. Compression technologies may permit some reductions in bandwidth use, but may not be relevant for all applications.

18 It should be noted in particular, that we do not make any assumptions around willingness to pay for additional bandwidth.

## 0.4 **Which technologies can meet users' needs?**

Future applications and the increased prevalence of cloud computing are likely to require not just increased download speeds, but also higher upload speeds and better quality, as measured by characteristics such as low latency, jitter and packet loss, and high availability (uptime) of services. The achievable speeds as well as quality parameters are affected by whether bandwidth in the access network is dedicated to each end-user or is shared.

**FTTP is the most future-proof technology offering further upgrade potential significantly beyond 1Gbit/s.** International benchmarks suggest that FTTP can bring significant quality benefits including low latency. In the UK, point to multipoint FTTP is likely to be the prevalent architecture. This architecture would deliver bandwidth well above 1Gbit/s and improve quality. However, it is a shared medium, and will require periodic upgrades to meet growing demand. Point to point FTTP – used today for dedicated business connections in the UK and for mass-market fibre broadband connections in countries such as the Netherlands, Sweden and Switzerland – offers even higher standards of quality and a nearly unlimited upgrade path.

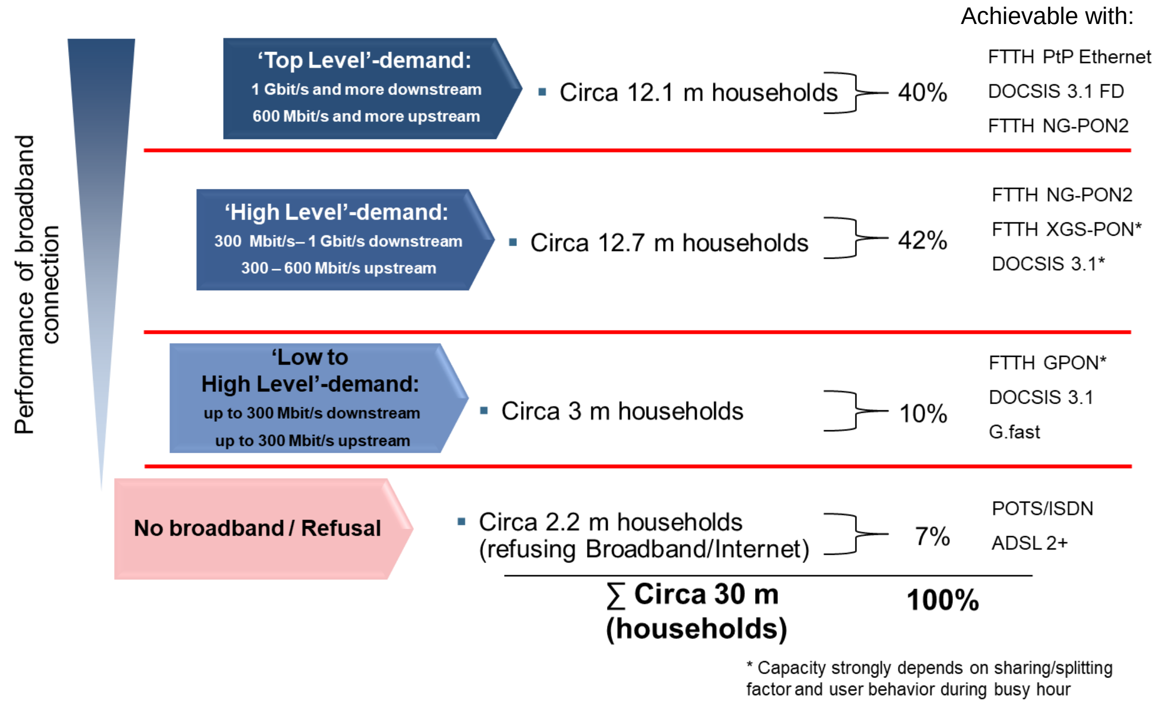
**The cable standard DOCSIS 3.1 will enable cable to readily deliver 1Gbit/s downstream, and full duplex will further extend its capabilities and enable symmetric bandwidth at 10Gbit/s.** However, full duplex may require fibre to the last amplifier, and the shared nature of cable networks and involvement of active equipment in the access network may limit quality, especially compared with point to point FTTP.

In contrast with cable and FTTP, bandwidths available over copper-based ADSL connections are limited, and deteriorate as the length of the line increases. To reach optimum speeds, upgrades of copper technology such as **G.fast** therefore typically require the deployment of fibre closer to the customer. Although incremental deployments to upgrade copper networks allow CAPEX to be spread over time, they can delay later fibre investment and introduce inefficiencies and stranded investment. Due to the significant investments (and potential delays) involved in subsequent upgrades, incremental upgrades of copper technologies e.g. to supervectoring or G.fast are unlikely to enable a ready upgrade path towards 1Gbit/s. The provision of Gigabit connectivity could be achieved by directly deploying XG.fast. However, this technology requires the deployment of fibre to the building (in the case of apartments) or very close to the end-user.

**5G mobile** will require significant fibre installation close to the customer in order to enable ultrafast speeds. Its reliance on fixed infrastructure for backhaul means that it may in practice be deployed in tandem with wider investments in fibre to support higher capacities for fixed broadband networks. Although it has many important applications, limitations on the spectrum required to deliver Gigabit speeds through 5G and the shared nature of the medium are also likely to limit its potential to act as an alternative to very high capacity fixed connections. 5G at a fixed location might however be a relevant solution in areas which could not otherwise be reached by a fixed network.

A comparison between the capabilities of different technologies and the needs of users, suggests that the majority of customers are likely to be adequately served by DOCSIS 3.1. cable updates towards 2025. However, **FTTP/B**[19] **and DOCSIS full duplex technologies are likely to be the only solutions which are sufficiently highly performing to serve the interests of the most demanding consumers and small businesses in the longer term.** Moreover, if point to multipoint FTTP solutions are pursued, we anticipate that attention will be needed to ensure appropriate sharing/splitting factors and install more up-to-date technologies such as XGS-PON or FTTH NG-PON2 as usage evolves.

Figure 0-1: Bandwidth, Quality of Service and technologies[20]




Source: WIK Consult 2017

## 0.5 What benefits have other countries experienced as a result of ultra-fast broadband?

The experience in countries such as Sweden, Finland and parts of the US and Canada, which have already deployed advanced FTTP networks, suggests that the use of these networks can deliver tangible benefits to consumers – both directly by benefiting end-users, and indirectly by creating spillover effects that benefit the economy, society and the environment.

19 FTTB refers to Fibre to the Building, and is relevant in case of multi-dwelling units (MDUs)
20 The sums do not add up to 100% in the diagram due to rounding.

Examples of private benefits from ultrafast broadband include home care and healthcare applications. One study assessing developments in Sweden[21] found significant savings in using digital FTTP-based homecare especially in rural areas. It concluded that even with limited adoption,[22] these solutions could contribute to annual net cost reductions of $0.6m in a rural municipality with 8,000 residents by 2020.

Users with faster broadband also tend to make more use of teleworking,[23] which can in turn create significant environmental benefits through reduced commuting.[24] Further environmental benefits can be derived from the fact that FTTP is associated with lower energy requirements than copper and cable technologies.[25]

Studies of the impact of fibre in countries such as Sweden,[26] Canada[27] and the US[28] have also identified a link between fibre connectivity and employment. Fibre has also been linked with reduced migration away from rural areas and increased employment in those areas, thereby contributing to a more even distribution of economic benefits.

A challenge faced by policy-makers is that while end-users may pay more when there are clear benefits that directly affect them, wider benefits for example to society (through improved support to remote communities or the elderly) and the environment may not be taken into account by end-users or suppliers of broadband services, potentially resulting in insufficient investment in new network technologies.

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**21** Forzati, M. and C. Mattson (2014), FTTH-enabled digital home care – A study of economic gains, Department for Networking and Transmission, Acreo AB.

**22** This estimate is based on 10% home care service recipients using digital services.

**23** SQW (2013), UK Broadband Impact Study found that teleworking driven by faster broadband (although not ultrafast broadband specifically) could save about 60 million hours of leisure time per annum in the UK by 2024.

**24** The same study estimated that faster broadband could lead to a reduction in the UK's annual commuting distance of about 2.3 billion kms by 2024, which would reduce greenhouse gas emissions.

**25** Aleksix, S and A.Lovric (2014), Energy Consumption and Environment Implications of Wired Access Networks, American Journal of Engineering and Applied Sciences 4 (4), 531-539 concluded that deployment of 'all FTTH/B' infrastructure could result in 88% less greenhouse gas emissions per Gigabit in Europe, as a result of the lower energy requirements associated with FTTH/B compared with copper and cable technologies. The study reports that 10.5mg of Carbon Dioxide Equivalent (CO2e) are produced by HFC network equipment when transferring 1Gbit/s of data. This could be reduced by 47% by using VDSL2 and 93% when using a GPON FTTH network. The reduction of 88% was calculated by comparing the status quo in terms of the technological mix against an alternative scenario involving broad use of optical access networks.

**26** One study in Sweden found that 10% higher FTTH penetration was correlated with a 1.1% higher employment rate, Mölleryd, B. (2015), Development of High-speed Networks and the Role of Municipal Networks, OECD Science, Technology and Industry Policy Papers, No. 26, OECD Publishing, Paris.

**27** A study focused on Canada found that 100% fibre coverage in a given region was linked to a 2.9% increase in employment. Singer, H., Caves K. and A.Koyfman (2015) Economists Incorporated: The Empirical Link Between Fibre-to-the-Premises Deployment and Employment: A case study in Canada, Annex to the Petition to Vary TRP 2015-326, Bell Canada.

**28** A study focused on the US found that faster broadband speeds of 100 Mbit/s – 1 Gbit/s were more effective in boosting country employment than lower speeds of 3-100Mbit/s, although there were diminishing returns for speeds above 1Gbit/s. Bai, Y. (2017), The faster, the better? The impact of Internet speed on employment, Information Economics and Policy, 40, 21-25.

## 0.6 What might be the impact on economic growth?

Greater deployment and take-up of ultrafast broadband should raise the overall average broadband speed experienced by end-users. For example, WIK has estimated that whereas in an illustrative scenario where 36% of broadband users have cable or full-fibre connections by 2025 in the UK, the projected average actual download speed would be expected to reach around 140Mbit/s, the average actual speed would increase to more than 210Mbit/s if 60% of customers have cable or full-fibre connections.[29]

In turn, a number of cross-country studies suggest that higher average broadband speeds might be associated with higher GDP growth.[30]

One study[31] of OECD countries dating from 2012 estimated that **doubling the connection speed related to an additional 0.3 percentage points to annual GDP growth**. WIK, together with Ecorys and VVA also identified a correlation between broadband speeds across the EU and Total Factor Productivity across a number of sectors in the context of a study for the European Commission,[32] and concluded that if past relationships between broadband speed and GDP growth were to be replicated going forwards, **an accelerated deployment of FTTP/B infrastructure which resulted in 55% of households using FTTP by 2025 could result in GDP levels 0.54% higher than the status quo**.

As these studies focus on countries with at least some comparable characteristics[33] or include the UK within the dataset, it also seems **plausible that the effects described might apply in the UK.**

However, it is harder to ascertain what would be the magnitude of this effect. One reason is that the effects on GDP from different studies vary according to the methodologies used and time period studied. Another reason is that these studies rely on the assumption that relationships found between increases in broadband speeds and GDP in the past, when broadband speeds were much lower, will continue to apply in the future. However, there is little evidence on the extent to which this past relationship between increases in speed and GDP can be extrapolated for much larger increases in speeds in the future. At least one study suggests that there might be diminishing marginal re-

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29 The methodology is shown in the annex to this report

30 As these studies have attempted to control for endogeneity, it seems plausible that faster broadband may in part drive GDP growth through increasing productivity, rather than being a by-product of economic growth.

31 Rohman, I.K. and E.Bohlin (2012), Does broadband speed really matter for driving economic growth? Investigating OECD countires, SSRN.2034284.

32 WIK, Ecorys and VVA (2016) support for the Commission in the Impact Assessment for the Review of the EU framework for electronic communications SMART 2015/0005

33 The analysis of effects on advanced countries from the 2016 WIK/Ecorys/VVA study for the EC is based on Germany

turns.[34] Alternatively, it is possible that if higher bandwidths and lower latency enable the development of groundbreaking applications, that they could support a step change in productivity.[35] Thus, while a positive impact on GDP from deploying ultrafast broadband more widely in the UK seems likely, it is not possible to quantify the scale of this impact with a high degree of certainty.

## 0.7 Structure of the report

The report is structured in the following way.

- Chapter 1 discusses what might drive demand for ultrafast broadband in the years to come. Firstly, we describe applications which may be enabled by ultrafast broadband, with reference to case studies and interviews in the field of automotive, healthcare, and virtual reality services. Then, on the basis of a market model, we estimate the likely demand amongst different groups of users for broadband speeds and quality in the period to 2025, under a range of scenarios.
- Chapter 2 looks at the supply side, with an assessment of how broadband technologies may evolve. Firstly, we define what is meant by different speed and quality parameters for connectivity. Then we discuss the speed and quality characteristics of the different technological solutions for the access network – looking at both current technologies and their upgrade path.Finally, we bring together the conclusions from this chapter on 'broadband supply' with our analysis of demand to identify which technologies could meet the projected needs of users in the period towards 2025.
- In Chapter 3, based on a literature review, we describe the potential private and public benefits that might arise from FTTP or faster broadband speeds and provide illustrative estimates of the magnitude of benefits that might accrue to the UK economy from more widespread take-up of FTTP and other ultrafast technologies.
- Conclusions are presented in Chapter 4

Further information is presented in the annexes on (i) the evolution of copper, cable and fibre technologies; (ii) practical experiences around broadband speed and quality; and (iii) what might be the implications on speed of various illustrative scenarios for FTTP deployment in the UK.

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34 In a Danish-based study by Jespersen and Hansen (2010), The Socio-Economic value of digital infrastructures, Copenhagen Economics, Studie für die Dankks Energi. the authors reach the conclusion that the positive effect of bandwidth on GDP decreases with increasing bandwidth. However, the study focused on bandwidths of up to 30Mbit/s, well below the capabilities of modern NGA networks. The SQW (2013) study estimating the effects of bandwidth increases on UK GDP also makes the assumption of diminishing marginal returns.

35 Although it does not draw any conclusions about how the relationship between speed and GDP might evolve over time, it is interesting to note that a later (2014) study drawing on data which included a period covering the early deployment of NGA, found a greater effect from broadband speeds on GDP than the 2012 Rohman, I.K. and E.Bohlin study which relies on data during a period where in most countries ADSL and lower speed cable technologies were prevalent.

# 1 What are the main demand drivers for ultrafast broadband?

In this chapter, we focus on drivers of demand for ultrafast broadband.

Firstly, we describe current and future applications, with reference to interviews and case studies in the field of automotive, healthcare, and virtual reality services. Then, on the basis of a market model, which draws on user behaviour and forecast bandwidth requirements for various applications, we estimate how demand for bandwidth and quality amongst different user groups may evolve in the period to 2025.

Within the case studies, specific reference is made to the degree to which certain applications are likely to require additional downstream and/or upstream bandwidth as well as short response times (low latency). A definition of these technical terms can be found in Table 2-1.

**Key findings**

- The main driver of increasing bandwidth demand has been video. In 2016, in the UK, Internet video accounted for 68% of Internet traffic. Notwithstanding developments in compression technology, video traffic is expected to increase as traffic moves from other media to the Internet and as the quality of video increases.

- Consumer cloud traffic is also expected to grow significantly – and will add to demand for upstream connectivity. Gaming is a further growth sector.

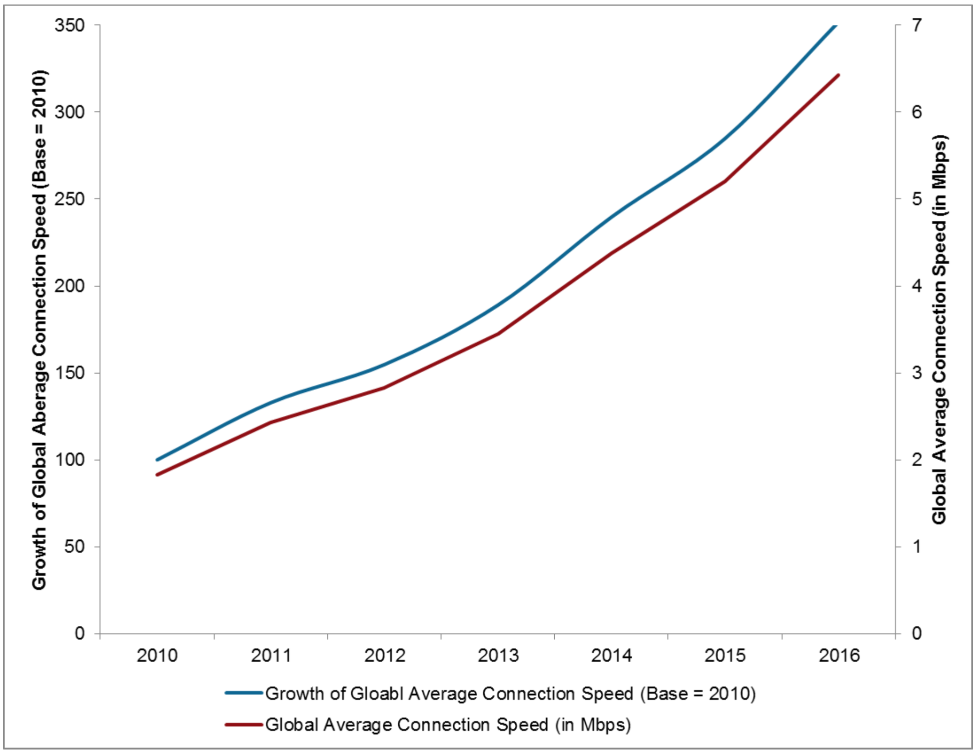
- Looking forward, the main new developments are expected in the 'tactile Internet' and immersive media. Remote diagnostics and autonomous driving are examples of tactile applications requiring very low latency. Virtual reality (which has applications in many other spheres) will also place significant demands on the quality of broadband connections. As broadband in the home improves, these connections may become increasingly suitable for home working and small business use as well.

- Based on WIK's modelling of expected demand for current and future consumer and business applications in the home, we estimate that around 40% of UK households may require at least 1Gbit/s downstream and 600Mbit/s upstream by 2025, with more than 40% having demand for at least 300Mbit/s symmetric. Even under a less aggresssive scenario, in which forecast bandwidth for some services are reduced, and we assume there is no use of advanced media such as 8K and VR (except for gaming). We estimate that more than 50% of households would still require download speeds of at least 300Mbit/s by 2025 of which 8% would require Gigabit bandwidths.

## 1.1 What is driving bandwidth demand today?

Over the last five to six years, the global average connection speed provided by broadband technologies has more than tripled (Figure 1).

Figure 1-1: Growth of Global Average Connection Speed




Source: Akamai's state of the Internet – Report (years 2010-2016).

At the same time, global annual data traffic has risen from 0.24 zettabytes in 2010 to more than 1.2 zettabytes. Cisco expects annual global IInternet traffic to reach 3.3 zettabytes by 2021.[36]

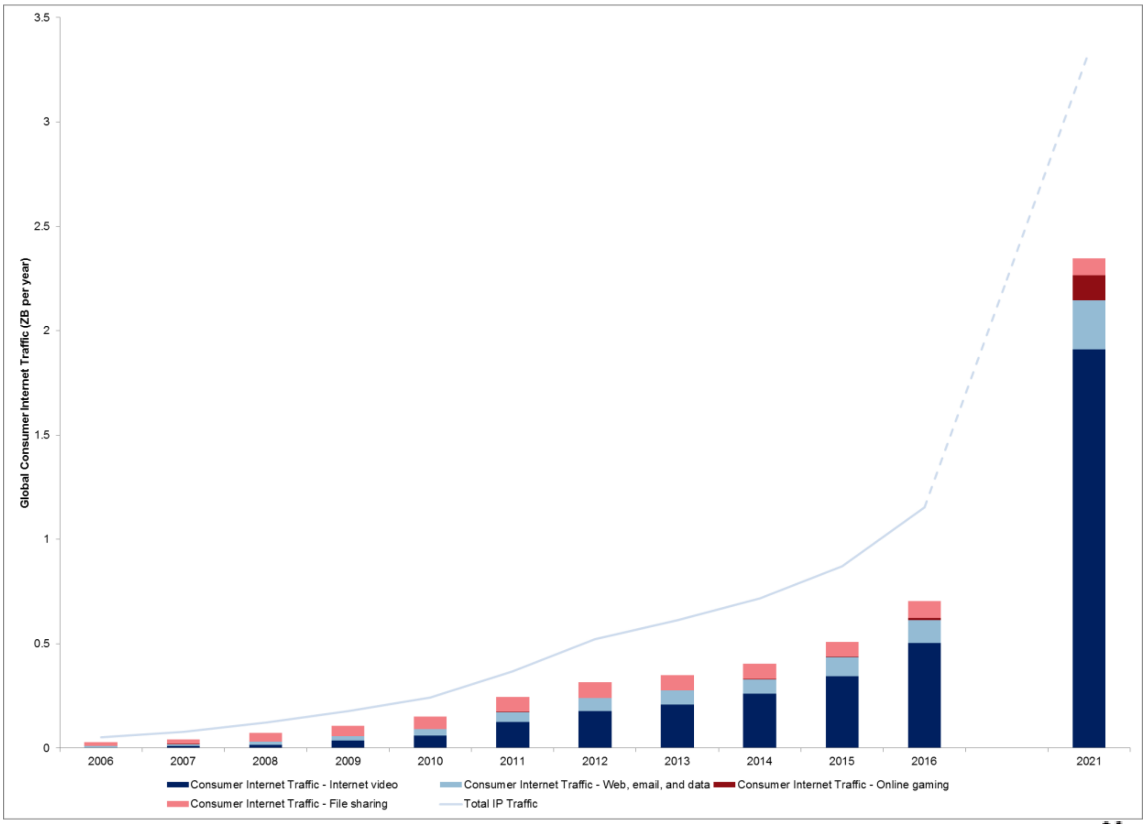
Data shows that the main driver of this increasing bandwidth use has been video, while gaming and cloud computing are emerging as key sources of bandwidth demand going forwards. Increasing use of multiple devices is also having a significant impact on the demand for bandwidth. We discuss each of these factors in turn.

**36** Cisco (2011), "Cisco Visual Networking Index: Forecast and Methodology, 2010 – 2015", White Paper, CA: San Jose, p.6; Cisco (2017), "Cisco Visual Networking Index: Forecast and Methodology, 2016 – 2021", White Paper, CA: San Jose, p.1.

### Video traffic

Data from Cisco (Figure 1-2) suggests that, while in 2006, file sharing was the most bandwidth intensive service, data usage increases since that time have largely been as a result of the transmission of high definition video.[37] By 2016, more than 70% of all consumer IInternet traffic globally (68% in the UK) was attributed to video alone. Global consumer Internet video traffic is expected to increase on average by 31% annually between 2016 and 2021,[38] and is likely to dominate consumer IInternet traffic volume in the foreseeable future.

Figure 1-2: Global Consumer Internet Traffic by Category (Zetabyte per year)




Source: Cisco Visual Networking Index (VNI) – Years 2006-2016

37 Cisco (2011). *Broadband Access in the 21th Century: Applications, Services, and Technologies*. White Paper, CA: San Jose, p.2.
38 Cisco (2017). *Cisco Visual Networking Index: Forecast and Methodology, 2016 – 2021*. White Paper, CA: San Jose, p.9.

Several parallel trends are driving video traffic volume. First, a steadily increasing share of video content is consumed via the IInternet.[39] Second, the resolution of the transmitted content is continuously increasing.[40] Innovative coding techniques may reduce bit-rates. However, compression may always cause a loss of information which in turn may undermine the consumer experience.[41] In addition, there is an increase in the number of devices per household which are being used to view video. [42]

## Gaming

Although there is moderate traffic associated with online gaming today, this segment is expected to grow rapidly in the future. For example Cisco has forecast that online gaming traffic could expand elevenfold by 2021. The following case study explains how online gaming and VR are likely to contribute not only to demand for bandwidth, but high quality measures such as low latency.

**Case Study – Entertainment**

The rollout of ultrafast broadband could bring significant changes in the experience of entertainment. Whereas in the past, entertainment was a rather passive experience, going forward, it is likely to evolve into a more interactive and immersive experience.

A prime example is gaming. The gaming experience has changed over the last few years with increased resolution and the interconnectedness of multiple active players. Recently, the gaming industry has moved towards enhancing the experience through virtual and augmented reality (VR/AR) and sensing technologies, which enable the gamer to fully immerse into the game.[43] However, VR/AR ideally requires a user throughput of several hundred Mbit/s. Moreover, latency should be less than one millisecond and high reliability is necessary to provide a smooth action-reaction experience.[44]

Games such as World of Warcraft enable the connection of hundreds of players around the world via different data centres. Today's networks already transmit high definition images to each player – consuming significant amounts of bandwidth and requiring low latency. If VR/AR were introduced in games such as this, multiple realities would have to be rendered simultaneously in real time. To archive this, massive volumes of data would need to be processed and transmitted via the network instantaneously.

39 Most notably, music and video streaming services such as Spotify, Tidal, Deezer, or Netflix, HBO Now, Amazon Prime / Instant Video, BBC iPlayer, etc. are rapidly increasing their user numbers. For more information see e.g. Arnold, R., & Schneider, A. (2017). *OTT Services: Colour to the Internet*. Bad Honnef, Cologne: WIK and Fresenius University of Applied Sciences.

40 Several Internet-based services provide ultra high-definition or even 4K content. Netflix offers a premium plan with UHD content. The company also allows user to stream 4K content if they own a 4K-capable device like an Apple TV, Amazon Fire TV and a Sony TV (https://www.theverge.com/2017/11/1/16593310/netflix-4k-comcast-xfinity-x1-users-stranger-things-house-cards). Further, companies like BBC and Amazon are also offering 4K content if you meet the requirement of having a 4K-capable device.

41 Cisco (2011). *Broadband Access in the 21th Century: Applications, Services, and Technologies*. White Paper, CA: San Jose, p.3.

42 Ofcom (2017). *Communications market report,* London, p.10.

43 Lema, M.A.; Laya, A.; Mahmoodi, T.; Cuevas, M.; Sachs, J.; Markendahl, J. & Dohler, M. (2017).Business Case and Technology Analysis for 5G Low Latency Applications. *IEEE Access, 5,*5917-5935, p.5921.

44 ITU (2014).*The Tactile Internet*. ITU-T Technology Watch Report, Geneva, p.6; Lema, M.A.; Laya, A.; Mahmoodi, T.; Cuevas, M.; Sachs, J.; Markendahl, J. & Dohler, M. (2017).Business Case and Technology Analysis for 5G Low Latency Applications. *IEEE Access*, 5, 5917-5935, p.5922.

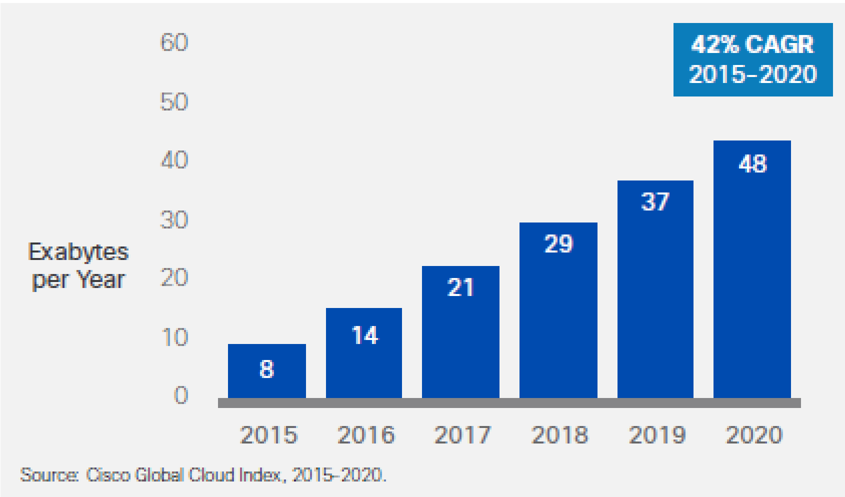
Ericsson also note that ultrafast broadband could support new methods of live broadcasting for events like concerts and sporting events, giving the viewer the feeling that they are actually present at the event. This type of broadcasting requires high bandwidth, low latency and reliability as well, as each interruption would create disruption and destroy the illusion. According to Isgró, Trucco, Kauff and Schreer (2004) immersive broadcasting needs to enable panoramic large-screen viewing, stereo viewing, and head motion parallax viewing.[45] Each of these features might require the transmission of immense amounts of data in real time.

