plum

Future proofing Wi-Fi – the case for more spectrum

A report for
Cisco

January 2013

Brian Williamson
Thomas Punton
Paul Hansell

About Plum

Plum Consulting offer strategy, policy and regulatory advice in the telecoms, media and online sectors; and on radio spectrum as a key sector input. We draw on economics, our knowledge of the sector and our clients' perspective to shape and respond to convergence.

Plum Consulting, 26-27 Southampton Street, Covent Garden, London, WC2E 7RS
T: +44(20) 7047 1919, **www.plumconsulting.co.uk**

Table of Contents

Executive Summary

This study focusses on the potential benefits, in terms of enhanced speed and capacity, of additional 5 GHz spectrum for unlicensed Wi-Fi use in Europe.

Wireless is becoming the default way in which devices connect to the internet. Wi-Fi first gained commercial traction around 1999 and has grown enormously since. The development of the fixed broadband market provided a stimulus for Wi-Fi, and Wi-Fi enhanced the value of broadband connectivity by supporting multiple devices and wireless connection to a single access point.

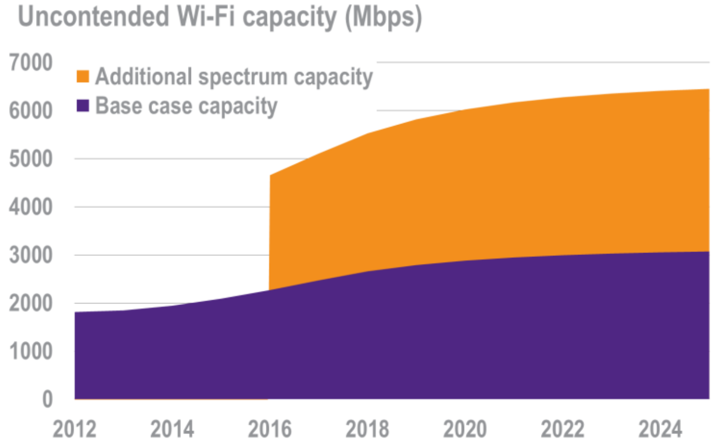
Wi-Fi supports a substantial share of access traffic to the internet in Western Europe; and this share is anticipated to grow to 60% of total internet traffic by 2016. In addition, Wi-Fi is increasingly utilised for direct device-to-device connectivity (additional to internet traffic).

In terms of existing demand there is evidence that Wi-Fi (primarily utilising 2.4 GHz spectrum), at particular times and locations, is heavily contended resulting in reduced quality of service. Although existing 5 GHz spectrum is lightly used in many locations today this is expected to change quickly and in the foreseeable future additional spectrum would offer benefits.

Not only is the diversity of devices utilising Wi-Fi growing rapidly, but devices increasingly incorporate the potential to utilise the 5 GHz band (which was previously held back with 2.4 GHz only devices). For example, smartphones have grown since 2007 from zero to over 50% adoption in some countries, yet the ability of smartphones to utilise the 5 GHz band is comparatively recent (for example, from September 2012 for the iPhone). As dual band devices and simultaneous dual band routers proliferate use of 5 GHz will increase rapidly.

Demands in terms of expected quality of service will also increase due to rising broadband access speeds and growing use of cloud services. Further, the new 802.11ac Wi-Fi standard, to be finalised in 2014, can support higher speeds, however the full benefit depends on the availability of wide spectrum channels (up to 160 MHz compared to 20-40 MHz today). The likelihood that a wide channel is available for a given user would increase with more available spectrum.

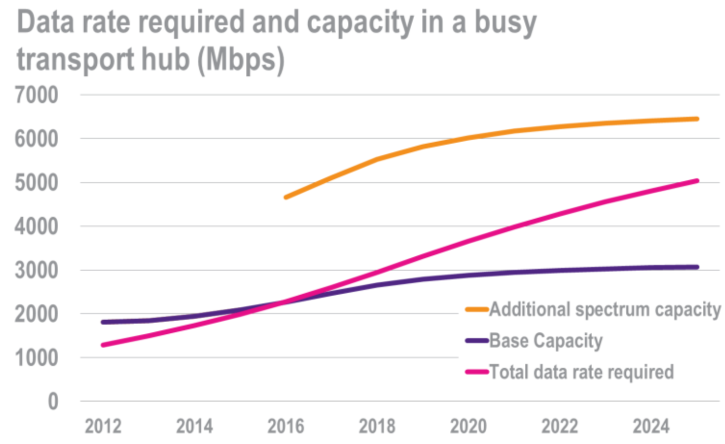
The existing 455 MHz of 5 GHz spectrum for Wi-Fi, pioneered by Europe, was assigned over 10 years ago. Now Europe and the US are contemplating allowing Wi-Fi to share additional 5 GHz spectrum. Additional spectrum would provide greater capacity and support higher speeds in contended environments involving shared use. The following illustrates the capacity of Wi-Fi with and without additional spectrum at 5 GHz.



Source: Plum Consulting

Analogous with the transition from 3G to LTE and the allocation of additional licensed spectrum and wider spectrum channels for mobile broadband, the full benefits of the development of Wi-Fi will only be achieved with additional shared spectrum.

To model spectrum demand we considered a range of use cases and found that total data rates could exceed available capacity without additional spectrum in the near term; as illustrated for the transport hub case study shown below.



Source: Plum Consulting

We also considered residential case studies and found that the speeds Wi-Fi delivers in a contended environment may fall below the 100 Mbps Digital Agenda for Europe target without additional spectrum.

To quantify the benefits from additional spectrum we considered the potential improvement in speed for residential users (valued based on evidence in relation to willingness to pay for higher speeds) and the potential for increased mobile offload (valued based on mobile network costs avoided). The estimated benefits for Europe, in net present value terms, were €12.3 billion and €4.0 billion respectively giving a total of €16.3 billion.

Other potential benefits, which we did not quantify, include time savings from faster device-to-device file transfers, cost savings in managed networks e.g. sports stadiums, potential new applications in health care and industry and competition benefits.

Potential benefits must be considered alongside potential costs, which can be substantial where there are potentially competing spectrum uses, clearance costs and/or interference issues that must be addressed. However, 5 GHz spectrum is above the frequency range favoured for mobile use (globally agreed IMT mobile bands go no higher than 3.6 GHz) and Wi-Fi has a detect and avoid technology in relation to use of the band by radars.

Nevertheless, a study undertaken by CEPT is required before it is decided that additional 5 GHz spectrum could be utilised for Wi-Fi. We propose, given the potential benefits and lead times that such a study is undertaken now.

1 Introduction and context

Plum was commissioned by Cisco to conduct a study on whether there is a case for additional 5 GHz spectrum for unlicensed Wi-Fi use in Europe.[1]

1.1 Europe has played a leading role in the development of Wi-Fi

Wi-Fi technology is based on the IEEE 802.11 standard for Wireless Local Area Networking (WLAN) first ratified in 1997, at that point capable of data rates of just 2 Mbps. It was not until 1999 and the launch of 802.11b that Wi-Fi gained commercial traction. In 2002 the 802.11g standard was launched with headline speeds of up to 54 Mbps. Increased speeds and falling prices meant that Wi-Fi began to grow in popularity in the home and office. Wi-Fi was also complementary to fixed broadband, allowing more mobility and portability and supporting multiple users/applications from a single access point.

The availability of spectrum in the 5 GHz band for Wi-Fi, in addition to spectrum at 2.4 GHz, was pioneered by Europe from 1996, with extension to 455 MHz of 5 GHz spectrum agreed in 1999[2] and harmonised in Europe in 2004.[3] In parallel with the availability of additional spectrum Wi-Fi standards have evolved to enable higher speed connectivity and improved range.

Fourth generation Wi-Fi, 802.11n, began to emerge in 2007. 802.11n is capable of delivering headline speeds of up to 600 Mbps through the use of Multiple-Input Multiple-Output technology (MIMO), although the more common version has headline speeds of 150 Mbps.

802.11ac is currently in development with the standard expected to be finalised in February 2014.[4] Due to its ability to utilise much wider channels than previous technologies, 802.11ac is only targeting the 5 GHz band.[5]

802.11ac will be capable of “headlines speeds” of up to 3.6 Gbps – though maximum speeds are around 60% of the headline speed at best allowing for data overheads. The actual throughputs achieved depend on network protocols and distance from the access point, achievable rates will vary from zero to around 60% of the headline speeds.

[1] The term “Wi-Fi” is a trademark of the Wi-Fi Alliance signifying device certification. We use the term generically throughout this report given its widespread usage.

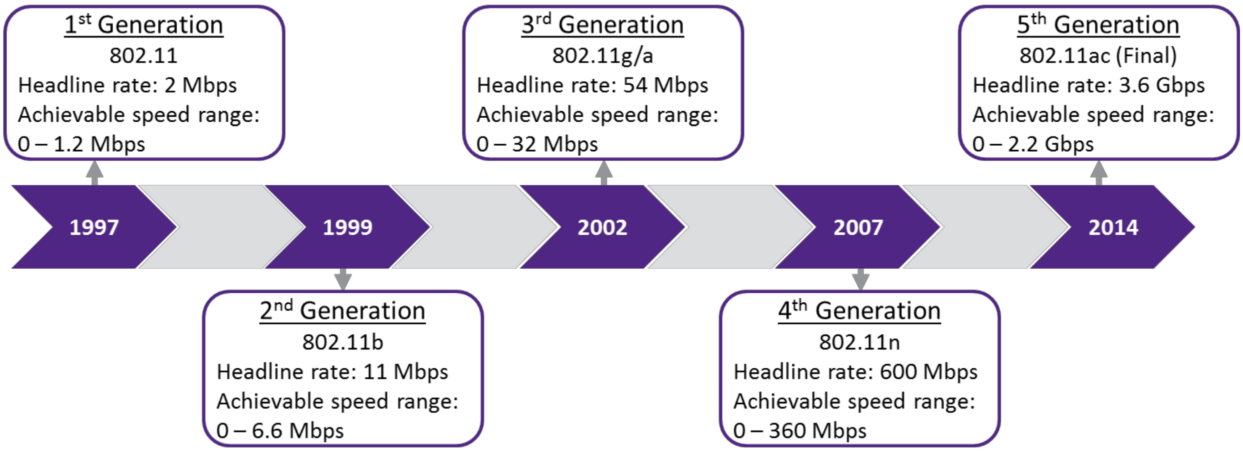
[2] ERO. May 1999. “Compatibility studies related to the possible extension band for HIPERLAN at 5 GHz.” http://www.erodocdb.dk/Docs/doc98/official/pdf/REP072.PDF

[3] ECC/DEC/(04)08 of 9 July 2004 on the harmonised use of the 5 GHz frequency bands for the implementation of Wireless Access Systems including Radio Local Area Networks (WAS/RLANs).

