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Mobile first, fibre as required -
The case for "Fibre to 5G" (FT5G)

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About the Author

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This is an independent report funded by Deutsche Telekom. The opinions offered herein are those of the author. They do not necessarily represent the views of Deutsche Telekom, nor do they represent a corporate opinion of Communications Chambers.

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1. Executive summary

The European Commission has proposed a gigabit society vision and revised EU telecommunications code. A specific 100 Mbps ambition in terms of speed, Gigabit connectivity for "socio-economic drivers" and a new definition of very high capacity (VHC) networks based on the performance of fibre to the premise (FTTP) are amongst the proposals. This paper considers the vision and code in light of the pivot of markets towards mobile and wireless.

Implications of the pivot towards mobile and wireless

Mobile devices, coupled with apps stores, have seen rapid adoption. Mobile device sales dominate PC sales globally, and more than half of our online time is now spent on mobile devices.

Applications providers have adopted global mobile first strategies, and accordingly developed apps that are bandwidth efficient to serve consumes wherever they may be. Mobile devices also connect via cellular and/or Wi-Fi, so the last leg of a connection is wireless and wireless may constrain connectivity, regardless of how far fibre is extended.

The individual user, device and application is now the underlying driver of demand for access. In assessing connectivity requirements, we should therefore focus on the individual and app, and work back via points in the network where traffic is aggregated, rather than focus on the premise and fixed connectivity *per se*.

Our current approach to assessing connectivity requirements, which focusses on the premise and fibre to the premise in particular, is backward looking. The focus should be on ubiquitous wireless connectivity indoors and outdoors, and on fibre as required to support this vision. More fibre will be required, but not necessarily to the premise.

We refer to this as fibre to 5G or "FT5G", where 5G encompasses mobile and Wi-Fi utilising millimetre and other spectrum bands, and tailored connectivity matching different consumer and business requirements.

Growth in peak bandwidth demand versus data traffic

In assessing demand, it is important to distinguish demand for peak bandwidth from overall traffic. The latter may grow even though the former does not. For example, if users spend more time watching online video their data consumption would grow but not the size of the final pipe, or on-ramp to the core network, required.

Demand and connectivity requirements

A growing fraction of traffic is aggregated directly at cellular sites, with aggregate demand at such sites projected to range from a few 100 Mbps to over 10 Gbps per site by 2025 – depending on the cell location and size.

Those households that are not smartphone only will also see wireless demand aggregated, via indoor Wi-Fi, with wireless or wired connectivity back to the core network. For a larger household, assuming per device-app demand of 10 Mbps, aggregate peak demand might be around 50 Mbps. Institutions such as schools, hospitals and larger businesses would have higher demand, depending on their size.

The internet of things (IoT) will also be a growing source of demand, though predominantly in terms of the number of connections rather than speed or capacity requirements. To achieve coverage and long battery life low data rates are required, though some IoT applications will be more demanding in terms of speed and/or latency and will be connected via Wi-Fi or 5G.

Aggregated demand will therefore cover an enormous range - there is no one-size-fits-all. A Gigabit per second may greatly exceed residential requirements, and the capability of in-home Wi-Fi, whilst falling short of the requirements from larger mobile sites by 2025.

More fibre will be required for mobile, but not FTTP; whilst the requirement for mobile will evolve over time and is not amenable to a plan or targets. The extent of fibre required to meet residential demand will vary, with intermediate copper (cable DOCSIS, VDSL and G.fast) and wireless links. Wireless links to the premise may offer an alternative to fibre and copper, particularly with the advent of 5G.

Prioritising rapid deployment and upgrades utilising a mix of technologies will also stimulate near term applications development and adoption, thereby improving the prospects for further investment.

Factoring in uncertainty

Whilst there are different views regarding future connectivity requirements, the honest answer is that we don't know. Further, whilst we know that the performance of fixed and wireless technologies will improve, we do not know by how much.

We can, however, be reasonably assured that the pivot to mobile will continue, and that the performance-cost ratio of wireless will improve rapidly. Indeed, there is growing interest in what some refer to as “wireless fibre” as an early 5G use case. Wireless fibre may help overcome the cost and logistics constraints involved with the civil works typically required for FTTP.

With such uncertainty, it is wise to keep options open where possible, take incremental steps where feasible and learn from others and from early deployments of different technologies.

It is also unlikely that we have the time and money to build both a dense 5G network and widely deploy FTTP by 2025 (at current investment rates doing both would take around 25 years to deliver). It is therefore prudent to focus investment on the most likely bandwidth bottlenecks and other priorities including delivering ubiquity.

Refining the gigabit vision & code

The gigabit vision and electronic communications code should be adapted for a mobile and wireless first world. There should be less emphasis on targets for ever higher speeds for those already well served, with emphasis on an “outside-in” approach where the worst served are prioritised for upgrades. This shift could be coupled with a more ambitious approach to mobile ubiquity, capacity and 5G transition; supported by very high capacity - multi-Gigabit per second - fibre as required.

Less weight should be placed on plans and targets with more on strong and predictable incentives, to ensure the market responds to unpredictable demand. Scope for innovation and end-to-end competition should also be maximized, via a technology and business model agnostic approach.

To offer strong and predictable investment signals the code should be simplified and made consistent. Pricing freedom and regulatory forbearance should extend to all network upgrades, subject to an assessment of the risk of market abuse. To the extent that unilateral, contractual or co-investment undertakings contribute to competition, that should be taken into account in assessing the need for intervention, but specific business models should not be preferred *a priori*.

Delivering a FT5G vision is feasible, but requires freedom to innovate and experiment in terms of technology, business models, service differentiation and pricing. It also requires freedom to adapt as technology and demand evolve. Finally, it requires the courage to embark on a journey without knowing or attempting to set in stone the precise end point at the outset.

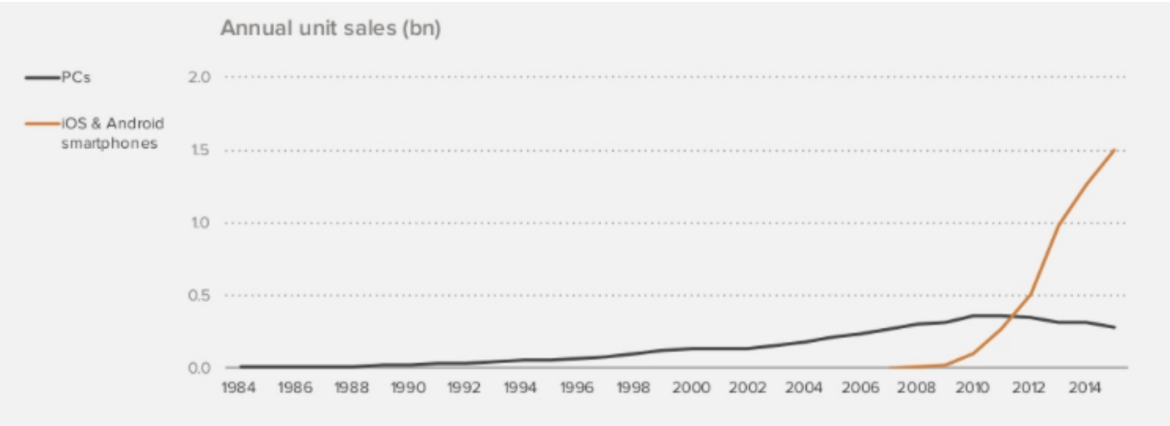
2. The pivot towards mobile & wireless

"The trend has been that mobile was winning, it's now won" Google Chairman Eric Schmidt, 2014[1]

The pivot towards mobile

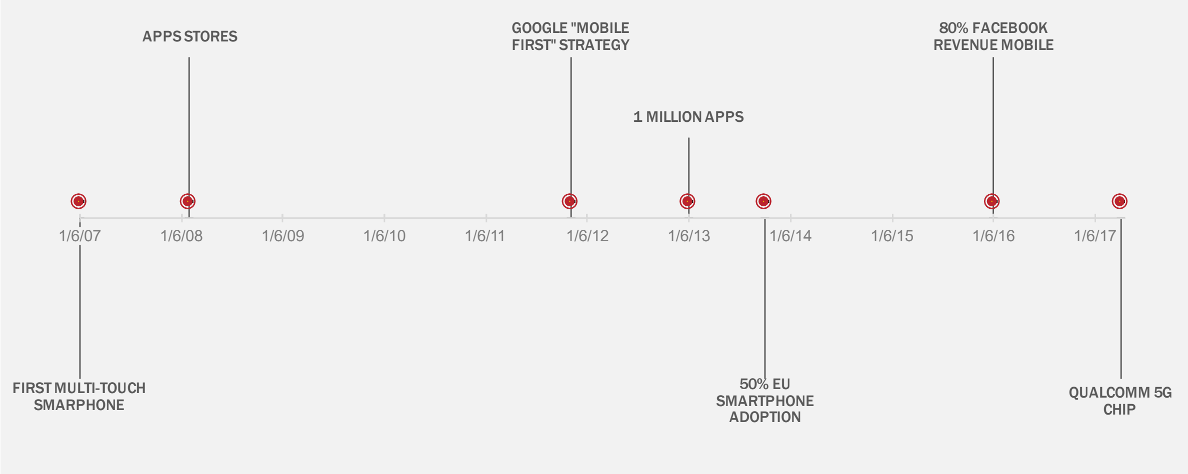
A measure of the global pivot towards mobile is sales of smartphones versus PCs (Figure 1).

Figure 1: Smartphone sales overtake PC sales globally from 2011[2]



The pivot began with the launch of multi-touch smartphones in 2007 and apps stores in 2008 (Figure 2). At the Mobile World Congress in 2012 Google announced a mobile-first strategy, others soon followed. Mobile has now overtaking the PC in terms of attention, application revenues and innovation.

Figure 2: Pivot to mobile first



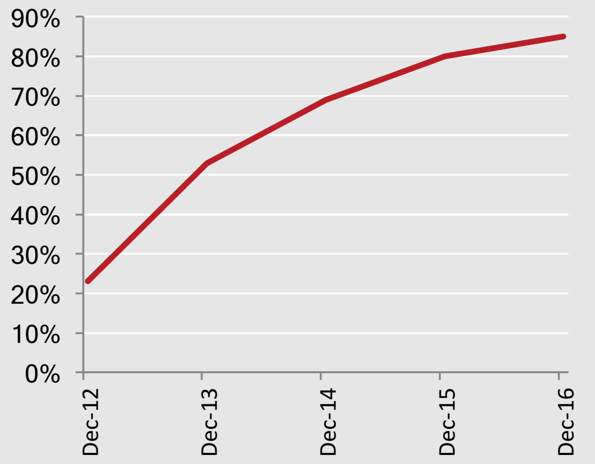
[1] Bloomberg, *Ask a Billionaire: Eric Schmidt's 2014 Predictions*, 2014.
[2] Benedict Evans, *Mobile is eating the world*, March 2016.