Note: Some of those insights are generated via interviews conducted with Microsoft (21 Nov 2017) and Ericsson UK (29 Nov 2017).

### Cloud computing

Cloud computing is a further application that is likely to drive demand for symmetric bandwidth, as it involves two-way transmission of data. Cloud has important residential user applications including the storage and back-up of personal photos and videos online. Businesses are also increasingly relying on cloud computing (both private and public) to outsource their IT requirements and ensure that content is accessible across sites and to home and remote workers. Cisco projects that 59% of the IInternet usersInternet will use personal cloud storage in 2020, up from 47% in 2015. Moreover, Cisco anticipates that the amount of traffic associated with consumer cloud storage will increase from 513 MB per user per month in 2015 to 1.7 Gigabytes in 2020, resulting in an annual growth rate in consumer cloud traffic of 42% (see following figure).[46]

Figure 1-3: Consumer cloud storage traffic growth




Source: Cisco Global Cloud Index 2015-2020

**45** Isgró,F.; Trucco, E.; Kauff,P. & Schreer, O. (2004).Three-Dimensional Image Processing in the Future of Immersive Media. *IEEE Transactions and Circuits and Systems for Video Technology*, 14(3), 288-303, p. 292.

**46** Cisco Global Cloud Index: Forcast and methodology 2015-2020 https://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/global-cloud-index-gci/white-paper-c11-738085.pdf

An interview with Microsoft reveals how cloud computing has the potential to transform business efficiency, for example in the field of e-commerce, subject to the availability of fast two-way (symmetric) transmission of data.

**Case Study – Microsoft**

Microsoft is an international operating software and hardware supplier and provider of cloud solutions.

They note that one of the examples of the efficiencies available through cloud computing is handling peak demand for online shopping during the holiday season.

In the past, shops would have to organize their own infrastructure and dimension it to accommodate the busy period. However, most of the time their infrastructure would be idle with only 20% load. Because with cloud computing, demand is scaled over hundreds of applications and services, efficiency is much improved, but for that to work, Microsoft needs the capability to move data to wherever it needs to be. However,this depends not only on high download speeds, but also requires high upload speeds.

Furthermore, each service offered by Microsoft is intended to be available on a global basis. For example, an Office 365 user in the UK might be using a server which is located in the U.S. or somewhere in Asia. However, the user should still be able to access their data instantly. This means that transmission speeds should be as fast as possible across the whole infrastructure.

“We will always have more need for speed and capacity than we actually have. Connectivity needs to be so instantaneous that data should appear as if it is right with us. We have never gotten there, but need to shoot for this target. Cloud services rely on it.” (Microsoft)

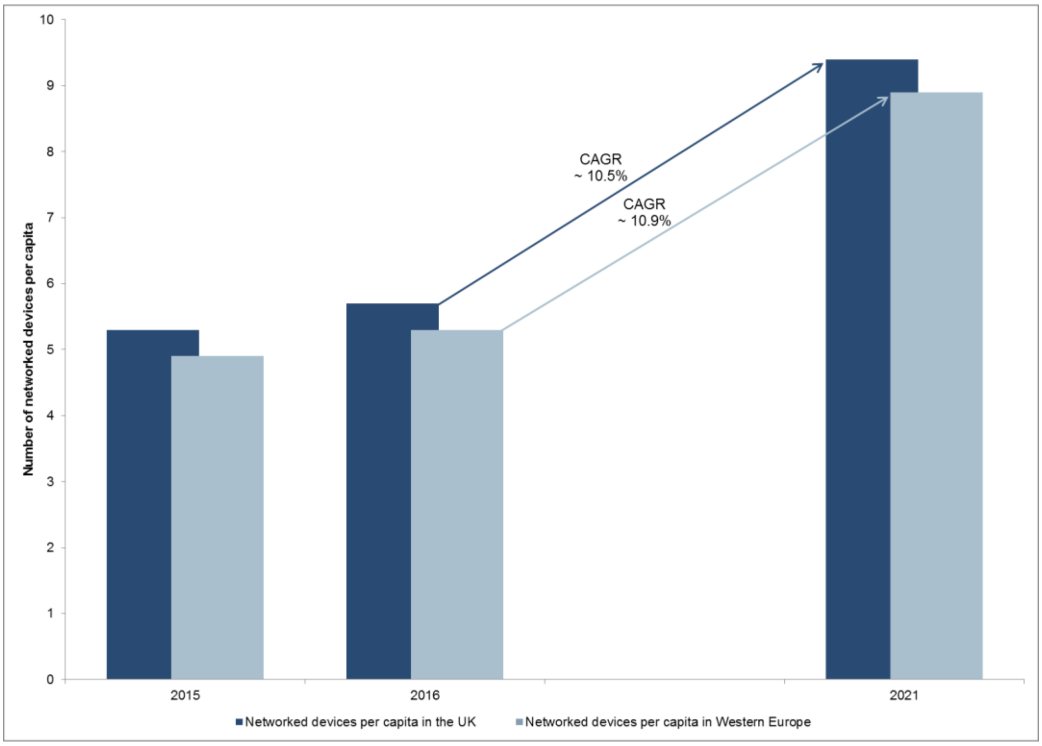
Note: Some of these insights are generated via an interview conducted with Microsoft (21 Nov 2017).

### Number of devices

As end-users increasingly use media individually instead of, or in addition to clustering around a single screen in the home, this is also likely to translate to an increase in the simultanous use of devices (and therefore consumption of bandwidth) in the home. Following a gradual increase in recent years, Cisco expects a much more significant expansion in the number of connected devices per capita in the period to 2021. In the UK, the average number of devices or connections per user had already reached 5.7 in 2016, and is expected to increase to 9.4 by 2021.[47]

47 https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html#

Figure 1-4: Networked devices per capita (UK and Western Europe)




Source: Cisco Visual Networking Index (VNI) – Years 2015-2016.

## 1.2 What services may require ultrafast broadband in future?

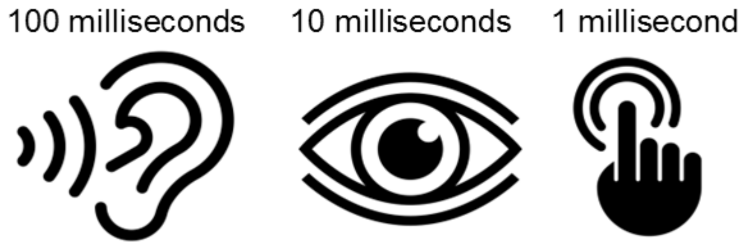
Future services and applications will depend even more strongly on fast broadband, low latency and high reliability than services and applications today. More forward-looking scenarios for bandwidth-intensive services revolve around two underlying trends: (1) the so-called **tactile Internet** and (2) **immersive media,** both of which are based on the idea of real-time human-machine interaction.

Human reaction times differ depending on the sense involved. Audio stimuli prompt human reactions with a delay of around 100 milliseconds, while visual and tactile stimuli (i.e. things which elicit reactions through touch) can prompt even quicker reactions (Figure 1-5).[48] This means that content which is delivered over broadband networks with high latency can sometimes confuse or disturb users, because audio-visual or tactile responses lag behind the user’s reaction time (e.g. delayed lip-

48 ITU (2014), "The Tactile Internet", ITU-T Technology Watch Report, Geneva, p.2.

synchronization of a movie, or a delay in the transmission of voice over the telephone).[49] This damages the user’s quality of experience.

Figure 1-5: Human reaction times




Source: The figure is inspired by Fettweis, G. (2014), "The Tactile Internet – Applications and Challenges", IEEE Vehicular Technology Magazine, 9 (1), 140-145, p.142. Icons (from left to right): Gregor Cresnar, Carin Marzaro, Sergey Demushkin.

The term tactile Internet refers to a network system which is characterised by very low latency and ultra-high reliability, enabling reaction times similar of those of humans.[50] By transmitting content within the parameters of human reaction times, these networks have the potential to open up a wide range of new applications and services and may change communication and interaction habits in the future.

The tactile Internet holds great potential especially for the healthcare sector. While today’s doctors and patients have to be physically present at the same location, this might not be necessary in the future. Physicians may be able to use tele-robots and receive real-time feedback over the network.[51] One example might be the performance of a physiotherapeutic treatment on a patient living in a remote area. By using a exoskeleton the tactile movements of the physiotherapist could be transmitted in real-time on the patients body. However, to obtain a reliable diagnosis the data signals being transmitted over the network have to be reliable, accurate and in real-time. Being able to perform such treatments might particularly help patients living in areas characterised by a low physician density.

In the following case study, NHS Scotland and Ericsson provide their perspectives on the importance of bandwidth and low latency for healthcare today and in the future.

**49** ITU (2014), "The Tactile Internet", ITU-T Technology Watch Report, Geneva, Geneva, p.2.; Fettweis, G. (2014), "The Tactile Internet – Applications and Challenges", IEEE Vehicular Technology Magazine, 9 (1), 140-145, p.142.

**50** Maier, M. et al. (2016), "The Tactile Internet: Vision, Recent Progress, and Open Challenges", IEEE Communications Magazine, 54(5), 138-145, p.139.

**51** ITU (2014), "The Tactile Internet", ITU-T Technology Watch Report, Geneva, p.8.

**Case Study – Healthcare**

The healthcare sector provides a prime example of the need for broadband connections with high bandwidth, high reliability and low latency.

NHS Scotland reports that the Scottish Wide Area Network (SWAN) delivers all their broadband services. The majority of its bodies are connected via ADSL2+ or fibre, providing speeds between 20 Mbit/s(GP) and 500 Mbit/s (Hospitals). Two national data centres are also equipped with broadband connections with data rates of 1 Gbit/s. To perform their day to day business operations, each body of NHS Scotland relies on the network. The Picture Archive and Communication System (PACS)[52] currently requires the most bandwidth, whereas video conferences and consulting require low latency and high network reliability.

It is possible that bandwidth and reliability to homes, clinics and surgeries will become even more crucial with the development of new applications.

One example concerns remote diagnostics and surgery.

Ericsson, a major supplier of networking and telecommunications technology, is conducting more than 30 trials of 5G use cases worldwide. One such trial is research at King's College, London to develop a glove that is able to transmit sensation remotely. The gloves provide touch feedback from sensors on robot arms, while Virtual Reality equipment places the surgeon in the same sensory environment as the patient. Ericsson considers that "the combination of these two technologies removes both the obstacle of distance and the burden of travel cost, giving patients access to specialists, no matter where they are located."[53]

In order to match human sensory reaction times, the network must be capable of transmitting large volumes of data almost instantaneously. Ericsson suggests that a latency of less than one millisecond and a reliability of nearly 100% is required.[54] The use of virtual reality also requires low latencies and bandwidths of potentially more than 200 Mbit/s[55]

Note: Some of those insights are generated via interviews conducted with NHS Scotland (20 Nov 2017), Microsoft (21 Nov 2017), and Ericsson UK (29 Nov 2017).

In the automotive sector, tactile mobile Internet supported by fibre infrastructure could make fully autonomous driving possible. Each vehicle could interact with other vehicles or the whole traffic system, reducing traffic congestion and accidents. Remote driving may also be possible.

In the following case-study, we draw on literature to highlight the implications of autonomous driving for connectivity.

**52** PACS allows diagnostic images of each patient to be stored accessed and shared anytime (htto://searchhealthit.techtarget.com/definition/picture-archiving-and-communication-system-PACS).

**53** https://www.ericsson.com/en/networked-society/innovation/reliable-communications/kings-college/kings-healthcare

**54** Ericsson (2017).*5G Systems – Enabling the transformation of industry and society*.White Paper, p.4.

**55** Wireless World Research Forum (2016). *Outlook: Visions and research directions for the Wireless World – A New Generation of e-Health Systems Powered by 5G*. White Paper, p.19.

**Case Study - Automotive**

With connected applications now standard in new cars, attention has turned to developing truly autonomous vehicles.

For example, since 2016, Jaguar Land Rover, one of the biggest car manufacturers in the UK, has been engaged in the UK's first road trials of autonomously driving vehicles within the UK Autodrive project.[56] These trials are intended to test innovative vehicle-to-vehicle and vehicle-to-infrastructure communications technologies.[57]

To ensure safe and efficient travelling autonomous vehicles need to be equipped with multiple sensor technologies, like sonar devices, stereo cameras, lasers, radar and vehicle-to-X communication.[58] These devices must in turn be connected to enable communication between the vehicle and the surrounding infrastructure, other vehicles and the servers of the manufacturer.

In 2016, Intel claimed that an autonomous vehicle would produce 4000 GB of data each day.[59]

Seif & Hu (2016) further identified that being able to apply a simultaneous localization and mapping algorithm might be the most promising strategy for autonomous driving. They note that real-time data from sensors and cloud-based map data will enable the construction of a virtual image of the vehicle and its surroundings. However, these kinds of technologies require high computing power and fast data transmission, as each vehicle would produce several terabytes of data each hour under this scenario.[60]

Seif & Hu estimate that broadband connections of up to 2.2 Gbit/s would be needed and latency should be lower than 10 milliseconds.[61] While the immediate connectivity with autonomous vehicles will most likely be realized using 5G or other wireless connections, fibre networks will be required along the highways for the backhaul of the large volumes of data that need to be transmitted in (almost) real time.

The tactile Internet also provides a wide range of new possibilities for the educational sector. With the help of virtual or agumented reality applications, teachers can improve the learning experience of their students, as discussed in the following case study.

**56** http://www.bbc.com/news/business-42024880; http://www.jaguarlandrover.com/news/2017/11/first-road-tests-self-driving-jaguar-land-rovers.

**57** https://www.landrover.com/experiences/news/land-rover-to-start-real-world-tests.html

**58** Seif, H.G. & Hu, X. (2016), Autonomous Driving in the iCity – HD Maps as a Key Challenge of the Automotive Industry. *Engineering*, 2 (2), 159-162, p. 160.

**59** https://newsroom.intel.com/editorials/krzanich-the-future-of-automated-driving/

**60** Seif, H.G. & Hu, X. (2016)., "Autonomous Driving in the iCity – HD Maps as a Key Challenge of the Automotive Industry.", Engineering, 2 (2), 159-162, p. 160.

**61** Seif, H.G. & Hu, X. (2016).Autonomous Driving in the iCity – HD Maps as a Key Challenge of the Automotive Industry. *Engineering*, 2 (2), 159-162, p. 160.

**Case Study – Education**

In 2015, around 87% of all primary and secondary schools in the United Kingdom (UK) were equipped with an appropriate broadband connection of at least 5 Mbit/s.[62] Although this is slightly better than the EU average (82%), innovative and modern learning applications will require broadband connections with much more than 5 Mbit/s. E-learning applications are able not just to provide rich media content, which might be several GB in size, but also allow the simultaneous use of that content by a virtually infinite number of students. Both of these characteristics require strict broadband conditions. For these, schools might need almost 1.0 Gbit/s per 1,000 users.[63] For example, an educational video stream in ultra HD quality requires a download speed of about 25 Mbit/s for seamless transmission. If hundreds of students simultaneously watch a video stream, particularly high bandwidths are required to prevent delay and packet loss.

Future applications might further push the limits of current broadband technologies, not only in terms of bandwidth, but also in terms of latency and reliability, as interactivity will play a crucial role in future applications. For example, remote teaching in sports or music should enable the teacher to be able to correct the student's movements instantly. However, these types of applications will only work correctly when the data is transmitted in a manner that enables human sensory reactions. This means that latency of less than 5 milliseconds may be required.[64] Low response times might also be needed when transmitting lessons or university lectures, which involve live participation from remote students.[65] The same applies to virtual and augmented reality applications that will be relevant in education.[66] Using virtual and/or augmented reality application in a learning environment is expected to have positive effects on students. Several studies argue that these applications might enhance students' motivation to learn as well as their social and cognitive skills.[67] For example, they could enable students to explore places which they otherwise would not be able to explore, like foreign countries or even planets or historical places.[68]

*Note: Some of these insights were generated via an interview conducted with Ericsson (29 Nov 2017).*

Tactile Internet should in turn facilitate developments in immersive media. Immersive media describes the next step in virtual reality which will enable us to experience other environments without wearing a virtual reality headset. According to ABI Research, the agumented and virtual reality market is estimated to be worth US$179 billion by 2021.[69] Both technologies are still in their infancy and face multiple obstacles. They require a high-resolution feedback system in real time to provide a seamless user experience. However, with current broadband infrastructure, most virtual and augmented reality systems suffer communication delays due to high latency.[70] Today's VR systems require 100-to-200 Mbit/s to provide only a one-way immersive

**62** European Commission (2015).*Satellite broadband for schools: Feasibility study*. p. 17.
**63** SETDA (2016).*The broadband imperative II: Equitable Access for Learning*. p.2. This number revers to the US Market.
**64** ITU (2014):*The Tactile Internet*.ITU-T Technology Watch Report, p.10-11.
**65** Interview with Ericsson conducted on 29 Nov 2017.
**66** Mirzamany, E.; Neal, A.; Dohler, M. & Rosas, M. L. (n.d.). *5G and Education*. p.3.
**67** Martín-Gutiérrez, J.; Mora, C. E.; Añorbe-Díaz, B. & González-Marrero, A. (2017).Virtual Rechnologies Trends in Education. *EURASIA Journal of Mathematics Science and Technology Education*, 13(2), 469-486, p.478.
**68** Piovesan, S. D.; Passerino, L. M. & Pereira, A.S. (2012).Virtual Reality as a Tool in the Education. *IADIS International Conference on Cognition and Exploratory Learning in Digital Age*, 295-298, p.296.
**69** ABIresarch & QUALCOMM (2017), "Augmented and Virtual Reality: The First Wave of 5g Killer Apps", NY, Oyster Bay, p.1.
**70** ITU (2014), "The Tactile Internet", ITU-T Technology Watch Report, Geneva, p.6.

experience. Photorealistic virtual and augmented reality devices may need 16K screens,[71] which could only be effectively supported by ultrafast broadband.

## 1.3 Modelling ultrafast broadband demand

In order to assess how bandwidth requirements may evolve in the near future (i.e. to 2025), WIK has developed a 'market potential' model.[72] Originally developed in 2011, this model was revised and updated in 2016[73] to reflect emerging applications such as those described in the previous section. For the purpose of this report we have also adapted this model to reflect the specificities of the UK market.

### 1.3.1 Methodology

The starting point for our estimation of bandwidth demand is the end customer's usage behaviour. In order to understand the full potential benefits of ultrafast broadband networks, we have focused on "unconstrained" bandwidth demand i.e. household demand assuming no technical and commercial restrictions, such that connections of any bandwidth are available.We do not seek to explicitly estimate end users' willingness to pay for additional bandwidth.

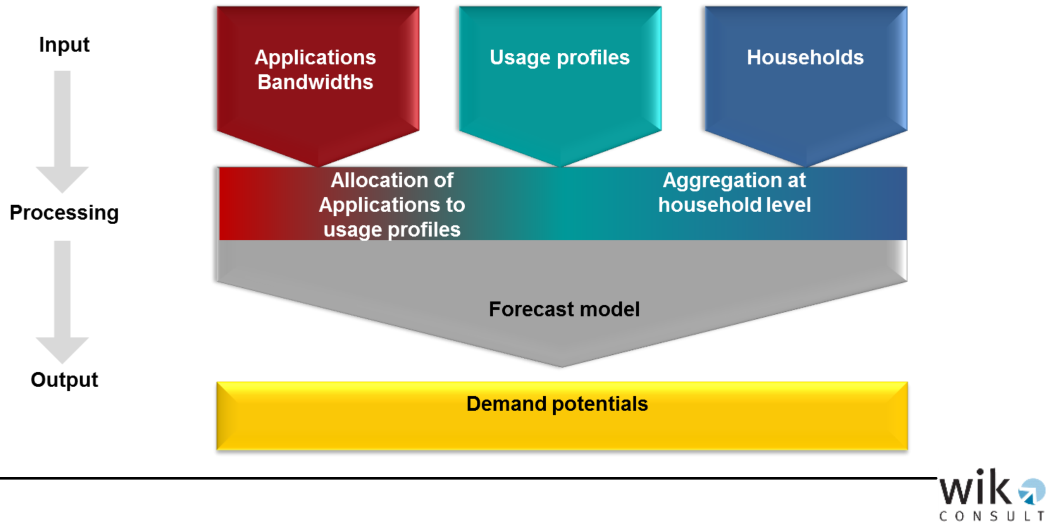
The following figure shows the methodology we have used for the market potential model.

**71** Bastug, E. et al. (2017), "Towards Interconnected Virtual Reality: Opportunities, Challenges and Enablers", IEEE Communications Magazine, 55 (6), 110-117, p.114.

**72** See Doose, A.-M.; Monti, A.; Schäfer, R. (2011): Mittelfristige Marktpotenziale im Kontext der Nachfrage nach hochbitratigen Breitbandanschlüssen in Deutschland, WIK Diskussionsbeitrag Nr. 358, Bad Honnef and Monti, A.; Schäfer, R. (2012): Marktpotenziale für hochbitratige Breitbandanschlüssen in Deutschland, Abschlussbericht für den BREKO, Bad Honnef.

**73** See Strube Martins, S.; Wernick, C.; Plückebaum, T.; Henseler-Unger, I. (2017): Die Privatkundennachfrage nach hochbitratigem BreitbandInternet im Jahr 2025, WIK Bericht, Bad Honnef, März 2017, available at: http://www.wik.org/fileadmin/Studien/2017/Die_Privatkundennachfrage_nach_hochbitratigem_Breitband Internet_im_Jahr_2025_FINAL.pdf

Figure 1-6: Methodology of the WIK market potential model




Source: WIK

The model projects the future demand for bandwidth from residential customers on the basis of three parameters:

- The applications that will be used by residential customers in 2025 and their bandwidth requirements
- The user profiles (i.e. different types of customers) that are to be expected in the future, and the applications that each user profile is likely to use
- The population structure expected in 2025 and the distribution of user profiles among the population structure

Applications are assigned to user profiles in order to estimate the bandwidth and quality requirements of different user types. In a further step, the user profiles are assigned to 1-person, 2-person or 3+-person households. The allocation of applications to user profiles and the merging of user profiles at the household level can be used to derive overall bandwidth requirements for households in 2025.

### 1.3.2 Applications and bandwidth requirements

The model considers the applications listed below. The list of applications reflects those which we have identified as the most important drivers of bandwidth usage and quality requirements in 2025. While most of the applications were already included when the model was developed in 2011, ‘progressive media and entertainment’ including virtual reality were added in 2016 as the significance of these applications for bandwidth demand became clear.

- Basic Internet[74]
- Homeoffice and VPN[75]
- Cloud Computing
- State of the Art Media and Entertainment (4k, 3D, HD)
- Progressive Media and Entertainment (8k, VR)
- Communication[76]
- Videocommunication
- Gaming
- E-Health
- E-Home/ E-Facility[77]
- Mobile Offloading[78]

For each of the applications listed above, we have forecast the likely bandwidth requirements (both downstream and upstream), as well as packet loss and latency requirements, by 2025. These are set out in Table 1-1.

Bandwidth growth rates have been estimated based on an analysis of the development of historic data volumes and data rates. As they have been constrained by the availability of high bandwidth broadband connections, this means that, other things being equal, they tend to understate growth in unconstrained bandwidth demand.

These assumptions have also been supported by a review of desk research on data requirements of individual applications[79] and have been discussed with industry experts.

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**74** Basic Internet refers e.g. to surfing the Internet (including e-commerce) and social networks.

**75** Homeoffice and VPN refers to the file exchange and online usage of ressources such as software in the context of teleworking.

**76** Communication refers e.g. to telephony, chats on social networks etc.. Videocommunication includes videotelephonyy, videoconferencing.

**77** E-Home refers to anything in the home that can be controlled remotely by a smartphone, tablet or computer; e.g. a thermostat that 'learns' the desired temperature of a user throughout the day to a washing machine that orders washing powder before it runs out.

**78** WiFi-Offloading of mobile data.

**79** See for example Fraunhofer FOKUS (2016): Netzinfrastrukturen für die Gigabitgesellschaft, available at: https://cdn2.scrvt.com/fokus/5468ae83a4460bd2/65e3f4ee76ad/Gigabit-Studie_komplett_final_einzelseiten.pdf; BIU (2015): Positionspapier Agenda 2020: für eine starke Computer- und Videospielbranche in Deutschland, available at: https://www.biu-online.de/wp-content/uploads/2015/06/20150608_BIU_Positionspapier_F%C3%B6rderung_Standort_Deutschland.pdf ; Cisco (2017): Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021, White Paper, downloadble at: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.pdf; FTTH Council (2016): FTTH Business Guide, Edition 5 Financing Committee, Revision date: 16/02/2016, available at: http://www.ftthcouncil.eu/documents/Publications/FTTH_Business_Guide_V5.pdf

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

| Application category | 2015 Downstream bandwidth (Mbit/s) | Assumed CAGR in% | Downstream (Mbit/s) in 2025 | Upstream (Mbit/s) in 2025 | Packet loss | Latency |
|---|---|---|---|---|---|---|
| Basic Internet | 2 | 25 | ≈20 | ≈16 | o | o |
| Homeoffice/VPN | 16 | 30 | ≈250 | ≈250 | + | + |
| Cloud Computing | 16 | 30 | ≈250 | ≈250 | + | ++ |
| State of the Art Media and Entertainment (4k, 3D, UHD)… | 14 | 20 | ≈90 | ≈20 | ++ | + |
| Progressive Media and Entertainment (8k, Virtual Reality) | 25 | 30 | ≈300 | ≈60 | ++ | + |
| Communication | 1,5 | 20 | ≈8 | ≈8 | ++ | + |
| Videocommunication (HD) | 8 | 15 | ≈25 | ≈25 | ++ | ++ |
| Gaming | 25 | 30 | ≈300 | ≈150 | ++ | ++ |
| E-Health | 2,5 | 30 | ≈50 | ≈50 | ++ | + |
| E-Home/E-Facility | 2,5 | 30 | ≈50 | ≈50 | o | o |
| Mobile Offloading | 2 | 30 | ≈15 | ≈12 | o | o |

Source: WIK

The main drivers of these bandwidth increases are further described below.

The bandwidth requirements of applications such as progressive TV/VR, VPN,[80] cloud and gaming are assumed to grow with a CAGR[81] of around 30%. In the area of progressive TV, a significant increase in bandwidths is expected due to the introduction of new technologies such as 8K and Virtual Reality.

The main driver of bandwidth demand in gaming is expected to be virtual reality, high-definition graphics and sophisticated software that allows players to play online in a networked environment. These developments are also likely to require high levels of quality of service including low latency.

Cloud computing includes the storage of high-resolution images, movies and data as well as the use of software in the cloud. The need for bandwidth is growing in this area because, amongst other things, the amount of data transferred via the Internet is constantly increasing. While only a few kilobytes of data are needed to transmit a text message, a Full HD[82] video often requires several gigabytes of data volume.

The increasing use of e-health and smart home applications may also generate data volumes, potentially in conjunction with cloud computing.