[4] http://www.ieee802.org/11/Reports/802.11_Timelines.htm

[5] http://blog.broadcom.com/connecting-everything/5g-wifi-introducing-a-wi-fi-powerful-enough-to-handle-next-gen-devices-and-demands/

Figure 1-1: Evolution of Wi-Fi standards and “headline” speeds



Source: Plum Consulting, Broadcom

1.2 The US and Europe are considering allocating additional 5 GHz spectrum for Wi-Fi

Wi-Fi has become a key part of the ICT ecosystem playing a role in mobile offload, public access and in-premise access. Wi-Fi is also expected to play an expanding role in terms of device-to-device connectivity, for example, streaming content from a smart device to a large screen. Wi-Fi connectivity already accounts for more traffic than the wired internet and far more than the mobile internet.

Wired and wireless broadband connectivity more generally is undergoing upgrades; with fibre closer to the premise and the transition to LTE. Europe also has explicit goals in terms of the Digital Agenda targets for universal availability of 30 Mbps and take-up by 50% of households of 100 Mbps broadband services by 2020. Further, wired device-to-device connectivity is also undergoing upgrades with the transition to, for example, USB 3.0.

As Wi-Fi will increasingly be incorporated into almost everything, and as other elements of the ICT ecosystem including last mile connectivity evolve, Wi-Fi too needs to adapt to ensure that it continues to facilitate – and not constrain – data capacity and high speed connectivity; as the following indicates;[6]

> *“Lord Clement-Jones: But on fibre to the cabinet, for the foreseeable future, you really have enough capacity?*
>
> *Sean Williams [Group Strategy Director for BT]: Yes. In our experience, once you put an 80 Mb fibre to the cabinet service into a premises, the broadband network is no longer the speed bottleneck. What you find is that the home network is the thing that cannot cope with the speeds, or the home devices cannot cope with the speeds, or the home wi-fi cannot cope with the speeds…”*

Analogous with the evolution from 3G to LTE (or 4G) Wi-Fi technology standards are in transition to 802.11ac which offers higher speeds and more efficient use of spectrum. However, as with LTE, the new Wi-Fi standard offers the greatest benefit if additional spectrum is also made available (802.11ac

---

[6] http://www.parliament.uk/documents/lords-committees/communications/Superfastbroadband/ucCOMMS120612ev7.pdf

can utilise spectrum channels of up to 160 MHz) to support higher speeds, in addition to the additional capacity available with more spectrum.

In both Europe and the US there are spectrum reallocation goals and targets, and the opportunity to provide additional 5 GHz spectrum for Wi-Fi is under consideration. Further, in China the MIIT announced in September 2012 that it would open an additional 455 MHz of spectrum in the 5 GHz band, bringing China into alignment with the existing position in Europe and improving global economies of scale in relation to development of the 5 GHz band.

In the US the government has identified additional spectrum in the 5350–5470 MHz band and in the 5850–5925 MHz band to be investigated for use by Wi-Fi.[7] In Europe the Radio Spectrum Programme of March 2012 includes a reference to spectrum availability for wireless access:[8]

> *"Wireless access systems, including radio local area networks, may outgrow their current allocations on an unlicensed basis. The need for and feasibility of extending the allocations of unlicensed spectrum for wireless access systems, including radio local area networks, at 2,4 GHz and 5 GHz, should be assessed in relation to the inventory of existing uses of, and emerging needs for, spectrum, and depending on the use of spectrum for other purposes."*

Further, in September 2012 the European Commission issued a Communication promoting the shared use of spectrum which noted that:[9]

> *"The trend towards a connected society demonstrates the added value of low spectrum access barriers in licence-exempt shared bands as the breeding ground for wireless innovation that stimulates the development and deployment of more resilient wireless technologies." Page 5.*

> *"A new generation of RLAN equipment (known as 802.11ac), expected to be on the market by the end of 2012, could approach the user speeds of fixed line networks. While depending on existing RLAN spectrum at 5 GHz, such developments will require very broad frequency channels that are currently limited in number." Page 8.*

The Communication, proposed that:

> *"Depending on the outcome of technical sharing studies and of the impact in the market, considering the designation of additional harmonised licence-exempt spectrum for RLAN services (Wi-Fi) at 5 GHz through a revision of Decision 2005/513/EC."*

1.3 This study focusses on the benefits of additional 5 GHz spectrum for Wi-Fi

The focus of this study is on the possible extension of the availability of unlicensed spectrum for wireless access systems at 5 GHz. We focus on the rising demands on Wi-Fi in terms of capacity and speed and the potential for additional spectrum to ensure that the full range of applications, including offload, that Wi-Fi can support is not constrained.

[7] Middle Class Tax Relief and Job Creation Act of 2012. http://docs.house.gov/billsthisweek/20120213/CRPT-112hrpt-HR3630.pdf

[8] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:081:0007:0017:EN:PDF

[9] European Commission. September 2012. Promoting the shared use of radio spectrum resources in the internal market. http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/com/com-ssa.pdf

In relation to the costs of utilising additional 5 GHz spectrum for Wi-Fi we assume natural replacement of equipment (i.e. no up-front equipment cost) and note that it appears unlikely that there would be a significant opportunity cost in terms of foregone alternative uses at 5 GHz (IMT allocations for mobile go no higher than 3.6 GHz and assuming the Wi-Fi detect and avoid capability proves effective in relation to additional 5 GHz spectrum).

Nevertheless a study, undertaken by CEPT (Spectrum Engineering Working Group and ratified by the Frequency Management Working Group), would be required before it is decided that this spectrum could be released for RLAN use. The time required for a study and approval process, combined with the time involved with router replacement cycles, implies that the process would need to be initiated now in order for additional spectrum to be available and utilised by, say, 2016.

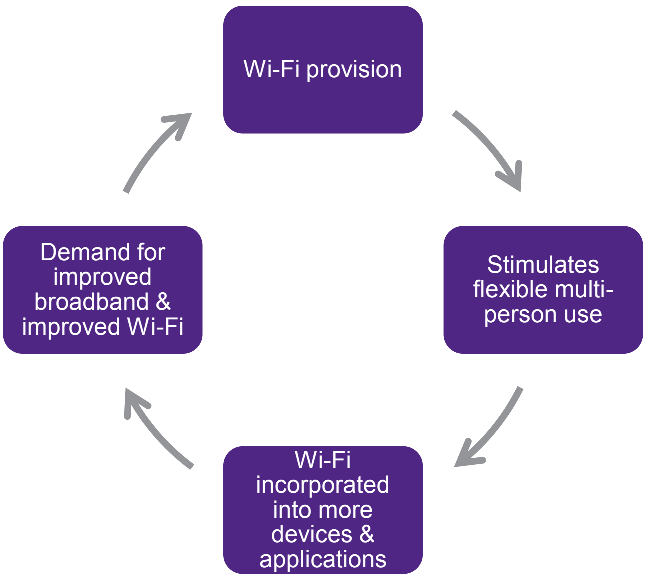
2 Wi-Fi use has grown fast and continues to develop

2.1 Wi-Fi is a key part of a wider ecosystem

Wi-Fi, through its ability to support flexible shared wireless access and to facilitate wireless network "innovation without permission" in relation to wireless networking (analogous to innovation without permission over the open internet) has become a key part of the wider ICT ecosystem and an important driver of broadband demand.

Wi-Fi growth has been stimulated by the synergy between growth of access points and incorporation of Wi-Fi capability into a growing variety of devices including laptop computers, smartphones and tablets (and increasingly other devices, for example, cameras, printers, internet enabled radios, portable music players, Hi-Fi systems, set-top boxes, televisions and even a pen[10] and light bulb control[11]). Figure 2-1 illustrates this virtuous cycle between Wi-Fi access and device availability and the associated shift in behaviour.

Figure 2-1: Virtuous circle of Wi-Fi provision, behaviour change and demand for improved broadband and Wi-Fi



Wi-Fi also has a complementary role to mobile networks in providing data offload and indoor wireless connectivity. Applications are also emerging for use of Wi-Fi to communicate directly between devices, thereby providing an alternative to physical connections such as USB and device to large screen connections including HDMI.

[10] http://www.livescribe.com/uk/

[11] A hybrid Wi-Fi and Zigbee solution. http://blogit.realwire.com/Introducing-Philips-hue-the-worlds-smartest-LED-bulb-marking-a-new-era-in-home-lighting

2.2 The future prospects for Wi-Fi are bright

Wi-Fi has developed rapidly both in terms of the technology and its use. There are a number of indications that the role of Wi-Fi and the demands upon it will expand enormously over the coming decade. Six key drivers are summarised in Figure 2-2.

Figure 2-2: Six key drivers for improved Wi-Fi capacity and speed

The post PC era: The rise of smart personal devices is expanding the market for Wi-Fi. For example by 2012 three countries in Europe – Norway, the UK and Sweden - had over 50% smartphone penetration,[12] a device category that has only really existed since the first Apple and Android devices in 2007. Smartphones can also be used to establish mobile Wi-Fi hotspots. Tablet ownership is also growing rapidly with 25% of the population in the US owning a tablet in July-August 2012 versus 4% in September 2010.[13]

Wi-Fi in everything: Intel announced "Moore's Law Radio" in September 2012 which allows a Wi-Fi transceiver to be fabricated on a chip allowing incorporation into almost everything - Intel Chief Technology Officer Justin Rattner said "… *if it computes, it connects…without wires*."[14] Further, a growing number of devices are Wi-Fi only i.e. they do not have Ethernet, USB or 3G/LTE connectivity options. Wi-Fi is becoming the default mode of connectivity for a proliferating range of devices.

Device to device Wi-Fi: The industry standard "Wi-Fi Direct" and other applications such as Apple "AirPlay" enable device-to-device streaming and mirroring; enabling, for example, content on a smart personal device to be displayed on a large screen or music to be streamed directly to a compatible music player. Wi-Fi Direct may also be used as a substitute to USB for quickly transferring large files.

***Mesh networks*:** Wi-Fi can also operate in mesh network mode, for example to support low cost deployment of multiple Wi-Fi access points in public places, since each access point does not require wired connectivity. Additional Wi-Fi repeaters' can also be used to extend the range of Wi-Fi in residential and business premises.