During November 2016 alone we have seen a number of announcements indicating that mobile will increasingly dominate internet use, and influence future connectivity requirements:

- Google algorithms will eventually primarily use the mobile version of a site's content to rank pages from that site.[3]
- Wal-Mart, the world's largest retailer by revenue, said 60% of Black Friday online orders came through mobile devices.[4]
- Worldwide mobile and tablet internet usage exceeded desktop usage for the first time in October 2016.[5]

The pivot to mobile is reflected in a shift in terms of application revenues. The estimated proportion of advertising revenue Facebook derive from mobile is shown in Figure 3 illustrates this shift (Facebook introduced mobile advertising in the mobile news feed during 2012).

Figure 3: Facebook ad share from mobile[6]



Applications development has therefore shifted to focus on mobile, with a growing number of applications now mobile only including health and fitness apps, navigation and messaging apps (namely apps that must be with the user all the time to deliver value, which utilise sensors including the camera and which utilise location based information).

We are moving into an era where development is mobile native.[7] Mobile is no longer an afterthought.

The pivot towards wireless

Smartphones connect via cellular and Wi-Fi only, and a growing number of other devices and things are wireless only. Most internet of things applications will also be connected wirelessly, including via the mobile Narrow-Band Internet of Things (NB-IOT) standard.

[3] Google blog, *Mobile-first indexing*, 4 November 2016.
[4] WSJ, *Mobile Looms Larger With Holiday Shoppers*, 27 November 2016.
[5] StatCounter, *Mobile and tablet internet usage exceeds desktop for first time worldwide*, 1 November 2016.
[6] Facebook, Annual reports. Q4 2016 estimated based on Q3 2016.
[7] Benedict Evans, *From mobile first to mobile native*, November 2016.

Almost all demand is now aggregated via wireless - Wi-Fi or cellular. By 2020, Cisco estimate that Wi-Fi and mobile-connected devices will generate 78 percent of Internet traffic.[8]

Implications of the pivot towards mobile and wireless

The pivot to mobile and wireless has several implications:

- Most applications are developed for the global market and therefore often for comparatively low quality connectivity.
- Since nearly everything connects via wireless, wireless constraints may dominate end-to-end latency and speed constraints, irrespective of the extent of fibre.
- Bandwidth requirements are heterogeneous with no one-size fits all. NB-IOT operates at around 200 Kbps whilst the largest mobile macro sites may require over 10 Gbps backhaul to the core network.

Conclusion

More fibre will be required, but not necessarily to the premise, and certainly not to the device. Fibre, often with fixed-wireless or copper-fibre hybrids as intermediate links, will connect to wireless access points where demand is aggregated.

We refer to this as fibre to 5G or "FT5G", where 5G encompasses advanced mobile and Wi-Fi utilising millimetre and other spectrum bands, and tailored connectivity matching different consumer and business requirements.

[8] Cisco, *Cisco Visual Networking Index Predicts Near-Tripling of IP Traffic by 2020*, June 2016.

3. Demand for fibre

> "In the longer-term, we will forget this stupid debate about rolling out fibre cables… My sense is that there's a more forward-looking context for the delivery of regulation and policy there [in the US], which is adopting the notion of a digitally-led mobile first" Ronan Dunne[9]

In this section the demand for fibre in a mobile first world is explored focusing on applications and working back up through wireless access points to the core network. At each level demand is aggregated.

Applications demand

WIK, Deloitte and IDATE (for the EC)[10] forecast very high levels of future demand for peak residential bandwidth – a Gbps downstream and 600 Mbps upstream for the most demanding households. These forecasts include very aggressive assumptions regarding, for example, future video streaming and video conferencing requirements.

The analysis below points to much more modest requirements, given the pivot towards mobile and advances in compression. Further, whilst future demand is uncertain, a prudent approach may be to keep options open where possible and move fast incrementally (the balance of risk in pursuing this strategy is considered in Section 4).

Mobile devices are wireless – Wi-Fi and cellular, with a growing number Wi-Fi only and most having no direct means of fixed connectivity. They have smaller screens requiring less bandwidth, whilst many applications are optimised to ensure they work globally, at the cell-edge and over 2G and 3G mobile networks. Applications may also make intelligent use of patchy connectivity.[11]

A view of application demands, and their relationship to mobile app coverage, is provided in Figure 4.[12] Individual applications are not necessarily that demanding. The challenge is delivering a consistent user experience by focusing on ubiquity and end-to-end connectivity, including the cell edge and Wi-Fi edge.

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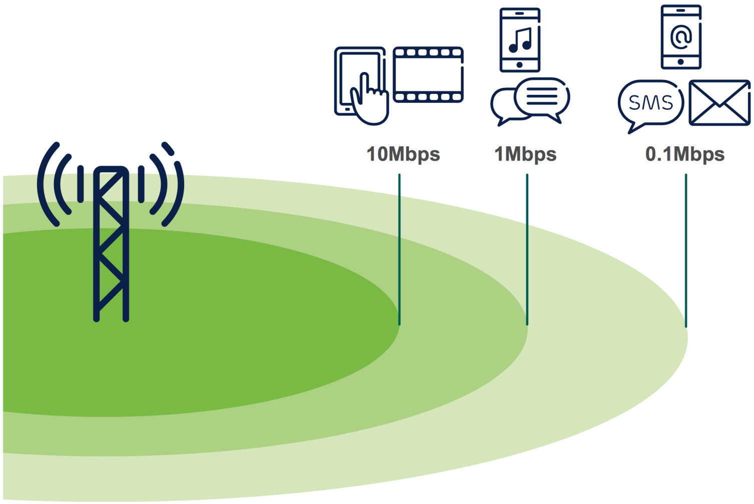
[9] FT, *UK must switch off 'analogue' thinking or lose 5G race, says outgoing O2 chief*, 18 September 2016

[10] WIK, Deloitte and IDATE, *Regulatory, in particular access, regimes for network access investment models in Europe*, September 2015.

[11] Google blog, *Don't let a spotty connection stop you from searching*, January 2017.

[12] Internet.org, *Measuring and improving network performance*, A whitepaper from Ericsson, Facebook and XL Axiata, October 2014.

Figure 4 – Applications requirements in relation to network coverage



For browsing, page load times decrease with downstream throughout, but only up to 8-18 Mbps.[13] Further, a study by Sandaresan *et al* (2016)[14] of network access constraints found for the US that:

> "Access link bottlenecks rarely occur in home networks where downstream access throughput exceeds 20 Mbps. Rather, in these cases, throughput bottlenecks are often introduced by the home wireless network."

> "…nearly 80% of the bottlenecks are in the wireless network when access throughput exceeds 20 Mbps."

Online video is considered one of the more demanding applications; though improved compression, caching content closer to users and the shift to adaptive streaming have delivered good performance for most content at speeds around 5-10 Mbps or less for HD – in particular for mobile device based consumption. In relation to mobile bandwidth requirements Ericsson note that:[15]

> "As a point of reference, a downlink throughput rate of at least 1.5 Mbps is recommended for collaboration services, while 2.5 Mbps is recommended for HD video viewing."

Skype recommends 1.5 Mbps for an HD video call, BBC iPlayer recommends up to 2.8 Mbps, Google recommends 2.5 Mbps for HD YouTube playback and Netflix recommend 5 Mbps for HD video. 4K video is more demanding, with Netflix recommending 25 Mbps –

[13] Sundaresan *et al*, *Measuring and Mitigating Web Performance Bottlenecks in Broadband Access Networks*, 2013.
[14] Sundaresan, Feamster and Teixeira, *Home Network or Access Link? Locating Last-Mile Downstream Throughput Bottlenecks*, March 2016.
[15] Ericsson, *North America – Ericsson Mobility Report,* June 2016.

however, this may not be relevant to mobile consumption where the highest bit rate for Netflix is 5 Mbps. BBC iPlayer also uses a lower bit rate for mobile devices - up to 1 Mbps.

Further, Ericsson research shows that since 2012, the average consumer globally has increased their viewing on mobile devices by 4 hours a week, while their fixed screen viewing has declined by 2.5 hours a week.[16] Between 2011 and 2015, teens increased their TV/video viewing at home on smartphones by 85 percent and nearly halved their time spent watching on a traditional TV screen – with smartphone viewing and TV comparable by 2015.[17] As video consumption moves to mobile devices, peak speed requirements may decrease.

Demand for higher quality video will grow, though there are limits in terms of human perception in relation to further increases in resolution. Increasing the colour gamut and contrast ratio offers significant gains, but involves very modest demands in terms of bandwidth.

Compression is improving with H.265 compression offering a reduction in data rate of around 50% compared to H.264 compression which is widely used today (though licensing fees and hardware requirements have constrained adoption of H.265). However, alternative compression standards may overcome licensing constraints and are expected to offer efficiency gains compared to H.265.

In April 2015 YouTube introduced VP9 compression – which is open source and royalty free - halving the required bit rate.[18] AV1 (a successor to VP9) is scheduled to ship by March 2017, and is expected to offer a 50% improvement over VP9 and H.265 i.e. around 75% versus the still widely used H.264 standard.[19]

Improvements in compression may therefore offset the impact of the shift to higher quality video, whilst the shift to mobile consumption will reduce bandwidth requirements. 4K video may require less than 10 Mbps in the medium term, with HD video requirements in the low Mbps range.

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[16] Ericsson, *TV and media 2016*, November 2016.
[17] For a consumer sample drawn from Brazil, China, Germany, South Korea, Spain, Sweden, Taiwan, UK and US. Ericsson, *Mobility report*, June 2016.
[18] YouTube, *VP9: Faster, better, buffer-free YouTube videos*, April 2015.
[19] Streaming media.com, *What is AV1?,* June 2016.

Machine learning may also support further reductions in still image and video file size, for a given end user quality of experience.[20]

Less certain is how augmented reality (AR), virtual reality (VR), 360-degree video and mixed reality (MR) will impact demand. Existing applications range from the comparatively undemanding Pokemon GO, to 360 cameras that output at up to 25 Mbps (Orah)[21] or 150-600 Mbps (Odyssey).[22] MR devices include the Microsoft HoloLens for which processing is local.[23]

Consumption requires less bandwidth, since only part of the view need be transmitted. An illustration of progress in reducing bandwidth requirements is Facebook "pyramid geometry"[24] and use of view dependent streaming which has enabled a reduction of 80% in file size. Google have also open sourced Draco, a compression library which offers a more efficient way of storing and transmitting 3D graphics.[25]

Qualcomm, note, however that that higher quality frame rates would offer an improved experience and would require higher data rates:[26]

> "Today, 360-degree video is readily available at 4K resolution, but only at 30fps [frames per second] and sometimes even lower. That would provide a decent viewing experience, but it's not immersive by any means. To achieve that, the frame rate would need to be pushed up to 60fps and, ideally, even 120fps. All of a sudden, the data rate requirements climb significantly from ~45 Mbps to ~68 Mbps for 60fps, and up to an estimated ~103 Mbps for 120fps."