80 Virtual Private Networks
81 Compound Annual Growth Rate
82 High Definition

More moderate increases in bandwidth requirements are also expected from services that are prevalent on the market today. For instance, bandwidth requirements for basic Internet and communication will increase, as high-resolution images and videos are increasingly transmitted via the Internet. We assume that bandwidth requirements for current TV applications (termed 'state of the art media') such as 4K, UHD[83] and video-communication grow at slower CAGRs of 20% and 15% respectively.

WIK's model does not reflect aggressive assumptions concerning compression. This means that, if there are substantial advances in compression technologies in future, the unconstrained bandwidth demand forecasts would (other things equal) tend to be overstated. More conservative approaches e.g. reflecting aggressive assumptions concerning compression technologies, assume lower bandwidth requirements.[84] There are several reasons behind the decision not to assume aggressive compression scenarios in the WIK model:

- In this model there are no technical and commercial restrictions. Content providers which do not have to consider technical restrictions are likely to develop applications without the need to concentrate on reducing the bandwidth requirements of their innovative products.
- There may be advantages from the absence of restrictions in that better broadband infrastructure is likely to create incentives for new and innovative applications to be developed, without the need to consider infrastructure as a potential bottleneck.
- For a number of digital applications, bandwidth is not the only or even the main requirement to make them attractive and usable. Rather, the quality requirements concerning low latency, packet loss rate and jitter are of great importance. However, these parameters cannot so readily be addressed using compression techniques.
- Compression methods are not only detrimental to quality (signal quality and delay times) but also involve high costs themselves. Moreover, the codecs of compression rates have grown at a lower rate than the growth rate of the data volume for audiovisual content (without compression).[85]

As explained above, the bandwidth requirements assumed in the WIK model have been scrutinized in discussions with market stakeholders and crossed-checked through desk research.

**83** Ultra High Definition
**84** See for example Frontier Economics (2017): Future benefits of broadband networks, downloadable at: https://www.nic.org.uk/wp-content/uploads/Benefits-analysis.pdf,
**85** There are predictions that codecs will not be able to compress efficiently by 2020 so that efforts are being made to develop a video codec based on neurological science to achieve an efficient compression. See Doutsi, E. (2017): Compression d'images et de vidéos inspirée du fonctionnement de la rétine, downloadable at https://tel.archives-ouvertes.fr/tel-01584114/document.

Nevertheless, we have tested the impact of taking a more optimistic view of compression technologies by also modelling scenarios where applications such as cloud, VPN and progressive media have lower bandwidth requirements by 2025. We find that overall broadband demand is only patially sensitive to these assumptions. As discussed in more detail below, the primary reason for this lies in the importance that the parallel use of applications in multiperson households has on bandwidth demand (rather than the individual requirements of a given application).

### 1.3.3 User types

The WIK market potential model projects the bandwidth needs of broadband households in 2025 based on user types which are assumed to have distinct usage patterms with regard to the application categories assigned to them. These user types has been based on the user profiles which have been developed for Germany. Based on data about Internet and media usage from Eurostat (statistical office of the European Union), Ofcom, BARB (Broadcasters' Audience Research Board) and ONS (Office for National Statistics) we have assessed the applicability of the chosen user profiles for the UK.[86]

The data suggests that the user profiles and the shares used in the model for Germany can be used for the application of the WIK market potential model to the UK. However, the number and type of relevant applications for each user type have been adapted to the UK situation. For example, in Germany Internet users subscribe to IPTV as a broadcasting service (as an alternative to satellite or cable TV) to a greater extent. This means that the share of user profiles using state of the art media in the UK is lower. In contrast, cloud services have a higher usage share in the UK so we have assumed a higher share of user profiles using cloud in the UK.[87] E-Health data suggests a higher usage in the UK while the share of E-Home is assumed to be lower than in Germany in 2025 (see also explanation of user profile shares below).

**86** See for example Eurostat (2017), Use of Internet storage space for saving and sharing files, http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Use_of_Internet_storage_space_for_saving_and_sharing_files,_2014_(%25_of_individuals)3.png; Eurostat (2017), Internet use by individuals, http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tin00028&plugin=1; Eurostat database, http://ec.europa.eu/eurostat/data/database; Ofcom (2017), Communications Markets Report, https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf; BARB (2017), UK TV households by reception type; ONS (2017), Internet access – households and individuals: 2017, https://www.ons.gov.uk/peoplepopulationandcommunity/householdcharacteristics/homeInternetandsocialmediausage/bulletins/Internetaccesshouseholdsandindividuals/2017.

**87** For example, the transmission of IPTV does not play the same role as in Germany.

Table 1-2: Overview of user types

| User type | Description |
|---|---|
| Sceptical outsider | Digital sceptics are mainly older users who have the lowest usage of digital applications compared to other user types. They rarely use computers and the Internet and have the most negative attitude towards ICT. |
| Occasional user | Occasional users have a basic or medium level of formal education and live mostly in multi-person households. They have basic ICT skills which they use in the areas of basic Internet, communication, and mobile offloading. Applications perceived as essential such as e-health, may also be used. |
| Digital professional | Digital professionals possess a high level of ICT competence and have extensive technical equipment with the corresponding ICT infrastructure. This category uses computers, tablets and 8k TV intensively. Virtual reality offers and e-home applications are also represented in this technology-oriented user group. Digital professionals include both highly-educated users and users from socially disadvantaged groups who value being up to date in the media sector. Younger generations of digital professionals are likely to use progressive TV applications, which require very high bandwidths. |
| Trend user | The group of trend users has a high proportion of men. They are strongly represented in households with two or more persons, have a good digital infrastructure and comprehensive ICT competence, which is used in a variety of ways, although not in bandwidth-intensive applications such as gaming, or 8k TV. The preference of trend users is for applications such as state of the art media, video communication and e-health applications. Cloud computing and mobile offloading run in the background with this user group, with the result that demand for bandwidth and quality of Internet access is also demanding for trend users. |
| Home office user | Home office users live predominantly in households with two or more persons. They have a very good digital infrastructure and use the Internet more than average. Since they use ICT applications intensively during working hours, their ICT skills have been significantly expanded. The outstanding digital infrastructure enables them to work in the home office on the basis of VPN. in addition, they use baisc Internet with high-resolution images as well as video communication and, like all other user groups, mobile offloading to relieve the load on mobile data use. |
| Digital avant-gardist | The group of digital avant-gardists has the best digital equipment. The avant-garde user is very competent and professional in handling hardware and software. This user group includes both professionals with a high level of formal education and young people who spend a large proportion of their time in gaming. It is therefore very heterogeneous. Broadband connectivity requirements are driven by digital applications such as gaming and E-Home/E-Facility. Applications such as cloud computing and mobile offloading run in the background. As with the other user groups, the Basic Internet is part of everyday digital life. |

Source: WIK.

Table 1-3 shows an overview of the digital applications used by the different user types.

Table 1-3: Overview of digital applications and user types

| Categories / User Types | Occasional | Sceptical Outsider | Home office User | Trend User | Avantgardist | Professional |
|---|---|---|---|---|---|---|
| Basic Internet | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Homeoffice/VPN | | | ✓ | | | |
| Cloud Computing | | | | ✓ | ✓ | ✓ |
| State of the Art Media and Entertainment (4k, 3D, UHD)… | | | | ✓ | | |
| Progressive Media and Entertainment (8k, Virtual Reality) | | | | | | ✓ |
| Communication | ✓ | | | | | |
| Videocommunication (HD) | | | ✓ | ✓ | | |
| Gaming | | | | | ✓ | |
| E-Health | ✓ | | | ✓ | | |
| E-Home/E-Facility | | | | | ✓ | ✓ |
| Mobile-Offloading | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Source: WIK.

Based on the descriptions of each user profile above, the assumption is that three user profiles – the home office user, the digital avant-gardist and the digital professional – use one of the three most bandwidth-intensive applications: VPN, progressive TV and gaming.

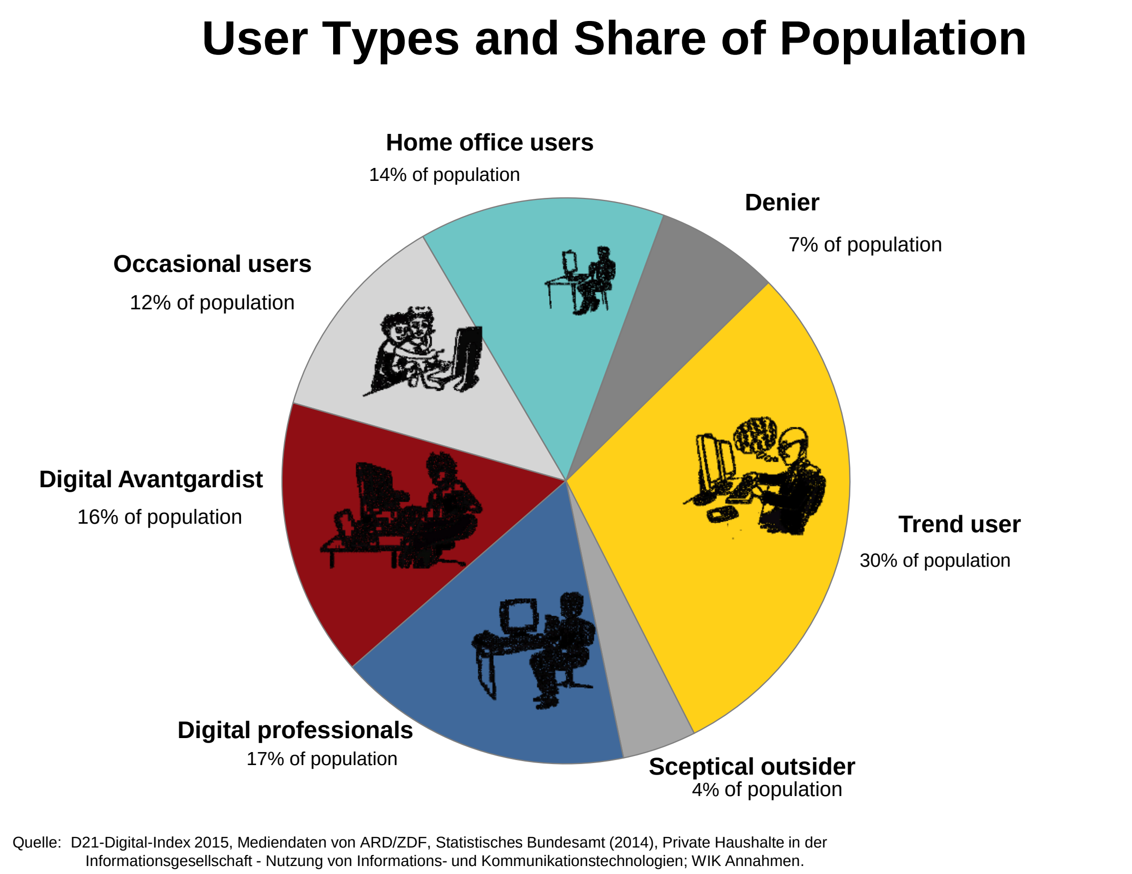
Against the background that cloud computing has a comparatively high usage in the UK, three user types use cloud computing in the background, the trend user, the avant-gardist and the digital professional. It is assumed that cloud serves not only to store data (high-resolution images and videos, music, etc.), but also to use software and support applications in the e-home and e-health sector.

Two user profiles, the occasional user and the sceptical outsider, are more reluctant to use digital applications. The trend user does not use VPN, 8k or gaming, but relies on a variety of digital applications, including audio-visual communication and e-Health.

In addition to these six user profiles which use digital applications more or less intensively, there is also a group of "fixed broadband deniers" who either exclusively use mobile Internet, or do not use broadband Internet at all.

The assumed share of different user types as a proportion of the population is shown in the following figure.

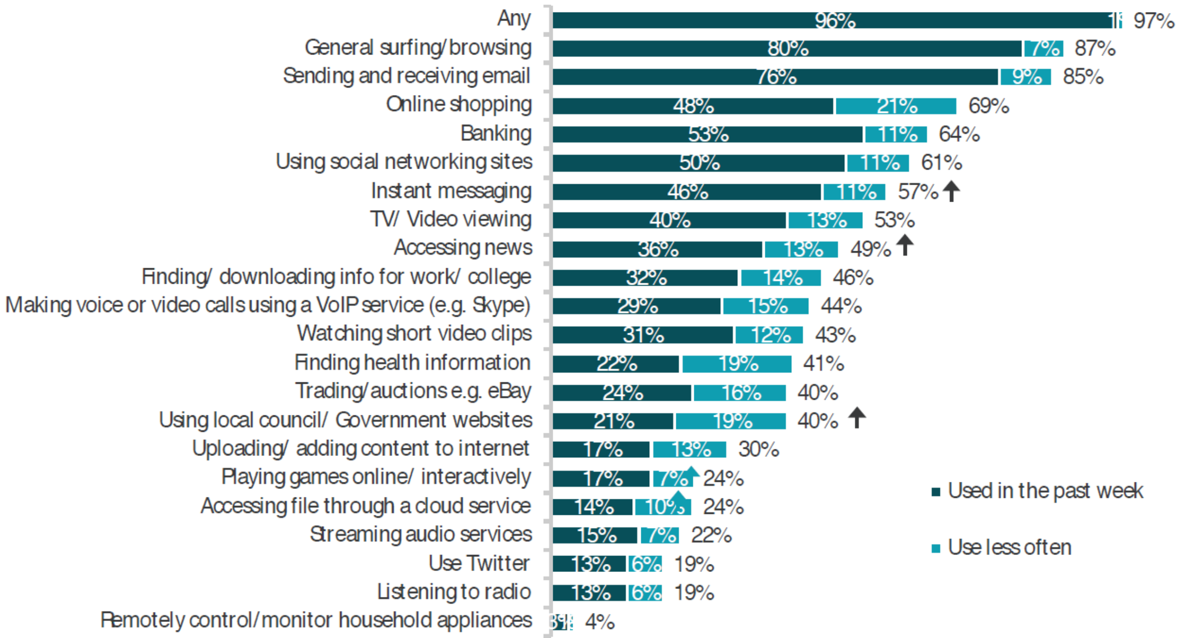
Figure 1-5: User types and share in population




Source: WIK.

These shares have been developed based on an assessment of the available data concerning the proportions of the population using particular applications. The figure below shows the results of survey data collected for Ofcom on the use of the Internet for selected activities. This has been complemented with other data to validate the estimates as detailed below.

Figure 1-7: Use of the Internet for selected activities

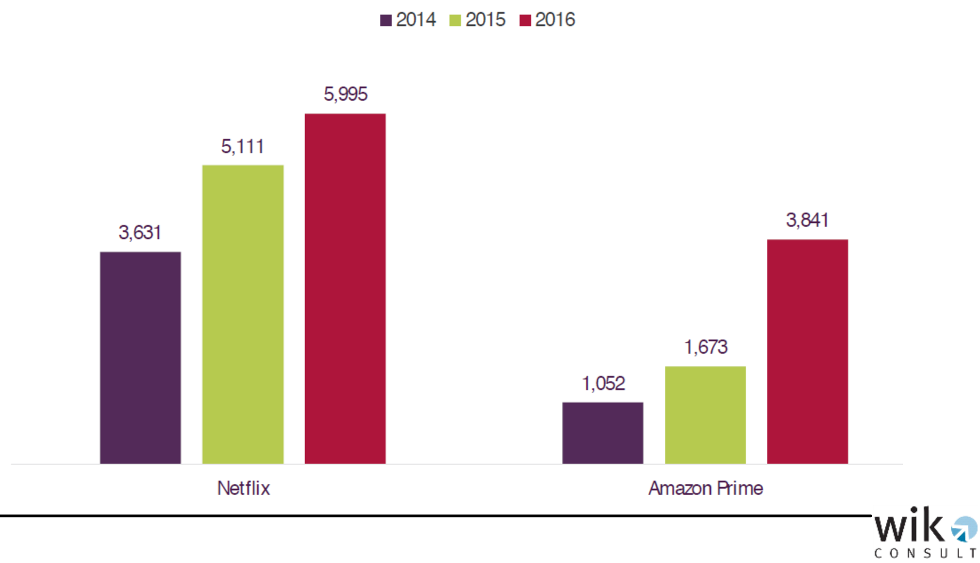



Source: Ofcom (2017), Communications Markets Report, p. 186, https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

- **Trend user:** The estimated 30% share of trend users by 2025, is based on usage of Video on Demand (VoD). In this context, we note that in 2017 32% of homes in UK used VoD services[88]. The usage of VoD in the UK has increased significantly, with subscriptions to Netflix showing a year on year growth rate of 17%, while the number of subscriptions to Amazon Prime more than doubled in 2016 (see following figure). However, the importance of IPTV for bandwidth requirements is likely to be lower in the UK than in Germany because terrestrial, satellite and cable platforms have a considerably higher share of broadcasting transmissions than IPTV.

88 See BARB (2017). UK TV households by reception type, http://www.barb.co.uk/tv-landscape-reports/tracker-uk-households-by-tv-platform/

Figure 1-8: On-demand/streaming service subscription numbers: 2014-2016 (000s)




Source: Ofcom (2017), Communications Markets Report, p. 40, https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

- **Digital professional:** The share of digital professionals, estimated at 17% by 2025 is influenced by the growth of virtual reality markets and 8k TV services and reflects the growth which is expected for Internet video, VoD and other innovative applications based on these technologies. In this context, we note that in 2017, 6% of the UK population were already reported to be using a virtual reality device,[89] with the popularity of these devices exceeding those of tablets and wearables at the same stage of their development.

- **Home Office User:** The proportion of home workers in the UK was 13.7% in 2015.[90] Accordingly, the model assumes that 14% of the population will be home office users in 2025. This could however be considered a conservative estimate, as this proportion could increase over time, especially if higher bandwidths facilitate home working. [91]

- **Avant-gardist:** The proportion of avant-guardist users draws on the popularity of gaming. As previously mentioned, according to the UK games industry, the UK is estimated to have the largest and fastest growing VR hardware market in EMEA, growing at 76% CAGR in the next five years.[92] Further, the UK games

**89** https://yougov.co.uk/news/2017/05/19/vr-headsets-more-popular-tablets-and-wearables-wer/
**90** ONS (2016), Labour force survey, https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/adhocs/005578homeworkersratesandlevelsjantomar2015
**91** See UK Commission for Employment and Skills (2014), The Future of Work, Jobs and Skills in 2030, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/303334/er84-the-future-of-work-evidence-report.pdf
**92** See ukie (2017), UK Video Games Fact Sheet, https://ukie.org.uk/research

market will be Europe's largest video games market in 2021.[93] Noting that 17% of Internet users played online games (excl. Internet users doing it less often), the share of 16% for the digital avant-gardist in 2025 may underestimate the use of gaming services in the model.

- **Occasional users:** The occasional user of the WIK model can be compared to the "narrow user" in the Ofcom report on adults' media use and attitudes.[94] In 2017 28% of Internet users were considered to be narrow users. When estimating the share of occasional users it should be taken into account that there is a high share of adults and those aged 75 and higher in this group. In 2025 it can be assumed that the number of occasional users will decrease as younger generations with higher Internet usage and more affinity to technological innocation grow into older age groups. As a result we estimate that the share of occasional users will decrease significantly to 12% in 2025.

- **Sceptical outsiders:** The share of sceptical outsiders has been estimated on the basis of the share of "newer users" in the Ofcom report on adults' media use and attitudes.[95] In 2017 there were 9% newer users. When estimating the share of sceptical outsiders, it should be taken into account that there is a high share of adults and those aged 75 and higher in this group. In 2025 it can be assumed that the the number of secptical outsiders will decrease as younger generations with higher Internet usage grow into older age groups. As a result we estimate the share of sceptical outsiders in the population to be 4% in 2025.

- **Deniers:** When estimating the share of deniers in 2025 it should be noted that today's younger generations (with a significantly higher affinity for technology)[96] are likely to grow into user profiles with high bandwidth and quality requirements. It can therefore be assumed that only a small proportion of the population will not use the Internet in 2025. The group of deniers is estimated at around 7% of the population, a decline from the 12% of adults who were estimated to have had no Internet access at home in 2017.

In addition, we cross-checked the distribution of usage of key applications such as cloud computing and e-health across user types with reference to current usage and trends.

**93** PWC (2017), The 2017 UK entertainment and media outlook, https://www.pwc.co.uk/industries/entertainment-media/insights/entertainment-media-outlook.html

**94** See Ofcom (2017): Adults' media use and attitudes Report 2017, downloadable at: https://www.ofcom.org.uk/__data/assets/pdf_file/0020/102755/adults-media-use-attitudes-2017.pdf

**95** Compared to established Internet users who first went online five years ago or more, newer users spend less time online, are less confident Internet users and are more likely to only use websites or apps they have used previously. See Ofcom (2017): Adults' media use and attitudes Report 2017, downloadable at: https://www.ofcom.org.uk/__data/assets/pdf_file/0020/102755/adults-media-use-attitudes-2017.pdf

**96** The percentage of Internet usage is highest among younger age groups, although over half (53%) of over-74s are Internet users See Ofcom (2017), Communications Market Report 2017, p. 164, https://www.ofcom.org.uk/__data/assets/pdf_file/0017/105074/cmr-2017-uk.pdf

- In 2017 49% of individuals used cloud services in the UK.[97] This is one of the highest percentages of cloud usage among Internet users in comparison to other European countries.[98] Cisco forecasts that by 2020, 59% of the consumer Internet population will use personal cloud storage, up from 47% in 2015.[99] Against this background, the share of cloud users in sum (trend users, digital professionals and avant-gardists) is estimated to be 63% in 2025 in the WIK model.

- The UK was an early adopter of using telemedicine (sometimes referred to as telecare in the UK).[100] As a result, telecare is a mature market in the UK with the highest penetration per capita in the over 65s category of any global market. On the other hand, the market is well established and therefore not expected to grow so rapidly in future (the UK market in 2014 was forecast to grow at a compound annual growth rate (CAGR) of four to five per cent to 2018).[101] Accordingly, E-Health is assumed to be used by occasional users and trend users with a total share of 42%.

- In 2014 11% of UK households were estimated to use smart home applications and the market was expected to grow at rates of almost 30%.[102] More recent reports forecast the Internet of Things market to grow at 17% CAGR in 2017 and at 9% in 2021.[103] The share of user profiles using E-Home applications is estimated to be 33% in sum in 2025.

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**97** Eurostat (2017): cloud usage by individuals, downloadable at: http://appsso.eurostat.ec.europa.eu/nui/show.do?query=BOOKMARK_DS-445196_QID_-32049F16_UID_-3F171EB0&layout=TIME,C,X,0;GEO,L,Y,0;INDIC_IS,L,Z,0;UNIT,L,Z,1;IND_TYPE,L,Z,2;INDICATORS,C,Z,3;&zSelection=DS-445196INDICATORS,OBS_FLAG;DS-445196IND_TYPE,IND_TOTAL;DS-445196UNIT,PC_IND;DS-445196INDIC_IS,I_CC;&rankName1=UNIT_1_2_-1_2&rankName2=INDICATORS_1_2_-1_2&rankName3=IND-TYPE_1_2_-1_2&rankName4=INDIC-IS_1_2_0_0&rankName5=TIME_1_0_0_0&rankName6=GEO_1_0_0_1&sortR=ASC_-1_FIRST&sortC=ASC_-1_FIRST&rStp=&cStp=&rDCh=&cDCh=&rDM=true&cDM=true&footnes=false&empty=false&wai=false&time_mode=ROLLING&time_most_recent=true&cfo=%23%23%23%2C%23%23%23.%23%23%23&lang=en

**98** In 2016 46% of Internet users used Internet storage space to save documents, pictures, music, video or other files. See Eurostat (2017), Use of Internet storage space for saving and sharing files, http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Use_of_Internet_storage_space_for_saving_and_sharing_files,_2014_(%25_of_individuals)3.png

**99** See Cisco (2016): Cisco Global Cloud Index: Forecast and Methodology, 2015–2020, White Paper, downloadable at: https://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/global-cloud-index-gci/white-paper-c11-738085.pdf.

**100** See U.S. Department of Commerce International Trade Administration (2017): 2017 Top Markets Report Health Information Technology Country Case Study, downloadble at: https://www.trade.gov/topmarkets/pdf/Health_IT_UnitedKingdom.pdf

**101** Please note that despite the maturity of the market the bandwidth and quality requirements change because of the introduction of new applications which for example include the transmission of high definition audiovisual files.

**102** https://www.alliedmarketresearch.com/smart-home-automated-building-market

**103** https://www.strategyanalytics.com/strategy-analytics/news/strategy-analytics-press-releases/strategy-analytics-press-release/2017/10/26/smart-home-will-drive-Internet-of-things-to-50-billion-devices-says-strategy-analytics#.WnA76nkxmos

### 1.3.4 Aggregating demand across households

The aggregation of bandwidth demand from individual users into household demand, is based on the population size and household structure estimated for 2025. The age group under 15 years (17.5% of the population) was excluded from the estimated total population of 68.9 million for 2025. The proportion of users per user group set out in Figure 1-5 is then combined with the household structure of households, which is based on the household structure published by the ONS for 2016.[104]

All users are represented in all household sizes, i.e. all user profiles live in all households types. However, the distribution of user profiles among household types reflects which household size is more frequent in the respective user profile. For example, more than half of sceptical users live in one person households. Occasional users typically live in one and two person households. As mentioned above, home office users predominantly live in households with two or more persons, similar to professional users. Trend users have a considerable share living in two person households while avantgardists live to a great extent in one and two person households.

In multiple user households the profiles are assigned based on the assumption that user profiles within a household are similar. This means e.g. that a sceptical outsider mainly lives either with other sceptical outsiders or with occasional users in the household. Occasional users live with sceptical outsiders, other occasional users and with home office users in multi-person households, but not with trend users, professional users or avantgardists. The home office user is assumed to live with occasional users or trend users in a household while trend users are also combined with professional users. If the assumption that user profiles in one household are similar were not applied, there would be more households with high level demand and less at the extremes with low or top level demand.

The share of households with more than 3 persons is lower than the national share of 3-person households, as the age group under 15 years was not taken into account and this group lives in multi-person households. This means that the estimate ignores a considerable proportion of users with a bandwidth-intensive user profile, which is likely to be strongly represented among young people (e. g. due to the use of videostreaming and gaming).

Based on these assumptions, we can estimate aggregated demand across all users for each household in the UK. This is shown in the next section.

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**104** There is no projection of household structure differentiated by number of persons available only differentiated by household type. The ONS points out that the household structure has remained rather stable in the last 10 years so that the current household structure can be seen as a good approximation of the household structure in 2025.

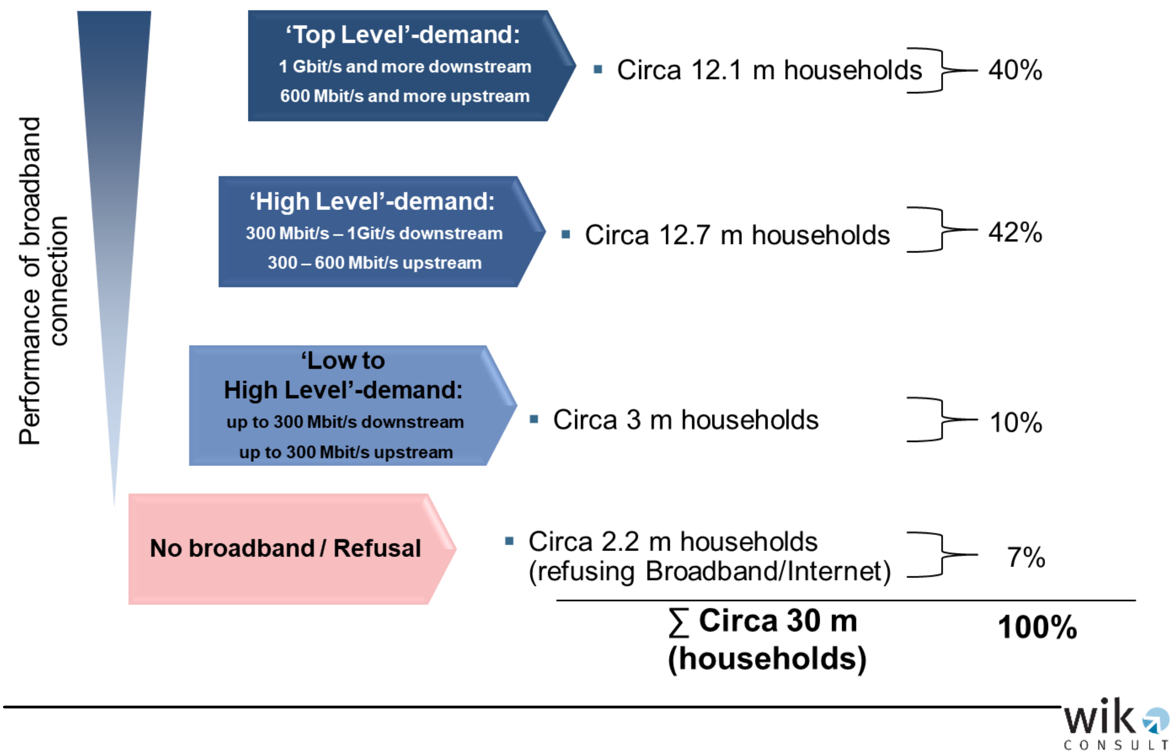
### 1.3.5 Unconstrained broadband demand and QoS requirements in UK in 2025

The estimated unconstrained demand potential based on the assumptions and conditions described in the WIK market potential model is shown in Figure 1-9.