Mobile offload and ease of use: Expected improvements to the user experience of Wi-Fi will increase the volume of mobile offload. [15] For example, "Hotspot 2.0", the Wi-Fi Alliance's certification programme to allow Wi-Fi users to seamlessly move between hotspots without manual re-authentication whilst the Wireless Broadband Alliances is working on inter-service provider roaming. Further, integrated LTE and Wi-Fi services are also being commercialised.[16]

The need to match improved fixed connectivity: up until recently Wi-Fi was more than capable of matching residential fixed connectivity which has evolved from around 1 Mbps a decade ago to an average 10 Mbps today. However, as progress is made towards the European Digital Agenda targets of 30 Mbps for all and 50% take up of 100 Mbps by 2020 the capacity of existing shared spectrum for Wi-Fi to match these speeds will be called into question.

[12] Our mobile planet. http://www.thinkwithgoogle.com/mobileplanet/en/

[13] Pew. October 2012. "25% of American adults own tablets." http://www.pewinternet.org/Reports/2012/Tablet-Ownership-August-2012.aspx

[14] http://newsroom.intel.com/community/intel_newsroom/blog/2012/09/13/intel-labs-tunes-into-a-wireless-future-where-everything-that-computes-is-connected

[15] http://stakeholders.ofcom.org.uk/binaries/research/telecoms-research/infrastructure-report/Infrastructure-report2012.pdf

[16] For example, Alcatel Lucent lightRadio™ Wi-Fi simplifies the process of switching between cellular and Wi-Fi networks. http://www.alcatel-lucent.com/wps/portal/!ut/p/kcxml/04_Sj9SPykssy0xPLMnMz0vM0Y_QjzKLd4x3tXDUL8h2VAQAURh_Yw!!?LMSG_CABINET=Docs_and_Resource_Ctr&LMSG_CONTENT_FILE=News_Releases_2012/News_Article_002589.xml

Figure 2-3 shows the global number of Wi-Fi chipsets shipped each year, in 2011 over 1 billion Wi-Fi chipsets were sold. Figure 2-4 shows how the number of smartphones and tablets shipped has grown since 2009; nearly all of these devices are Wi-Fi enabled and will drive traffic over Wi-Fi and help stimulate a wider ecosystem of Wi-Fi devices and applications.

Figure 2-3: Global Wi-Fi chipsets sold

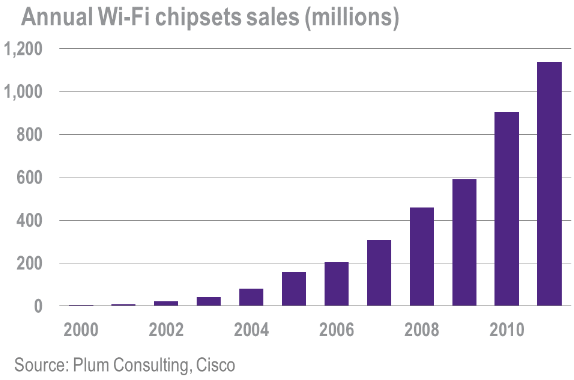
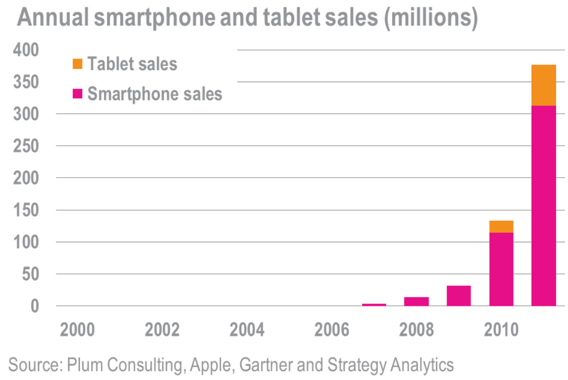


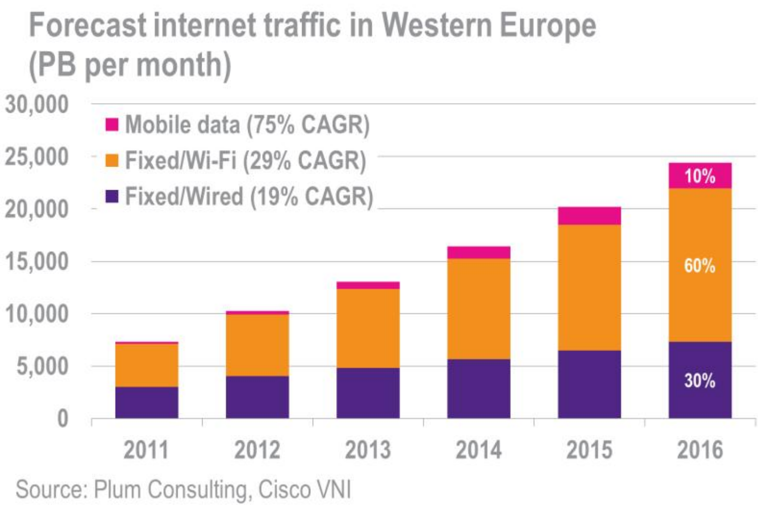
Figure 2-4: Global Android and iOS sales



2.3 Wi-Fi is becoming the dominant form of internet access

As more devices are able to connect via Wi-Fi (with a growing number, including many tablets, only able to connect via Wi-Fi) and given the flexibility of wireless connectivity, Wi-Fi is rapidly growing in importance and Wi-Fi data is anticipated to exceed fixed-wired and mobile data by 2015, and greatly exceeds mobile data today (as illustrated in Figure 2-5 for Western Europe).[17]

Figure 2-5: Anticipated traffic in Western Europe[18]



[17] In some instances non-Wi-Fi wireless is restricted. For example, apps from the Apple store can only be downloaded via wide area 3G/LTE if the file size is less than 50 megabytes.

[18] The country coverage differs slightly from a European Union definition of Western Europe.

The Cisco forecast focuses on sources of internet traffic only and therefore does not assess direct device-to-device traffic over Wi-Fi.

2.4 Wi-Fi will play a key role in device-to-device connectivity

The Cisco forecasts focus on internet traffic. However, a growing and potentially large source of traffic over Wi-Fi is direct device-to-device traffic which may or may not originate from or terminate over the internet. An illustrative example of such traffic would be content streaming from a device to a TV display which may originate from stored content including video and games (or may involve streamed internet content to the device and a further stream to the TV). Apple "AirPlay" is an example of a device-to-device streaming and mirroring application.

Wi-Fi may also be used as a wireless substitute for fixed connectivity (say USB) for file transfer including connection to external storage devices for back-up and local content caching. Such applications put a premium on connectivity speed, particularly as portable device storage capacity grows.

2.5 Conclusion

The range of applications supported by Wi-Fi and the use of Wi-Fi has grown enormously since Wi-Fi was launched in 1999 and continues to grow. Wi-Fi is almost synonymous with broadband and use of Wi-Fi only devices such as tablets is growing rapidly. Wi-Fi is also an established mobile offload technology. New applications including device-to-device content streaming, file transfer and machine to machine applications (M2M) etc. are now also emerging.

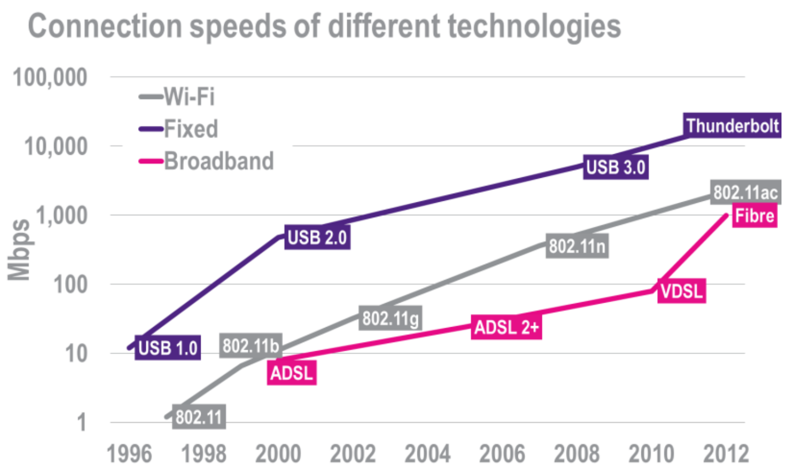
These applications place demands on available technology and spectrum in terms of both the capacity available and the speed that can be supported for multiple simultaneous users/uses. In the next section we assess the capability of Wi-Fi to support these trends with the next generation of technology but with existing spectrum.

3 Wi-Fi needs to match end-to-end connectivity demands

The entire ICT ecosystem continues to develop with data volumes increasing (90% of all digital data is less than 2-years old),[19] and both wireless and fixed access speeds increasing.

Figure 3-1 illustrates how the headline speeds (which may significantly exceed experienced speeds) have developed over time for fixed (wired) broadband, wired device connectivity and Wi-Fi. In order that Wi-Fi does not act as a constraint, and can expand its role in terms of wireless connectivity, it needs to keep pace with other forms of connectivity and with consumer expectations in terms of capability.

Figure 3-1: Headline throughputs of different technologies



Source: Plum Consulting

Note: With contended use of Wi-Fi available speeds may be a fraction of the speeds shown.

As Wi-Fi becomes the default form of connectivity it needs to keep pace with developments in the wider ecosystem if it is not to become the weakest link. The demands Wi-Fi needs to meet in order that it enhances rather than acts as a break on development of the overall ICT ecosystem are two-fold:

- Speed: Wi-Fi needs to deliver speeds consistent, on a shared contended basis, with available broadband access speeds (around 100 Mbps by 2020) and capable of meeting for short durations (with low likelihood of contention) high speed device-to-device connectivity needs (1 Gbps or more).
- Capacity: Wi-Fi needs to be capable of delivering the above speed requirements whilst meeting demand from multiple simultaneous competing uses including user initiated demand and background activity such as automatic synchronisation, update, backup and monitoring tasks.

Since wireless access is inherently shared the above two concepts are related – there must be sufficient capacity to support shared use whilst preserving sufficient headroom for high speed (bursting) data transfer.

[19] IBM, http://www-01.ibm.com/software/data/bigdata/

3.1 The limitations of Wi-Fi today

In order to assess the potential benefits of additional spectrum for Wi-Fi it is important to start from a realistic baseline in terms of what Wi-Fi can deliver. Below we discuss two elements of this:

- First, what speeds Wi-Fi can deliver in theory and in practice. We find that maximum feasible speeds are significantly below headline speeds and that realistic speeds (at distance etc.) are lower still.
- Second, that whilst there is no simple point at which Wi-Fi capacity runs out, performance will deteriorate as utilisation increases.

Future needs in terms of spectrum for Wi-Fi therefore need to be assessed taking account of what Wi-Fi will deliver now and in future as demand grows and as consumer expectations of performance grow (particularly as other elements of end-to-end connectivity improve and use of cloud services grows).