Oculus have however introduced a frame interpolation technique called "asynchronous spacewarp" which reduces the required framerate.[27]

AR and VR are evolving rapidly, with their likely use cases, adoption and bandwidth requirements uncertain. On the one hand they may require higher bandwidth than video. On the other hand, those involved in AR and VR development want to reach the widest possible market, and are working to reduce bandwidth requirements. Some have also expressed the view that AR and MR

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[20] Google blog, *Saving you bandwidth through machine learning*, January 2017.
[21] Orah, *Technical specifications*, accessed November 2016.
[22] GoPro, *Introducing Odyssey*, accessed November 2016.
[23] Microsoft, HoloLens.
[24] Facebook, *Next-generation video encoding techniques for 360 video and VR*, January 2016.
[25] Google Open Source Blog, *Introducing Draco: compression for 3D graphics*, January 2017.
[26] Qualcomm, World's first commercial Gigabit Class LTE device and network arrive, October 2016.
[27] Oculus, *Asynchronous Spacewarp*, November 2016.

will be the more important applications[28] [29], and for that to play out AR and MR will ultimately need to work with mobile devices – increasing the incentive to push down bandwidth requirements.

Demand related to cloud based artificial intelligence (AI) is also uncertain. AI will utilise information from the internet of things, though much of this will be very low data rate. As the visual "understanding" of AI develops it will process images including video. However, whilst training is done in the cloud and is compute intensive, implementation of AI can be local and undemanding. For example, Google Translate is implemented locally on smartphones and works offline, whilst Facebook have condensed an AI model 100-fold to allow it to function on a smartphone following cloud based development and training.[30]

File downloads differ from other applications in that the time to download a file decreases asymptotically to zero as speed is increased i.e. there is no threshold speed beyond which there is no further benefit. However, the benefit of the first doubling of speed in terms of time saved is equal to the benefit of all subsequent doublings combined.[31]

Further, for music and video in-home content streaming is replacing downloads, so speeds beyond those sufficient for streaming offer no additional benefit; whilst downloads such as software updates now tend to involve just the change (delta updates) rather than the entire app or operating system. Downloads may also be scheduled to happen in the background by smart devices/networks.

The internet of things

Internet of things (IoT) includes machine to machine and machine to person communication. Certain IoT applications will require connectivity deep indoors and outdoors, some of it mobile. A low data rate is a necessary counterpart of high coverage, in-building penetration and long battery life. For example, the cellular standard NB-IOT operates at up to 250 kbps.

Indoor IoT devices may connect via Wi-Fi, including high bandwidth applications such as video monitoring. Some wide area applications may also require high bandwidth and/or very low latency, as envisaged by 5G standardisation bodies. 5G wireless could include,

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[28] The Verge, *Tim Cook says augmented reality will be bigger than virtual reality*, 14 September 2016.
[29] The Wall Street Journal, *Microsoft CEO Envisions a Whole New Reality - Satya Nadella talks about how augmented reality and artificial intelligence will transform life*, 30 October 2016.
[30] Facebook, *Delivering real-time AI in the palm of your hand*, November 2016.
[31] Since ½ + ¼ + … = 1.

for example, vehicle-to-vehicle coordination or critical control of the power grid.

Some systems may be fully autonomous (for example, sensing and immediate "decision" making for autonomous vehicles) whilst others may require edge servers connected wirelessly to the application to deliver low latency.

Future network architectures will be designed to support applications, including IoT, with widely differing quality requirements.

Macro and small cell demand

Applications and devices predominantly connect via indoor and outdoor wireless access points. Typically, more than one user or thing will connect to each access point, so demand from multiple users and things will be aggregated.

Mobile use is almost exclusively via macro and small cell cellular (with Wi-Fi mostly for nomadic and indoor use, and some indoor use via mobile networks).

Currently there are around 1000 mobile subscribers per cell site in Europe i.e. the potential level of demand aggregation is far greater than at the household level. Whilst not all demand occurs simultaneously, the level of aggregation is reflected in overall peak demand per site.

Ericsson (October 2016) estimates aggregate demand at macro and small cell mobile sites for advanced mobile broadband as shown in Figure 5. Ericsson estimates that whilst the majority of sites will require less than 1 Gbps by 2025, high capacity sites will require backhaul in the 5 Gbps range with extreme capacity sites requiring backhaul in the 10 Gbps range.

Figure 5: Cellular backhaul requirements[32]

Sites	2016	2025
80%	90 Mbps	600 Mbps
20%	300 Mbps	3-5 Gbps
Few %	1 Gbps	10-20 Gbps

"Backhauling" cellular demand to the core network

Whilst fibre will be used to connect mobile sites to the core network, around 50% of sites in Europe are connected using microwave links (with a similar proportion forecast for 2025). Wireless will be particularly important as sites are added including small cells – not all of which would be commercially attractive to connect with fibre. As Ericsson (October 2016) note:

[32] Ericsson, *Ericsson Microwave Outlook*, October 2016.

> "Microwave backhaul technology will continue to evolve and be able to handle 100 percent of all radio access sites' capacity needs, today and towards 2025."

Copper-fibre hybrid based access is also likely to play an important role in extending mobile coverage and capacity. Researchers at BT's Adastral Park Labs, in collaboration with US-based semiconductor manufacturer Cavium, have demonstrated that they can use G.fast technology to deliver cellular "fronthaul" data over copper lines:[33]

> "This removes the need for mobile operators to invest in costly, high capacity backhaul links over dedicated fibre connections. By providing a far more economic "fronthaul" connection between the base station and the mobile operators' core network, a C-RAN service delivered over G.fast would significantly lower the cost of deployment for mobile operators building out 4G networks today and 5G architectures in the future."

Fibre, copper and microwave links will all play a role in providing "backhaul" and "fronthaul" in the transition to 5G. By utilising a mix of technologies, the pace and extent of 4G densification and 5G deployment can be maximised.

Indoor residential demand

Around 10% of households are smartphone only in Europe.[34] If mobile unit costs fall faster than fixed traffic increases, then *ceteris paribus* the proportion of mobile only households may grow.[35] Nevertheless, a substantial proportion of households are likely to deploy Wi-Fi access points requiring fixed and/or wireless connectivity to the core network.

For residential households aggregate peak bandwidth demand is determined by the number of people within a household and the extent of overlapping use at the busy hour. Demand from applications used on mobile devices may be up to 5-10 Mbps.

In the EU-28 single person households comprise 31.4% of households, two person households 33.5%, three person households 15.9%, four person households 13.4% and five person households or more 5.8% of total households.[36] Assuming bandwidth requirement

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[33] Cavium, *BT trials cloud RAN over G.Fast in step towards 5G*, 2016.
[34] Eurobarometer, *E-Communications and Telecom Single Market Household Survey*, March 2014. Question B.6.
[35] Williamson and Wood, *Mobile Value, Spectrum and Data Demand - A Bootstrap Approach*, Digital Policy, Regulation and Governance, Volume 19 Issue 1, January 2017.
[36] Eurostat, *Household composition statistics*, August 2016.

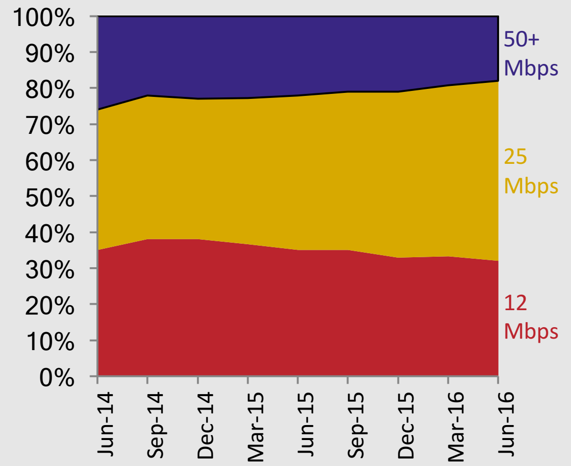
of 5-10 Mbps per individual, aggregate Wi-Fi backhaul demand for the majority of households, including HD and 4K video allowing for improved compression, might be met with connectivity to the premise of 25-50 Mbps (for a five-person household).

A forecast for the UK Broadband Stakeholder Group in 2013 estimated that the median household will require bandwidth of 19 Mbps by 2023, whilst the top 1% of high usage households will have demand of 35-39 Mbps.[37]

The comparatively low aggregate demand versus outdoor wireless sites reflects the fact that there are many less residential indoor users potentially sharing Wi-Fi than mobile users potentially sharing outdoor cellular sites.

A market test of demand for bandwidth to the premise is provided by the NBN in Australia, where different speeds are offered at different price points.[39] Figure 6 shows revealed behavior, with 84% of fixed line customers taking a speed of 25 Mbps or less.[40] The distribution of customers across packages is consistent with research on stated consumer preferences which showed incremental willingness-to-pay falling to close to zero for speeds approaching 100 Mbps.[41]

Figure 6: Declining willingness to pay for higher speeds[38]



Indoor business demand

Business demand is diverse, ranging from a sole trader with a smartphone only to enterprises with multi-Gbps demand and low latency requirements. At the top end demand may be met via dedicated fibre and microwave links. Indoor aggregation may be over both Wi-Fi and wired Ethernet connections.

An estimate of small business demand for the UK forecast median demand in 2025 of 8/2 Mbps down/up,[42] in part because 90% of UK small businesses have 4 employees or fewer. The 95th percentile in 2025 however required 41/36 Mbps down/up, and a smaller group

[37] Robert Kenny & Tom Broughton, *Domestic demand for bandwidth*, 5 November 2013
[38] NBN, *NBN Annual Report 2015-16*, November 2016 (and earlier results).
[39] For example, the price premium for 50/20 Mbps over 25/5 Mbps is AUS$10 (approximately €7) based on *V4 NBN Pricing and Product Information*, [accessed 27 November 2016]
[40] Wholesale tiers include 12/1, 25/5, 25/10, 50/20 and 100/40 Mbps. The two 25 Mbps download packages, and 50 and 100 Mbps packages, are combined in the figure.
[41] Dr Michael Vertigan (lead), *Independent cost-benefit analysis of broadband and review of regulation*, August 2014.
[42] Communications Chambers for BSG, *The broadband requirements of small businesses in the UK*,2 September 2015

of the most demanding businesses (such as some software businesses) require much more.

An example of a demanding business connectivity requirement is for digital special effects and animation. Framestore, which produced special effects for the film Gravity, has render farms spread over locations in central London, and has its own dark fibre network offering sub-millisecond latency and 10 Gbps speeds.[43] Such requirements would be unlikely to be met via a mass-market network, and would not be met via the European Commission's gigabit ambition for 2025. It is likely to be both timelier and more cost efficient to meet such requirements on a bespoke basis.

"Backhauling" indoor demand to the core network

A range of copper, fibre and wireless technologies can be utilised to "backhaul" aggregate indoor demand to the core network. A substantial amount of video demand is also met currently via terrestrial and satellite TV broadcasting.

The mix of technologies chosen depends on their cost and performance, which both depend on local circumstances. Focusing on performance first, we consider the capability of fibre, fibre-copper hybrids and wireless solutions in terms of speed, latency and resilience.