This shows that, based on the assumptions outlined above, around 82% of households would have unconstrained demand for bandwidths of more than 300 Mbit/s by 2025, while around 40% may demand bandwidths of 1Gbit/s plus with more than 600Mbit/s in upload capacity. These forecast bandwidth demands are not primarily driven by individual applications such as TV/Video viewing, but rather by the simultaneous use of digital services in households. This mainly reflects several people in one household using applications with high bandwidth requirements and also, but to a lesser extent, the parallel use of applications/devices, such as simultaneous use of cloud and mobile offloading by one person.

It is important to note that these forecasts are based on the assumption that there are no technical restrictions, such that users do not have to worry about overloading their broadband connection, e.g. when they synchronize their devices with the cloud while they are watching an 8K movie on a TV streaming platform.

Figure 1-9: Forecast of unconstrained broadband demand in the UK in 2025

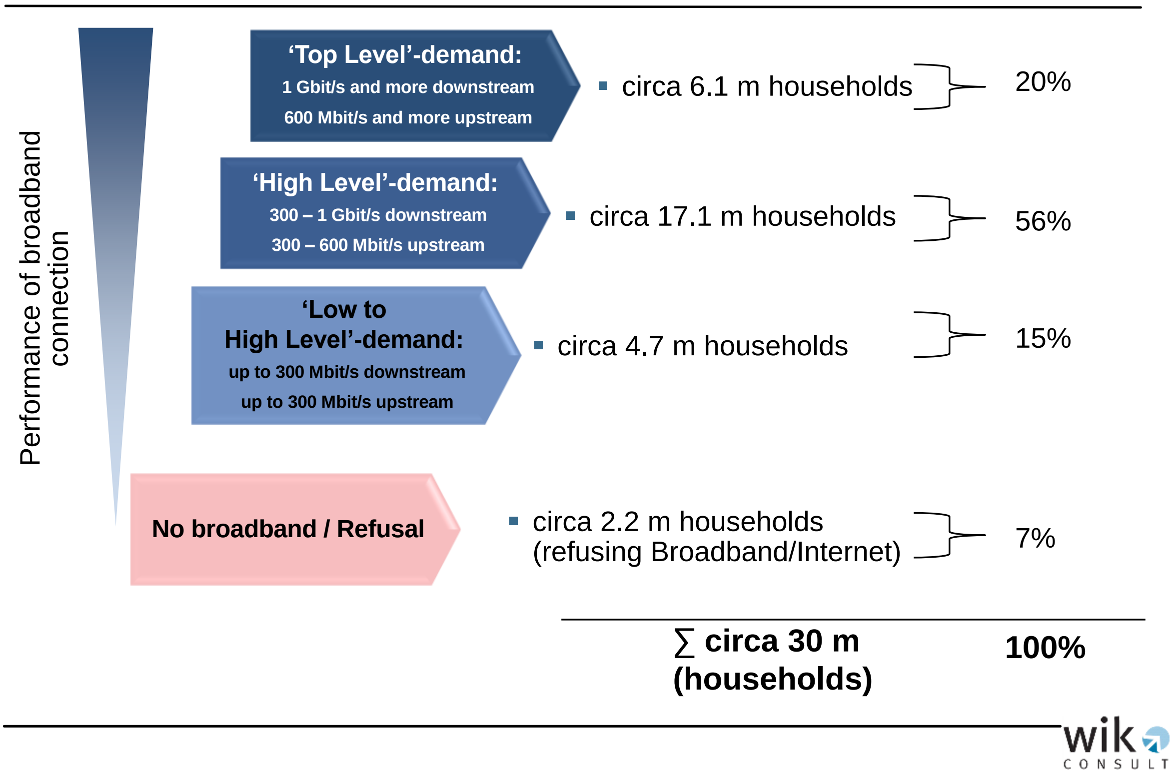



Source: WIK market potential model 2015

The results of the model can only be indicative as they are based on many assumptions about how demand for future services might develop, particularly the importance of simultaneous usage. It is possible however to identify other plausible outcomes through conducting sensitivity tests.

In an alternative scenario, which assumes a slower bandwidth development for the application categories state of the art media (40 Mbit/s instead of 90 Mbit/s), progressive TV in 8k quality (200 Mbit/s instead of 300 Mbit/s) and VPN/Home Office (200 Mbit/s instead of 250 Mbit/s),[105] around 77% of households would continue to demand download and upload bandwidths above 300 Mbit/s but the proportion requiring 1 Gbit/s and above would fall to around 20%.

Figure 1-10: Forecast of unconstrained broadband demand in the UK in 2025, assuming lower bandwidth requirements

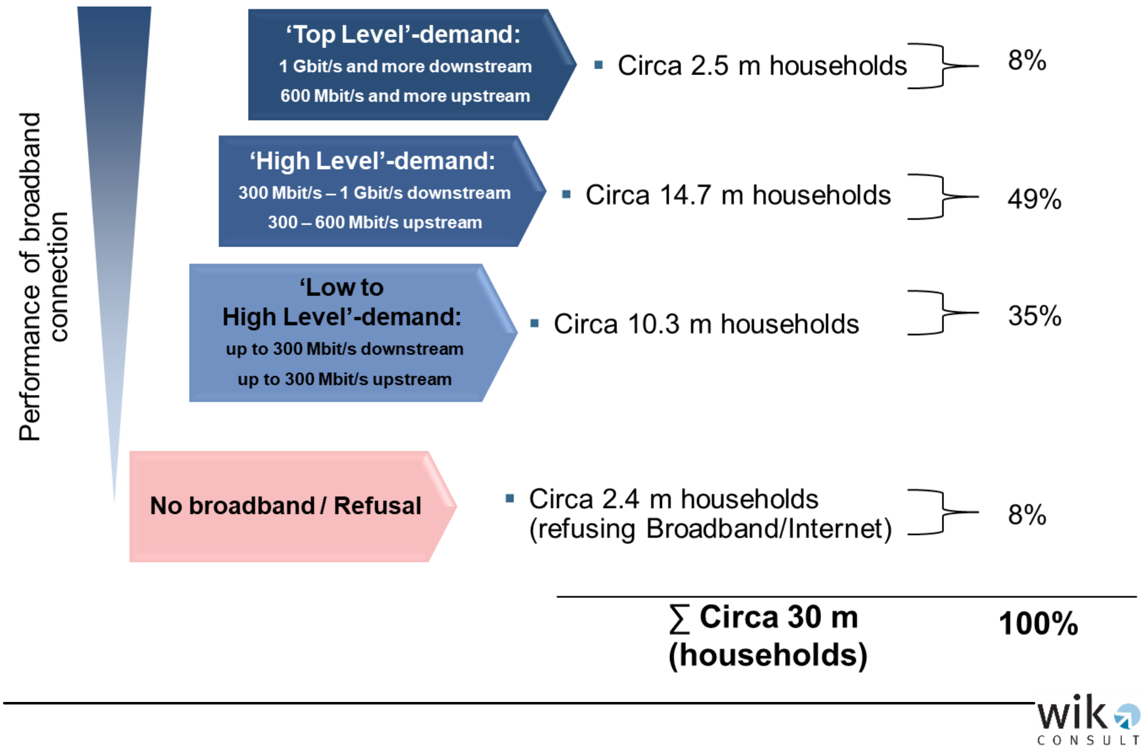



Source: WIK market potential model 2015

Under an even more conservative demand forecast which assumes both lower bandwidth needs and no use of 8K or VR (except in the context of gaming), even fewer customers (around 8%) would need Gigabit connectivity.

**105** This scenario is based on lower bandwith growth rates for the two applications for which compression could play a significant role to reduce bandwidth requirements (State of the art media; and TV in 8K quality). VPN has also been reduced to show that the bandwidth requirements of one single application is not decisive for the results. Rather, it is the simultaneous use of applications which drives broadband demand.

Figure 1-11: Forecast of unconstrained broadband demand in the UK in 2025, assuminglower bandwidth requirements and no progressive media




Source: WIK market potential model 2015

However, it is important to note that many of the applications used in 2025 not only require high bandwidth, but also low latency, packet loss rates as well as reliable connections.

Table 1-4 shows the quality requirements of the user profiles (see also Table 1-1 and Table 1-3). It illustrates that, while applications such as e-health and videocommunications do not require bandwidths as high as gaming and progressive audiovisual content, they may still require specific access technologies to satisfy their demand for low packet loss rates and low latency.

Table 1-4: Quality requirements of user profiles

| Application category | Packet loss | Latency | Application driving quality requirements |
|---|---|---|---|
| Sceptical outsider | o | o | - |
| Occasional user | ++ | + | Ehealth |
| Home Office user | ++ | ++ | Videocommunications |
| Trend user | ++ | ++ | Videocommunications and ehealth |
| Avantgardist | ++ | ++ | Gaming |
| Professional user | ++ | ++ | Progressive audiovisual content |

A further consideration is that, even if only 8% of households demand Gigabit connectivity, if the network is not dimensioned to meet these needs, there would still be a (small, but not insignificant) portion of individuals whose demands would not be catered for. Moreover, the needs of small businesses, which may be located in residential zones and lack business-specific connectivity, have not been modelled in this exercise. However, it is likely that some small businesses would also have high bandwidth (including upload) and quality of service requirements.

## 2 Which technologies will meet end-user demand?

In this previous chapter, we identified that a significant proportion of end-users may need bandwidths of 300Mbit/s or more, while some may even require Gigabit connections. Applications that are likely to expand or emerge in the coming years may also require increased upstream connectivity and higher levels of quality of service.

In this chapter, we elaborate what is meant by downstream and upstream bandwidth as well as 'quality of service' (from a technical perspective), and discuss the capabilities of different technologies to meet potential user needs in this respect.[106] In this context, we consider not only their current capabilities, but the potential for given technologies to be readily upgraded to meet the needs of more demanding users.

Although bandwidth needs will increase across the whole of the network, we concentrate in this chapter on assessing the capabilities of the access network, as it is in this portion of the network that there is most likely to be bandwidth scarcity, as well as specific factors which contribute to quality degradation.[107] In order to provide appropriate granularity about the relative performance of different technologies, in this chapter we distinguish between Fibre-to-the-Premise (FTTP) – also called Fibre-to-the-home (FTTH) and Fibre-to-the-Building (FTTB), noting that with FTTB, copper may be used to connect units (houses or offices) within the same building.

**Key findings**

- The quality of broadband connections can be measured, not just in terms of download speeds, but also upload speeds, and various measures of quality including latency, jitter, packet loss, delay and availability. Factors that may limit quality include electromagnetic interference (which applies to copper connections) and, unless correctly dimensioned, network architectures which involve shared bandwidth.

- The majority of customers are likely to be adequately served by DOCSIS 3.1 cable updates towards 2025. However, FTTB/P and Docsis full duplex technologies are likely to be the only solutions which are sufficiently highly performing to serve the interests of all consumers and small businesses including top level users in the

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**106** Ofcom has identified ultrafast broadband as broadband with download speeds of at least 300Mbit/s (with an upgrade path to 1 Gbit/s), and higher upload speeds than superfast broadband. It also considers that the reliability with which the speed is delivered is an important attribute, and expects the definition of ultrafast to evolve to take account of the importance of this reliability. Paragraph 1.10, Ofcom 2017 WLA market review consultation and subsequent updates https://www.ofcom.org.uk/consultations-and-statements/category-1/wholesale-local-access-market-review

**107** The quality of a connection is the result of the quality of the chain of network segments passed. All contribute. Access networks still often include legacy infrastructure which can contribute to quality degradation. Conversely, the contribution of the core and backhaul network segments to quality degradation are typically more minor, because they can be dimensioned appropriately and are based on high bandwidth fibre connections in all networks. eg a VDSL Dslam is backhauled by a fibre link, which in principle is shared by all customers connected to the DSLAM, but its capacity can be dimensioned above the sum of all access lines' capacity..

medium term. For both cable and point to multipoint FTTP solutions, attention will be needed to ensure appropriate sharing/splitting factors and install more up-to-date technologies such as XGS-PON or NG-PON2 for FTTP and in time, full duplex for cable.

- Copper upgrades to VDSL supervectoring and G.fast may serve users' needs in the short term, but they are unlikely to be readily upgradable to deliver on the bandwidth and quality needs of the most demanding groups of consumers in the medium term. A core challenge is that, as copper speeds are constrained by distance, further upgrades to increase download speeds and achieve more symmetric connections are likely to require significant investments to deploy fibre closer to the customer. However, in a scenario of incremental upgrades, these investments might be delayed as investments in previous technologies are depreciated.
- 5G mobile will require significant fibre installation close to the customer making it a complement for other solutions. Although it has many important applications, the shared nature of the medium and scarcity of spectrum is likely to limit its potential to act as an alternative to fixed very high capacity connections.

## 2.1 Quality characteristics of access networks

The quality of the broadband connection received by customers is affected by the telecommunications network as a whole. However, a chain is only as strong as its weakest link. This means that any quality deficiencies present in the access network (which is typically the last part of the network to be upgraded), will tend to constrain the service quality received by customers – adding to any delays that may already be present in other parts of the network. The table below summarises the main parameters which are used to describe quality in broadband networks. These concepts and the main causes of loss of quality are further elaborated below.

Table 2-1: Terms used to describe speed and quality in broadband services

| | |
|---|---|
| Download speed | Data rate that can be conveyed over the connection to be received by the end-user (typically measured in Megabit per second (Mbit/s) or for connections of more than 1,000Mbit/s in Gigabit (Gbit/s) |
| Upload speed | Megabits per second at which data is sent (uploaded) from the user to the network |
| Symmetry | The degree to which the upload speed approaches the download speed. In a symmetric connection, the download and upload speed are the same. |
| Latency | Latency (or delay) describes the time taken by a packet to travel from its source to its destination. |
| Jitter | Jitter is a measure of the variation (differences) in latency. |
| Packet loss | Packet loss refers to the degree to which packets are lost during transmission. Packet loss can occur when more data is sent than the transmission system can handle. |
| Reliability | Reliability describes the degree to which transmission does not fail. |

Source: WIK

Most users of broadband services are already familiar with the *'download' speed* or bandwidth associated with broadband connections. This is described in terms of Megabits per second that can be conveyed over the connection. The advertised download speed may not however always reflect the speed actually received by customers. Download speed may of course be affected by bottlenecks elsewhere in the network (beyond the access network), but could also fall below the advertised speed in the access network if the capacity is shared between a number of users, and there is significant demand at that time (e.g. in the busy hour). Certain technologies may also be limited by distance – resulting in speeds below those advertised if the line is longer than average. Speeds can also be affected by external conditions such as moisture within copper cables.

Upload speeds (the Megabits per second at which data is uploaded from the user to the Internet) are often not widely advertised. However, this quality parameter is likely to become increasingly important with the development of services which involve two-way interaction such as cloud computing. Different technologies have different capabilities to offer higher or 'symmetric' upload speeds.

Modern electronic communication systems apportion the information to be communicated into digital packets of an appropriate size. These packets are sent separately and reassembled at their destination. Besides speed, broadband quality can therefore also be described in terms of characteristics relating to these packets such as latency (delay), jitter and packet loss.

*Latency* refers to the time between the entrance of a packet into the network and its exit. Latency may be caused by the time it takes data to be switched or routed across network elements. This time may be extended when the network is busy, so that data is held in queues. Latency arising from the time it takes a signal to travel along a copper or fibre connection is likely to be small for access connections, and may only be a factor on very long routes across the network. Additional active transmission equipment tends to introduce latency. Shared network architectures are also associated with higher latency than those using an unshared medium. This is because, when there are simultaneous transmissions on a shared transmission medium, some will need to be delayed until others are delivered.

*Jitter* is a measure of the variation in latency between different packets. Variation in latency experienced by packets may occur where the network is busy, such that the time for each network element to process a packet varies, or where packets are sent via different routes across the network. In access networks, jitter may be caused when two or more senders compete for access to the network over a shared medium, so that the packets must be ordered in sequence.

If a connection is heavily loaded with packets, there may be too many packets for a network element to queue and so packets will be discarded. This may take into account indications in priority settings in the packet header. This is called *packet loss.* Shared media and additional transmission equipment in the access network can increase the risk of packet loss. Packets may also be deleted if the content is damaged e.g. due to electromagenetic interferrence which can occur over copper networks.

In circuit switched networks (such as the legacy telephone network), dedicated resources are allocated to a connection between two end points for the duration of the connection. This means latency, jitter and packet loss can be minimised. However, when the network is congested, users may not be able to establish a connection at all. In packet switched networks, the packets of multiple messages are transmitted one after the other in an interleaved line through the network on the same path (i.e. packets of different messages between different originating and destination points share resources. This in principle increases jitter). In addition, the packets of a message may be sent via different routes. For this reason latency, jitter and packet loss increase and can be more problematic in packet switched networks. Network planning/traffic engineering strategies can be used to minimise these problems by taking into account the expected network load, and defining an appropriate degree of overbooking, which takes into account that not all customers will be using the network at the same time. But even with these strategies, the risk of quality degradation at busy hour in packet switched networks is higher than in the circuit switched networks of the past.

Problems with transmission quality have an impact on the quality of real-time traffic such as voice and video transmission (impacting the user's ability to understand and recognise content), and can impact business processes, and the speed and reliability of content transmission.[108]

*Symmetry* is another aspect of transmission quality. It describes if the transmission bandwidth and speed in the direction from the network to the end-customer (called downstream) is equal to the bandwidth and speed from the end-customer to the network. If they are different, the connection is asymmetric. Symmetry is important in using peer to peer applications where up- and downloads are equal (i.e. in video chats or conferences).

Another important quality parameter is the *availability* of an access line and the wider network i.e. how often an access line or the network fail, and how long these outages last, resulting in downtime for the end-customer. Single points of failure in network architecture and systems determine how many customers can be affected by one single failure. Network resilience is affected by the robustness of the network, its architecture and ability to withstand attack from outside and inside the network (which may include intended and unintended physical attack, fraud, viruses and illegal interception). All these factors can be influenced by the technologies used to operate the network and its access lines.

**108** Plückebaum,T.; Homogenous and reliable nervous system for large business, FTTH Council Europe, FTTH Conference 2016, 16. – 18. February 2016, Luxembourg

As well as quality issues at the retail level, network architectures can affect the degree to which it is possible to enable greater *competition on quality* at the wholesale level. Network architectures which can be unbundled at the physical layer provide most scope for competition in quality parameters, whereas network architectures which cannot be unbundled necessitate the use of virtual wholesale products, which although they approach physical unbundling in some ways,[109] offer less capability for differentiation.

## 2.2 What are the characteristics of broadband access technologies?

The main technologies for the provision of broadband access are:

- **Copper pairs:** now mostly upgraded with Fibre-to-the-cabinet and VDSL technology (FTTC/VDSL2) and operated by the incumbent, which provides wholesale access to other service providers through Virtual Unbundled Local Access (VULA). Future upgrades will rely on replacement of the active VDSL equipment with G.fast and XG.fast – alongside deployment of fibre closer to the customer

- **Coax Cable:** now upgraded with DOCSIS 3.0 technology. Upcoming upgrades involve the deployment of DOCSIS 3.1 technology. A potential further enhancement to Full Duplex will allow symmetric connectivity, but require additional fibre deployment to the last amplifier close to the homes. Bandwidths on coax cable networks can also be increased by node splitting and adjustments in spectrum use.

- **Full-fibre (FTTP):** deployed today by Openreach only to business premises and a limited number of households such as new build households and specific target areas. FTTP is also provided to some households in areas within Virgin Media's expansion programme, and households in areas served by specialist operators. Full-fibre can be deployed as a dedicated point to point connection (used for business connections and residential connections in countries such as Sweden, Netherlands and Switzerland) or in a Point to multipoint architecture, in conjunction with PON technology. Upgrade paths for PON include XG.PON and XGS.PON. NG-PON2 further splits each fibre into wavelengths, enabling additional capacity. TWDM-PON is still under standardisation and development and will further split each fibre into wavelengths, enabling additional capacity (a comparable multi wavelength DWDM today is used in backbone and core networks only); and

**109** A VULA (virtual Unbundled Local Access) is a Layer 2 (Ethenet) bitstream with charcteristics allowing wholesale customers to differentiate and define their accees products close to the case of using unbundled infrastructure

- **Mobile:** mobile broadband is currently provided via fourth generation LTE technology. Standardisation and subsequent deployment of 5G technology is planned from 2020 onwards. LTE and 5G technologies can also be used to provide broadband at a fixed location, but due to the scarcity of spectrum and shared nature of bandwidth its use is likely to be limited to circumstances in which wireline connectivity is not feasible. A detailed description of the history, characteristics and evolution paths for these technologies is included in Annex I.

## 2.3 How do these characteristics match end-user needs?

An overview of the current and medium term capabilities of these access technologies is shown in the following table, alongside the degree to which they can each meet a presumed high level user profile (with 300Mbit/s+ download capacity) and top level user profile (requiring 1Gbit/s + download and upload *capacities in excess* of 600Mbit/s).

Table 2-2: Overview of broadband access network technologies

| Transmission technology | FTT… | Bandwidth down | Bandwidth up | individual/ shared | QoS | Ultrafast BB 0.3G | Ultrafast BB upgrade 1G |
|---|---|---|---|---|---|---|---|
| **Copper pair** | | [Gbit/s] | [Gbit/s] | | | | |
| **ADSL2+** | FTTC/N | 0.01 | 0.004 | i | 1 | n | n |
| **VDSL2** | FTTC | 0.05 | 0.015 | i | 1 | n | n |
| **VDSL2 Vectoring** | FTTC | 0.09 | 0.04 | i | 1 | n | n |
| **VDSL2 Super-vect.** | FTTC | 0.25 | 0.1 | i | 1 | n | n |
| **G.fast** | FTTC/S/dp | 0.5 | 0.5 | i | 1 | y | n |
| **XG.fast** | FTTB | 5 | 5 | i | 1 | y | y |
| **Coax** | | | | | | | |
| **Docsis 3.0** | fibre node | 1.2 | 0.12 | s | 2 | y | n |
| **Docsis 3.1** | fibre node | 10 | 1 | s | 2 | y | y |
| **Docsis 3.1 FD/XG-Cable** | deep fibre | 10 | 10 | s | 2 | y | y |
| **Fibre** | | | | | | | |
| **GPON (PMP)** | FTTP | 2.5 | 1.25 | s | 2 | y | n |
| **XG.PON** | FTTP | 10 | 2.5 | s | 2 | y | y |
| **XGS.PON** | FTTP | 10 | 10 | s | 2 | y | y |
| **TWDM GPON** | FTTP | 4 - 8 x 10 | 4 - 8 x 10 | s | 2 | y | y |
| **Ethernet P2P** | FTTP | n x 10 | n x 10 | i | 3 | y | y |
| **Mobile** | | | | | | | |
| **LTE adv.** | ? | 1 | 0.15 | s | 1 | n | n |
| **5G** | ? | 50 | 0.5 | s | 1 | y | y |

When considering the potential for these technologies to meet user needs as discussed in section 1.3.5, download and upload bandwidths as well as Quality of Service (ranked from 1=low to 3=high)[110] should all be considered. Download and upload bandwidths as stated are derived from equipment manufacturers' estimates, but the actual achieved bandwidths, especially for copper technologies, can vary depending on operational context. Quality is affected by the degree to which the technology is subject to electromagnetic interference (which particularly affects copper and mobile connections), and whether the architectures are shared (e.g. cable, mobile and FTTP PON) or dedicated (i.e. individual to each end-user e.g. FTTP Point to Point).

The first column (FTT…) shows how close fibre needs to be deployed towards the customer in order for the technology to deliver the stated bandwidths. This is an important consideration when looking at the degree to which technologies currently in operation or planned to be deployed are reasdily 'upgradable' to 1Gbit/s or more. If an upgrade to achieve higher speeds requires significant deployment of fibre – for example to bring fibre from a street cabinet up to the base of an apartment building or small group of builldings, then this upgrade could not be made without significant investments. Copper is particularly affected by this challenge, because the achievable bandwidths are significantly dependent on line length. A review of the capabilities of the technologies against the potential requirements for high and top level users of broadband as projected in section 1.3.5 leads to the following conclusions about their comparative capabilities.

**Copper technologies**: FTTC/VDSL with supervectoring may fall short of the requirement from users with a high level of demand for 300Mbit/s download capacity and will not meet needs for any significant increases in upstream bandwidth. Additional bandwidth sufficient to meet 'high level demand' could be achieved by G.fast (coupled with fibre deployment to within 250m of the customer premise). However, it is likely that the needs of the most demanding users including for 1Gbit/s download and significant upstream capacity could be achieved only through **XG.fast** deployment very close to or at the base of the building (for apartments), leaving only a very short portion of the network remaining copper. This would require more than a minor level of investment, suggesting an extended upgrade path from G.fast.

**Cable technologies:** DOCSIS 3.0 performs relatively well in downstream capacity and can reach upstream bandwidths of 120 Mbit/s. However it is unlikely to provide a ready upgrade path towards 1Gbit/s connectivity with a higher upload speed, i.e. above 400

**110** The expected Quality of Service (QoS) of the different technologies is shown using a scale of between 1 and 3, with 1 being the highest score. This aims to provide a rough ranking between the technologies of their performance against QoS parameters such as latency, jitter, packet loss and reliability. The copper and radio based systems are valued at 3 because of the intermediate systems and the increased fault probability due to electromagnetic interference. With fibre and coax cables, this interference cannot occur, a significant QoS improvement step. However, the PTMP fibre and hybrid fibre-coax systems use a shared medium and therefore still experience some quality degradation due to intermediate transmission systems and the use of shared media. They are thus valued at 2. PtP fibre involving unshared access networks provides a further QoS improvement and is thus valued at 1.

Mbit/s, and therefore is unlikely to serve the needs of the most demanding users in the medium term. **DOCSIS 3.1 shows promise in having an upgrade path sufficient to meet the needs of demanding users**. DOCSIS 3.1 full duplex will further extend bandwidth to 10 Gbit/s symmetric in a shared manner, but unlike fibre, it does not offer a clear potential for upgrades thereafter and does not support parallel systems on different wavelengths as can be achieved through WDM.PON solutions. In any case, it also requires fibre to the last amplifier, comparable to G.fast copper network fibre infrastructure. One limitation of cable infrastructure is that it is a shared medium. This becomes relevant in the busy hour,[111] as when the user traffic increases, the number of simultaneous users also increases and may start to compete for bandwidth.[112] The shared nature of the medium is also likely to limit quality parameters such as jitter and delay. Annex II illustrates with reference to measurements within and across different countries, the differences in latency measures between cable and 'full-fibre'.