3.1.1 Wi-Fi's typical speeds are well below headline data rates

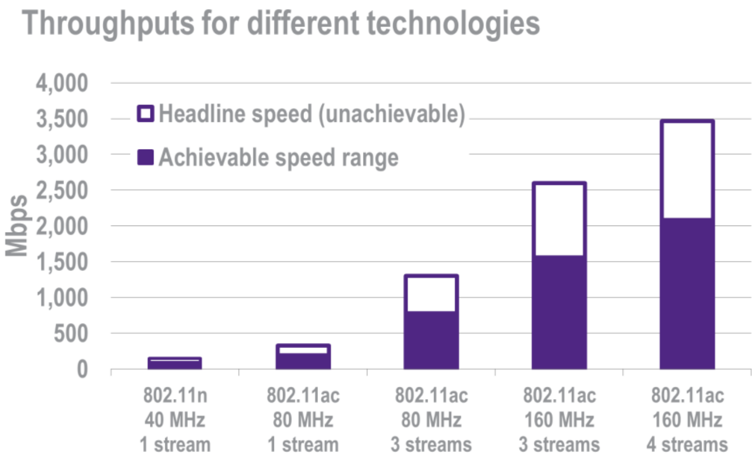
Just as there is a difference between advertised and delivered broadband (wired) speeds there is a difference between advertised headline speeds for Wi-Fi, what is achievable even in ideal circumstances and what may be experienced in practice. Indeed headline speeds for Wi-Fi are never achievable since they represent a maximum bit rate, not a maximum user data transfer rate after allowance for overheads.

The maximum headline speed for a single stream 40 MHz channel is 150 Mbps, this is the speed quoted on the majority of routers sold today (two and three stream variants are available with corresponding headline speeds of 300 Mbps and 450 Mbps). However the maximum feasible speed that can be achieved is only about 60% of this, 90 Mbps (in case of a single stream), due to the overheads mentioned above. In reality the realistic speeds that are achieved will be even lower and depend on the range and attenuation from obstacles. Speed tests are often run by transferring large packets, in everyday use the average packet size will be much smaller than used in ideal test conditions; this further reduces the speeds Wi-Fi delivers in realistic scenarios. Note that these speeds are for a single user (no contention) and in the absence interference.

The maximum headline speed for Wi-Fi has improved with the evolution of Wi-Fi standards and the scope to utilise multiple data streams (Wi-Fi has evolved through a number of standards including 802.11g, n and from 2014 'ac'). The latest 'ac' standard is able to utilise wider spectrum channels - up to 160 MHz – compared to previous limits in the range 20-40 MHz. Multiple streams, perhaps up to 4 in practice, are also feasible with the n and ac standards. However we note that portable batter powered devices tend to be limited to a single stream and until recently smartphones did not utilise the 5 GHz band.

Figure 3-2 shows how headline speeds and achievable speeds have evolved with different technologies. The actual speed achieved will depend upon the number of users, range from the access point and attenuation from obstacles, it will be between zero and 60% of the headline speed.

Figure 3-2: Single user (uncontended) with no interference



Source: Plum Consulting

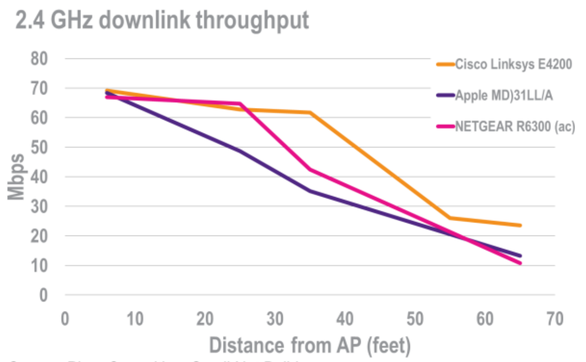
The maximum feasible speed for a single stream 802.11ac in an 80 MHz channel is sufficient to match a 100 Mbps fibre connection speeds. However, as range from the access point increases and spectrum is shared with other nearby users, available speed over Wi-Fi would be likely to fall below the capability of fibre. Further, higher speed fibre connectivity - say 300 Mbps to 1 Gbps – would be likely to offer little if any benefit to users connecting via Wi-Fi.

With multiple streams much higher speeds are possible, though as noted previously this may be challenging for portable battery powered devices. Further, to achieve the speeds shown a substantial quantity of uncontended spectrum must be available, 160 MHz channels compared to the currently used 20 MHz, to achieve a realistic rate of 1 Gbps.

Not only are realistic speeds significantly lower than headline speeds, the maximum realistic speed is only achievable close to the access point. As distance from the access point increases and attenuation from walls and other obstacles reduces signal strength, the throughput received at the device will decline. Figure 3-3 and Figure 3-4 show test results for a number of currently available access points.[20]

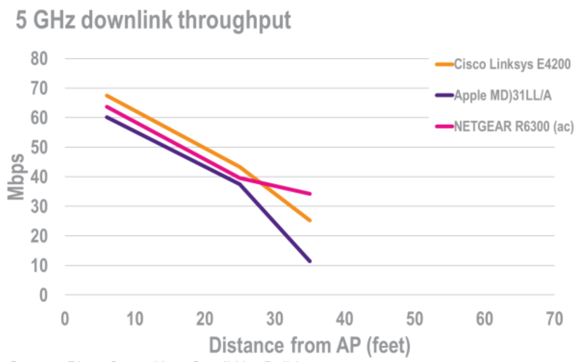
[20] As distance from the access point increases the attenuation from walls and other obstacles also increases, full details of the test conditions can be found on the Small Net Builder website, http://www.smallnetbuilder.com/

Figure 3-3: 2.4 GHz



Source: Plum Consulting, Small Net Builder

Figure 3-4: 5 GHz



Source: Plum Consulting, Small Net Builder

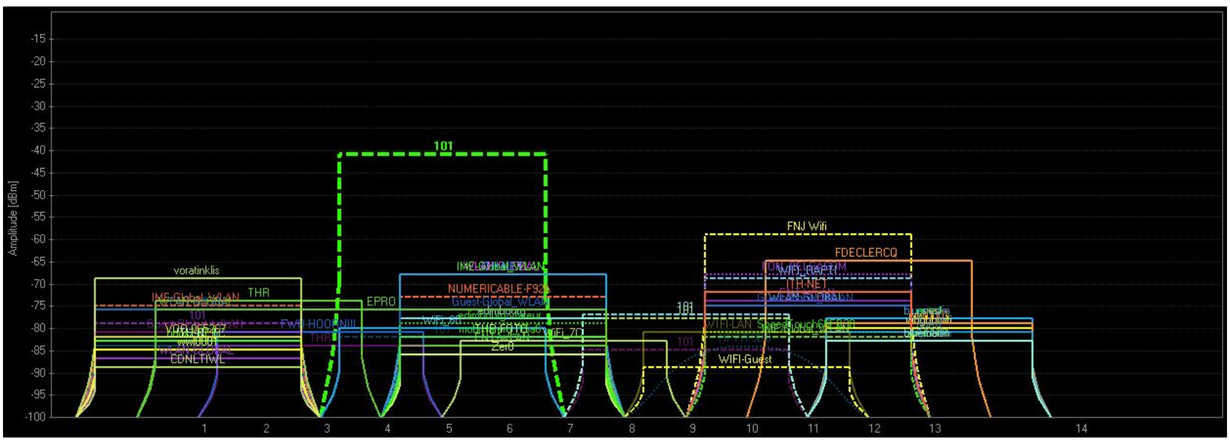
These results highlight how important distance from the access point is in determining real throughputs. The decline in throughputs is greater for the 5 GHz band because the higher frequency reduces the effective range.

3.1.2 Wi-Fi can be contended today

Whilst Wi-Fi offers capacity and speeds that exceed demand in many instances there are a growing range of circumstances in which the demand for capacity and/or speed will exceed the capability of Wi-Fi. However, given that Wi-Fi adapts and shares available resources there is no simple cut-off point at which capacity runs out, rather service degrades. The question of when available spectrum for Wi-Fi is fully utilised therefore requires an answer to the question of what minimum performance is acceptable.

A proxy for the extent of use is provided by the following screen shot of 2.4 GHz Wi-Fi channel use at the CENELEC building during a CENELEC ETSI meeting in Europe. Over 50 access points were detected, which would have presented a busy picture today even had all access points utilised the 5 GHz band in addition to 2.4 GHz.

Figure 3-5: Multiple routers in 2.4 Wi-Fi channels (CENELEC building 2012)



However, ideally one would consider service levels rather than spectrum utilisation in contended environments. Degradation of service levels with utilisation may also depend on the particular service in question as some, for example video streaming, are more demanding in terms of Wi-Fi protocols than others.

It has for several years now been the desire of regulators, in particular Ofcom in the UK, to determine whether the licence-exempt bands are or will become congested. This has been examined at an RF signal level, through modelling and more recently by packet sniffing, acknowledging that privacy issues are significant in the case of the latter.[21] A further study for Ofcom found that:[22]

> *"We have found that it is rare for the user data frame rate to exceed 10% of the total frame rate. The implication is that over 90% of the frames are typically being used to keep the networks running and are not carrying user data. This is an important result, as it suggests that the existing WiFi protocols can use a substantial part of the 2.4 GHz band without carrying significant quantities of user-generated content."*

A study in the Netherlands also gives some indication of overhead mechanisms that come into play when an RLAN channel is used in a dense device environment.[23] While this improves the view of when congestion might or might not occur, it does not directly relate the situation to the user experience. The study found that:

> *"In a busy WiFi environment (college room) only 20% of all frames are data frames. Of these data frames only 1/10 are actual data frames as most data frames are so-called null frames; used to keep a WiFi connection alive in power save mode…It is likely that there is significant interference, probably due to the many WiFi devices."*

Whilst there is no single simple measure of Wi-Fi use of spectrum or what constitutes congestion (or alternatively adequate quality of service), it is clear that today in some locations Wi-Fi offers a low quality of service. Whilst expanded use of the existing 5 GHz band can improve quality of service the anticipated rapid expansion of use and rising expectations in terms of speed will see constraints on speed and capacity at particular times/locations.

3.2 In future Wi-Fi will need to support more traffic and higher speeds

We discussed the growing demands on Wi-Fi in Figure 2-2, these will increase the number of Wi-Fi streams and the amount of traffic, reducing speeds in practice as contention grows. At the same time Wi-Fi will need to support rising expectations in terms of the speed of end-to-end connectivity:

- Fixed broadband connectivity speeds are anticipated to increase around 10-fold to meet Digital Agenda targets of universal availability of 30 Mbps and take-up by 50% of households of 100 Mbps. Fibre to the premise connections may offer higher speeds of 300 Mbps to 1 Gbps or more.