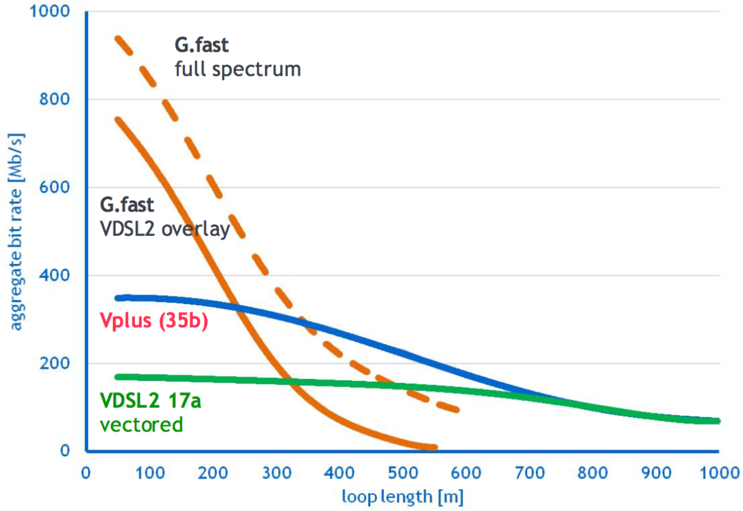
Speed (Mbps/Gbps)

FTTP can offer very high (multi Gbps) download and upload speeds. Passive optical fibre offers capacity on a shared basis with GPON currently supporting 2.5 Gbps downstream and 1.2 Gbps upstream, typically shared in practice between 16 and 32 households.

Copper-fibre hybrid VDSL, VDSL35b ('super vectoring') and G.fast offer speeds that depend on the line length (Figure 7). Multi-hundred Mbps speeds are achievable today.

[43] Ars Technica, *From Paintbox to PC: How London became the home of Hollywood VFX*, April 2016.

Figure 7: Speed capabilities over fibre-copper hybrid technologies[44]



The choice of technology will depend on local circumstances, including the geographic distribution of customers, access to duct and copper line lengths and quality. A technology mix, including FTTP, copper-fibre hybrids and fixed wireless offers the best prospects for rapid and affordable upgrades.

Copper based technologies are also improving, both in terms of the maximum speed over shorter lines, where multi-Gbps speeds appear feasible, and speeds achievable over longer lines.[45] G.fast was originally envisaged as a short line fibre extension technology,[46] but is now capable of high speeds over hundreds of metres. Cable DOCSIS technology is also evolving with DOCSIS3.1 able to support Gbps speeds, with symmetric speeds in prospect.[47]

Mobile, and point-to-point wireless, can also support high speeds; with 5G trials demonstrating high peak speeds. An early 5G use case may therefore be as a fixed access, including fibre, substitute. Facebook have announced development of technology that could substitute for fibre (utilising 60 GHz spectrum), noting that: [48]

> "…the high costs associated with laying the fiber makes the goal of ubiquitous gigabit citywide coverage unachievable and unaffordable for almost all countries."

[44] Nokia, Gigabit technologies, Digital Executive Club Brussels, April 2016.
[45] BT, *The future of G.fast – an ultrafast update*, December 2015
[46] Fibre to the Home Council Europe, *G.fast*, 2014.
[47] CableLabs, *Full Duplex DOCSIS 3.1 Technology: Raising the Ante with Symmetric Gigabit Service*, February 2016; Nokia, *Nokia Bell Labs achieves world's first 10 Gbps symmetrical data speeds over traditional cable access networks*, May 2016
[48] Facebook, *Introducing Facebook's new terrestrial connectivity systems — Terragraph and Project ARIES*, April 2016.

Whilst Qualcomm have announced a 5G millimetre band (28 GHz) modem, noting that:[49]

> "the Snapdragon X50 5G modem can replace fiber-to-the-home"

In the US, where the FCC made bands including 28 GHz available for 5G in July 2016[50], a number of announcements of intent have been made focusing on fixed wireless access:

- "Fixed-wireless millimeter wave technology gives us the ability to make ultra-fast internet speeds available to additional locations in less time and with less disruption." AT&T, 6 October 2016[51]
- "[O]ur strategy going forward will be a hybrid approach with wireless playing an integral part," Google Fibre, 4 October 2016[52]
- "With wireless fiber, the so-called last mile can be a virtual connection, dramatically changing our cost structure." Verizon, 26 July 2016[53]

Huawei also envisage wireless as an alternative to fixed, referring to this vision as wireless to everything (WTTx):[54]

> "We believe that WTTx will be the first major commercial use case for 5G." Ken Hu, Huawei

Latency

Fibre to the premise, cable and G.fast all offer latency of a few milliseconds or less, with, for example, <1 ms latency reported for G.fast.[55] In practice, latency is dominated by constraints other than access, including delays in the core network and over Wi-Fi.

The delay over a fibre across the Atlantic is around 60 ms, whilst Wi-Fi latency follows a long-tail distribution with 50th, 90th and 99th percentiles of around 3 ms, 20 ms and 250 ms; and mean latency of around 10 ms.[56]

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[49] Qualcomm, *Meet Snapdragon X50—Qualcomm's first 5G modem*, October 2016.
[50] FCC, *FCC takes steps to facilitate mobile broadband and next generation wireless technologies in spectrum above 24 GHz*, July 2016.
[51] AT&T, *AT&T Trialing Fixed-Wireless Millimeter Wave to Deliver High-Speed Internet Outside of its Traditional Wireline Service Area*, October 2016.
[52] The Verge, *Google Fiber is now a fibre and wireless ISP*, October 2016.
[53] Verizon, *2Q 2016 Quarter Earnings Conference Call Webcast - Transcript*, July 2016.
http://www.verizon.com/about/investors/quarterly-reports/2q-2016-quarter-earnings-conference-call-webcast
[54] Computerworld, *Huawei dreams of all-wireless future*, November 2016.
[55] Adtran, *Accelerating Gigabit Broadband*, 2014.
[56] Sui *et al*, *Characterizing and Improving WiFi Latency in Large-Scale Operational Networks*, 14th ACM International Conference on Mobile Systems, Applications, and Services, Singapore, June 2016.

To reduce latency, content and applications need to be hosted closer to users and end-to-end connectivity optimised. Compared to other latency constraints, differences between access technologies may not be a material consideration.

Resilience

Both short (tens of seconds) and longer service interruptions (hours/days) can impact the user experience. Resilience, as well as speed and latency, is important.

Copper technologies are susceptible to radio interference. However, provided recovery is rapid, the interruption may go unnoticed for applications such as video streaming. Recovery times can be reduced from around 30-90 seconds to around 1 second utilising G.INP – an error correction solution – which makes copper more "fibre like".

Longer interruptions can occur for a range of reasons. Fibre may be more resilient to service problems due to water (for example following Hurricane Sandy in New York[57]), but along with copper may be cut due to digging. Mobile networks also suffer outages due to software and hardware faults.

For those who value high resilience the best solution may be independent multi-path connectivity utilising some combination of fibre, copper, cable, mobile and point-to-point microwave links. With the extension of 4G coverage most users now have the option of falling back on mobile if their fixed broadband fails, for email etc.; and potentially tethering a laptop or PC as a temporary solution.

Wireless can also be included alongside fixed connectivity in hybrid routers, offering an automatic back-up and higher peak speeds. Deutsche Telekom offer this option, whilst Telekom Austria subsidiary A1 plan to offer a hybrid router option.[58]

Multipath TCP – resilience and higher speeds

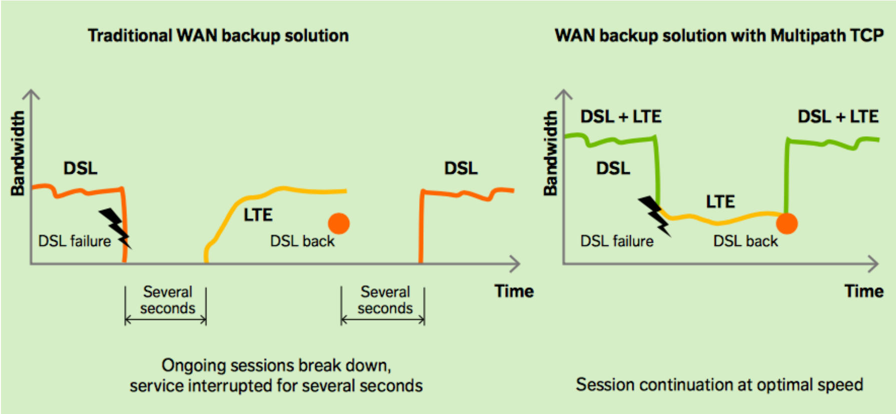
The scope to use multiple access technologies together will be expanded by multipath TCP - a protocol that enables a service to operate seamlessly over more than one form of connectivity simultaneously. The approach is used by Korea Telecom to offer its "Gigapath" mobile service by combining Wi-Fi and 4G.[59]

The approach offers resilience, higher speed, greater consistency and potentially lower latency. Traffic routing can be optimised across two

[57] The Verge, *Into the vault: the operation to rescue Manhattan's drowned internet*, November 2012.
[58] Telekom Austria Group, *Austrian subsidiary A1 presents the Internet of the Next Generation for the first time in Austria – Hybrid-Boost Technology*, 15 July 2016.
[59] MTPCP blog, *In Korean, Multipath TCP is pronounced GIGA Path*, July 2015.

paths based on transit time, speed or a cheapest-link first policy. The benefits in terms of speed and consistency from combining DSL (or VDSL) and LTE are illustrated in Figure 8.[60]

Figure 8: Resilience gain from multipath access



Core and transit networks

Fibre links dominate for transit and core given the speed and capacity achievable over dedicated fibre. 40 Gbps and 100 Gbps fibre Ethernet links are available commercially; whilst Microsoft and Facebook have announced investment in a 160 Tbps transatlantic fibre link.[61] Even higher speeds have been achieved in tests.[62]

For some links, microwave is preferred to fibre because it offers lower latency (the speed of light in air is 300,000 km/s versus 200,000 km/s in copper or fibre) and the path may be more direct. For example, Colt offer a low latency microwave link between London and Frankfurt.[63]

Potential future role of satellite broadband

Satellite fills a narrow niche today due to limitations in terms of latency and capacity. However, a constellation of up to 4,425 low earth orbit satellites has been proposed in an application to the FCC by SpaceX who claim that the full system would:[64]

> "…be able to provide high bandwidth (up to 1Gbps per user), low-latency broadband services for consumers and businesses in the US and globally"

[60] Skog *et al*, *Bolstering the last mile with Multipath TCP*, Ericsson Technology Review, October 2016.
[61] *Microsoft and Facebook to build subsea cable across Atlantic*, May 2016.
[62] Ars Technica, *65Tbps over a single fibre: Nokia sets new submarine cable speed record*, October 2016.
[63] *Colt first to offer both fibre and microwave ultra low latency services between London and Frankfurt*, November 2012.
[64] Ars Technica, *SpaceX plans worldwide satellite Internet with low latency, gigabit speed*, November 2016.