**Full-fibre: FTTP networks are capable of very high and symmetric transmission** and therefore can in principle meet the requirements of high and top level users in the medium term. However, there are some differences in the capabilities of a point to point vs a point to multipoint FTTP connection:

- In a PtP fibre topology there are individual fibre links between each of the end-customer homes and an Ethernet switch at a central network site, the ODF location (local exchange). In this architecture, the fibre link is transparent for more or less any speed, and is limited only by the speed supported by the customer premise equipment (CPE) and by the speed of the ports in the Ethernet switch. So end-customers can be served individually according to their bandwidth needs, with a ready path for future upgrades. The dedicated nature of the connection also means that Quality of Service is maximised, and that physical unbundling is possible.

- In PtMP fibre deployments, fibre is shared amongst a number of customers under a 'tree' architecture. This architecture requires additional active equipment compared with with a point to point fibre connection (GPON)[113]. GPON technologies operate with an upper limit for the bandwidth of the individual end-customer. With XGS.PON this upper limit – at 10 Gbit/s – is high and symmet-

**111** In Europe the busy hour typically lies between 20.00h and 22.00h and is predominantly influenced by residential customers.

**112** Since DOCSIS is an active access network with intermediate amplifiers for the coax network and a fbre PtP network from the fibre node to the CMTS location with less power split than GPON and the principle option of repeating the fibre signals at intermediate locatons DOCSIS access networks can have a significantly longer reach than GPON networks, which are strictly determined by the optical power plan and the ingerent losses through splitting the optical signal and by slice attenuation through the splitters at least.

**113** This equipment is intoduced between the end-customers' routers and the central side Ethernet switches to which the OLTs are connected. Some equipment suppiers may provide OLTs already integrated into Ethernet switches, e.g. as special port cards. Even then the OLT function is required on top of the Ethernet port behind. An advantage of GPON may be saving Ethernet interface ports comparing to a PtP Ethernet technology, This effect may be achieved on both fibre topologies PtP or PtMP rical. However, the bandwidth is shared by the number of users per splitter (string). Next generation technologies which involve the use of several wavelengths are also constrained by that maximum. The fact that it is a shared medium, means quality levels for PtMP fibre are lower than PtP fibre (Annex II provides an illustration). However, it is likely to produce satisfactory results for mass-market applications. The limitations of shared bandwidth can be addressed to a degree by applying lower splitter ratios. There are also already higher performance systems of the GPON family market available, so additional network planning and upgrades should ensure that it is suitable at least for residential and most small business[114] needs for the foreseeable future. A disadvantage of PtMP architectures however is that physical unbundling is not possible, thereby limiting the degree of competitive differentiation possible through wholesale access.[115]

**Mobile:** 5G offers the potential for significantly higher speeds than LTE, meeting at least the high level medium term customer requirement of 300 Mbit/s. However, mobile networks provide shared capacity, which like cable and GPON, can affect bandwidth available at the busy hour, as well as quality parameters. Mobile bandwidth is also constrained by available spectrum. It is also important to note that 5G will itself rely on the deployment of fibre closer to the end-user. For these reasons, 5G mobile deployment is likely to be complementary to the deployment of fibre closer to the customer for fixed broadband rather than provide a substitute. Its deployment is also likely to extend beyond 2020. Fixed 5G connections could however be used in areas where the geography and demographics may make deployment of wireline connections challenging.

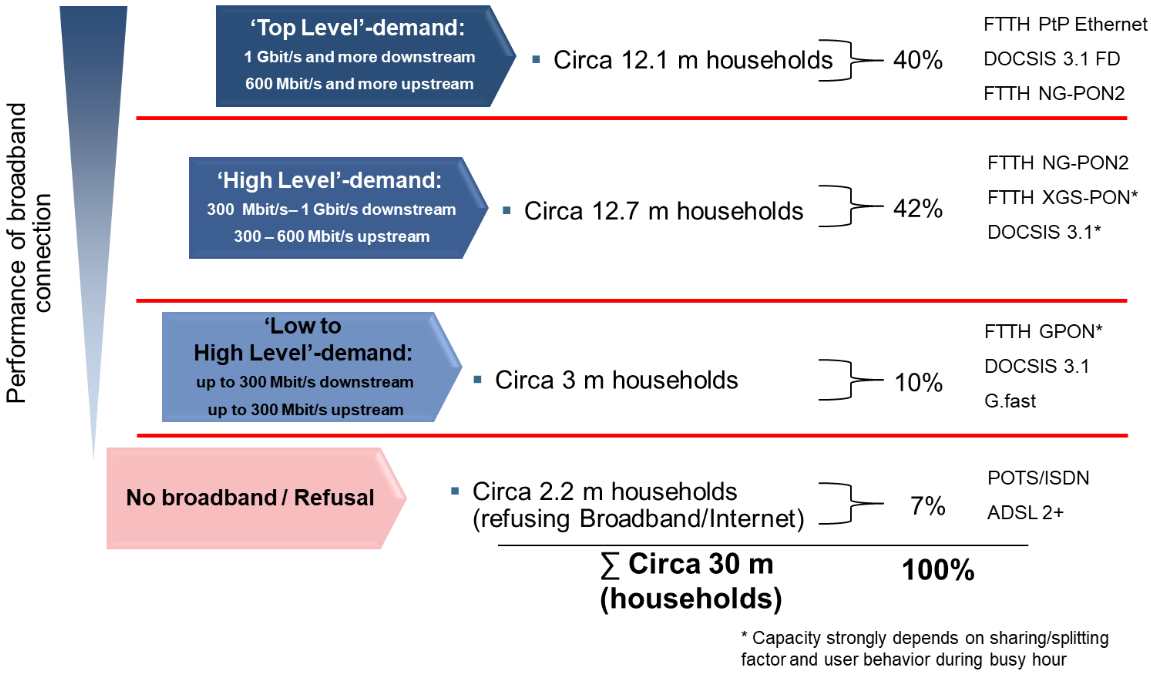
## 2.4 Matching supply and demand towards 2025

Figure 2-1 matches the speed and QoS characteristics of various technologies discussed in this chapter with the demand projections resulting from the WIK potential market model described in the previous chapter. It shows that households with high broadband demands (accounting for a substantial portion of households under all scenarios assessed) will need technologies which offer greater upload bandwidths than FTTC/VDSL and also likely G.fast. By 2025, the model suggests that only DOCSIS 3.1 FD and full fibre (PtP Ethernet or under certain conditions NG-PON2) would be able to satisfy the requirements of Top level demand. We also estimate that more advanced versions of GPON (XGS-PON or NG-PON2) or DOCSIS 3.1 would be required to meet ‘high-level’ demand, and would meet user requirements only if sharing/splitting factors are organised to maximise available bandwidths and quality.

**114** high grade business connections with very high quality requirements may continue to require point to point fibre infrastructure.

**115** This means that virtual access would be needed at least in the short term. WDM.PON technologies enable unbundling at the level of wavelengths (See also: BEREC Report on the New Forms of Sharing Passive Optical Networks Based on Wavelength Disvision Multiplexing, BoP (17) 182, 5. October 2017), so in theory could provide a solution when they become suitable for mass-market. However, this presumes that GPONs are installed in a manner that allows this technology to be readily provided – otherwise high costs could be incurred to retro-fit consumer premises equipment.

Figure 2-1: Bandwidth, Quality of Service and technologies




Source: WIK Consult 2017

Although the precise proportions of households falling into the categories cannot be predicted with certainty, it seems likely based on the scenarios we have analysed that sufficient households will fall within the categories of high-level and top-level demand, that a lack of suitable upgrades could hamper the UK's ability to meet future broadband demand.[116]

For those which might challenge the need for increased upload capacities, it is also relevant to note that smaller business sites and home offices may be situated in residential districts where there is limited business-specific connectivity, while telecommuting and home working can also expect to become increasingly prevalent. Business customers in many cases use peer-to-peer business applications requiring symmetric access lines. So it is helpful for the mass-market access network to be capable of meeting the demands of these specific user groups. Conversely, technologies which offer asymmetric connectivity may not be suitable for smaller businesses and home workers, or may be constrained by the (lower) upload speeds.

**116** For example. according to the 2016 Broadband Coverage in Europe report for the EC Spain, Portugal, Denmark and Sweden are amongst a number of EU member states which have already achieved FTTP coverage of around 60% or above, while even higher FTTP coverage has been achieved in Japan and South Korea.

# 3 Impact of ultrafast broadband: literature review

Experience in countries such as Sweden and parts of the US and Canada where FTTP is prevalent suggests that ultrafast broadband bring benefits not only to the residential and small business customers demanding high levels of performance and quality, but to the wider economy and society.

In this chapter, we summarise the available literature concerning benefits that could be realised through ultrafast broadband, and estimate what the effects might be on the UK. Private benefits are those which can be directly experienced by those using fast broadband, while public benefits describe the wider economic and societal benefits of ultrafast broadband. An important distinction is that, as public benefits do not directly benefit end users of services delivered using ultrafast broadband, they may not be reflected in private willingness to pay.

We focus, where possible, on literature which describes the effects of FTTP. However, as such literature is still limited due to the limited availability of FTTP in many countries, we also include relevant literature on the effects of increasing broadband speeds more generally.

**Key findings**

- Available literature suggests that higher broadband speeds as well as FTTP specifically have been associated with benefits to consumers, businesses, public authorities and the wider economy and society.
- One benefit to individuals and public authorities is the potential to improve services while reducing the costs of homecare.[117] Digital homecare could be particularly important in serving more remote areas.
- Faster broadband also tends to be associated with higher rates of teleworking, which in turn carries environmental benefits by reducing commuting and associated greenhouse gases.
- Several studies have found that regions with higher fibre penetration attract more business registration and increase employment. Fibre has also been found to be associated with reduced migration away from rural areas and increased employment in those areas.
- Several studies have found a link between increased broadband speeds and GDP growth. Extrapolating the results of some of these studies suggests that significant GDP gains could be reaped in the UK, if broadband speeds increase as a result of greater deployment and adoption of ultrafast broadband. However, it is harder to

117 Homecare in this context includes videocommunication and ongoing monitoring

estimate the magnitude of effect. One challenge is that available literature assessing the effect of speeds on GDP are based on an analysis of broadband speeds in the past and assume that past trends will continue as speeds increase further. Although it seems plausible that there may be additional GDP gains from higher speeds, the degree of the increase is harder to estimate as there may be grounds to support diminishing or even increasing marginal returns.

## 3.1 **Private benefits**

Several studies examining the private benefits of ultrafast broadband have focused on its potential advantages for digital homecare, teleworking and smart homes. A number of studies have also concluded that ultrafast broadband increases the attractiveness of particular areas for business.

### 3.1.1 Digital homecare services

As homecare becomes increasingly important with an ageing population, attention has been given in some countries to digitization of homecare as a means of both improving the quality of care and reducing costs.

A particularly interesting example in this respect is a 2014 study by Forzati and Mattsson[118] which assessed, based on pilot projects in Sweden and Finland, the socio-economic impact of fibre-based (FTTP) digital home-care services, in terms of cost savings and quality-of-life impact.

The Forzati and Mattsson study includes video communications, services which are used to manage planning, booking and follow-up of services by end users as well as a nightvision camera to enable the supplementary monitoring of individuals. The cost-benefit analysis shows significant cost reductions through using digital services in home care**: if just 10% of home care service recipients use digital services, the annual net cost reductions are estimated to be USD 0.6 million for a rural municipality with 8 000 residents by 2020**; a medium-sized city with 90,000 residents can lower the cost with USD 3.6 million; and a large city with 500,000 residents can lower the cost with USD 9.2 million.[119] The authors conclude that a widespread introduction of digital services could stabilise the cost of home care or even decrease it by up to 50% for sparsely populated municipalities, but this outcome is dependent on end-users having access to high quality, reliable broadband connections.

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**118** Forzati, M. and C. Mattson (2014), FTTH-enabled digital home care – A study of economic gains, Department for Networking and Transmission, Acreo AB.

**119** The saving of a municipality is directly proportional to the cost per user and the number of home help recipients. The savings in transportation costs is proportional to the root of the mean distance of home help recipients. Average distance between home care users are inversely proportional to end-user density.

### 3.1.2 Teleworking

Numerious studies have highlighted that ICT acts as a key facilitator for teleworking, with those who have good provision being able to work from home more efficiently, effectively and ultimately more frequently.[120] As business applications including cloud computing generally require a high upload capacity, the availability of *ultrafast* broadband services should in theory tend to stimulate teleworking further.

Based on an online survey, RVA (2011)[121] shows that the **average numbers of days worked from home per month was 12.8 days for FTTP users compared with 11.5 days for cable users and 10.2 days for DSL uses**. Furthermore, within the FTTP sample, the users of higher speed services were much more likely to have ever worked from home.

Access Economics (2010)[122] further reports that there may be various reasons why the introduction of the National Broadband Network (NBN) in Australia may have an impact on the extent of teleworking in the future. First, the improved quality and reliability of fast broadband will encourage employers to utilize teleworking. Second, the ubiquity and cross-network reliability of the NBN will reduce differences in household technology. Third, new applications through fast broadband will stimulate remote working.

A quantitative model estimation by SQW (2013)[123] of the projected social impacts of faster broadband speeds[124] (although not FTTP per se)[125] shows that the increase in **teleworking driven by faster broadband will save about 60 million hours of leisure time per annum in the UK by 2024**. By avoiding commuting costs, the additional teleworking enabled by faster broadband will lead to total household savings rising to £270 million per annum by 2024. Furthemore, annual teleworker productivity impacts reach £1.8 billion by 2024. Figure 4-3 demonstates that roughly half of the net gross value added (GVA) impact is from teleworkers living in the three least dense deciles.[126]

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**120** Penfold, C., Webster, S., Neil, H. Ranns, H and J.Graham (2009), Understanding the Need, attributes and behviors of teleworkers.

**121** RVA (2011), Broadband Consumer Research.

**122** Access Economics (2010), Impact of Teelworking under the NBN.

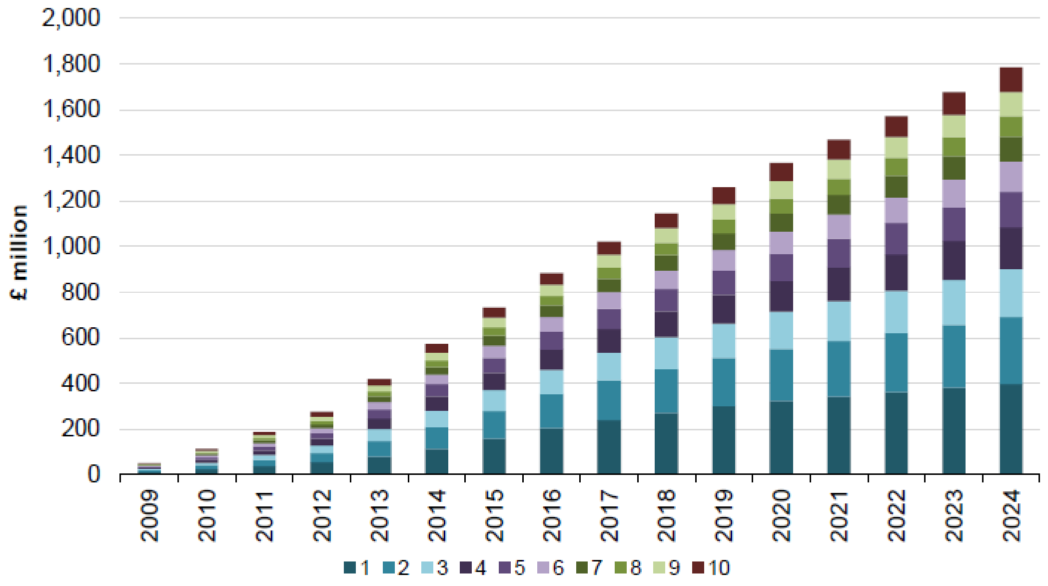
**123** SQW (2013), UK Broadband Impact Study

**124** The SQW study looked at the impact of faster broadband speeds from 2008 onwards. 2008 was the launch date for Virgin's 50Mbit/s service. Broadband speeds are projected by SQW by decile up to 2024.

**125** The broadband technologies include ADSL, ADSL2+, FTTC, FTTP as well as cable of Virgin Media.

**126** As development of broadband technologies and thus speeds vary by geography, the authors divide the UK into ten 'density deciles', ranging from the 10% of Census output areas with the fewest premises per square kilometre (sq km), to the 10% of Census output areas with the most premises per sq km.

Figure 3-1: Net annual GVA impact of faster broadband speed on increased tele-worker productivity in the UK, 2008 – 2024 – split by population density decile




Source: SQW (2013), UK Broadband Impact Model.

### 3.1.3 Smart home applications

Smart homes are currently on the rise, as part of the Internet of Things (IoT) phenomenon. Key technologies driving the development of IoT include the miniaturization of sensors, and corresponding reduction in the amount of power required. On their own, none of the IoT applications planned for the home will generate the traffic needed to make full use of an ultrafast broadband connection. However, it is anticipated that IoT will create an explosion in the number of connected devices and add to network demands from other applications, contributing to the need for cost-effective, reliable and high speed connections in both home and business environments. This could support the growth of in-building fibre deployments.

Ericsson Consumer Lab defines the connected home as a home “where household appliances and services are enhanced by Internet connectivity” (Ericsson, 2015).[127] Smart home has also been described as “the industry around the creation of living spaces inter-connected for communication”, either between different automated IoT devices in the home, or from devices to an off-site location (Dawson, 2015).[128] Along-

**127** Ericsson (2015) Consumer Lab Report: Connected Homes.
**128** Dawson, F. (2015), How To Make Money From 'Smart' Homes, http://www.forbes.com/sites/freddiedawson/2015/11/27/how-to-make-money-from-smarthomes/#57de8fb779df.

side the devices themselves, the associated applications will play a significant role in differentiating services and adding value.

Bergh Insight (2014) gives a comprehensive overview of smart home categories such as energy management and climate control systems; security and access control systems; lighting, window, and appliance control systems; home appliances; audiovisual and entertainment systems; healthcare and assisted living systems.[129] Security solutions, including surveillance and home monitoring, are currently the most widespread smart home application among existing Western European users of smart home solutions (Frost and Sullivan, 2015a).[130] Entertainment is also viewed as an integral part of the smart home concept (Frost and Sullivan, 2015b[131]; Melber, 2016[132]).

The value created from smart home services ranges from saving cost by adapting the consumption of utilities, feeling reassured due to a sophisticated surveillance system, to having a customised entertainment experience. In the survey by Frost and Sullivan (2015a), the perceived benefits of home entertainment appear to be low compared to other applications such as security, surveillance, energy and healthcare. However, Melber (2016) argues that “entertainment can be leveraged as a driver for smart home adoption on a bundle level, as it is universally appealing and can serve to familiarize consumers with the benefits of the IoT”. According to the survey study by Weinswig (2015), around 46% of consumers consider entertainment as an important factor in smart home adoption, and 5% state that entertainment is their number one reason to purchase a smart home system.[133]

### 3.1.4 Fibre as an enabler for 5G and associated use cases

As discussed in chapter 1.2, fibre closer to the premise will also be necessary for 5G mobile deployment.[134] This suggests that countries which have a greater density of fibre are better placed to deploy 5G rapidly and achieve the associated benefits from that.

**129** Bergh Insight (2014), M2M Research Series. Smart Homes and Home Automation.

**130** Frost and Sullivan (2015a), Home of the Future. European Consumer Demands for a Connected Lifestyle and Expectations for their Ecosystem. Ericsson Business Intelligence Center.

**131** Frost and Sullivan (2015b), Next Steps for Smart and Connected Homes. Cross-industrial Partnerships to Adopt Internet of Everything (IoE) for Value Creation. Ericsson Business Intelligence Center.

**132** Melber, L.F. (2016), IoT-enhanced Entertainment: A new case use case for 5G Fixed Wireless Access.

**133** Weinswig, D. (2015), The Connected Home Series: 3. Smart Home Appliances & Entertainment, Fung Bussiness Intelligence Centre.

**134** Previously, when the primary mobile services were narrowband voice services, MNOs relied for their backhaul needs on a combination of microwave links and low bandwith physical links. With inceasing data volume carried over the networks, fibre based Ethernet backhaul is becoming the preferred option as fibre costs are generally lower for high bandwidths. Backhaul requirements are expected to increase significantly for 5G, due both to the increased number of antennas required in comparison with 4G and increased bandwidth consumption. In the vast majority of cases, 5G antennas are expected to require fibre connections, while other high capacity wireless backhauling could also be used for remaining cases European Commission (2016), 5G for Europe: An action plan, Communication from the Commission to the European Parliament, the Council, the European Economic and Cosial Committee and the Committee of the regions, SWD(2016) 306 final.

A considerable number of papers have discussed the characteristics of 5G networks and identified the key use cases of 5G. IHS (2017)[135] suggests three key areas of use of 5G: (i) enhanced mobile broadband, (b) massive machine-type communications (MMTC), (c) ultra-reliable and low latency communication.

In terms of consumer mobile broadband services, 5G will facilitate the operation of existing online content, applications and services during demand ‘spikes’[136]. The use of 5G may be conducive to providing greater coverage and capacity in low density regions. Moreover, due to its additional capacity as well as quality characteristics 5G could also enable the development and use of new types of innovative content, applications and services for consumers across a variety of mobile device platforms.

For the Mobile Broadband service platform, Real Wireless (2016)[137] derives several use cases as shown in Figure 4-2.

Figure 3-2: 5G Mobile broadband service platform and use cases

| | | Connected Car use cases | | | Railway use cases | | | Healthcare use cases | | | Utility & Supply Chain use cases | | | Media and Cloud use cases | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Entertainment Service | Driver Assistance | Vehicle Management | Passenger Broadband | Command & Control | Telemetry Service | Assisted Living | Remote Healthcare | Preventative Health | Smart Grid | Road Haulage | Drone Delivery | 4K Content Everywhere | Immersive Gaming | Mobile Office |
| Mobile Broadband | MBB | ✓ | (✓) | (✓) | ✓ | (✓) | ✗ | (✓) | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ |

Source: Real Wireless (2016). Primary and secondary use cases are marked green and yellow, respectively.

Real Wireless suggests that connected cars has been the most frequently cited use-case for 5G technology. Other applications that could be applied by 5G include bringing audio and video streaming services and general Internet access into cars, while passenger broadband in railways will enable passengers to work, stream content and access social media. Other use cases identified include remote healthcare and preventative health as well as “Media and Cloud” services including “4K Content Everywhere”, Immersive Gaming and Mobile Office. Real Wireless (2016) concludes that the priority in terms of national infrastructure for mobile telecoms is the provision of infrastructure that supports mobile broadband services.

135 HIS (2017), The 5G economy: How 5G technology will contribute to the global economy.
136 Since demand for mobile broadband services is not constant over time, data throughput constraints during ‘spikes’ in demand lead to contention over the access network, lowering the functionality and satisfaction of the end-user experience.
137 Real Wireless (2016), Future use cases for mobile telecoms in the UK, issued to National Infrastructure Commission UK, version 1.00.

### 3.1.5 Business attractiveness and corporate expansion

Beyond the benefits to individuals, various studies have found that the availability of broadband also supports the attractiveness of regions for business.

Most of the studies dealing with the relationship of broadband and corporate expansion are based on standard broadband technologies. However, there are a few studies which focus on the impact of high-speed broadband technologies. A regression analysis of the effect of fibre (FTTP) networks in 290 municipalities in Sweden by Mölleryd (2015) shows that a **10% higher fibre penetration is correlated with 0.08 more company registrations per 1000 inhabitants per year**.[138]

Based on panel data covering the time period 2010 – 2015 and 4,933 municipalities[139] located in metropolitan France, a study by Hasbi (2016) also suggests that the presence of very high-speed broadband networks enhances the attractiveness of municipalities for the creation of new businesses. The study defines very high-speed broadband as covering full fibre and upgraded cable (fibre-to-the-last amplifier FTTLA coupled with DOCSIS 3.0 technology) The analysis suggests that, on average, very high-speed broadband networks have a positive impact on the creation of small businesses, and have strong effects on establishments operating in the commerce, service and transport sectors, where jobs requiring ICT skills are mostly found.

Using data for US counties over the years 2001 to 2010, Whitacre et al. (2014)[140] also show that **rural areas with faster download speeds tend to attract more employers in knowledge-based sectors**.

## 3.2 **Public benefits**

Several of the ‘private’ benefits outlined above are also associated with wider public benefits. For example, increased business incorporation and success may be associated with lower unemployment and reduced migration from rural to urban areas, while increased teleworking can bring environmental benefits.

These benefits are further discussed below.

**138** Mölleryd. B. (2015), Development of High-speed Networks and the Role of Municipal Networks, OECD Science, Technology and Industry Policy Papers, No. 26, OECD Publishing, Paris.

**139** This represents approximately 75% of the population; the largest cities Paris, Lyon and Marseille are excluded from the anaylsis (Hasbi, M., 2016, Impact of Very High-Speed Broadband on Local Economic Growth: Empirical Evidence, Chalmers University of Technology).

**140** Whitacre, B., Gallardo, R. and S. Strover (2014), Broadband's Contribution to Economic Growth in Rural Areas: Moving Towards a Causal Relationship, Telecommunications Policy, 38(11).

### 3.2.1 Impact on employment

Several studies show that high-capacity broadband leads to growth and jobs creation.

Based on a sample of 290 Swedish municipalities for the period 2007 – 2010, Forzati and Mattson (2011)[141] found that a 10% increase in the proportion of the population with access to FTTP/FTTB was associated with a positive change in municipality-level employment after 2.6 years of up to 0.2%. An OECD report which examined the effect of fibre networks in the same 290 municipalities in Sweden for the period 2010 – 2012 further found that on **average 10% higher FTTP/FTTB penetration is correlated with a 1.1% higher employment rate**, when controlling for other significant factors such as urbanisation level, population evolution, income, education level and business creation.[142]

Using a two-way fixed effects regression model on a panel of 3,142 U.S. counties for the period 2001 – 2013, Lapointe (2015)[143] shows that a **10 % increase in the percentage of households with access to fibre (FTTP/B) network is associated with a 0.13% increase in total employment and a 0.1% increase in the number of firms at the county-level**.

Canada, Singer et al. (2015)[144] investigate the effect of FTTP rollout on employment on the basis of the deployment experiences in 39 regions between 2009 and 2014. They estimate that **fibre deployment to 100% of a region is associated with an increase in employment of about 2.9%** – even if the region already previously benefited from a broadband infrastructure. According to Acreo's econometric model estimation by Forzati and Mattson (2013), the accumulated job value which the fibre network has created in Stockholm up to 2012 is estimated at around 7.7 billion SEK.[145]

Utilizing a panel of 496 U.S. counties sampled from 2011 to 2014, Bay (2017)[146] investigates the nonuniformity in the impact of different types of broadband technologies on aggregate employment. He found that increasing broadband speeds from 100 Mbit/s to 1 Gbit/s was more effective in boosting country employment than increasing speeds from 3 Mbit/s to 100 Mbit/s. On the other hand, increasing broadband speeds beyond 1 Gbit/s would have a smaller, although still positive, effect on employment.

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**141** Forzati, M. and C. Mattson (2012a),Socio-economic return of FTTH investment in Sweden.
**142** Mölleryd, B. (2015), Development of High-speed Networks and the Role of Municipal Networks, OECD Science, Technology and Industry Policy Papers, No. 26, OECD Publishing, Paris.
**143** Lapointe, P. (2015), Does speed matter? The employment impacts of increasing access to fiber Internet, Georgetown University.
**144** Singer, H., Caves K. and A.Koyfman (2015) Economists Incorporated: The Empirical Link Between Fibre-to-the-Premises Deployment and Employment: A case study in Canada, Annex to the Petition to Vary TRP 2015-326, Bell Canada.
**145** Forzati, M. and C. Mattson (2013), Stokab, a socio-economic analysis, Acreo report, acr055698.
**146** Bai, Y. (2017), The faster, the better? The impact of Internet speed on employment, Information Economics and Policy, 40, 21-25.