---

[21] Aegis and Transfinite systems. 2004. "Evaluating spectrum percentage occupancy in licence-exempt allocations." http://www.aegis-systems.co.uk/download/1606/perc_ocp_lisc.pdf

[22] Mass. 2009. "Estimating the Utilisation of Key Licence-Exempt Spectrum Bands." http://stakeholders.ofcom.org.uk/binaries/research/technology-research/wfiutilisation.pdf

[23] Jan-Willem van Bloem and Roel Schiphorst. 2011. "Measuring the service level in the 2:4 GHz ISM band." http://eprints.eemcs.utwente.nl/20915/01/report.pdf

- Device to device fixed connectivity speeds continue to increase with the evolution of USB from USB 1 through 2.0 to USB 3.0 with speeds increasing from 1.5-12 Mbps in 1998, to 480 Mbps in 2000 and to 6 Gbps today. The new "thunderbolt" standard introduced in 2011 offers 10 Gbps over copper and 20 Gbps over fibre.
- Mobile broadband speeds are anticipated to increase approximately 5-fold with the transition from 3G to LTE, from 1- 3 Mbps to over 10 Mbps.

Wi-Fi therefore needs to be able to deliver net speeds of at least 100 Mbps in real world scenarios where there are likely to be competing uses/users if it is to keep pace with broadband connectivity. Wi-Fi will also need to deliver net speeds in the 500 Mbps to multi Gbps range for short periods of time if it is to match fixed device connectivity speeds (e.g. USB 3.0) and offer a high quality wireless alternative for file transfer.

3.3 In future Wi-Fi will need to carry much more traffic

Traffic volumes, connection speeds and growth in Wi-Fi use will all put strains on Wi-Fi:

- Wi-Fi will carry a rapidly increasing traffic volume driven by growth in video and cloud services:
  - Mobile data volumes are anticipated to increase 18-fold between 2011 and 2016 with a growing share offloaded via Wi-Fi.[24]
  - The majority of fixed connectivity traffic at home is likely to be via Wi-Fi for the final metres and device-to-device traffic for media streaming and file transfer may grow rapidly.
- Multiple simultaneous use/users of Wi-Fi will increase demand within a given location and increase contention from nearby Wi-Fi use. Wi-Fi chipset sales are expected to be over 1.5 billion in 2012[25] (Figure 2-3 shows the growth over time) and use of multiple devices within the home, office and public Wi-Fi environment is becoming more common.
- Typical device storage capacity is increasing as the cost of memory, in particular solid state memory, falls. Five years ago a smartphone might have had 4-8 GB of memory whereas a range more typical of smartphones and tablets today is 16-64 GB. Increased device storage and downloaded content and applications increase demand for high speed file transfer e.g. the time to transfer a 3GB movie file falls from four minutes to 24 seconds if connection speed increases from 100 Mbps to 1 Gbps.

3.4 Conclusion

The above developments will all increase the pressure on Wi-Fi which risks becoming the weakest link in the end-to-end connectivity ecosystem. Should Wi-Fi fall behind other elements in the chain, which increasingly comprises fibre closer to the end user with the "last metres" dominated by Wi-Fi, then the user experience and demand for faster "last mile" connectivity will be undermined.

---

[24] Cisco. February 2012. Mobile traffic forecast. http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

[25] http://www.abiresearch.com/press/wireless-connectivity-chipsets-revenues-to-exceed-

In the next section we look at the complementary roles of evolving Wi-Fi technology standards and spectrum availability in bridging the gap and ensuring that end-to-end speeds and capacity improve in-line with demands and that competition between Wi-Fi and mobile connectivity continues.

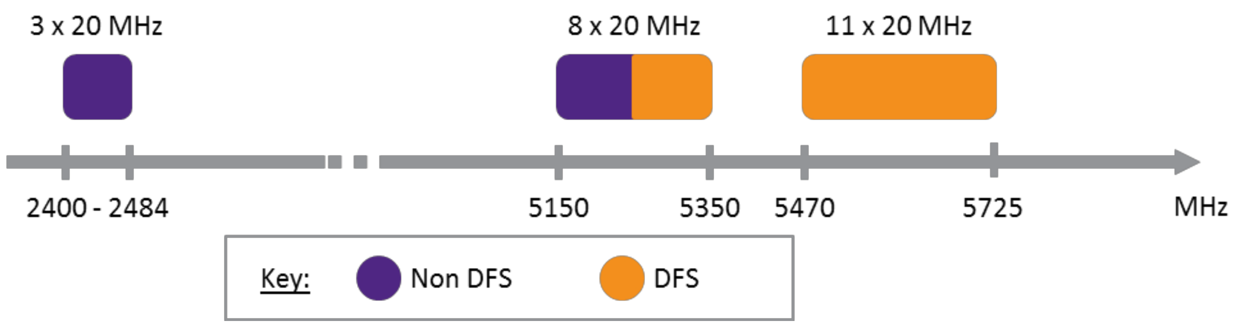
4 More spectrum would enhance the capacity and speed of Wi-Fi

In this section we consider the complementary roles of evolving Wi-Fi standards and spectrum availability in offering enhanced speed and capacity and why, even though the 5 GHz band may be relatively lightly utilised today, this position is expected to change quickly.

4.1 Existing spectrum for Wi-Fi was assigned over a decade ago

Spectrum is available at 2.4 GHz for Wi-Fi and, following an expansion of spectrum available initiated by Europe over a decade ago at 5 GHz. At 5 GHz Wi-Fi operates on a shared use basis and must detect and avoid use by radar (also referred to as dynamic frequency selection or DFS). Figure 4-1 shows the spectrum currently available for use by Wi-Fi devices within Europe showing 2.4 GHZ and 5 GHz spectrum and use on a non-DFS versus DFS basis.

Figure 4-1: Current spectrum availability



There is just over 80 MHz of spectrum available in the 2.4 GHz band; this is the spectrum most commonly used at the moment. Although there is over 80 MHz available this translates into just three 20 MHz channels because of how the band is assigned in the US. In the 5 GHz band there are two blocks of spectrum available; one 200 MHz block between 5150-5310 MHz and one 255 MHz block between 5470-5725 MHz.

The bottom half of the lower block is in non-DFS parts of the band while the rest of the band is shared with radar and therefore requires DFS. Guard bands reduce the total amount of spectrum that is usable to 19 x 20 MHz channels and the split in the band means that it is only possible to form two contiguous 160 MHz channels (within the 8 x 20 MHz and 11 x 20 MHz blocks shown above).

Further, given the possibility that use of one or more channels may be denied at a given location and time if radar use is detected availability of spectrum overall and, in particular, the likelihood that wide 160 MHz channels are available may be reduced in practice.

4.2 Use of 5 GHz spectrum for Wi-Fi will increase sharply

Use of the 5 GHz band has been feasible for many years, but an ecosystem of routers and devices which utilise this band is only now developing. In part this is because historically 2.4 GHz spectrum was sufficient in many locations. However, use of 5 GHz spectrum has also been limited up to now for the following reasons:

- Historically routers were not necessarily dual band (2.4 GHz and 5 GHz). Until recently it was only enterprises that had installed dual band infrastructure, and single band routers continue to be sold (including routers bundled by broadband providers). Further, many dual band routers are not *simultaneous* dual band routers, which limits them to the 2.4 GHz band where dual and single band devices connect at the same time.
- Smartphones were initially only able to operate on the 2.4 GHz band, which not only prevented their use of 5 GHz spectrum but also forced use of 2.4 GHz by all users sharing a non-simultaneous band router. Only recently have dual band smartphone become available e.g. the Samsung Galaxy S2 launched in May 2011 and the Apple iPhone 5 launched in September 2012.

The combination of a limited number of simultaneous dual band routers and a rapid rise in devices capable of utilising the 2.4 GHz band only may therefore have stalled and, in some circumstances, reversed use of the 5 GHz band over the past five years even where 2.4 GHz spectrum was heavily contended. A number of factors can now be expected to produce a rapid shift in this position whereby use of the 5 GHz band has in effect been suppressed:

- As smart devices increasingly adopt the 5 GHz band a rapid shift towards use of the 5 GHz band can be anticipated (recall that with many installed 5 GHz routers will only be utilised if all devices are 5 GHz capable).
- Direct device-to-device applications are anticipated to grow rapidly and can only operate in non-DFS bands since mains power is required to support DFS in practice (to provide sufficient power to support continuous detect and avoid operation).[26] This will tend to push existing applications at 2.4 GHz into the 5 GHz band to avoid increased contention in the 2.4 GHz band.
- The reduced range at 5 GHz will encourage consumers, who may previously have found Wi-Fi performance satisfactory, to adopt wired (including Ethernet over mains power) and wireless measures to extend range. To the extent that a wireless “mesh” of Wi-Fi repeaters are adopted to extend range the speed available over a given channel will be reduced or additional channels will be utilised.[27] In turn this will increase demand for additional 5 GHz spectrum to compensate for the shared use required to extend range.

The above imply that established trends will lead to a rapid transition towards utilisation of current 5 GHz spectrum. Based on assumptions regarding populations of different devices (see Appendix A) we have quantified the anticipated transition towards utilisation of the 5 GHz band.

Figure 4-2 and Figure 4-3 show the evolution of access points and devices respectively in terms of scope to utilise the 2.4 GHz and 5 GHz bands, whilst Figure 4-4 shows the combined impact of these changes in terms of the likelihood of 5 GHz operation. The likelihood of 5 GHz use rises rapidly from 2013.

[26] Mobile devices can receive and transmit data to/from an access point in both the DFS and non-DFS parts of the band because the access point can act as a master determining which channels in the DFS part can be used. However in direct connections between devices there is no master (a master requires mains power to detect radar) and it is therefore restricted to non-DFS parts of the band.

[27] This approach has also been used by O2 in the rollout of public Wi-Fi in the City of Westminster in the UK.