Such a constellation would offer considerable capacity and could play a part in providing mobile and residential backhaul and transit. It could offer high-speed low-latency service in areas not covered by high speed terrestrial networks.

Overcoming Baumol's cost disease via a FT5G strategy

Copper-fibre hybrids, wireless access and satellite[65] are all benefiting from advances in computing (Moore's law) and software which are increasing performance and lowering unit costs at a rate far higher than the economy wide average.

FTTP is also seeing cost reduction as more efficient approaches to laying and connecting fibre are developed, but not at the same pace as alternatives since computing and software doesn't help much when it comes to digging holes.

Fibre is therefore becoming relatively costlier compared to alternatives – a phenomenon known as Baumol's cost disease (a term originally coined for activities where it is not possible to economise on labour and which therefore become relatively costlier over time). Computing and software can increase the capability of fibre, for example, via wave division multiplexing, but beyond a certain point the value differences versus alternatives is negligible compared to the growing cost difference.

The concept of fibre to the 5G (FT5G) embraces the fact that the last leg will be wireless, and recongises that allowing computing and software to play a greater role may push the fibre aggregation point further back into the network, thereby overcoming Baumol's cost disease.

Traffic growth versus peak bandwidth demand

Traffic growth and peak bandwidth requirements are different things. The capacity of fixed access technologies, including ADSL, greatly exceeds typical data use. Usage at peak times may or may not be constrained by peak capacity (Mbps), but there is substantial scope for overall traffic (GB) to grow.

The reason for this is that an expansion of hours of use, for example for streamed video, could greatly increase traffic whilst having little, if any, impact on peak bandwidth requirements.

[65] In the case of satellite in terms of re-usable first stage boosters (which require software control to land), steerable antenna arrays and precise pointing for free space lasers.

A copper line offering just 10 Mbps could support data consumption of 3,240 GB/month if used continuously.[66] An all-fibre network is not required to support traffic growth.

Conclusion

Demand depends on the level of aggregation. An individual use might range from 250 Kbps for NB-IOT (a 4G internet of things standard) to 5-10 Mbps for video on a mobile device.

Aggregate within household demand might approach around 25-50 Mbps, whereas aggregate demand at a few macro cell sites might exceed 10 Gbps (with the majority under a Gbps). The wireless component of end-to-end connectivity is also more likely to constraint bandwidth and latency than the extent of fibre.

There is no one size fits all, and a mix of technologies will be capable of meeting anticipated requirements including fixed wireless, copper-fibre hybrids and fibre.

[66] Cisco forecast growth of 20% per annum for Western Europe between 2015 and 2020, below historical growth rates. Cisco, *Cisco VNI Forecast and Methodology, 2015-2020*, June 2016.

4. Weighing up uncertainty

> "Prediction is very difficult, especially about the future" Niels Bohr

The known unknowns

Whilst the previous section set out a view that the evolution of demand for peak bandwidth may be modest and that a range of technologies are well positioned to meet demand, the outlook is riddled with uncertainties:

- Demand for peak bandwidth is uncertain. Adoption of new applications could stimulate growth, whilst advances in compression and the pivot to mobile could see growth stagnate.
- The future capabilities, costs and pace of deployment of different access technologies is uncertain. The prospects for point-to-point wireless as a fixed substitute are also uncertain (trials in the US may help clarify this uncertainty).
- Willingness to pay for ubiquitous and consistent mobile access relative to nomadic access is uncertain – though applications benefiting from ubiquitous wireless are proliferating.
- The evolution of mobile networks, the location and capacity of future macro and small cells, the best way to connect cells to the core network and the nature of, and use cases for, 5G are uncertain.

The usual prescription in these circumstances is to keep options open where possible by waiting to see, taking fast incremental steps, maintain a technology agnostic stance and learning from experience and trials.[67]

Keeping options open

Two ways to keep options open are to take incremental steps and remain technology agnostic.

Mobile and Wi-Fi access

For mobile networks investment can be made site-by-site via upgrades and cell splitting as new technology becomes available and in response to growth in traffic across the network.

[67] Dixit and Pindyck, Investment under uncertainty, Princeton University Press, 1994.

Further, successive generations of technology – 2G, 3G, 4G and 5G – are not only more capable, but lower the unit cost of carrying data. Innovation and trials are required, but investment can occur incrementally and adapt over time (though up-front capital commitments may be required to acquire new spectrum tranches).

Backhaul to the core network

In relation to mobile backhaul, there is an evolving mix of technologies including copper, fibre and microwave links (and no policy plans or targets). In relation to backhaul from indoor Wi-Fi, existing targets include universal availability of 30 Mbps and adoption by 50% of consumers of 100 Mbps access by 2020.

The focus on the premise in relation to policy and target reflects priorities formed in an era when fixed access and the PC dominated, and may reflect the fact that the location of future premises is mostly known (whereas the location of future mobile sites is unknown). This focus is increasingly anachronistic.

An alternative approach, having achieved universal access to 2 Mbps and substantial ongoing progress towards near universal availability of 30 Mbps, would be to leave further increments to consumers and investors. A basic broadband USO might also be adopted to support social inclusion and participation in the digital society and economy.

Further, allowing a mix of market driven upgrades does not preclude further upgrades as technology develops, including the option of replacing fixed access with wireless or taking fibre all the way to the premise. The costs of doing so may also then be lower, as Figure 9 from a KPN investor presentation illustrates.[68]

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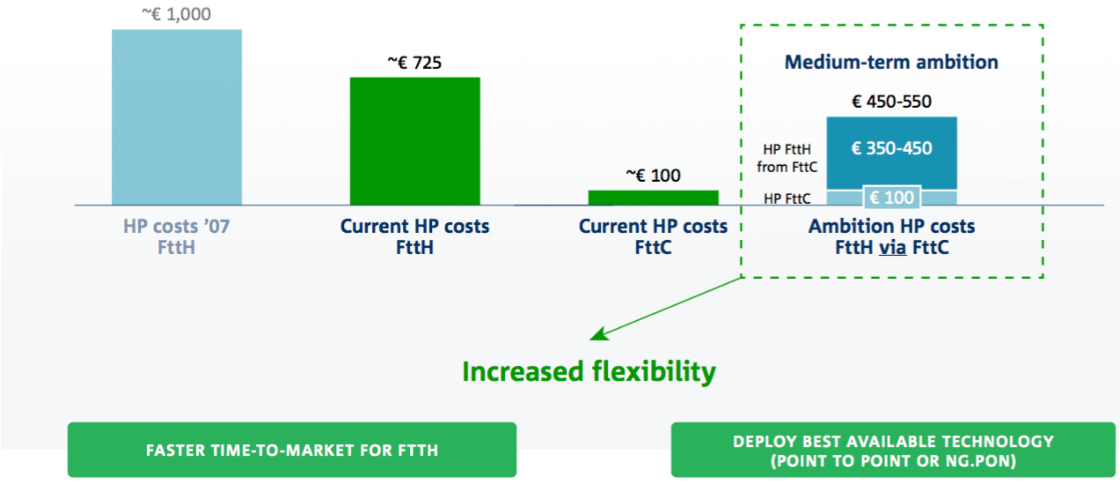
[68] KPN, *KPN capital markets day,* March 2016.

Figure 9

FttC offers great perspective to roll-out FttH if needed



Learning from others

A range of technology upgrades have been pursued globally, and trials of a range of technologies conducted. One can learn from this experience. The benefits, or not, of more "ambitious" early access upgrades can also be assessed. Finally, one can learn lessons where others revise their plans due to changing circumstances.

Early upgrades to FTTP

Japan and Korea were early to pursue FTTP (Korea also has a substantial amount of fibre to the building with VDSL, with upgrades to G.fast planned[69]), yet it is far from clear that new applications emerged as a result or that FTTP generated wider benefits in terms of ICT use. In relation to Japan Kushida noted that: [70]

> "Japan quickly discovered that taking advantage of the broadband environment to produce innovation, productivity growth, and economic dynamism, was far more difficult than facilitating its creation… Like Europe, Japan was not home to the ICT lead-user enterprises and industries that drove the ICT revolution, producing innovation and productivity gains. Moreover, the advent of US-centered cloud computing services potentially decreases the minimum bandwidth requirement to access global-scale computing power. The development of wireless technologies far cheaper than

[69] G.fast news, *Korea SK added to the G.fast map*, 2016.
[70] Kenji Kushida, "Public Private Interplay for Next Generation Access Networks: Lessons and Warnings from Japan's Broadband Success", *Communications and Strategies*, 2013.

> Japan's nationwide FTTH also merits serious consideration for European policy discussions."

In relation to South Korea the OECD noted that:[71]

> "While Korea is a world leader in the provision of ICT goods and benefits from extensive broadband deployment, the share of firms with less than 50 workers that engaged in e-commerce in 2013 was only 15%, one of the lowest in the OECD. For large companies, the share is higher at 25% but still below the OECD average of 40% (OECD, 2015e). Similarly, the share of Korean small firms using cloud computing was the fourth lowest in the OECD in 2014 (OECD, 2015c), reflecting a lack of skilled workers."

Others, who deployed some FTTP, have reassessed their investment options and priorities based on experience, evidence regarding demand and the development of competing technologies including fibre-copper hybrids and wireless (which utilise advances in software and computing to achieve higher bandwidth from existing copper and radio spectrum).

Amongst those who have reassessed their options and plans are Verizon and Google fibre who are exploring "wireless fibre"[72], the Australia NBN which has switched from FTTP to a mixed technology approach including VDSL[73]; whilst KPN and Swisscom have also switched from FTTP to VDSL and G.fast. Commenting on the Swisscom strategy their chief technology officer is reported as saying:[74]

> "Herren reckons 100 Mbps should be enough for anyone, but the carrier is making sure the network design will let it pull fibre out to premises if need be."

In favourable circumstances, where population density is high, duct and pole access are available and copper line lengths are long, FTTP may remain the technology of choice. For example, extensive investment in FTTP has been pursued in Portugal, Spain and Malta. There are also instances where FTTP, whilst not the main access technology, is seeing some expansion. For example, in the UK, BT have announced an expanded role for FTTP alongside VDSL deployment and planned a G.fast upgrade[75]; whilst Virgin have

[71] OECD, *OECD Economic Surveys Korea*, May 2016.
[72] Vox, *Why Google is giving up on its dream to bring super-fast broadband to everyone*, 26 October 2016.
[73] NBN, *Strategic Review*, December 2013.
[74] Light Reading, *Swisscom Claims Europe's First Commercial G.fast*, October 2016.
[75] Ars Technica, *BT Openreach boss says "we don't lack ambition," tight-lipped on breakup fight*, September 2016.

increased their footprint expansion share of FTTP from 25% to 50% (versus cable).[76]

However, FTTP is typically not the technology of choice for the entire market, with the possible exception of city states.