Although it does not specifically look at ultrafast broadband, on the basis of survey data from 166 businesses in Wales, WERU (2017) argues that SMEs with superfast broadband are more likely to engage in innovation activity than standard broadband users.[147] Moreover, superfast broadband users tend to be characterised by higher labour productivity growth.

The forward-looking estimation of broadband impacts by SQW (2013) covers the period from 2008 to 2024 and estimates that the **availability and take-up of faster broadband speeds in the UK**[148] **will lead to an increase of annual enterprise productivity impacts of about £14 billion by 2024.**[149] The largest share belongs to the industry group[150] which is the most ICT-intensive (Figure 4-4). In order to capture the effect of continuing improvements in broadband speed over the years, the study considers the projected broadband speeds available, the projected speeds used, and their projected net impacts.

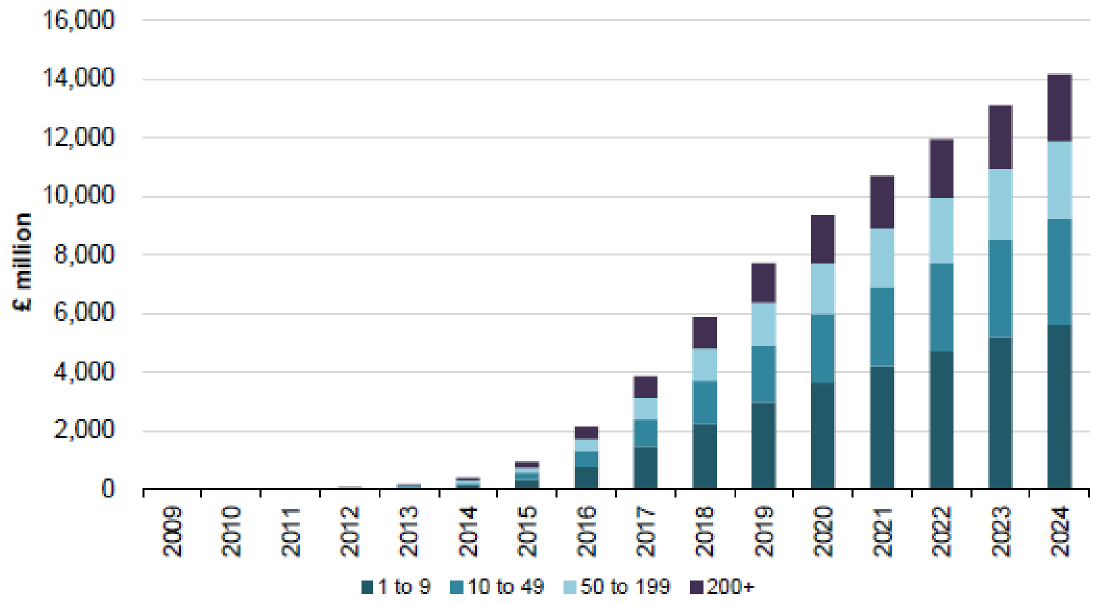
**147** WERU (2017), Superfast broadband business exploitation project: Economic impact report, Cardiff University.

**148** As previously discussed, SQW bases their estimates on estimated speeds by population density taking into account anticipated shares of ADSL, FTTC, cable and FTTP connections.

**149** The estimation model includes estimates of the average increase in the broadband speeds used by businesses each year (by industry group, size band and density decile), and the extent of the associated productivity benefits (SQW, 2013, UK Broadband Impact Model)

**150** This industry groip includes Information and communication; Financial and insurance activities; Real estate activities; Professional, scientific and technical activities; and Administrative and support service activities.

Figure 3-4: Net annual GVA impact from productivity growth for faster broadband-using firms in the UK in 2008 – 2024, by industry groups[151]




Source: SQW (2013).

### 3.2.2 Rural communities and migration

In bringing greater employment opportunities to more remote and rural communities, ultrafast broadband can also help to sustain and revitalize rural communities, ensuring that economic benefits are more evenly spread nationwide.

In this respect, a number of studies focus on the effects of ultrafast broadband on migration to rural areas. Using data from 290 municipalities between 2007 and 2010, Forzati and Mattson (2012)[152] found that an **increase in the proportion of the population living within 353 metres from a fibre-connected (FTTP) premise was linked to both higher migration and a positive change in employment** (resulting both from migration and independently).

Regression analysis by Xiong (2013) shows that FTTP penetration in 290 municipalities in Sweden has had a significant impact on the population's evolution, specially the

**151** A (Agriculture, forestry and fishing); B,D&E (Mining and quarrying; Electricity, gas, steam and air conditioning supply; Water supply; sewerage, waste management and remediation activities); C&F (Manufacturing; Construction); G,H&I (Wholesale and retail trade, repair of motor vehicles and motor cycles; Transport and storage; Accommodation and food service activities); J,K,L,M&N (Information and communication; Financial and insurance activities; Real estate activities; Professional, scientific and technical activities; Administrative and support service activities); P,Q,R&S (Education; Human health and social work activities; Arts, entertainment and recreation; Other service activities).

**152** Forzati, M. and C.Mattson(2012b), Socio-economic effects of FTTH/FTTx in Sweden, Acreo AB.

net amount of migration into a municipality.[153] Specifically, a higher fibre penetration of 10% at workplaces and 13% at residential places in a municipality in 2007 led to a 0.17% increase in population growth to that municipality between 2007 and 2010, caused by a higher migration rate (which is responsible for c.0.12% of the increase) and a higher birth rate (c.0.06%).

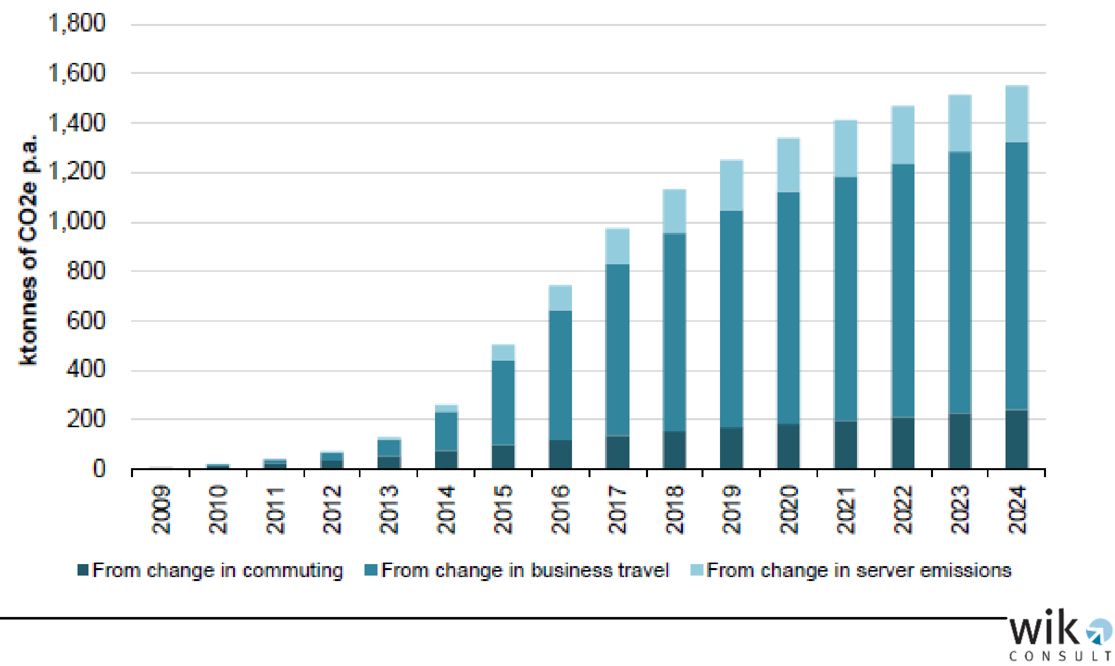
### 3.2.3 Environmental benefits

Ultrafast broadband is associated with two main environmental benefits. Firstly, the increased use of telecommuting contributes to reductions in pollution. In addition, the technologies used to provide broadband over FTTP are more efficient than those used for copper and cable networks, and therefore lead to reduced emissions for similar bandwidths.

SQW (2013) estimates that faster broadband will lead to a **reduction in the UK's annual commuting distance of about 2.3 billion kms by 2024**, predominantly in car use. This is about 2% of the current total annual UK commuting distance. Annual net carbon dioxide equivalent (CO2e) savings from increased teleworking, attributable to faster broadband, are estimated to be 0.24 million tonnes by 2024. Adding to that the CO2e savings from the changes in business travel and server emissions, SQW (2013) estimates the total net carbon savings from faster broadband to be 1.6 million tonnes of CO2e per annum by 2024 (Figure 3-2) which equates to a value of about £100 million.

**153** Xiong, Z. (2013), Socio-economic Impact of Fiber to the Home in Sweden, KTH Royal Institute of Technology, Stockholm.

Figure 3-2: Total net CO2e emissions saved, attributable to faster broadband in 2008-2014

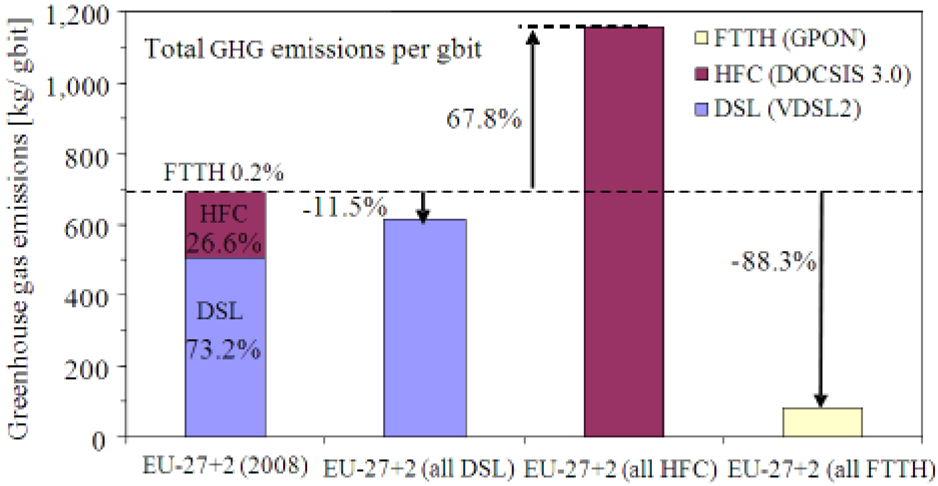



Source: SQW (2013).

As regards the energy requirements for different technologies,, Aleksix and Lovric (2014)[154] use data on broadband wired access subscribers in the EU 27 countries (plus Norway and Iceland) to show that **deployment of 'all FTTH/B' infrastructure could lead to environmental benefits resulting in 88% less greenhouse gas emissions per Gigabit in Europe,** relative to the mix of copper and cable technologies in use in 2008. Emissions per Gigabit associated with VDSL2 and particularly HFC were substantially higher than those associated with all-fibre networks (figure 4-6). The emissions estimates were based on electricity consumption associated with different technologies and therefore could also have operational cost benefits for operators, which in competitive environments could lead to lower prices for consumers.

**154** Aleksix, S and A.Lovric (2014), Energy Consumption and Environment Implications of Wired Access Networks, American Journal of Engineering and Applied Sciences 4 (4), 531-539.

Figure 3-3: Total greenhouse gas emissions per Gbit of various networks




Source: Aleksix and Lovric (2014).

## 3.3 **Impact on GDP**

Literature examining the effects of broadband on GDP has explored the linkage between broadband speeds and GDP. It is notable that such a linkage has been found in several studies conducted across a number of years using data ranging from 2008 to 2016. Common among these studies is an assumption that marginal benefits found in the past, will continue to apply as speeds increase. In this section we review three of these studies, and consider whether any conclusions can be drawn on the potential implications for GDP in the UK.

### 3.3.1 Studies highlighting the relationship between broadband speed and GDP growth

#### 3.3.1.1 The Impact assessment for the Review of the EU Framework for electronic communications

A recent study which supports the finding of a link between broadband speeds and GDP growth is a study by WIK, Ecorys and VVA Consulting[155] (WIK/Ecorys/VVA) in

**155** See WIK-Consult, ECORYS and VVA Consulting (2016): Support for the preparation of the impact assessment accompanying the review of the regulatory framework for e-communications, Study for the European Commission, DG Communications Networks, Content & Technology; in particular Annex II.

the context of the review of the EU Framework for electronic communications.[156] The study suggests that the estimated speed increase associated with an **accelerated deployment of FTTP/B infrastructure, resulting in 55% of broadband connections on the basis of fibre by 2025 would result in GDP levels 0.54% higher than the status quo**, while the less realistic scenario of achieving all-fibre connectivity by 2025 would result in a GDP increase by that point of 0.95% above the status quo. The results are based on correlations which were found between increases in actual broadband speeds (based on EU panel data) and Total Factor Productivity (TFP) across a number of industrial sectors.[157]

Table 3-1: Correlations between broadband speed and TFP across various industrial sectors

| Variable (in logs) | TOTAL | AGR | LOWMAN | HIGHMAN | ENERGY | TRANS | TELECOM | ECOM | SER |
|---|---|---|---|---|---|---|---|---|---|
| heritage | 0.225 | 0.3 | 0.058 | -0.163 | 0.107 | 2E-07 | -0.123 | -0.412 | 0.141 |
| mbb_ltecov | 0.003 | 0.001 | 0.005 | 0.003 | -0.006 | -4E-08 | -0.020 | 0.012 | 0.003 |
| speed | 0.021 | -0.078 | 0.032 | 0.035 | -0.136 | -9E-07 | -0.139 | 0.072 | 0.012 |

Signif. codes: 0 ‘dark blue’ 0.001 ‘medium’ 0.01 ‘light’ 0.05 ‘very light’ not significant ‘grey’

Source: Ecorys own calculations based on Eurostat, heritage refers to the Heritage index of economic freedom, mbb_ltecov refers to the coverage of 4G (LTE) mobile based on the EC Digital Agenda Key indicators dataset, speed refers to average actual broadband speed based on Akamai

AGR – agriculture, LOWMAN - low-tech manufacturing, HIGHMAN - high-tech manufacturing, ENERGY – energy, TRANS - transport, TELECOM - telecommunications, ECOM - other electronic communication-related services, SER - Other services

Source: Ecorys

The effects on TFP of projected broadband speed increases resulting from greater FTTP deployment, were then entered into a Computable General Equilibrium (GCE) model to estimate the impact on GDP, employment and investment.

**156** WIK, Ecorys and VVA (2016) support for the Commission in the Impact Assessment for the Review of the EU framework for electronic communications SMART 2015/0005

**157** The links were especially significant and positive in the fields of e-commerce, low-tech and high-tech manufacturing. Relationships with TFP in certain other sectors such as agriculture, energy and transport were also significant, but negative. However, the reasons are not clear.

#### 3.3.1.2 Rohman and Bohlin (2011)[158]

The macroeconomic indicators for this study are based on OECD data, while the speed data was sourced from Ookla. Overall, quarterly balanced panel data for 33 OECD countries during the period 2008-2010 were examined.

The main result of the study is as follows:

- A 1% higher mean speed leads to a 0.003 % additional GDP mean growth from base year. This implies that , if the speed level is doubled (100% higher), GDP growth would increase by 0.3% (relative to the growth in 2008).[159]

The variables are used in the regression equations in the form of natural logs which means that the estimated coefficients express elasticities.

#### 3.3.1.3 Kongaut, Rohman and Bohlin (2014)[160]

Enlarging the scope of the aforementioned study, this study again aims to study the effects of broadband speed to the wider economy. Moreover, it explicitly seeks to differentiate between the impacts of broadband speed on economic output in countries with higher and lower income.

Again, the variables are used in the regression equations in the form of natural logs which means that the estimated coefficients express elasticities.

Countries covered are OECD countries.[161] The study mainly relies on data from World Bank (e.g. labour force ratio, population density, GDP growth) and OECD (e.g. GDP per capita, fixed capital, fixed broadband penetration). Broadband speed data is again taken from Ookla speedtest. Moreover, the economic freedom index of the Heritage Foundation is used. The study covers the period 2008 through 2012.

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**158** See Rohman, I.K. and E. Bohlin (2011): Does broadband speed really matter for driving economic growth?, Investigating OECD countries; Discussion Paper Division of Technology and Society, Department of Technology Management and Economics, Chalmers University of Technology, Gothenburg, Sweden; Electronic copy available at: http://ssrn.com/abstract=2034284.

**159** As an example, if the overall economic growth in 2008 is 2%, then the hypothetical ***isolated*** impact from doubling the speed level on growth would be: 2%+0.3%=2.3%.

**160** Kongaut, C., Rohman, I.K. and E. Bohlin (2014): The economic impact of broadband speed: Comparing between higher and lower income countries; research project between the European Investment Bank (EIB) and the Institute for Management of Innovation and Technology (IMIT), Gothenburg, Sweden; presentation at EIB INSTITUTE, 12 September; available at: http://institute.eib.org/wp-content/uploads/2014/04/EIB_broadband-speed_120914.pdf. A more comprehensive paper version is: Kongaut, C. and E. Bohlin (2014): Impact of broadband speed on economic outputs: An empirical study of OECD countries, paper presented at the 25th European Regional Conference of the International Telecommunications Society (ITS), Brussels, Belgium, 22-25 June; available at: https://www.econstor.eu/bitstream/10419/101415/1/795234465.pdf. The latter paper, however, does not differentiate between high and low income OECD countries, rather, it is based on the comprehensive OECD sample.

**161** The exception is Greece which is excluded due to data availability problems.

The following table comprises the results of the model's base case.[162]

Table 3-2: Estimated impacts of broadband speed and other control variables on GDP per capita according to Kongaut, Rohman and Bohlin (2014), values denote elasticities

| Variable | Estimates for countries with | |
|---|---|---|
| | lower income | higher income |
| Capital | 0.2416*** | 0.1590*** |
| Labour | 0.7272** | -0.3076 |
| Broadband speed | 0.0975*** | 0.0591*** |
| Economic freedom | 0.0042** | 0.0011 |
| Share of urban population | -0.0107** | -0.0122*** |
| *R-squared* | *0.8167* | *0.6106* |
| *Number of observations* | *248* | *272* |
| *The number of stars attached to the coefficient values indicate the statistical significance of the estimates, three stars = high, no star = low* | | |

Source: Kongaut, Rohman and Bohlin (2014), slide 21.

The following conclusions can be drawn from this Table:

- The estimated elasticities for speed are positive and statistically highly significant.
- Broadband speed appears to have a larger impact on GDP growth in (OECD) countries with lower income than in those with higher income.[163]
- A 1 % higher mean speed leads to a 0.0591 % increase in GDP per capita for higher income countries and to an increase in GDP per capita of 0.975% in countries with lower income.[164]

### 3.3.1.4 The endogeneity challenge

A challenge inherent in all studies which aim to identify the effects of (tele)communications infrastructures and services on economic outputs, such as GDP, is that estimated regressions are likely to suffer from **endogeneity bias**. The main concern of is reverse causality.[165] For example, in the context of the

**162** The authors have estimated several different models e.g. with/without fixed effects, OLS/2SLS.
**163** This finding should be considered in conjunction with the fact that the variable "share of urban population" has a negative impact on GDP growth. These two effects seen together imply that lower income economies, which are typically also more rural economies (have lower share of urban population), are growing faster than higher income countries and that this higher growth may in part be due to the fact that they benefit to a greater extent from increases in broadband speed.
**164** It should be kept in mind that the estimated elasticities for speed here are not directly comparable to the elasticity estimated by Rohman and Bohlin (2011). The estimated elasticities for speed here relate to GDP per capita, the latter refer to the growth rate of GDP.
**165** This problem refers to the fact that an explanatory variable used in an econometric regression equation is considered to be in part dependent on the variable which is to be explained.

WIK/Ecorys/VVA study one might argue thathigher broadband speeds may have positive effects on TFP. However, it could equally be argued that broadband speeds are higher in countries where TFP is higher.[166]

There are several methods to reduce endogeneity biases but in all likelihood it remains a best effort task..[167]

That said, the studies we have discussed above, do attempt to address the endogeneity problem. In the WIK/Ecorys/VVA study, TFP is calculated on the basis of an estimate where speed is not involved as an explanatory variable and only the estimated TFP values are used in the regression in which speed appears.

Rohman and Bohlin (2011)[168] follows a two-stage approach to mitigate the endogeneity problem as follows:

- First, a regression is run in which broadband speed is the variable to be explained. Explanatory variables are broadband penetration rate, broadband subscription price, urban density, proportion of urban population, and telecom revenue.

- Second, economic output, or, to be more precise, the GDP per capita growth rate is estimated. Explanatory variables are average growth, the predicted values of broadband speed from the first stage and some additional control variables.[169]

The 2014 study by Kongaut, Rohman and Bohlin pursues a similar approach, although there are some differences in the variables.

### 3.3.2 Implications for UK GDP

While the GDP impacts estimated in the Commission study cannot be readily extrapolated to the UK because they derive from complex macroeconomic modelling, the Rohman and Bohlin (2011) and 2014 studies discussed produce *elasticities* that could in theory be used to derive quantitative estimates for the potential effects on UK GDP

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**166** One might also argue that broadband speed may itself be partly determined by the corresponding country's level of GDP and/or GDP growth inasmuch as high income countries may have been able to make the investments into ultrafast networks earlier and to a larger extent than low income countries.

**167** See e.g. Thompson Jr., H.G. and C. Garbacz (2011): Economic impacts of mobile versus fixed broadband, in: Telecommunications Policy 35(11), pp. 999-1009. Thompson and Garbacz argue e.g. that truly exogenous variables are limited, and dealing with the endogeneity problem even with rigorous methods has limitations

**168** See Rohman, I.K. and E. Bohlin (2011): Does broadband speed really matter for driving economic growth?, Investigating OECD countries; Discussion Paper Division of Technology and Society, Department of Technology Management and Economics, Chalmers University of Technology, Gothenburg, Sweden; Electronic copy available at: http://ssrn.com/abstract=2034284.

**169** These control variables are urban density, the proportion of urban population, labour force, the proportion of tertiary education, and population.

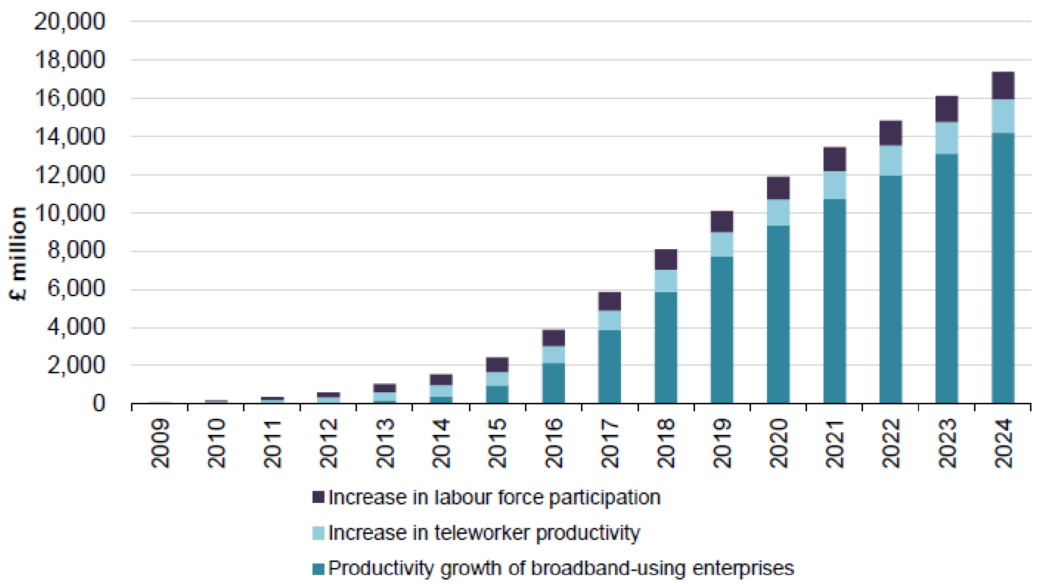
of a more widespread and/or faster deployment of ultrafast broadband. It should be noted at the outset however that uncertainties around the take-up of ultrafast broadband as well as the assumptions used in these studies and their reliance on past data mean that estimates can be only indicative.

#### 3.3.2.1 Estimates from an SQW study

One study which has drawn on the Rohman and Bohlin 2011 estimate of the marginal benefits of faster broadband, to produce estimates of potential benefits for the UK – in terms of Gross Value Added (GVA), is the faster broadband[170] impact study by SQW (2013).

Based on their own projections of increases in broadband speed in the UK, SQW estimated that the **total net annual GVA impact for the UK would be asround £17 billion by 2024** (Figure 3-4). This is equivalent to a contribution of 0.074 percentage points to the UK's real annual GVA growth over the period, which extends from 2008-2024.

Figure 3-4: Total net annual GVA impact from faster broadband in the UK in 2008 – 2024



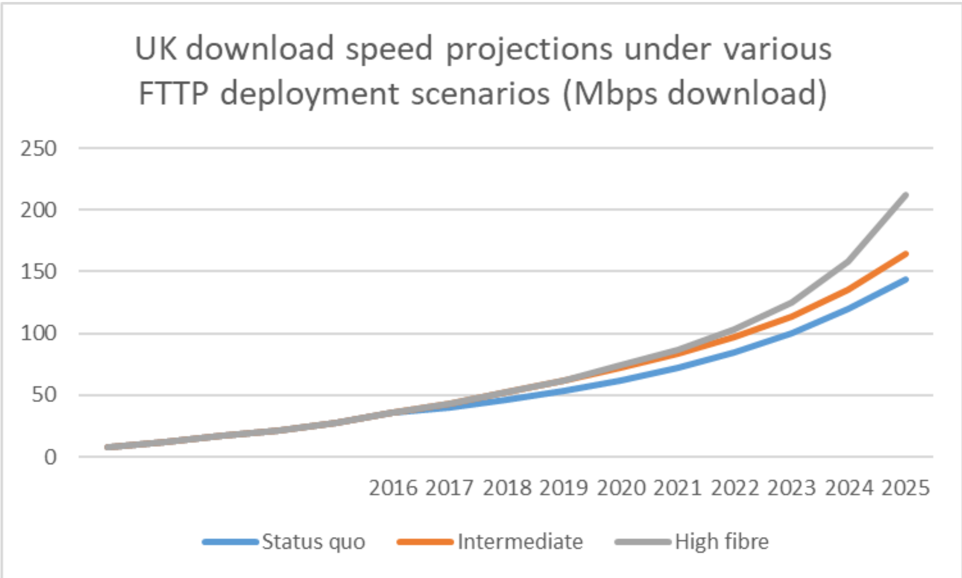

Source: SQW (2013).

170 Primary focus on broadband speed increases following from the introduction of superfast broadband offers in the UK from 2008 onwards

### 3.3.2.2 WIK's estimate

In order to provide an estimate of the effect of broadband speed increases on UK GDP based on more recent data concerning broadband speeds, we derived three illustrative scenarios for broadband speed increases in the UK based on different assumptions around the deployment of FTTP. These scenarios are elaborated in the annex. They are not intended to reflect planned or actual deployments in the UK; rather, they illustrate the degree to which average broadband speeds, and resulting GDP, could vary depending on the speeds and extent of FTTP rollout. The resulting speed increases are shown in the diagram below. Under our projections, whereas in the status quo, the projected average download speed is expected to reach around 140Mbit/s, this would increase to nearly 165Mbit/s in the intermediate scenario and more than 210Mbit/s in the maximum fibre scenario.

Figure 3-5: UK download speed projections under various FTTP deployment scenarios




We then pursued the following methodology to estimate the effect on GDP.

(1) We take the averages of the speed growth rates calculated for the UK (respectively between 2015 and 2020 and between 2021 and 2025) for the three scenarios.

(2) We multiply these growth rates with the broadband speed elasticities estimates by Rohman and Bohlin (2011) and Kongaut, Rohman and Bohlin (2014). In the first case, this elasticity is with respect to GDP growth rates, whereas in the latter case this is with respect to GDP.