Figure 4-2: Devices by technology in Europe

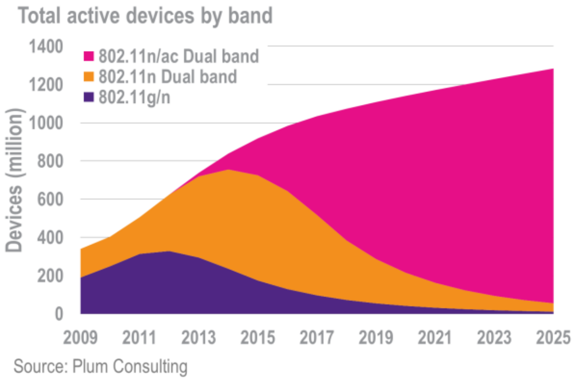


Figure 4-3: APs by technology in Europe

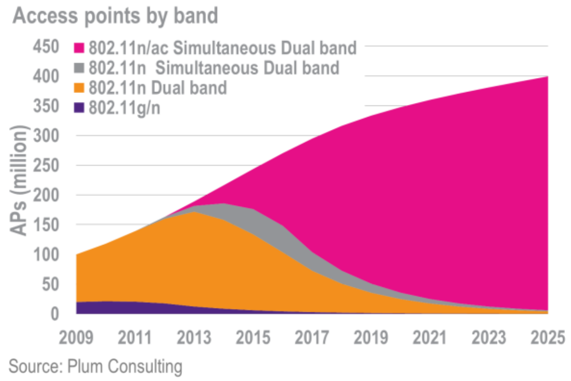
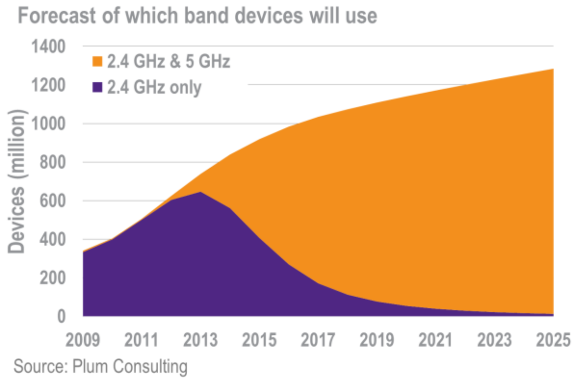


Figure 4-4: Number of devices using the 5 GHz band in Europe



4.3 Additional spectrum would enhance the capacity and speed of Wi-Fi

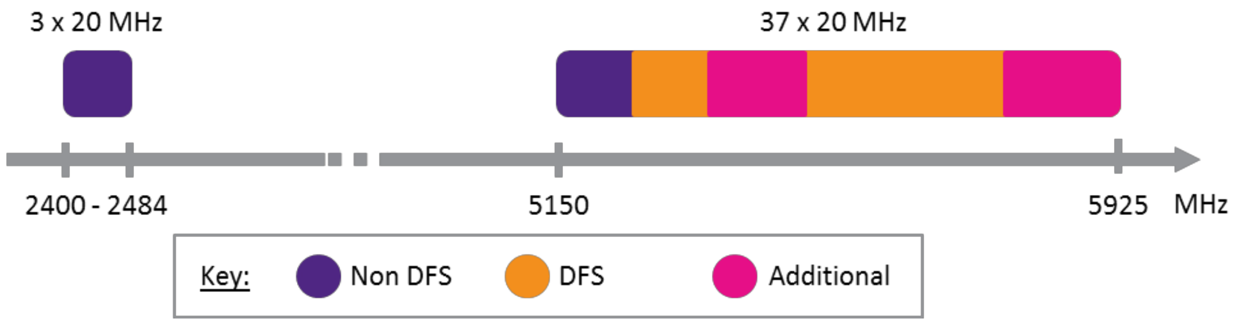
The development of new Wi-Fi standards (g, n and now ac) has increased the potential headline speed of Wi-Fi, but also the efficiency with which it utilises spectrum. However, both sufficient spectrum to meet demand and wide spectrum channels are required for the newest standard – 802.11ac – to achieve its full potential since the new standard can utilise 80 or 160 MHz spectrum channels to deliver peak performance.

Achieving the full potential of wireless technology via both the evolution of standards and suitable spectrum availability for Wi-Fi is analogous to the position regarding the 3G to LTE transition where both the LTE standard and wider spectrum channels (up to 2x20 MHz versus 2x5 MHz for 3G) are required to deliver the full potential of LTE.

4.3.1 Potential 5 GHz spectrum availability for Wi-Fi

We focus on additional 5 GHz spectrum which would be compatible with the growing number of devices able to operate in this band (routers would however need to be changed since they must comply with existing spectrum availability and control what spectrum devices can utilise).[28] At 5 GHz an additional 320 MHz is in principle available which nearly doubles the amount of usable 5 GHz spectrum, as illustrated below (after allowance for the reduced need for guard bands with contiguous spectrum).

Figure 4-5: Proposed spectrum availability



120 MHz of spectrum could be released in the middle part of the band and the top of the band could be extended from 5725 MHz to 5925 MHz, an additional 200 MHz. Apart from 5850 MHz to 5925 MHz this new spectrum is in DFS parts of the bands because radar currently occupies the spectrum. By removing the guard bands in the middle part of the band there would be 37 x 20 MHz channels of usable spectrum available, an increase of 95%; even though the amount of spectrum has only increased by 70%.

4.3.2 Potential wide spectrum channel availability for Wi-Fi

As discussed above, improvements in Wi-Fi technology have seen throughputs increase, however the speeds that 802.11ac will deliver depend on the number of spatial streams and the channel widths used. To deliver the highest throughputs either 80 MHz or 160 MHz channels are needed. In the 2.4 GHz band the maximum channel width is 40 MHz and this is rarely used because in a 40 MHz mode there is barely room left for a second 20 MHz channel. Therefore very high throughputs depend upon the use of the 5 GHz band, however the fragmented nature of the band (gap from 5350 MHz to 5470 MHz) means there are currently a limited number of wide channels. Table 4-1 shows the number of channels, of different channel widths, available under the base case and the scenario with additional spectrum.

[28] Use of spectrum at 60 GHz for Wi-Fi (the 802.11d standard) is also under development. However, 60 GHz spectrum is suitable for short range very high speed applications such as uncompressed video transfer and is not a substitute for additional spectrum at 5 GHz for the range of applications considered in this study. Further, whilst UHF "white space" technology is undergoing trials it also is not a substitute for additional spectrum at 5 GHz as less white space spectrum is available and availability varies significantly depending on the location. Neither does white space technology use a Wi-Fi standard compatible with existing devices. Both 60 GHz and white space use of UHF should therefore be considered as possible complements rather than substitutes for additional spectrum for Wi-Fi at 5 GHz.

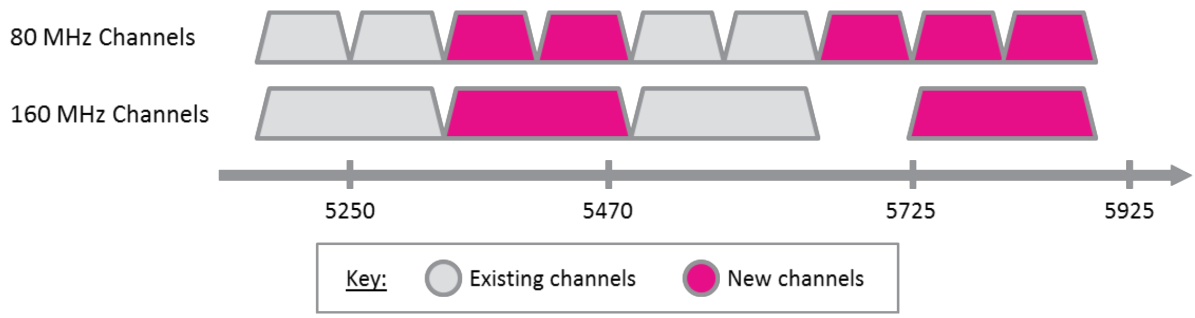
Table 4-1: Number of 5 GHz channels available

Channel Width	Number of existing channels	New number of channels	Percentage increase
20 MHz	19	37	95%
40 MHz	9	18	100%
80 MHz	4	9	125%
160 MHz	2	4	100%
Total spectrum	**455 MHz**	**775 MHz**	**70%**

Note: The increase in channels is greater than the increase in spectrum since a more efficient band plan is feasible with additional spectrum.

Figure 4-6 shows the current availability of wide channels and the impact of releasing additional spectrum.

Figure 4-6: Availability of wide channels



Currently there are just four 80 MHz channels or two 160 MHz channels for indoor usage (further restricted to only three 80 MHz channels or one 160 MHz channel in case of outdoor); this would limit the ability for concurrent high speed tasks. The release of the additional spectrum and removal of guard bands would increase the availability of wide channels, under the proposed band plan there would be nine 80 MHz channels and four 160 MHz channels.

4.3.3 Impact of additional spectrum on the capability of Wi-Fi

This section presents our estimates of uncontended Wi-Fi capacity, the full methodology behind our estimate is outlined in Appendix B. The uncontended speed and capacity that Wi-Fi can deliver is dependent upon the technology and the amount of spectrum available. Table 4-2 shows the throughputs and spectral efficiency of different Wi-Fi technologies.

Table 4-2: Different Wi-Fi technologies

Standard	Spatial streams	Headline speed (Mbps)	Maximum feasible speed (Mbps)	Average speed (Mbps)	Channel width (MHz)	Headline spectral efficiency (Mbps/MHz)
802.11n	1	150	90	29	40	3.75
802.11n	2	300	180	59	40	7.50
802.11ac	1	325	195	63	80	4.06
802.11ac	2	870	522	170	80	10.88
802.11ac	3	1,300	780	254	80	16.25
802.11ac	4	3,467	2,080	676	160	21.67

Source: Draws on http://www.wca.org/event_archives/2011/WCA_Peter_Ecclesine_White%20Space_Broad_20_Oct2011_r3.pdf

Although 802.11ac can support maximum feasible speeds of over 1 Gbps, this is dependent on four spatial streams which will not be possible for the majority of devices. We note that portable devices today can only support a single spatial stream; this is likely to increase in future but is unlikely to reach four streams in the forecast period. Therefore total capacity of Wi-Fi is dependent on the device mix.

Many of the benefits of 802.11ac come from the very high throughputs available over wide channels. The ability to perform very high speed transfers is dependent on the availability of spare capacity; if the spectrum is already congested maximum throughputs will be shared with other users. If sufficient capacity is not available many of the applications and uses of these high speed applications will not develop because fixed will be used as a substitute that guarantees the required speeds. Also many of these high speed uses will be sporadic and short lived, and therefore very difficult to forecast. Therefore we have included the option value for very high throughputs in our capacity forecast rather than in our demand modelling. To model this we have reserved 80 MHz of spectrum for high speed transfers and calculated the total capacity of the available spectrum less this headroom.