Weighing the upside & downside from accelerated fibre

Potential upside

The case for FTTP, beyond those instances where it is quick to deploy and costs are comparatively low due to favourable circumstances, is that delivering substantially higher bandwidth will generate benefits and that it is better to "future proof" the network by going all fibre in one step.

However, there is no clear evidence of benefits or user incremental willingness to pay for speeds approaching a gigabit/sec, whilst there may be quicker and cheaper ways of delivering substantial speed upgrades using other technology solutions.

Evidence that is advanced tends to be based on extrapolation from statistical inferences based on past low speed upgrades. For example, one study considered increases over the period 2008 to 2010, when speeds were around 8 Mbps.[77] Extrapolating from past changes in speed in the tens of Mbps to the Gbps range, as the Commission impact assessment does, is not well founded (it is also assumed that each doubling of speed delivers the same benefit i.e. benefits scale with the log of speed without limit).

However, and putting the challenge of statistical inference regarding GDP changes to one side, speed thresholds for applications including browsing, audio and video have been passed. For example, lossless FLAC music streaming involves a bit rate of 1.4 Mbps versus 320 Kbps for high quality streaming[78]; whilst 4K video approaches the limits of human perception for typical in-home screen sizes and viewing distances. Further, download time savings do not double for each 10-fold speed increase, they increase by 10%.

It has also been argued, in Article 13 of the proposed European Electronic Communications Code (the code) that extending fibre to the premise would pave the way for higher density cellular networks:

[76] Virgin, *Third Quarter 2016 Fixed Income Release*, November 2015.
[77] Ibrahim Kholilul Rohman and Erik Bohlin, *Does Broadband Speed Really Matter for Driving Economic Growth? Investigating OECD Countries*, April 2012.
[78] https://support.tidal.com/hc/en-us/articles/202401122-What-Is-The-Difference-Between-Normal-High-And-HiFI-

> "The roll-out of such 'very high capacity networks' will further increase the capabilities of networks and pave the way for the roll-out of future mobile network generations based on enhanced air interfaces and a more densified network architecture."

However, the need to densify mobile networks is likely to arise in the near-term, so fibre may be deployed to new cellular sites ahead of deployment to premises in many locations. Reality is also likely to be a far cry from the claim by the Fibre to the Home Council Europe that:[79]

> "…without FTTH or FTTB there will be no 5G deployment."

FTTH is not necessary to deploy 5G. Further, it is not clear that an FTTP network would offer strong complementarity to deployment of fibre to new cell sites, and the costs and time required to deploy FTTP may make the two mutually exclusive in large parts of the EU in the near-term. However, near-term extension of fibre to serve a denser cellular network may lower the costs of subsequent extension to the premise on a targeted basis.

The risk in terms of potentially foregone benefits of not moving immediately and directly to FTTP appear small, and the decision is in any case reversible if new evidence emerges.

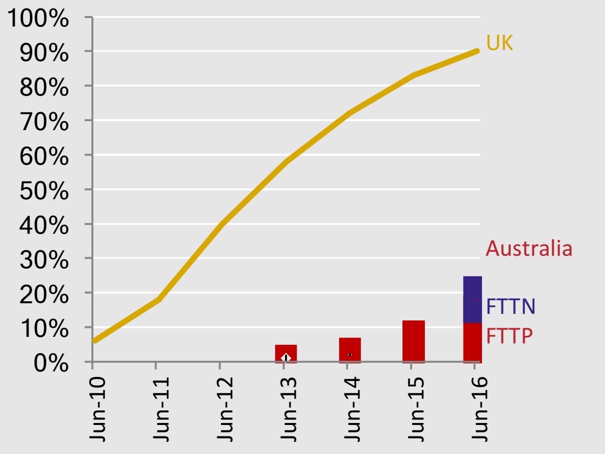
Potential downside

In a range of circumstances FTTP is both more costly and slower to deploy than alternatives. Doubling down on FTTP may therefore result in a slower upgrade of capability, and can therefore involve a tradeoff between:

- "Future proofing" (which may in any event not be required or prove premature); and
- "Now proofing" via a rapid upgrade based on more readily deployed wireless and copper upgrades.

Doubling down on FTTP may therefore delay upgrades, applications development and use – thereby pushing back demand for higher capacity networks.

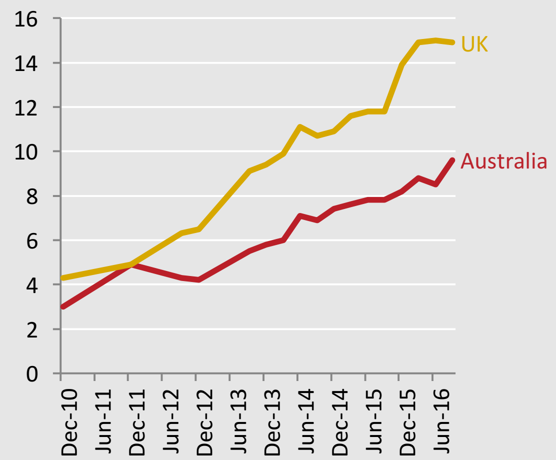
Figure 10: FTTN can be faster to deploy[80]



[79] Fibre to the Home Council Europe, *Europe needs an ambitious Gigabit connectivity agenda based on ubiquitous fibre network*, December 2016.
[80] nbn & BT, annual and quarterly reports.

Experience in Australia illustrates the risks - FTTP proved slow to deploy, but the planned approach also ruled out upgrades of existing copper networks utilising VDSL and DOCSIS technology. The result, in terms of the pace of deployment benchmarked against the predominantly VDSL strategy pursued by BT in the UK, is illustrated in Figure 10. Following a switch in strategy in Australia to FTTN in September 2015[82], deployment is accelerating.

Figure 11: Broadband speed, Mbps (Akamai)[81]



Slow deployment of FTTP in Australia has dragged down improvements in average speed, as Figure 11 illustrates. However, the switch to FTTN in Australia should see a pick-up in average speed as deployment and adoption accelerate.

The likely outcome of an accelerated or all fibre scenario may therefore be the reverse of that assumed in the EC impact assessment,[83] namely that broadband speeds would be higher at all points in time versus the counterfactual upgrade scenario. Shifting to an all fibre scenario would be likely to slow increases in average speed, at least in the near term.

Financial crowding out

Given the cost of pursuing accelerated FTTP, not only might it crowd out other potentially competing upgrades, but it may also crowd out other investment priorities including investment in universal service, mobile coverage, mobile network densification and 5G transition.

A BCG study found that comprehensive FTTP would involve substantial capital expenditure relative to other priorities including 5G[84] (a study by Analysys Mason for the EC reached a similar conclusion[85]). BCG found that the required connectivity investment would be around €360bn to enable FTTH broadband for all European households and €200bn in 5G radio access networks, and that this would take 25 years to deliver at the current pace. This leaves the following options:

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[81] Akamai, *State of the Internet* reports (various dates)
[82] *nbn scales to meet first quarter targets*, 8 November 2016.
[83] https://ec.europa.eu/digital-single-market/en/news/proposed-directive-establishing-european-electronic-communications-code (Part 2, Figure 3 on page 273)
[84] BCG, *Building the Gigabit Society: An Inclusive Path Toward Its Realization*, November 2026.
[85] Analysys Mason, *Costing the new potential connectivity needs*, 2016.

- Utilise public funds to fill the gap, which may be challenging given the economic and fiscal situation in Europe, and might in any case not deliver rapid FTTP deployment (as proved the case in Australia).
- Reprioritise capital expenditure with a mixed technology approach for fixed access whilst accelerating mobile expansion, densification and 5G transition.
- See wireless ambitions scaled back in order to accommodate accelerated FTTP.

Given the pivot towards mobile and the potential economic and social payoff from ubiquitous connectivity, as opposed to doubling down on fibre access to the premise, the 2nd option above appears preferable.

A FT5G vision would keep options open

A FT5G vision recognises that the last leg is wireless (mobile or Wi-Fi) and keeps options open in terms of where traffic is aggregated over fibre. It recognises that a mix of technologies can provide the initial link from the wireless edge back to fibre including copper and point-to-point wireless, and that the precise way in which the point of fibre aggregation changes over time is subject to considerable uncertainty.

Conclusion

Deployment of FTTP at scale does not appear to have delivered benefits (to date) in comparison with alternative upgrade options, and some have scaled back planned FTTP investment in favour of copper upgrades and fixed wireless.

There is no one size fits all solution, with the appropriate choice depending on circumstances, with a growing range of technologies capable of delivering very high speed broadband.

Accelerating an all fibre vision involves little, if any, upside versus an incremental approach, would delay near term "now proofing" and would crowd out or delay other investment options including mobile ubiquity and 5G transition given capital constraints.

A balance of risks analysis therefore suggests keeping options open where possible and learning from experience. A FT5G vision is consistent with this conclusion.

5. Policy implications of a mobile & wireless first vision

"Wireless has no future" Lord Kelvin

This section considers the policy implications of a mobile and wireless first vision, whilst the following section applies the findings to the European gigabit vision and code.

Relevant market changes from a policy perspective

Relevant changes, from a network policy perspective, include the following:

- Mobile is personal (with mobile the "PC" has finally arrived). Underlying demand therefore stems from applications running on the individual device or thing (and not the household *per se*).
- End-to-end connectivity includes wireless. Mobile devices connect via wireless, with some Wi-Fi only and others connecting via cellular or Wi-Fi. End-to-end connectivity should therefore be assessed including the wireless access element i.e. fibre does not extend to the user/device even where fibre reaches the premise.
- Developers develop for mobile. The global market is mobile and more than half of users' attention in developed markets is on mobile. Developers and applications providers therefore strive to make their applications bandwidth efficient.
- There is no one size fits all. In the voice era, voice had a well-defined, and dedicated, network requirement. Bandwidth demand now varies enormously by application (from IoT to video) and with the point of network aggregation (from home Wi-Fi router to large macro cell site).
- More fibre will be required. However, we don't know where, and connecting premises is not the obvious priority. More wireless access points will be installed in response to demand growth, and some will be connected using fibre. The location, timing and required capacity of future wireless access points will evolve dynamically and is uncertain.

Telecoms dynamics versus utility networks

Telecoms networks differ from utility networks including pipes and wires businesses; with telecoms networks having the following dynamic characteristics:

- Rapid innovation and falling unit costs with advances including 5G, VDSL, DOCSIS 3.1 and higher capacity satellites.
- Competition between cable, telco and mobile networks and entry by fibre and wireless startups, and possibly low earth orbit low-latency high-capacity satellite.
- Differentiation on a customer by customer basis e.g. on the basis of speed; whereas residential electricity is 240 volts.
- Uncertainty regarding spatial demand, with the location of future mobile sites not known, and residential fixed broadband adoption far from universal.

Utilities – pipes and wires - are stable in comparison. There is less innovation, competition, service differentiation and more universal and predictable adoption (though advances in battery storage and local generation may make electricity distribution more dynamic).

Telecoms is different, and the pivot towards mobile and wireless is accentuating the difference. In deciding the approach to policy and regulation, we should take the dynamic nature of telecoms networks and markets into account.