(3) We assume a GDP growth rate of 2 % p.a. in the baseline.

(4) We add the outcome of step (3) to 2 %.

(5) We take the nominal 2015 UK GDP as a starting point and calculate respective trajectories for the annual GDP between 2015 and 2025 by applying the aforementioned different growth rates across the three scenarios.

(6) We calculate the difference of the 2025 values for GDP in the intermediate fibre scenario, relative to the status quo. scenario. Likewise, we calculate the respective difference for the high fibre scenario.

This procedure yields the following outcome based on elastricities from the Rohman and Bohlin (2011) study:

- Accelerated fibre scenario: GDP is £1.2bn. higher in 2025 than in the baseline scenario.

- High fibre scenario: GDP is £4bn. higher in 2025 than in the baseline scenario.

For the Kongaut, Rohman and Bohlin (2014) study, this procedure yields the following outcome:

- Accelerated fibre scenario: GDP is £27.4bn. higher in 2025 than in the baseline scenario.

- High fibre scenario: GDP is £87.6bn. higher in 2025 than in the baseline scenario.

It is notable that the GDP effects implied by extrapolating from the Kongaut, Rohman and Bohlin (2014) study are significantly higher than those based on the Rohman and Bohlin (2011) study as well as the conclusions of SQW.

This may result from differences that arise from the longer time series used in the 2014 study,[171] which may have allowed more time for the effects of broadband quality improvements to flow through to economic output. It might also be suggestive of effects that increase as speeds increase over time – noting that the widespread deployment of NGA began around 2008, and accelerated from 2010 (see discussion below). On the other hand, it may simply illustrate the weakness of relying on a simplistic approach to the estimation of GDP effects based on elasticities. The authors of the study themselves argue that the exact numbers of the coefficients (i.e. the elasticities) "should be interpreted with caution".[172]

**171** The later study used time series from 2008-2012 compared with the earlier study's reliance on 2008-2010.

**172** See Kongaut, Rohman and Bohlin (2014), op.cit., slide 23.

#### 3.3.2.3 Are there diminishing marginal returns?

All of the studies mentioned above rely on the assumption that relationships between speed and GDP in the past will continue to hold in the future. However, this assumption is open to question.

On the one hand, it is conceivable that there could be a step change or increasing returns in the event that the deployment of ultrafast networks unlock applications with significant implications for productivity. The higher GDP effects from the 2014 Kongaut, Rohman and Bohlin study compared with the earlier 2011 study could provide an indicator of this. Moreover, one of the very few studies to focus on ultrafast broadband specifically, by the Analysis Group (2015)[173] estimated that **Gigabit broadband communities in the US exhibited a per-capita GDP approximately 1.1% higher than the 41 similar communities** with little to no availability of Gigabit services.

On the other hand, it would be seem reasonable to expect that there could be diminishing marginal returns associated with higher speeds. The SQW (2013) study notes that their calculations assume that *'the incremental benefits of greater speed increases progressively decline until the impact curve 'saturates'.* This assumption may be supported by a Danish-based study by Jespersen and Hansen (2010)[174], in which the authors predict the macroeconomic effect of an increase of the average bandwidth on GDP across different bandwidth ranges. The authors come to the conclusion that the **positive effect decreases with increasing bandwidth**: for example, an increase of the average bandwidth from 5 Mbit/s to 10 Mbit/s within 10 years in Denmark led to an increase of 1.9% in GDP, whereas an increase of 25 Mbit/s to 30 Mbit/s was associated with a smaller increase of 0.5%.[175] However, this study looked at relatively low broadband speeds and was not specifically focused on the effect of achieving a step change through ultrafast speeds.

Overall, we consider that although there is a range of evidence to suggest that increasing speeds are associated with an uplift in GDP, we cannot make firm statements about the scale of GDP effects resulting from additional ultrafast broadband deployment .

**173** Analysis Group (2015), Early Evidence Suggests Gigabit Broadband Drives GDP.

**174** Jespersen and Hansen (2010), The Socio-Economic value of digital infrastructures, Copenhagen Economics, Studie für die Dankks Energi.

**175** In concrete terms, this means for Denmark that an increase in average bandwidth from 9 Mbit/s to 42 Mbit/s in the time period 2010 – 2013 will result in additional GDP growth of 4.9 % until 2020. An even more far-reaching increase to an average speed of 92 Mbit/s, i.e. by an additional 50 Mbit/s, implies an increase in GDP of 7.3 % only, e.g. by only incremental 2.4 percentage points.

# 4 Conclusions

Our analysis of the supply and demand conditions for ultrafast broadband, as well as our analysis of the literature concerning its direct benefits and wider economic impact, leads us to reach the following conclusions:

- Current and next generation applications including video, cloud computing and virtual reality (which has applications in the field of gaming, education and beyond), will require an increasing amount of bandwidth – upstream as well as downstream. Homeworking is likely to add to bandwidth demand. Quality parameters such as low latency will also be vital for certain applications which require very quick response times. These developments alongside trends towards the use of multiple devices within each household, mean that it is reasonable to assume that a high proportion of households will require symmetric or near symmetric bandwidths of 300Mbit/s and above by 2025, while some will require Gigabit connectivity.

- Meeting user needs in the longer term when speeds of 1 Gbit/s with a greater degree of symmetry may be demanded by some users is likely to require network upgrades both for cable (to DOCSIS 3.1 full duplex) and to replace the copper network with FTTP. [176] Copper upgrades to VDSL supervectoring and G.fast may serve users' shorter term needs, but they are unlikely to be readily upgradable to deliver on the bandwidth and quality needs of the most demanding groups of customers as substantial speed and quality increases would require further significant investments to deploy fibre closer to the customer. 5G will provide an important complement, but is unliklely to be a substitute for full-fibre for most households.

- The experience in countries in which FTTP is prevalent suggests that it can bring benefits in fields such as digital homecare as well as fostering teleworking and increasing the attractiveness of specific regions for business incorporation. In turn, these benefits can translate into higher employment (including in rural areas) and reduced pollution. One of the effects may be to distribute social and economic benefits more evenly across the country.

- A number of academic and expert studies have also found links between increasing broadband speeds and economic growth. It seems plausible that the UK could reap economic benefits through an accelerated deployment of ultrafast broadband. However, the scale of these effects cannot be estimated with any certainty, as literature is based on an analysis of previous data, and it is not clear to which extent the relationship can be extrapolated for much larger increases in speeds in the future.

**176** The majority of customers are likely to be adequately served by DOCSIS 3.1 cable updates towards 2025. However, the asymmetric and shared nature of the medium may limit its effectiveness for the most demanding users. Attention will be needed for both FTTP PtMP and DOCSIS to ensure appropriate splitting factors.

# 5 Annex I: Technological evolution

## 5.1 Copper pair access technologies

Copper pairs were originally used for low frequency analogue voice transmission and could reach up to 7 km between the last local switch and the customer premises. However, the speeds possible over copper line based transmission technologies have been subject to ongoing improvements in recent years.

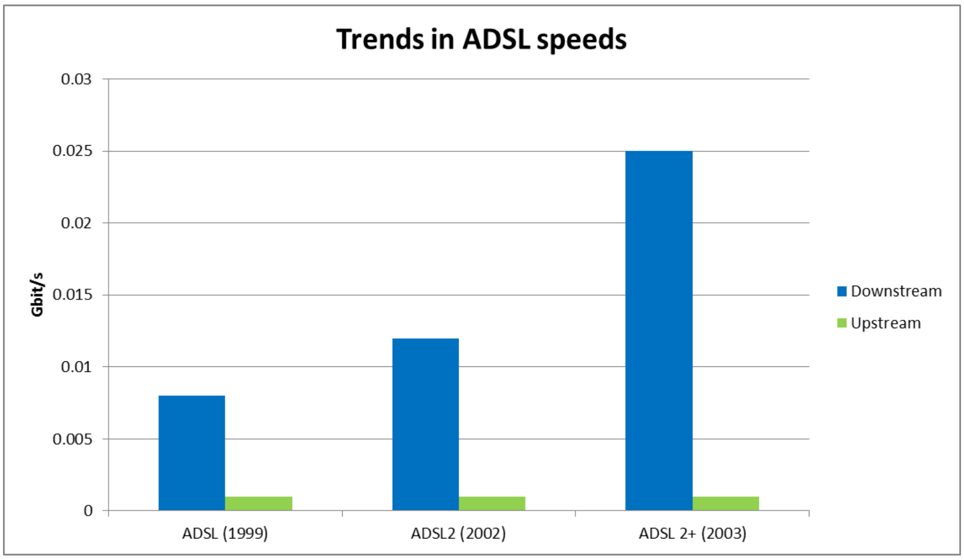
The original improvements involved the upgrade of equipment placed on either end of the copper line.

In the 1980s improved transmission technologies allowed the transmission of digitized voice and data signals (ISDN)[177] over the same distance. For higher bandwidths (up to 2 Mbit/s), generally used for larger business access, the distance supported was shorter (up to approximately 4 km) and either more copper pairs or interim amplification was required.

Subsequently, ADSL[178] technologies were developed to meet the increasing demand for data services, particularly access to the Internet. ADSL was developed to meet the communications needs of residential users, which were considered to be asymmetric (low upstream bandwidth into the network, higher bandwidth required for richer information content downstream, i.e. a click on a homepage upstream and the page's rich content downstream). This allowed the data service to be provided over the existing copper lines, and the existing telephony services to be used at the same time as the data service by line sharing. ADSL technology has developed to provide increasing maximum transmission speeds (see Figure 5-1).

**177** Integrated Services Digital Network
**178** ADSL, Asymmetric Digital Subscriber Line

Figure 5-1: Trend in ADSL-speed over time by technological improvements




Source: WIK-Consult

However, the speeds achieved are still significantly affected by the length of the line, and this distance effect increases for higher transmission rates. The 2016 Ofcom report on UK home broadband performance[179] highlights the difference between actual ADSL speeds in urban compared with rural areas of the UK. While urban customers received an average download speed of 10Mbit/s, rural customers received only 6.3Mbit/s at the end of 2016. Different line lengths may have been one of the causes alongside a lack of upgrades to ADSL2+ technology.

Further speed increases in copper technologies have therefore necessitated shortening the copper access line, and installing fibre to an intermediate point.

VDSL was designed for shorter copper loops of up to approximately 1.5 km[180] and required the relocation of electronic transmission systems operating the copper access lines closer to end customers – with equipment now typically hosted in the street cabinets. Emerging G.fast (and XG.fast) technologies will allow greater flexibility in choosing the degree of traffic symmetry for the transmission in both directions (up and down), taking into account trends towards more symmetric data traffic. However, while G.fast covers up to 250m with reasonable bandwidth, under prevailing conditions, XG.fast is typically usable only for much shorter copper cable lengths of below 50 m[181]. These

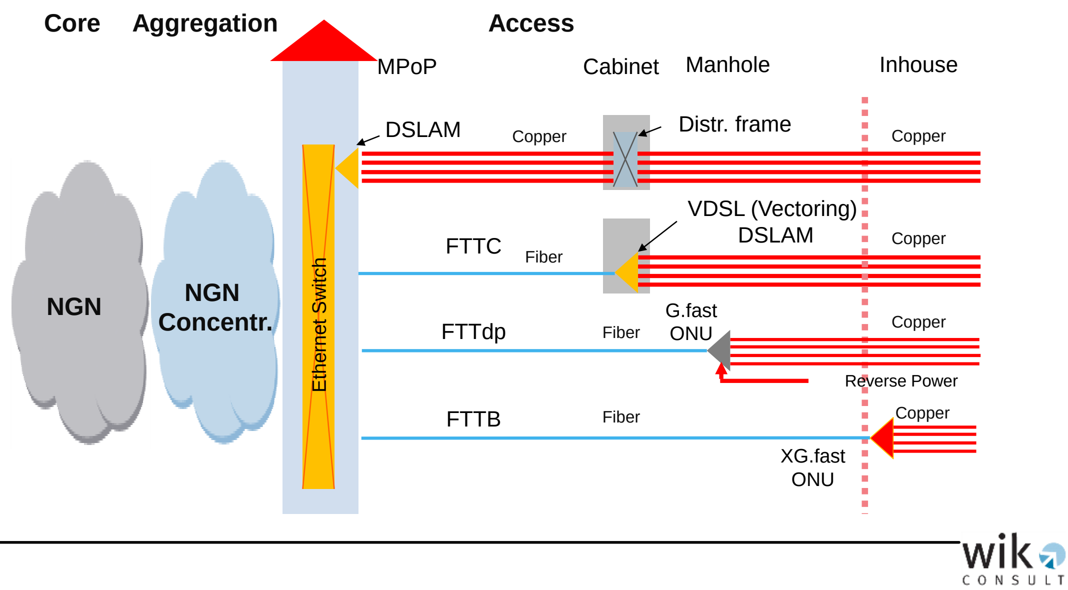
**179** https://www.ofcom.org.uk/research-and-data/telecoms-research/broadband-research/uk-home-broadband-performance-2016

**180** DSL-signals bandwidth depends on copper line length: The longer the line the smaller the bandwidth. After a lin length of 1.5 km the VDSL capacity has decreased to a value below the ADSL2+ transmission, since it has been designed for FTTC and shorter subloops.

**181** The bandwidth of G.fast decreases significantly over copper line length, and other line codes and better Vectoring algorithms may influence bandwidth and reach.So far the G.fast systems available line speeds however depend on local conditions (i.e. the topology and type of inhouse cabling) and rely on implementations of the standard that are not yet finalised. Although the G.fast ONU are located in drop/distribution points (dp), in countries or areas with sufficiently short sub-loops[182] the cabinets can also be used.

This evolution of increases in access line bandwidth, will require deployment of fibre lines deeper towards the end-customer premises, first to deploy new, larger street cabinets and the appropriate FTTC VDSL[183] equipment including power access points, and later – for G.fast – new small cabinets or manholes and G.fast ONUs[184] aggregating the copper access lines. The final step (short of end-to-end FTTP) would be to enter the building with fibre lines (FTTB, only relevant for MDU) before converting the signals from optical to electric XG.fast for transmission over in-building copper lines (see Figure 5-2).

Figure 5-2: Progression of copper technologies with incremental fibre deployment




MPoP: Metropolitan Point of Presence, also called ODF location (Optical Distribution Frame), is equal or comparable to a Local Exchange

Source: WIK-Consult

on the market support frequencies of up to 106 MHz, while the standard allows up to 212 MHz. Capacity will also depend on co-existence with legacy transmission systems, so the frequency below 35 MHz could be excluded when co-existing with the VDSL profile 35b thereby reducing the G.fast capacity. Special line codes may be applied to reduce peak bandwidth on short length and thus improve medium bandwidth over longer copper lines. See also Kroon, P.; Plückebaum, T.; Sanchez Gracia, J.; Sabeva, D.; Zoz, K.; Study into current and future technological access options to all fixed telecommunications infrastructures in the Netherlands, den Haag, 21. June 2017, https://www.acm.nl/nl/publicaties/publicatie/17463/Onderzoek-toegang-tot-vaste--telecommunicatienetwerken/

**182** i.e. areas in U.K. or Italy

**183** Fibre to the Cabinet, Very Highspeed Digital Subscriber Line

**184** Optical Network Unit

An important consideration from a financial perspective is that a progressive approach could require the components used for each technology to be fully depreciated before installing the subsequent technology. Otherwise, each upgrade would create stranded investments. This multi-step process raises the question as to whether upgrades will be made in time to reflect evolving consumer demand. If, as suggested in reports such as the 2016 study by WIK for the European Commission “Regulatory, in particular access, regimes for network investment in Europe”,[185] application development and demand for bandwidth is significantly affected by supply, an incremental approach also raises the risk that demand may be restricted by supply compared with markets in which direct investments in FTTP have been made.

An advantage of the incremental approach is that it may allow capex to be distributed over a longer period. For example WIK estimates that the capex involved in deploying fibre to the street cabinet may be as low as 10% of the total investment required for FTTP[186]. However, there is a risk of inefficiencies and cost increases if the deployment of intermediate technologies such as FTTC is not planned to be future-proof e.g. through ensuring sufficient space for the installation of additional fibre in the segment between the Local Exchange and the cabinets (feeder segment) to meet future demand.

Another challenge associated with technologies which increase available speeds over copper lines is that, under current standards, they restrict the potential for competition through physical unbundling. Increases in bandwidths for both FTTC/VDSL and for the upcoming G.fast and XG.fast technologies are typically supported by ‘vectoring’. Vectoring technology works by estimating the cross-talk that each copper pair within a cable creates in other copper lines within that cable. The expected cross-talk is then removed from the signal received, thus supporting the delivery of pure, undistorted signals. This allows for higher bandwidth transmission, but the estimation process requires knowledge of all signals transmitted over all copper lines within a cable. This is realistically possible only if all lines are controlled by the same operator[187]. Thus, infrastructure competition through physical unbundling of the access lines is no longer possible in cases where vectoring is installed. This may affect not only sub-loop unbundling, but also unbundling at the local exchange. Declines in unbundling and greater reliance on VULA[188] or bitstream solutions have already been seen in countries such as Germany, Austria and Denmark, where vectoring has been widely installed.

**185** SMART 2015/0002

**186** Jay, S.; Neumann, K-H.; Plückebaum, T.;
Comparing FTTH access networks based on P2P and PMP fibre topologies, Conference on Telecommunications, Media and Internet Tecno-Economics (CTTE) 2011, Berlin, 16. - 18. May 2011

**187** International standardisation on the exchange of line code information between VDSL DLSAMs of different suppliers so that these could operate on the same cable could be an option to overcome this but has not yet occurred. There seems to be limited demand from operators and suppliers. Approaches of the Italian NRA AGCOM towards such node level vectoring standardisation or agreement have not yet borne fruit.

**188** Virtual Unbundled Local Access: instead of physical unbundling a form of electronic bitstream is provided, which has to meet dedicated characteristics, especially for enabling product differentiation between the competitive operators (see EC market definition 2014).

## 5.2 Cable-TV access networks

Cable-TV access network infrastructure is today based on a hybrid fibre coax (HFC) architecture. The network elements which are based on coaxial cables, enable high frequency (typically 800 MHz –2,5 GHz) transmissions.

Coax is constructed in a different manner from the twisted copper pair, and involves one core copper wire, a relatively thick insulation around it and a coaxial outside metal shield. Such networks originally connected the TV-signal headend downstream to several thousand customer premises using a tree structure, thereby providing a shared medium to support the delivery of downstream analogue TV-antenna signals. Communication in the upstream direction was not intended. The facility for bi-directional telephone and data communication over the shared coaxial tree structure was added later, following the DOCSIS[189] standard.

Implementing DOCSIS requires amplifiers, which support amplification of these frequency bands in the coax cable segment in both directions, down- and upstream[190]. Since DOCSIS networks are based on a shared medium, the central Cable Modem Termination System (CMTS) communication manager[191] allows the individual endpoint cable modems to send and receive at dedicated time windows.

All end-customers share the same bandwidth. This means that increasing usable bandwidth per end-customer may necessitate reducing the number of end-customers per shared network segment (called node splitting). Today, the coax cable access network no longer consists in one single coaxial tree, but involves fibre links from the headend to fibre nodes in the field, structuring the network into smaller coax cable islands, where the fibre nodes serve smaller coaxial cable trees (e.g. 70 end customer premises). Hence, the term HFC is used.

Another way to increase the network's capacity is to increase the Cable-TV network bandwidth (i.e. from 800 MHz to, 1.8 or even 2.5 GHz). This has been performed several times from DOCSIS 1.0 to 3.0 and now 3.1.

Thus far the DOCSIS structure foresees an asymmetry whereby 10% of the  bandwidth is used for upstream traffic. If, as expected (see Chapter 1), traffic demand becomes more symmetric, this degree of asymmetry may result in a bottleneck. In order to overcome this, DOCSIS 3.1, which has recently been standardized, will be amended by Full Duplex (FD) capability, which is announced, but not yet available in the market (full availability not planned before 2020). This FD capability requires the deployment of new fibre nodes at the location of the last amplifier close to the front of customer prem-

**189** Data over Cable Service Interface Specification

**190** The downstream TV-Signals and its frequencies only require inidirectional amplifiers (until DOCSIS 3.1 FD will be introduced.

**191** Cable Modem Termination System, located close to the head end at central sites and coordinates the bidirectional communication between the cable modems at the customer sites and the central site over the shared medium.

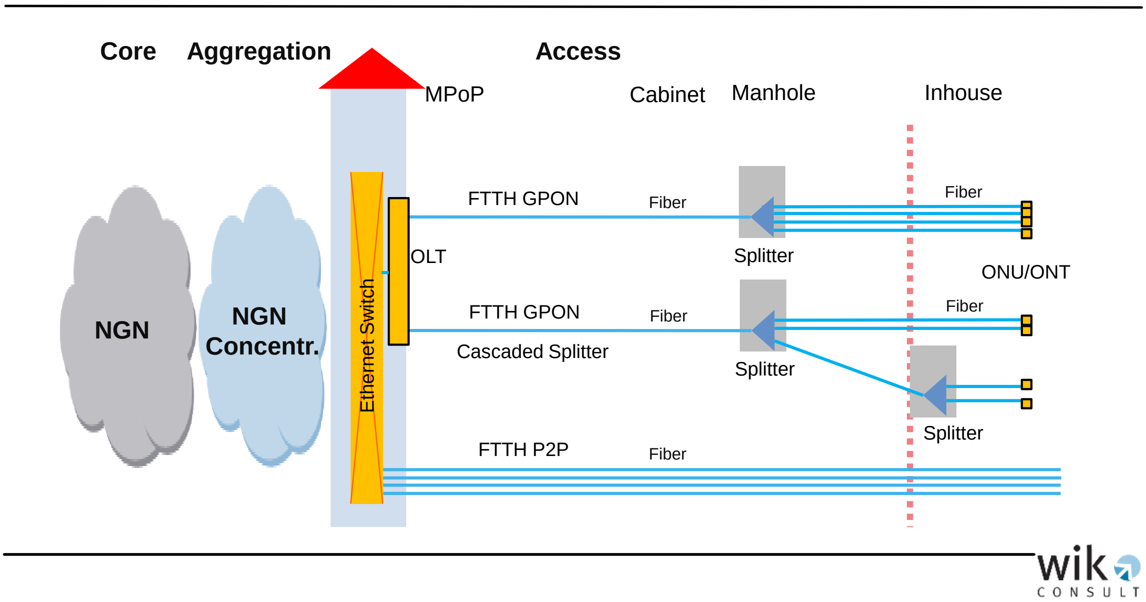
ises. CPEs (cable modems) will also need to be replaced to benefit from the new technology. Once this installation is completed, 10 Gbit/s full duplex (symmetrical) capacity should be available for the few end-customers sharing the rather short remaining coax-cable segment.

## 5.3 FTTP based access networks

An important difference between fibre and copper technologies is that its transmission capacity is much less affected by distance. Signal attenuation is relatively low and cross-talk and other electromagnetic interference does not occur. Depending on the optical transmitters' (laser diodes) and receivers' quality and characteristics a fibre link can reach distances of 150 km. Fibre also readily allows symmetric transmission (same high download and upload bandwidths).

There are two FTTP fibre topologies deployed in Europe, fibre Point-to-Point (PtP) and fibre Point-to-MultiPoint (PtMP). With the former, each end-customer premise is connected to the central Optical Distribution Frame (ODF) location by an individual fibre strand (or pair). With the latter, several fibres of end-customer premises (up to 256) are aggregated onto one single fibre strand through a passive optical splitter located somewhere between the customer premises and the ODF location. These splitters could also be subdivided into several cascaded splitters as long as the upper limit of connections per splitter string is not exceeded (see Figure 5-3). The single fibre strand between splitter and ODF is a shared medium for all end-customers connected and thus requires an administrative unit to manage the traffic. This unit is called an OLT (optical Line terminator).

Figure 5-3: FTTP PtP compared to PtMP




Source: WIK-Consult

Advantages of the PTMP topology are cost savings from fewer fibre strands in the fibre plant (feeder links between Splitter and ODF in the MPoP) and electronic port savings for access lines at the OLT, which forwards several splitter (OLT) strings to the next network layer, typically an Ethernet switch.[192] However, these savings require an additional access network transmission layer[193], which restricts the bandwidth per access line. The technology used to operate the splitters is called GPON[194]. In contrast, a PtP fibre topology allows every customer to be served individually according to its demand, typically by connecting the fibre access links directly to an Ethernet switch with ports of different speeds, as required.

Table 5-1: Overview currently available GPON technologies

| Technology | Standard | Year of standard | Status of deployment |
|---|---|---|---|
| GPON | ITU-T G.984 | 2003 | Widely deployed by the largest operators worldwide |
| XG-PON | ITU-T G.987 | 2010 | Few deployed networks |
| XGS-PON | ITU-T G.9807.1 | 2016 | Trials carried out, but not yet deployed |
| TWDM-PON | ITU-T G.989 | 2015 | Field trials carried out; one live network in the USA |

Source: WIK 2016[195]

GPON has a central OLT and additional ONT/ ONU at the customer premise wihich coordinates the use of the shared fibre medium between the splitter and the OLT in order to prevent signal distortion. The associated electronics constrain the bandwidth available through the GPON system. While the early systems supply 2.5 Gbit/s down- and 1.25 Gbit/s upstream, the XG-systems provide 10 Gbit/s, XGS enables symmetrical bandwidth and the TWDM-systems provide up to 8 wavelengths of 10G symmetrical each. Some operators, including BT, use a splitting ratio of 1:32, but the standard allows for 1:64, while TWDM-PON allows for the fibre to be shared between 1:256 customers. TWDM-PON wavelengths can also be used in parallel by different operators (so-called wavelength unbundling).

A single wavelength today allows transmission of up to 400 Gbit/s (used today in backbone networks), although in standard environments 100 Gbit/s is the typical maximum. The speed available via a single fibre, can be further increased through creating different wavelengths in parallel. DWDM (used today in backbone networks) is designed for up to 162 parallel wavelengths. While today developed for core networks and in a first step being rather expensive one can expect that these technologies will become

192 WIK studies have shown only marginal cost differences of less than 1% between PtP and PtMP with GPON, see Jay, S.; Neumann, K-H.; Plückebaum, T.: Comparing FTTH access networks based on P2P and PMP fibre topologies, 10th Conference on Telecommunications, Media and Internet Tecno-Economics (CTTE) 2011, Berlin, 16. - 18. May 2011,

193 The GPON OLT and ONT/ONU (Optical network Terminator/Optical Network Unit)

194 Gigabit Passive Optical Network

195 Plückebaum, T.; Sanchez Garcia, J.E.; GPON and TWDM-PON in the context of the wholesale local access market, WIK-report for ComReg, 9. Juni 2016, https://www.comreg.ie/publication/gpon-twdm-gpon-context-wholesale-local-access-market/

cheaper in mass market production for access networks. So this is a future perspective for PtP fibre network topologies.

Its current capacity and upgrade path makes fibre the most future proof transmission medium from amongst the technologies considered.

Fibre also has installation benefits compared with copper. Fibre cables can be significantly smaller than copper cables: first, because the fibres are significantly thinner, second because the coating can be thinner because no effective electric insolation is required, and third only one fibre strand is needed for transmission in both directions. Furthermore fibre is significantly lighter than copper, so easier to install on aerial poles. In many cases it can be installed in addition to already existing aerial infrastructure for telecommunication or electrical power distribution (only by authorized people observing minimum distance working criteria), because there is no electromagnetic interference as occurs with parallel copper lines or other electrical sources (i.e. switches, motors, …).

There are also significant operational advantages of fibre access networks resulting in OPEX reductions. A first benefit is that, in contrast with copper, fibre is not sensitive to humidity or electromagnetic interference (which may be caused for example by lightning). Fibre access cables also involve significantly fewer splices compared to copper cables, and thus there are fewer points of failure.