In addition to reserving spectrum for high speed transfers we have also reserved some spectrum for the probability that some of the DFS spectrum is unavailable. The DFS spectrum must operate on a detect and avoid basis, if radar is detected in part of the band, Wi-Fi cannot operate in this spectrum. Therefore for a given time and location there is a probability that some of the 5 GHz spectrum will not be available for Wi-Fi use. There is no data available on how often radar restricts the use of the DFS spectrum for Wi-Fi, however we have assumed that 10% of the 5 GHz spectrum is unavailable due to the detect and avoid restrictions. The combined impact of the high speed headroom and the detect and avoid headroom on the base case headline capacity is shown in Figure 4-7.

Figure 4-8 shows the forecast headline capacity for the current spectrum availability (minus 80 MHz headroom and 10% detect and avoid headroom) and the scenario where the additional spectrum outlined above is made available in 2016. The figure does not allow for the time required to transition routers to be able to utilise additional spectrum i.e. it represents potential capacity where suitable access equipment is available.

Figure 4-7: Impact of headroom on base capacity

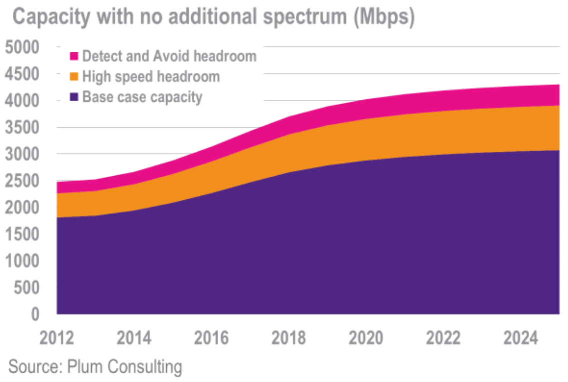
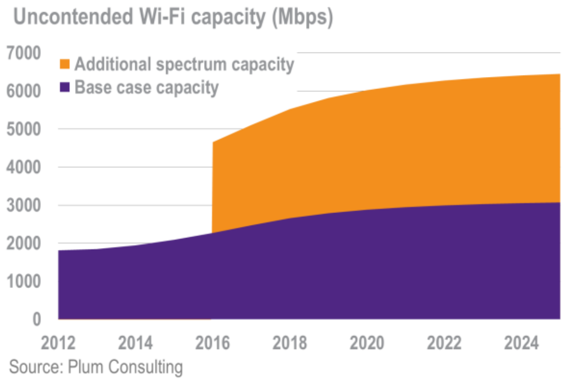


Figure 4-8: Potential uncontended Wi-Fi capacity



Under the existing spectrum assignment, capacity grows over time as devices transition from 802.11n to 802.11ac and incorporate additional spatial streams; by 2025 total uncontended capacity is just over 3000 Mbps. If additional spectrum is made available in 2016 capacity jumps as devices are able to utilise the entire 5 GHz band; by 2025 total uncontended capacity is 6400 Mbps.

4.4 Demand is anticipated to exceed existing capacity over the next decade

There is only a case for additional spectrum if demand will meet or exceed current capacity. In reality no single scenario can characterise Wi-Fi demand and the implied value of additional spectrum, since demand is highly localised in time and space and is also uncertain. Additional spectrum may therefore deliver immediate benefits in some circumstances even where demand is not expected to exceed supply for a number of years under a steadily growing scenario for demand. However to see if there are any feasible situation in which demand exceeds current capacity we have modelled a number of separate scenarios.

By comparing our demand scenarios with anticipated capacity with and without additional 5 GHz spectrum, we are able to assess the likelihood that additional 5 GHz spectrum for Wi-Fi will prove valuable. We have used the capacity estimate explained in the previous section, including headroom for high speed transfers and detect and avoid. For the demand scenarios we have modelled four situations with high intensity of Wi-Fi use:

- A block of apartments with one to two people in each apartment
- Terraced housing with a family of four in each house
- A shared office block with 10 different companies each with 10 employees
- A busy transport hub with significant mobile offloading

Full assumptions behind each scenario can be found in Appendix C. In each scenario we have assumed that the Wi-Fi network is unmanaged, i.e. no frequency planning has been conducted, and therefore if demand exceeds capacity service quality begins to fall. To estimate total data demand we have assumed that the number of devices and the throughput per device grows over time. We use this to estimate the total user demand i.e. the capacity required at the device summed across all devices. This is then adjusted to account for the three overheads present in Wi-Fi use:

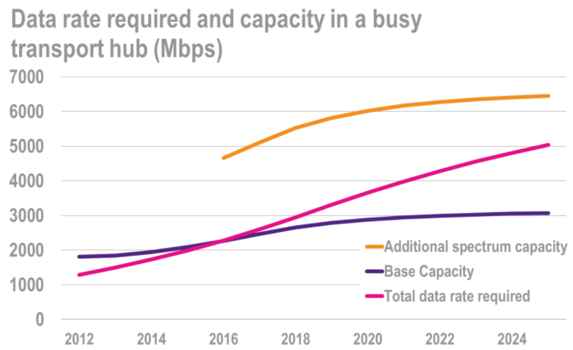
- Wi-Fi protocol efficiency – Wi-Fi does not deliver the headline speeds, we assume this is 60%
- Network protocol overhead – applications often use small packets and therefore don't achieve the maximum feasible speeds achieved when testing with very large packets, we assume this is 65%
- Wi-Fi range overhead – as distance from the access point increases, throughputs fall, we have assumed on average you are half way between the maximum feasible distance and the access point therefore this overhead is 50%

This gives a total data required which can be compared with the headline capacity.

In all four scenarios we find that demand exceeds existing Wi-Fi capacity by 2025. Demand exceeds capacity first in the busy transport hub, where there is a spectrum crunch by 2016; this is shown in Figure 4-9. Demand exceeds capacity in the apartment block, shown in Figure 4-10, and office block scenarios in 2021 and in the terraced housing scenario by 2022.

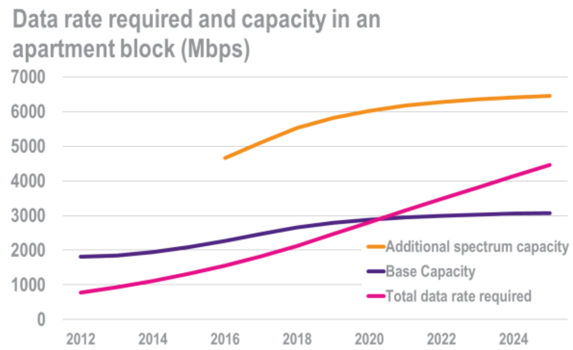
In the apartment block scenario the average user demand per apartment is 68 Mbps in 2021. This will include non-IP traffic, for example Wi-Fi Direct, as well as IP or internet traffic. This suggests that in some scenarios Wi-Fi will not be able to deliver on the digital agenda target of 100 Mbps. Contention from other users reduces the maximum throughput in an individual apartment to less than 100 Mbps; therefore, when the majority of devices are mobile, there will be no additional benefits from a fixed broadband connection capable of delivering over 70 Mbps.

Figure 4-9: Busy transport hub scenario



Source: Plum Consulting

Figure 4-10: Apartment block scenario



Source: Plum Consulting

The four scenarios above have focussed on unmanaged deployments; managed deployments can meet higher demand by deploying more access points and reducing the power of each access point, however, this does not mean there are no benefits from additional spectrum. In 1999 an ERC study which supported allocating 5 GHz spectrum for Wi-Fi (HIPERLAN) considered potential demand scenarios and their spectrum requirements. The amount of additional spectrum required was based on a managed network solution.

The ERC study found that you would need 14 separate channels to effectively reuse 5 GHz spectrum in a managed environment.[29] With 14 separate channels you can add new access points without interference by reducing the power of each access point. This gives an upper limit on the amount of spectrum needed to maintain a managed network, regardless of demand. The total amount of spectrum needed depends on the channel width used, if a 20 MHz channel is used you only need 280 MHz, if a 40 MHz channel is used you need 560 MHz etc.

Therefore the current assignment of 5 GHz spectrum can support a managed network with 20 MHz channels but not 40 MHz or higher. The proposed release of additional spectrum at 5 GHz would allow a managed network to use 40 MHz channels. By doubling the channel width you half the number of access points that need to be deployed in a capacity constrained environment.

4.5 Conclusion

Both the development of more advanced Wi-Fi standards and equipment and additional spectrum can deliver greater speed and/or capacity for existing and new applications. Making additional 5 GHz spectrum available could approximately double the capacity of Wi-Fi and allow higher speeds. However, to achieve its full potential the emerging 802.11ac Wi-Fi standard would also benefit from the availability of large contiguous blocks of spectrum. By modelling four different scenarios we have found that demand may exceed the current Wi-Fi capacity as early as 2016. If consumers are to experience the full benefits of the digital agenda target more 5 GHz spectrum must be allocated to Wi-Fi.

[29] This is an estimate and other studies found a different number of required channels, ranging from 12 – 16.

5 Additional spectrum for Wi-Fi would benefit consumers and the economy

Additional spectrum will deliver benefits wherever existing or new applications would otherwise be constrained in terms of capacity and/or speed. It is, however, difficult to isolate the benefits associated with improvements to elements of the ICT, and specifically connectivity, ecosystem.

However, it is clear that the full benefits of enhancements elsewhere, in particular in relation to broadband connectivity as part of the European Digital Agenda and to mobile broadband via allocation of additional spectrum, will need to be matched by improved Wi-Fi to deliver the full benefits anticipated for Europe.

It is also clear, subject to the necessary technical work, that allowing Wi-Fi to utilise additional spectrum at 5 GHz is not costly in terms of foregone existing or potential alternative uses.[30] Qualitatively there therefore appears to be a sound case for moving forward with the required technical studies and spectrum planning in relation to making additional 5 GHz spectrum available for wireless LAN.

However, in order to judge the magnitude of possible benefits we review estimates of the benefits of ICT generally and the benefits attributed to broadband connectivity in particular below. Two important trends – the rise of mobility and cloud computing – may be expected to generate further benefits and place increasing demands on connectivity including Wi-Fi.

5.1 ICT and the internet have delivered substantial benefits

There is a large empirical literature based on national growth accounting estimates and bottom up studies which strongly suggests a substantial productivity and income benefit from the effective use of ICT.