High-level implications for policy

The implications for policy are as follows:

- Ubiquity and greater consistency of indoor and outdoor wireless is likely to be more economically and socially valuable than ever-higher speeds to the premise.
- Incentives, rather than plans set in stone, are required to deliver continuous market driven upgrades to coverage, performance and capacity where and when required. Profit opportunities, rather than plans and fixed returns, are required to motivate efficient technology and pricing choices.
- Technology and business model agnosticism, and competition between rival technologies, are necessary to support continuous innovation consistent with user needs.

In the following section the gigabit society vision and proposed telecoms code are evaluated, based on the above principles.

6. Refining the gigabit vision & code

"In order to make progress, one must leave the door to the unknown ajar." Richard Feynman

Refining the gigabit society vision

The Commission proposes three connectivity objectives for 2025 as part of the gigabit society vision:[86]

> "1. All main socio-economic drivers, such as schools, universities, research centres, transport hubs, all providers of public services such as hospitals and administrations, and enterprises relying on digital technologies, should have access to extremely high - gigabit - connectivity (allowing users to download/upload 1 gigabit of data per second).
>
> 2. All European households, rural or urban, should have access to connectivity offering a download speed of at least 100 Mbps, which can be upgraded to Gbps.
>
> 3. All urban areas as well as major roads and railways should have uninterrupted 5G coverage, the fifth generation of wireless communication systems. As an interim target, 5G should be commercially available in at least one major city in each EU Member State by 2020."

The targets go beyond the exiting 2020 target for ubiquitous availability of 30 Mbps to the premise, and include 5G. They double down on the past approach, with a nod to our wireless future.

However, the focus on ever higher access speeds to the premise, in a world in which mobile and wireless dominate, appears anachronistic. It risks encouraging further upgrades for those who already have good broadband whilst moving the least well served – those who don't have next generation access or cannot get decent broadband at all - further down the queue. It also risks crowding out required capital expenditure to deliver wireless ubiquity, higher wireless capacity and 5G transition.

Future value will flow from ubiquitous high capacity connectivity, not just at home but on the move. 5G will be part of the mix, but more advanced versions of 4G will dominate in terms of coverage and use for the foreseeable future. More consistent delivery of 5-10 Mbps to individual users almost everywhere (which would require aggregate

[86] European Commission, *State of the Union 2016: Commission paves the way for more and better internet connectivity for all citizens and businesses*, September 2016.http://europa.eu/rapid/press-release_IP-16-3008_en.htm

speeds to the premise of around 25-50 Mbps to support up to five simultaneous users) should be the priority.

Both New Zealand and Australia have pursued extensive state funded fibre to the premise programmes (with Australia now de-emphasising FTTP), but neither country had aspirations for anything approaching universal availability of fibre, or 100 Mbps, to the premise. By 2025, the New Zealand Government's vision is for:[87]

- "99 per cent of New Zealanders able to access broadband at peak speeds of at least 50 Mbps (up from 97.8 per cent getting at least 5 Mbps under RBI)
- The remaining 1 per cent able to access to 10 Mbps (up from dial up or non-existent speeds)."

The requirement that connections can be upgraded to gigabit is unduly restrictive. One technology can substitute for another, and copper-fibre hybrids can be upgraded via software or by bringing fibre closer to the premise. "Wireless fibre", and potentially gigabit satellite[88], may also offer alternatives to fixed connectivity. A technology which could offer significant gains today should not be ruled out because that particular technology might itself not offer gigabit speeds in future.

Schools, universities and hospitals etc. will require higher speeds, and not all have high speed connections today. However, one size does not fit all and some may require considerably more than 1 Gbps by 2025, whilst others might be well served with less. The focus should be on user requirements, and a small school, business or health centre might be well served with speeds well below 1 Gbps at much lower cost (globally connectivity targets for schools tend to be tailored to the size of school[89]).

The Netherlands has expressed doubts regarding the Commissions proposed target of 100 Mbps across Europe.[90] A more fundamental question is whether such targets, beyond basic universal service levels, add value. Targets may help motivate needed regulatory reform, but blunt targets risk distracting attention from priorities including ubiquitous connectivity and rapid upgrades in response to demand. Targets also risk locking in a focus on old priorities and technologies in a changing market.

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[87] Communications Minister Amy Adams, *Ambitious target set for rural broadband*, October 2015.
[88] Ars Technica, *SpaceX plans worldwide satellite Internet with low latency*, gigabit speed, November 2016.
[89] Cisco, *School Connectivity for the 21st Century*, 2015.
[90] The Minister of Foreign Affairs, *Nr 2234 Letter from The Minister of Foreign Affairs*, November 2016.

If, on balance, non-binding targets are considered helpful, they should be targeted rather than blunt – recognising different needs, the cost of delivery in different circumstances and the role of a mix of technologies and competitive deployments.

Very high capacity networks

The draft electronic communications code introduces the concept of a very high capacity network (VHC network):[91]

> "…future 'very high capacity networks' will require performance parameters which are equivalent to what a network based on optical fibre elements at least up to the distribution point at the serving location can deliver. This corresponds in the fixed-line connection case to network performance equivalent to what is achievable by an optical fibre installation up to a multi-dwelling building…" Recital 13.

> "For the purposes of this Directive: (2) 'very high capacity network' means an electronic communications network which either consists wholly of optical fibre elements at least up to the distribution point at the serving location or which is capable of delivering under usual peak-time conditions similar network performance in terms of available down- and uplink bandwidth, resilience, error-related parameters, and latency and its variation. Network performance can be considered similar regardless of whether the end-user experience varies due to the inherently different characteristics of the medium by which the network ultimately connects with the network termination point." Article 2(2), Definitions.

The definition is focused on access to the premise and is narrowly defined; whilst in principle admitting technologies other than FTTP it may in practice restrict regulatory incentives to FTTP, limiting choice and therefore innovation, competition and investment.

From an end-to-end perspective, almost everything will connect via wireless and almost nothing directly via fibre (other than cloud computing facilities). Connectivity to the premise, and the difference a VHC network as defined would make in practice, should be reappraised given this reality, and a genuinely technology agnostic approach adopted.

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[91] European Commission, *Proposal for a Directive of the European Parliament and of the Council establishing the European Electronic Communications Code* and *Annexes*, October 2016.

An alternative connectivity ambition

An ambition in region of 50 Mbps would be consistent with real world Wi-Fi capabilities, anticipated mass market demand and a range of access technologies suited to different local circumstances. Increased scope for a technology mix consistent with the ambition would also increase the prospects for infrastructure competition.

An alternative approach would be to focus, in relation to access availability to the premise, on an "outside-in" strategy targeting improvements for those households with the lowest quality connectivity first, ahead of those with reasonable broadband access today.

This approach would minimise the risk of crowding out private investment whilst maximising network effects (where benefits for each user increase as a function of the total number of users). However, even 10 Mbps, delivered with low latency, is challenging for the final few percent of households (unless low earth orbit satellite technology becomes available).

This vision for fixed connectivity could be coupled with a more ambitious vision for ubiquitous high capacity mobile.

Incentives for investment and deep competition

Investment is driven by the anticipated return, versus the alternative of not investing or simply waiting to see. Both infrastructure competition and pricing freedom increase the payoff from anticipating and meeting end user needs versus failing to do so, and therefore promote investment. Initiatives to reduce costs would also improve anticipated returns and promote investment.

Risk and reward should also be aligned. Renting infrastructure (shallow competition) should not be preferred to building it (deep competition). Further, investment and deep competition are not in tension, but are mutually reinforcing.

Complexity, uncertainty and expectations

The code is unnecessarily complex. For example, it addresses in some detail how co-investment might be assessed, when what is required is a general assessment of the anticipated competitive impact access commitments irrespective of the specific business model.

Without simplification and clarification now, the complexity in the code may not be clarified for investors for some time, allowing for the time required for implementation and interpretation by national regulatory authorities.

It is possible that investors will take a favourable view of how the code will ultimately be interpreted. But it would not be surprising if they decided to keep at least some options open and held back from investing, particularly where large up-front commitments and a long-term view of returns is required.

Simplicity and adherence to clear principles would help promote trust and investment during the transition to the code.

Technology agnosticism, investment and deep competition

The definition of VHC networks risks deterring investment:

- It may raise the cost of investment, resulting in less.
- It may raise doubt regarding pricing freedom for investment that may not be classed as a VHC and the conditions for pricing flexibility, resulting in less.

The aim, rather than a pre-defined step change in capacity, should be incentives for upgrades over time, using the full range of technologies. No one knows enough to pre-judge the optimal plan for network evolution, which will in any case have to adapt over time.

The benefits of, and willingness to pay for, bandwidth beyond a few tens of Mbps per user may be low, and are unquestionably uncertain. It is not even clear that peak bandwidth demand will increase, given advances in compression and other "smart" techniques (data consumption almost certainly will increase but mainly requires a higher capacity core network rather than faster access "on-ramps").

On the supply side, the unexpected has happened before (G.fast over greater line lengths), and may happen again (gigabit wireless or a constellation of low earth orbit satellites). We should not presume that FTTP is a natural end-point, or is "future proof" against economic stranding.

If we are not sure what demand will emerge and how it should be economically met, then we don't need a plan we need incentives; and incentives rest on deep competition and pricing freedom.

Benefits of pricing freedom

The code notes that:

> "Due to uncertainty regarding the rate of materialisation of demand for the provision of next-generation broadband services it is important in order to promote efficient

> investment and innovation to allow those operators investing in new or upgraded networks a certain degree of pricing flexibility." Recital 178.

Uncertainty regarding demand is part of the rationale for pricing flexibility. However, the rationale goes further and includes promoting efficient investment choices, allowing differentiation to support adoption and inclusion, revealing information regarding demand, supporting efficient mobile offload and reducing the risk of fibre stranding.

With pricing freedom, needs are more likely to be met because service-price differentiation allows willingness to pay for higher capacity networks to be reflected in investment returns, thereby promoting investment.

Penetration of broadband is also fostered because, not only does differentiation allow higher prices for who value the top service tiers most highly, it also allows lower prices for more price sensitive customers. Differentiation also allows adoption of different service-price points to be monitored, thereby providing information regarding willingness to pay.

Pricing freedom, by encouraging adoption of fixed as well as mobile, also promotes efficient Wi-Fi offload to low incremental cost fixed networks. Absent pricing freedom, fixed adoption would be lower, with additional within premise traffic carried unnecessarily by mobile networks – either increasing congestion or requiring additional (inefficient) investment in sites and spectrum.

There is also a competitive rationale at work here, particularly if the high up-front costs of FTTP are to be recovered. The more households go mobile only the greater the risk of fibre stranding. Pricing freedom is necessary to reduce this risk for investors.

Requirements for service price differentiation

The September 2013 EC recommendation on costing and non-discrimination recognised the need for differentiation at the wholesale level to support retail differentiation:[92]

> "…pricing flexibility at wholesale level is necessary to allow both the access seeker and the SMP operator's retail business to introduce price differentiation on the retail broadband market in order to better address consumer

[92] European Commission, *Commission recommendation on consistent non-discrimination obligations and costing methodologies to promote competition and enhance the broadband investment environment*, September 2013.