## 5.4 Mobile 5G technology based access networks

5G is the next mobile telecommunication radio standard generation under development. It is characterized by high bandwidth per end customer, short delay and the capability to handle many individual systems (IoT)[196]. 5G still is under standardisation and development. Many features have been announced, but are not yet elaborated. Additional future frequency ranges are also under discussion, but will not be fully fixed before the World Radio Conference (WRC) in 2019.

Thus the first stage of standardisation is likely to be finalised by 2020 at the earliest, with further standard releases coming thereafter as experienced with the fourth generation (LTE) standardisation process.

5G, like all mobile technologies, is a shared medium, in which all end-customers served by a radio cell antenna beam share the capacity available from that cell beam. Like 4G, 5G also supports the potential to transport traffic using capacity from all cells which serve the mobile end-customer (in case of radio overlapping cells).

The capacity of a mobile network is affected by the frequency used. For high broadband speeds additional higher frequencies are needed. 5G will use additional frequen-

**196** Internet of things

cies throughout the GHz frequency space (3.5, 6, 26 and 60 GHz are debated and investigated today). However, higher frequencies have more restricted propagation characteristics as regards reach and indoor penetration, and therefore require smaller cells, with Micro- and Picocells inside larger buildings. Significantly more antenna locations must be provided and equipped, and microwave access lines to these locations will need to be substituted by fibre links, to support the high peak bandwidths that should be available from 5G antennas[197].

Like all mobile radio technologies, 5G can be used at fixed locations, but its major advantage is its usability for mobile devices. Thus it can support industries and applications which require mobility (such as transport, autonomous driving, …).

**197** And the new bandwidth consuming protocols required in the so called fronthaul towards the radio heads at the antennas

# 6 Annex II: Practical experience of broadband speed and quality

Although we describe the potential capabilities of different technologies, it is important to note that the actual speeds and quality received by customers over different technologies may fall short of their maximum capabilities. Operators may offer lower speeds and/or quality for reduced prices as part of a value-based pricing model, in which higher speeds are priced to attract high end and business use.

Customers may also receive lower speeds and/or quality than the theoretical maximum if they are receiving services over a shared medium or if part of the bandwidth is used for the delivery of bundled managed services such as IPTV.

Data from Samknows nonetheless suggests that customers in countries which have been significantly upgraded to FTTP, such as Spain, Sweden and Romania, experience higher download speeds than those in which incremental FTTC/VDSL upgrades have been pursued, and significantly higher upload speeds (with FTTP upload speeds measured at more than 5x those for FTTC).

Table 6-1: Actual upload and download speeds for FTTP vs FTTC

| down | | | | | up | | | | |
|---|---|---|---|---|---|---|---|---|---|
| FTTx | | | | | FTTx | | | | |
| | Mar-12 | Oct-13 | Oct-14 | avg growth | | Mar-12 | Oct-13 | Oct-14 | avg growth |
| BE | 15.83 | 26.53 | 34.73 | 49% | BE | 2.21 | 2.44 | 3.43 | 25% |
| DE | 38.78 | 39.6 | 36.91 | -2% | DE | 7.8 | 8.94 | 8.86 | 7% |
| UK | 35.3 | 48.5 | 48.19 | 18% | UK | 6.7 | 12.45 | 12.38 | 43% |
| FTTC | 29.97 | 38.21 | 39.94 | 16% | FTTC | 5.57 | 7.94 | 8.22 | 23% |
| | | | | | | | | | |
| ES | 36.03 | 57.37 | 68.26 | 39% | ES | 5.46 | 9.41 | 20.36 | 94% |
| SE | 46.31 | 55.91 | 63.29 | 17% | SE | 21.27 | 27.75 | 38.8 | 35% |
| RO | 53.95 | 31.75 | 67.64 | 36% | RO | 21.05 | 14.85 | 35.14 | 54% |
| LT | 50.76 | 61.63 | 67.42 | 15% | LT | 39.35 | 56.62 | 64.68 | 29% |
| FTTH | 50.34 | 49.76 | 66.12 | 16% | FTTH | 27.22 | 33.07 | 46.21 | 31% |

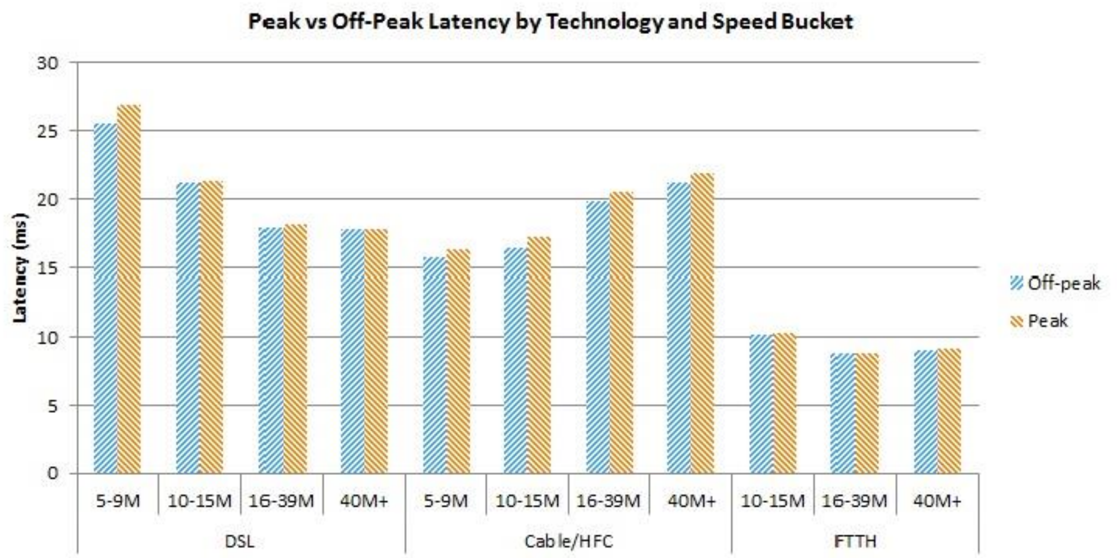
Source: WIK based on Samknows for EU (2015) Quality of broadband services in the EU

Samknows also reported that FTTP deployment in countries such as Bulgaria and Slovenia, had enabled those countries to achieve the best latency performances for FTTx technology, because the FTTP technology did not need to use xDSL-based last mile technology that causes a significant latency overhead.[198] DNS resolution time was also lowest in countries deploying FTTP technology such as Bulgaria, Lithuania and Slovenia. The results from other quality measurements in the Samknows EU-wide analysis of 2014 were however more ambiguous concerning the benefits of FTTP vs incremental FTTx upgrades – suggesting that complex factors may be at play which affect the performance and/or measurement of FTTx connections across the countries studied.

Looking at the performance for different technologies measured by Samknows within individual countries shows patterns closer to expectations. A 2016 study by Samknows

**198** Samknows Quality of broadband services in the EU October 2014 page 96 concerning broadband performance in Canada[199] for the CRTC clearly shows that FTTP technologies have lower latency and packet loss than cable/HFC or DSL irrespective of speed, although the architecture of FTTP is not recorded.

Figure 6-1: Peak vs Off-peak latency by technology and speed band in Canada 2016

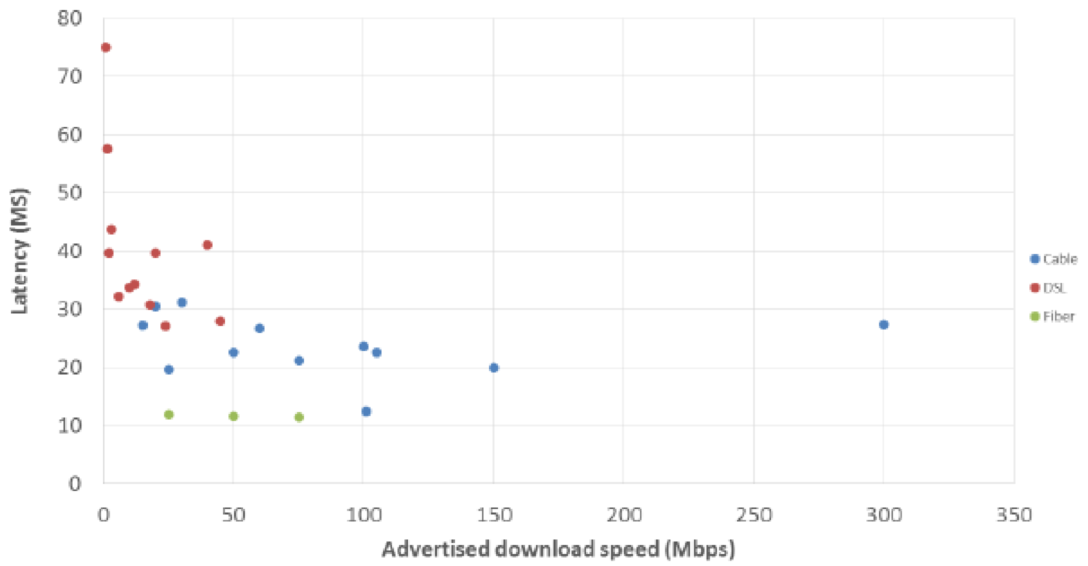



Source: Samknows for the CRTC

These findings are confirmed by FCC analysis of latency by technology and advertised download speed in the US. The figure below clearly shows that 'fiber' (understood to be Verizon FTTP PTMP connections) offers latency levels of around 10 ms[200] whereas the latency of cable connections is typically at least twice that level, with even higher latencies reported for DSL.

199 https://www.crtc.gc.ca/eng/publications/reports/rp160929/rp160929.htm
200 Milliseconds

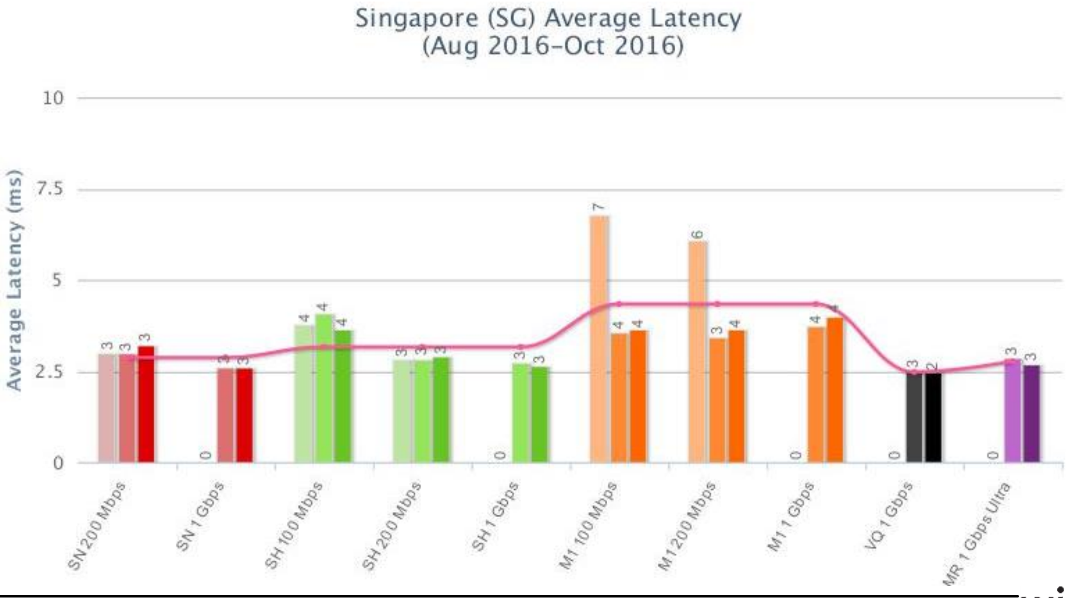
Figure 6-2: Latency for terrestrial ISPs by technology and advertised download speed in the US, 2016




wik CONSULT

Source: FCC 2016 Measuring Broadband America, Fixed Broadband Report

Some indication of the effects of point to point fibre compared with PTMP FTTP might be gathered from looking at latency statistics from those countries in which it has been installed. In Singapore for example, average latency in 2016 as measured by Samknows was between 3-4ms, less than half that reported for FTTP networks in the US and Canada.




wik CONSULT

Source: IMDA Consumer Broadband report https://www.imda.gov.sg/applications/rbs/chart.html

# 7 Annex III: Estimating speed increases resulting from FTTP deployment in the UK

## 7.1 Assessing the effects of ultrafast network deployment on speeds

A first important step in assessing the implications of ultrafast broadband for the UK economy is to understand how speeds in the UK would evolve in the absence of significant investment in ultrafast technologies – and specifically FTTP. The anticipated speed increases in this scenario can then be compared with speed increases under alternative scenarios in which there is accelerated deployment and/or take-up of ultrafast broadband.

In this section, we follow the same methodology as that used by WIK in the Impact Assessment for the Review of the Framework for electronic communications, to estimate speed increases for the UK under three scenarios.

We also briefly examine the implication of accelerated fibre deployment for speeds available in rural areas, which are currently under-served.

### 7.1.1 Speed increase scenarios for the UK

According to the Ofcom Communications Market Report for 2017 there were a total of 25.3m broadband connections as of 2016. These are broken down by technology in the following way.[201]

Table 7-1: Retail fixed broadband connections (millions)

| Technology | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|
| FTTP/B | 0,0 | 0,0 | 0,0 | 0,0 | 0,1 | 0,1 |
| Cable | 4,1 | 4,3 | 4,4 | 4,5 | 4,7 | 4,9 |
| VDSL | 0,4 | 1,1 | 2,3 | 3,7 | 5,4 | 6,6 |
| ADSL | 16,1 | 16,4 | 16,0 | 15,5 | 14,4 | 13,6 |
| Total | 20,6 | 21,8 | 22,7 | 23,7 | 24,6 | 25,2 |

Data from the UK Home Broadband Performance report produced for Ofcom in April 2017 provides further information concerning the average actual download speed per technology. FTTP speeds were not included due to the low penetration of this technology in the UK. Therefore, for FTTP we used estimates based on speeds for FTTx in countries which FTTP is the prevalent fibre technology.[202]

201 Figure 4.12 Ofcom Communications Market Report 2017 telecoms chapter
202 Average FTTP speeds for 2014 were derived from downstream speeds recorded in 'FTTP' countries in the Samknows 2015 study for the EC on the 'Quality of broadband services in the EU'

Table 7-2: Average download speeds for fixed broadband connections by technology

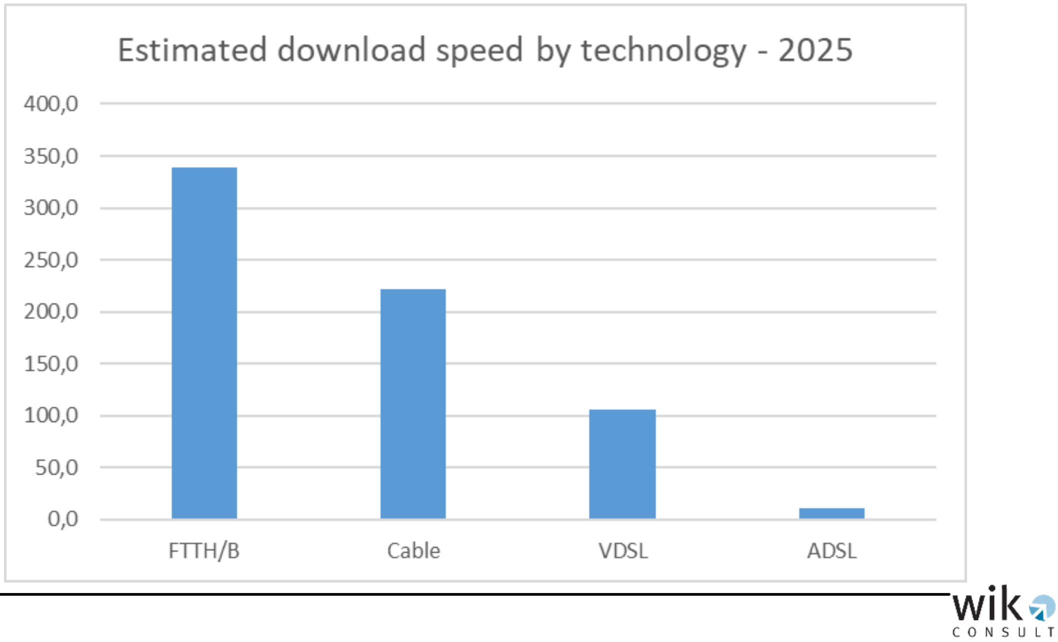
| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|
| **FTTP/B** | | | | 66,1 | 76,8 | 89,1 |
| **Cable** | 14,2 | 28,3 | 40,2 | 54,4 | 73,6 | 94,1 |
| **VDSL** | 36 | 41,1 | 42,9 | 41,6 | 41,2 | 44,9 |
| **ADSL** | 5,3 | 6 | 6,7 | 7,3 | 7,8 | 9,4 |
| **Ave. speed** | 7,6 | 12 | 17,8 | 22,8 | 28,9 | 36,2 |

Source: Ofcom based on Samknows (except FTTP/B – WIK estimates based on Samknows for EU)

As in the study for the European Commission, we estimate based on past trends in speed, and the untapped capabilities of the different technologies and ease of upgrade, that each technology would experience the following annual speed increases: 16% for FTTP; 10% for cable and VDSL; and 2% for ADSL (as a legacy technology).

Based on these assumptions, we estimate that the following average download speeds would be delivered over each technology by 2025.

Figure 7-1: Estimated average download speed by technology – 2025

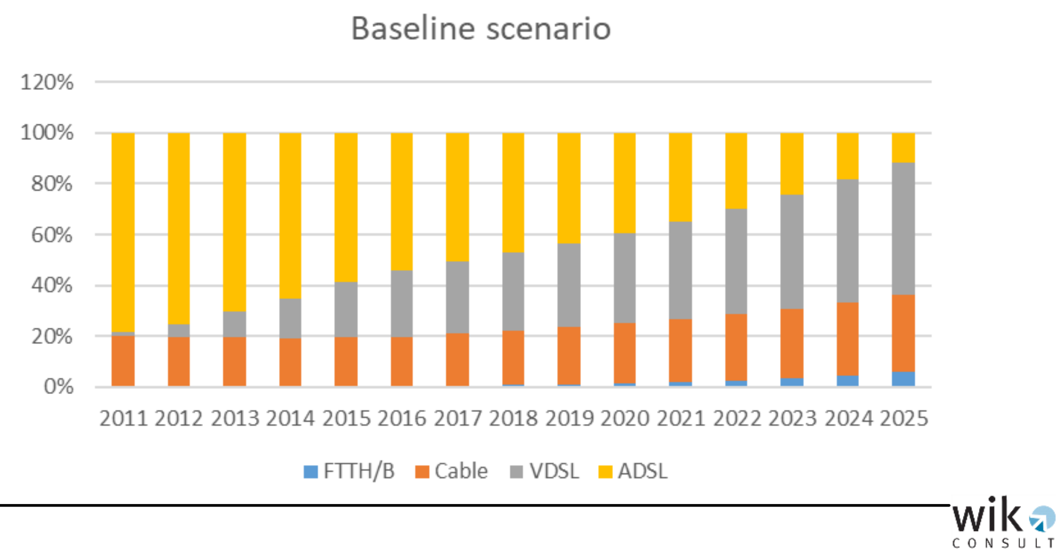



Projected average annual speeds and associated speed increases are then calculated by estimating the share of each technology under different scenarios.

For the baseline scenario, we assume that the largest operators focus on making incremental investments towards DOCSIS 3.1 and G.fast. In this scenario, with aggressive marketing, FTTC/VDSL/G.fast take-up is presumed to increase by 8% per year to reach more than 50% of all broadband connections by 2025. Benefiting from superior speeds, notwithstanding its limited footprint, we also project that cable would increase its market share, growing to 30% of all broadband connections by 2025. FTTP take-up increases by 35% annually in this scenario, but due to its low starting point (1% of UK broadband connections in 2016) and limited coverage, take-up reaches only 6% of broadband connections in 2025.

The resulting evolution in technological shares is shown in the chart below.

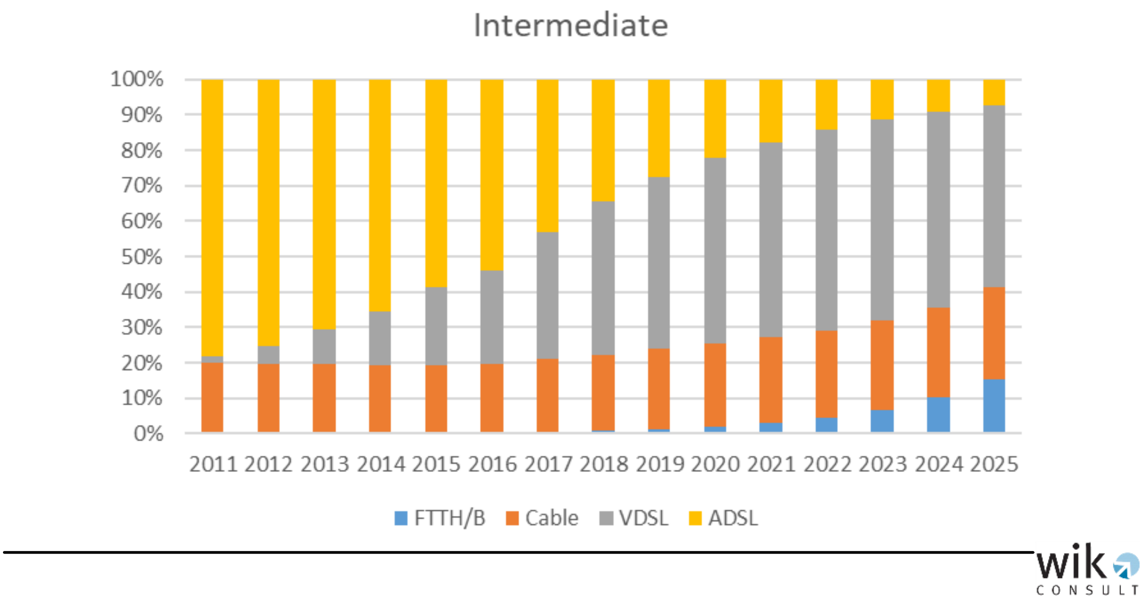
Figure 7-2: Evolution of technology shares in the UK – baseline scenario




Source: WIK

In an intermediate scenario of more widespread FTTP deployment, FTTP take-up expands at a rate of 50% per year reaching 15% of all broadband connections in 2025. Cable and FTTC continue to expand until around 2020, but cable subsequently grows more slowly while FTTC/VDSL declines as customers switch or are upgraded to FTTP.

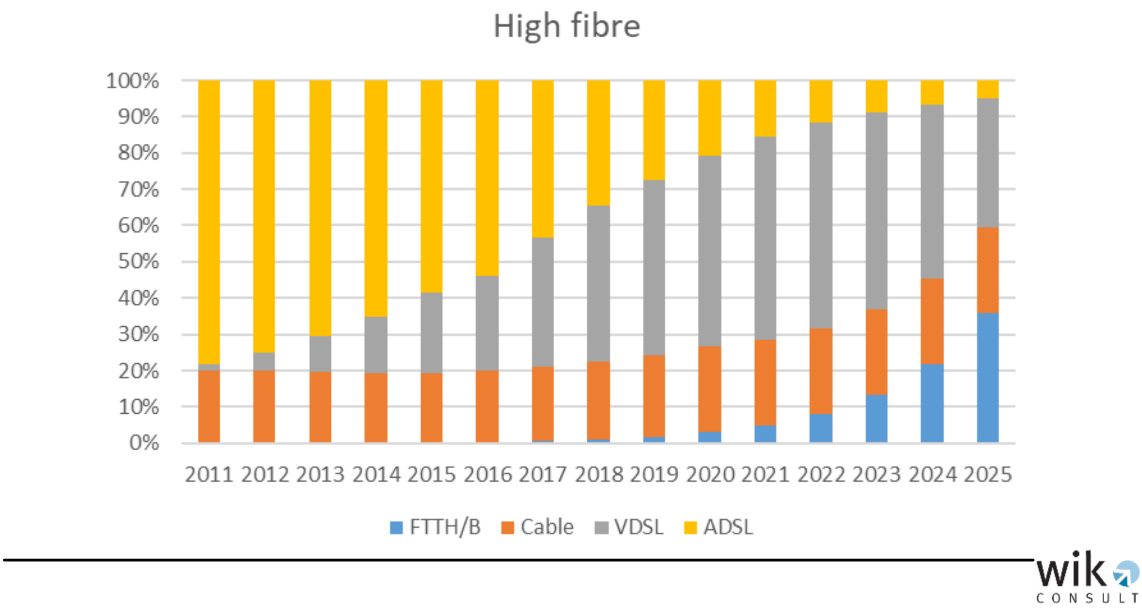
Figure 7-3: Evolution of technology shares in the UK – intermediate scenario




Source: WIK

Finally, under the most aggressive assumptions, fibre take-up grows at 65% per year to reach 36% of broadband connections in 2025, while cable stabilises and FTTC/VDSL take-up declines more sharply as customers switch or are migrated in areas where fibre has been fully deployed. In this scenario, just 5% of broadband connections are served by ADSL in 2025.

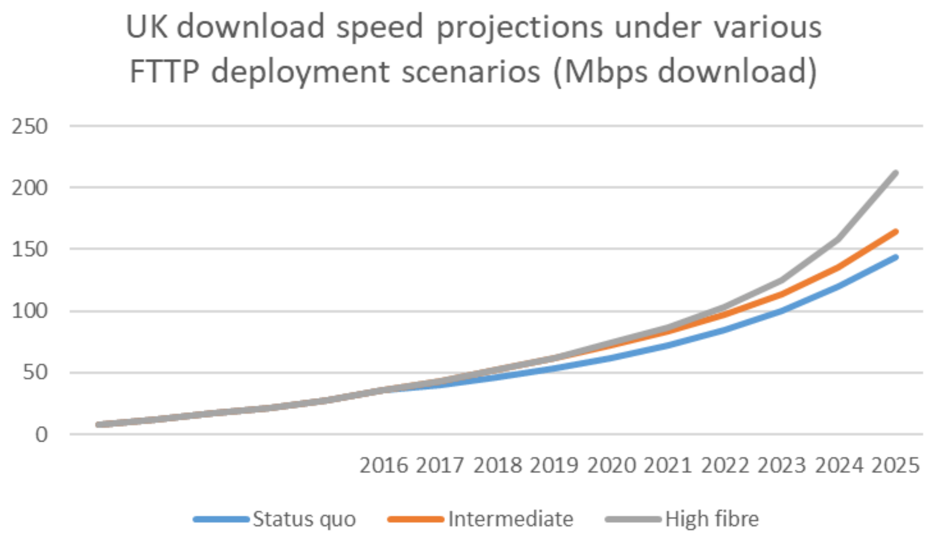
Figure 7-4: Evolution of technology shares in the UK – high fibre scenario




Source: WIK

The speed increases resulting from these different scenarios concerning the technological mix are shown in the figure below. In summary, whereas in the status quo, the projected average download speed is expected to reach around 140Mbit/s, this would increase to nearly 165Mbit/s in the intermediate scenario and more than 210Mbit/s in the maximum fibre scenario.

Figure 7-5: UK download speed projections under various FTTP deployment scenarios




A further dimension that is relevant to consider is that there is a significant gap between speeds achieved in rural areas – where cable is generally unavailable and copper loops are longer – and urban areas.

In fact, data compiled by Samknows for Ofcom shows that in 2016, while average download speeds in urban areas were 40Mbit/s, rural consumers had speeds averaging just 12.2Mbit/s. Moreover, 67% of rural customers experienced average download speeds of less than 10Mbit/s. One of the reasons is that ADSL speeds in rural areas average just 6.3Mbit/s – significantly below the national average of 10.3Mbit/s. FTTC speeds are also lower in rural than in urban areas at 39.2Mbit/s, although the difference is less marked compared with ADSL.

The implications for increasing speeds of deploying FTTP in rural areas are therefore likely to be substantially greater in rural than urban areas.

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