> preferences and foster penetration of very high-speed broadband services”

Pricing flexibility is required at the wholesale level, as otherwise it would be arbitraged away. If a single price control is set for access to fibre then no one can charge more than average for higher bandwidth (because they would be undercut), and no one can charge less than average (without losing money). Given that differentiation is required at the wholesale level, active not passive access to next generation access should be preferred.

Triggers for pricing freedom

Under the code, the trigger for pricing freedom introduced with the 2013 costing and non-discrimination recommendation is in principle preserved:

> “To prevent excessive prices in markets where there are operators designated as having significant market power, pricing flexibility should be accompanied by additional safeguards to protect competition and end-user interests, such as strict non-discrimination obligations, measures to ensure technical and economic replicability of downstream products, and a demonstrable retail price constraint resulting from infrastructure competition or a price anchor stemming from other regulated access products, or both.” Recital 178.

The focus should be on effective non-discrimination and proportionate remedies i.e. equivalence of inputs should not necessarily be required. Effective and proportionate non-discrimination obligations in a given situation depend on the balance of costs and benefits, and any existing commercial access commitments.

Moreover, the emphasis on investment in VHC networks as currently defined in the code, coupled with greater regulatory forbearance for co-investment and wholesale only models, could in practice see pricing freedom for network upgrades applied more sparingly. This concern is reinforced since the code refers to VHC networks as a consideration in deciding whether price controls are appropriate:

> “In determining whether or not price control obligations would be appropriate, national regulatory authorities shall take into account long-term end-user interests related to the deployment and take-up of next-generation networks, and in particular of very high capacity networks.” Article 72(1)

The code also refers to the risk involved in making investment, but "with particular regard to investments in and risk levels associated with very high capacity networks" (Article 71(2)(d)). However, the risk involved in investment in VHC networks is not necessarily higher, and may be lower, than other network investments – depending on how demand and willingness to pay for high speed access develops. An *a priori* view regarding the riskier investment is not warranted, neither is it necessarily desirable to reward risk *per se*.

Triggers for removal of ex ante regulation

In the code, different business models – notably co-investment and wholesale only - can trigger the removal of *ex ante* regulation if they meet certain conditions. The code offers an explicit prospect of forbearance in relation to co-investment and wholesale only models.

The preference in terms of regulatory forbearance for these models in the code, versus a vertically integrated operator subject to competition, does not clearly and directly relate to a competition based framework. It also adds unnecessary complexity. These models may not always be preferred by access providers and/or entrants. Provided an assurance of competition is provided by models including unilateral commitments or long-term commercial contracts, the prospect of forbearance should also apply to such models.

In relation to co-investment the code states that:

> "Due to current uncertainty regarding the rate of materialisation of demand for very high capacity broadband services as well as general economies of scale and density, co-investment agreements offer significant benefits in terms of pooling of costs and risks, enabling smaller-scale operators to invest on economically rational terms and thus promoting sustainable, long-term competition, including in areas where infrastructure-based competition might not be efficient. Where an operator with significant market power makes an open call for co-investment on fair, reasonable and non-discriminatory terms in new network elements which significantly contribute to the deployment of very high capacity networks, the national regulatory authority should typically refrain from imposing obligations pursuant to this Directive on the new network elements, subject to further review in subsequent market analyses." Recital 184.

However, risk regarding the rate of materialisation of demand remains with co-investment (each investor is sharing the cost of investment, but the risk remains). Co-investment, or other models including long-term contracts, can however ensure that access seekers share some of the upside/downside risk, but only if they are not free to enter and exit such arrangements at their discretion over time (at least not without penalty). Such terms should be negotiated between the parties and agreements treated as binding, irrespective of whether co-investment is involved or not.

Recital 184 goes on to say, in relation to non-participants on co-investment that:

> "Provided due account is taken of the prospective pro-competitive effects of the co-investment at wholesale and retail level, national regulatory authorities can still consider it appropriate, in light of the existing market structure and dynamics developed under regulated wholesale access conditions, and in the absence of a commercial offer to that effect, to safeguard the rights of access seekers who do not participate in a given co-investment through the maintenance of existing access products or – where legacy network elements are dismantled in due course – through imposition of access products with comparable functionality to those previously available on the legacy infrastructure."

This includes a provision which has parallels with the anchor product concept (and which is defined independent of the underlying access technology). Recital 178 should also define the legacy or anchor product in technology agnostic terms.

In relation to wholesale only models the code states that, provided there are no downstream retail interests, forbearance should apply even where the entity is found to have significant market power (Article 77). Whilst a wholesale only model removes the relevance of an economic replicability test, it does not alter other concerns in relation to market power. A wholesale only model should not therefore be treated more favorably than a vertically integrated model, other than in removing any relevance for an economic replicability test. The criteria regarding wholesale pricing freedom and forbearance should be the same.

In relation to commercial agreements the code merely recognises their potential role in lifting regulation, stating that:

> "During the gradual transition to deregulated markets, commercial agreements between operators will gradually become more common, and if they are sustainable and

> improve competitive dynamics, they can contribute to the conclusion that a particular wholesale market does not warrant ex ante regulation." Recital 156

Recognition of the potential role of commercial agreements is welcome. Commercial agreements, by potentially offering an extended commitment which would prevent foreclosure, should be sufficient especially alongside infrastructure competition and the presence of an anchor product (or infrastructure competition alone depending on its intensity) to warrant removal of *ex ante* regulation. This is consistent with a competition based analysis.

Absent commercial agreements, it should also in principle be possible to accept a voluntary undertaking from an operator not to foreclose wholesale access (an undertaking, if breached, could lead to the reintroduction of *ex ante* regulation).

Co-location and sharing of network elements

The code also contains new provisions regarding the sharing of network elements. Article 59(2) is a fixed symmetric provision which includes an extension of existing provisions:

> "National regulatory authorities may extend to those owners or undertakings the imposition of such access obligations, on fair and reasonable terms and conditions, beyond the first concentration or distribution point to a concentration point as close as possible to end-users, to the extent strictly necessary to address insurmountable economic or physical barriers to replication in areas with lower population density."

Article 59(3) is a new symmetric provision which is aimed at mobile and, under certain conditions, allows obligations beyond local passive infrastructure for all passive and active assets including spectrum:

> "Member States shall ensure that national regulatory authorities have the power to impose on undertakings providing or authorised to provide electronic communications networks obligations in relation to the sharing of passive or active infrastructure, obligations to conclude localised roaming access agreements, or the joint roll-out of infrastructures directly necessary for the local provision of services which rely on the use of spectrum, in compliance with Union law, where it is justified on the grounds that…"

Further, Article 70 is a new asymmetric provision:

> "1. A national regulatory authority may, in accordance with Article 66, impose obligations on operators to meet reasonable requests for access to, and use of, civil engineering including, without limitation, buildings or entries to buildings, building cables including wiring, antennae, towers and other supporting constructions, poles, masts, ducts, conduits, inspection chambers, manholes, and cabinets, in situations where the market analysis indicates that denial of access or access given under unreasonable terms and conditions having a similar effect would hinder the emergence of a sustainable competitive market at the retail level and would not be in the end-user's interest.
>
> 2. National regulatory authorities may impose obligations on an operator to provide access in accordance with this Article, irrespective of whether the assets that are affected by the obligation are part of the relevant market in accordance with the market analysis, provided that the obligation is necessary and proportionate to meet the objectives of Article 3…"

These provisions, which come on top of the symmetric access regime for civil engineering asserts introduced by the EU's cost reduction Directive 2014/61/EU, could be expected to discourage investment in new infrastructure, particularly risky infrastructure, including network extension and – in particular in the case of Aritcle 59(3) - 5G.

Regulation at multiple layers

The code allows for the possibility for regulation at multiple layers, but does not have clear provisions discouraging regulation at multiple levels in each network location (the efficient access layer may differ by location, for example, depending on the availability of duct).

Regulation at multiple wholesale levels is complex, and discourages investment and innovation. Where regulation is required it should be focused on one wholesale layer. Where an operator runs two network technologies in parallel during transition any price controls should also be focused on one anchor product on one network.

Spectrum availability and cost reduction

Clear spectrum rights, indefinite license duration and the opportunity to trade spectrum would help keep options open.

Additional licence exempt spectrum could also improve Wi-Fi performance.[93]

Further, efficient allocation of spectrum rather than revenue raising should be the aim; and recurring fees are not required to promote efficient use.[94]

Spectrum availability, and minimization of spectrum costs consistent with efficient allocation, should be coupled with initiatives to lower site and investment costs, particularly in relation to public infrastructure.[95]

One way to motivate improved access and planning requirements for both high speed fixed and ubiquitous mobile would be to make connectivity ambitions and coverage obligations conditional on agreement to an access charter on a community by community basis.[96]

Conclusion and way forward

The code, by interpreting and defining investment objectives in a narrow and technology specific way, is likely to discourage step changes in network capability that would otherwise be achieved more quickly, across a wider set of customers at lower costs using a mix of technologies. An aspiration for higher capacity networks would be better served by strong incentives for continuous upgrades of wired and wireless networks driven by emerging and anticipated demand.

The code, rather than reducing expectations of regulation for the predominant investment model, may lead to increased expectations of regulation; thereby discouraging investment. The impact could be particularly pronounced in the period leading up to 2020, given the complexity of the code and uncertainty over its interpretation.

The reason the code may be viewed as increasing, rather than reducing regulation, is that it places emphasis on investment in narrowly defined VHC networks and introduces new avenues for regulation in relation to access to, and sharing of, network elements.

The code introduces new opportunities for forbearance, yet these are focused on VHC investment alone and co-investment and

[93] Ofcom, *Improving spectrum access for consumers in the 5 GHz band*, May 2016.
[94] Williamson, Marks and Chan, *Annual licence fees - you cannot have your cake and eat it*, January 2014.
[95] *5G Manifesto for timely deployment of 5G in Europe*, July 2016.
[96] This is similar to the approach Google Fibre have used in the US to reduce local obstacles to deployment. Agreement to cost reduction measures is a condition for rollout in the given community. *Google Fiber City Checklist*, February 2014.

wholesale only business models that may not see widespread adoption, particularly in the near-term.

A preferable approach would be business model agnostic, but offer clear guidance to regulators as to how to take different business models into account in a competition based framework. Long-term commercial agreements, co-investment or potentially a unilateral commitment not to foreclose wholesale access could – coupled with infrastructure competition or an anchor product constraint – lead to forbearance. On the other hand, a wholesale only model, absent infrastructure competition, could be subject to access price controls but not an economic replicability test (given there are no retail prices controlled by the wholesale only network).

An approach along the above lines would allow considerable simplification and clarification of the code, whilst offering stronger incentives for investment and protecting customers long and short-term interests. It would also help to sustain the trend towards increased infrastructure competition which offers the best prospect of good outcomes over time.