Attempts have been made to estimate the level of impact of ICT or the internet on the economy and require a hypothetical comparison with a world without the internet. The OECD (2012) considered the following question for the US *"what if there was no internet"* and concluded that in 2010 the Internet in the United States contributed up to 7% of total GDP.[31]

A number of growth accounting studies have focussed on the contribution of ICT to the rate of growth of productivity and/or incomes. For example, Jorgenson estimates that:

> *"The computer equipment manufacturing industry comprised only 0.3 percent of U.S. value added from 1960–2007, but generated 2.7 percent of economic growth and 25 percent of productivity growth."*[32]

A survey of estimates for the OECD finds that post 2007 ICT continued to contribute to growth, but against a backdrop of negative growth overall.[33] Van Ark (2010) concluded that labour quality and ICT

[30] WIK, Aegis, IDATE and Plum. September 2012. "Inventory and review of spectrum use: Assessment of the EU potential for improving spectrum efficiency." http://www.plumconsulting.co.uk/pdfs/Plum_Oct2012_Inventory_and_review_of_spectrum_use.pdf

[31] OECD. October 2012. "OECD Internet economy outlook." http://www.oecd.org/sti/interneteconomy/ieoutlook.htm

[32] Jorgenson. 2010. "Innovation and productivity growth." http://www.economics.harvard.edu/faculty/jorgenson/files/Innovation%2Band%2Bproduction%2Bgrowth.pdf

investment continue to provide a positive contribution to growth, whilst Oulton (2010) quantified the impact of ICT on the long run growth rate of 15 European and four non-European countries and concluded that ICT contributed about half a per cent per annum on average.[34]

5.2 Connectivity is a key element of the ICT success story

Corrado (2010) focusses on the benefits of connectivity and concludes, for the US, that the contribution to growth of the internet and connectivity was around 0.47% pa compared with real US GDP growth of 2.3% pa over the period 2000-2007, a contribution of 20% of growth.[35]

The OECD have considered the benefits of broadband and concluded that globally broadband consumer surplus (the excess of willingness to pay over what is paid) associated with broadband amounted to over US$500 billion in 2010 and grew at a compound average rate of 41% between 2006 and 2010.[36] We note that this estimate focussed on fixed residential access and does not therefore account for the value of mobile broadband connectivity.

5.3 Enhanced Wi-Fi will deepen and help sustain growth in connectivity and mobility

Whilst there are existing estimates of the value of Wi-Fi these tend to be old (given the pace of change) and to focus on the value of Wi-Fi as a whole rather than the incremental value of improved Wi-Fi.[37] Incremental value flowing from additional spectrum for Wi-Fi may be expected to flow from the following:

- Time savings and applications benefit from an increased likelihood that Wi-Fi capacity and speed in contended environments can meet the capability of other elements of the end-to-end connectivity including fibre broadband access and devices supporting faster file transfers (including memory read/write speeds). Improved Wi-Fi could therefore also be expected to increase demand for very high speed broadband, or without improvements in Wi-Fi the full benefits of high speed broadband will not be realised.
- Greater savings from Wi-Fi offload of mobile traffic as additional spectrum both increases the capacity of Wi-Fi access points and improves service quality, thereby matching improvements in mobile service quality and encouraging offload (mobile service is also developing driven by deployment of LTE and provision of additional spectrum for mobile networks at 800 MHz, 2.6 GHz and other frequencies).

[33] Vicente. September 2011. "ICTNET Assessment Paper 1, ICT Growth and Productivity." https://community.oecd.org/community/ictnet

[34] Oulton. 2010. "Long term implications of the ICT revolution for Europe: applying the lessons of growth theory and growth accounting." https://community.oecd.org/docs/DOC-18559

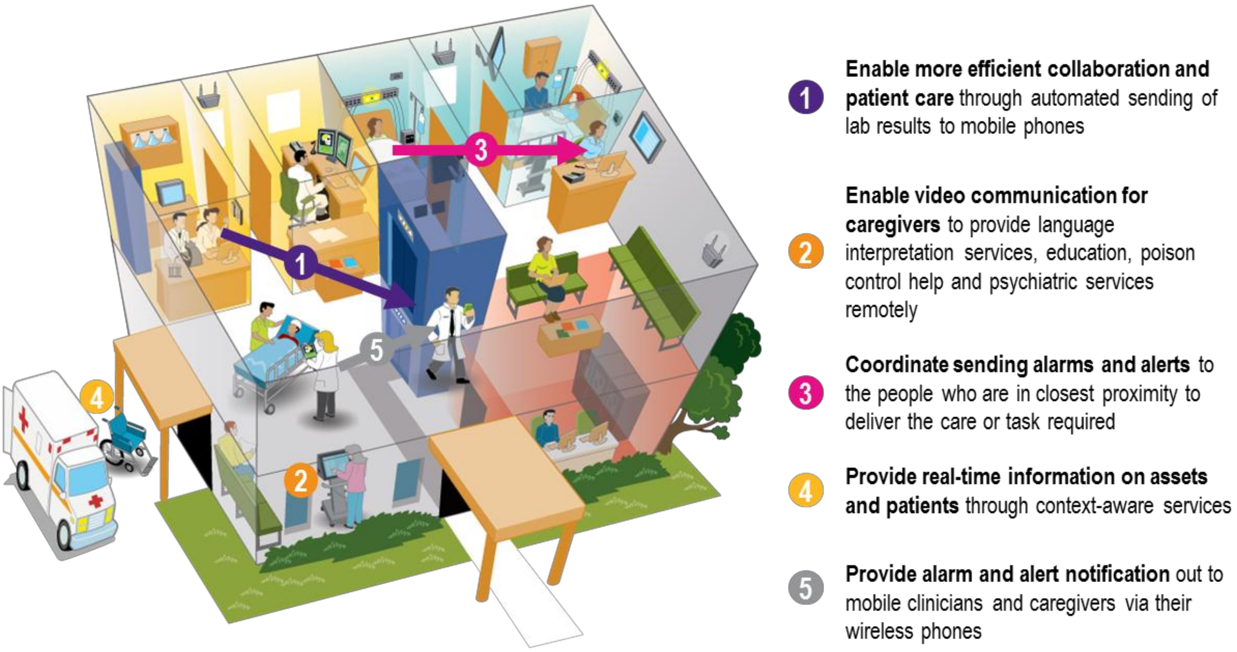
[35] Corrado. 2010. "Communication capital, Metcalfe's Law, and US productivity growth." http://www.crei.cat/conferences/cornucopia/confpapers/CREI%20paper_Corrado_15May10_V2.pdf

[36] Greenstein, S. and R. McDevitt. 2012. "Measuring the Broadband Bonus in Thirty OECD Countries." OECD Digital Economy Papers, No. 197. http://www.oecd-ilibrary.org/science-and-technology/measuring-the-broadband-bonus-in-thirty-oecd-countries_5k9bcwkg3hwf-en

[37] http://stakeholders.ofcom.org.uk/market-data-research/other/technology-research/research/exempt/econassess/

- Time savings due to faster file transfer and convenience, time and cost savings from the elimination of physical cable connections. These benefits can be expected to grow as device-to-device protocols develop, as device storage grows and as smart personal devices and nomadic behaviour become more ubiquitous.
- Competition benefits in the nomadic access market since improved Wi-Fi will strengthen competition between independent Wi-Fi providers, including fixed (wired) only access providers and media businesses, and mobile network operators.[38]
- Cost savings in managed networks. Additional spectrum will allow managed networks to be deployed utilising wider channels this reduces then number of access points that need to be deployed in capacity constrained environments (see section 4.4 above).
- New applications including applications in health care and industrial applications which would not be feasible without additional spectrum and expanded scope to utilise wide spectrum channels to offer very high speeds. An illustration of potential application to health care is shown in Figure 5-1.

Figure 5-1: Potential new applications of Wi-Fi in health care



We estimate the magnitude of benefits related to faster connectivity and mobile offload.[39] We do not quantity any additional benefits in terms of new applications that significantly higher capacity/faster Wi-Fi might support and in terms of enhanced competition between nomadic and mobile access provision.

---

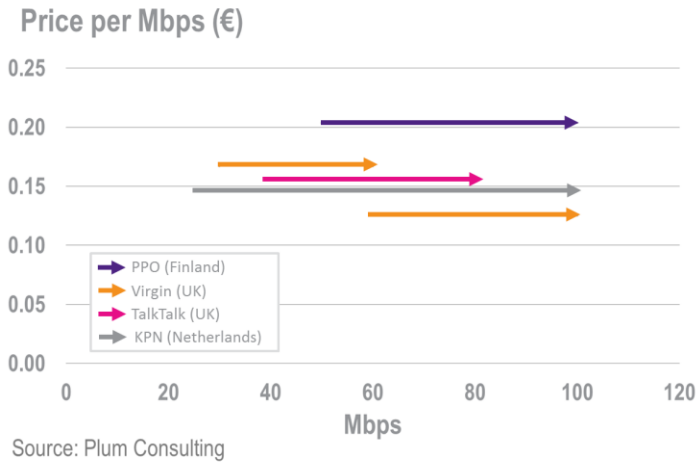
[38] HSBC concluded that *"Technical and spectrum issues mitigate WiFi's threat to cellular*". April 2012. "Honey, I shrunk the cells." https://www.research.hsbc.com/midas/Res/RDV?p=pdf&key=RTh351PFie&n=327750.PDF

[39] We have focussed on the incremental benefits of improved Wi-Fi. Other studies have attempted to quantify the overall benefits of Wi-Fi. For example, Thanki (2012), "The economic significance of licence-exempt spectrum to the future of the internet." http://download.microsoft.com/download/A/6/1/A61A8BE8-FD55-480B-A06F-F8AC65479C58/Economic%20Impact%20of%20License%20Exempt%20Spectrum%20-%20Richard%20Thanki.pdf

5.3.1 Value of increased quality of service

One of the European Digital Agenda targets is 50% take-up of 100 Mbps services; however this will only benefit consumers if they receive these speeds at the device. As the modelling in Section 4.4 showed there are a number of potential scenarios in which Wi-Fi will not be able to deliver these speeds in contended environments – Wi-Fi could act as a bottleneck. The value consumers place on faster connection speeds can be estimated from the premiums providers charge for top tier services; this information can be used to estimate willingness to pay per Mbps. Figure 5-2 shows the implied price per Mbps from upgrading broadband connection speeds. For example; TalkTalk in the UK charge a €6.25 premium for upgrading from a 40 Mbps package to an 80 Mbps package, a price differential of €0.16 per Mbps per month.[40]

Figure 5-2: Implied price per Mbps from increasing connection speed



Source: Plum Consulting

Based on this sample we assume that consumers value an incremental Mbps at €0.15 a month (we note that whilst not all consumers have adopted faster broadband where available we are in an early phase of adoption and those who have adopted faster broadband have revealed a willingness to pay which is at least equal to the price differential – we therefore utilise the price differential as an approximate proxy for value).

By comparing the data rate consumers demand and the rate Wi-Fi can deliver in a contested environment and multiplying this difference by the value of an incremental Mbps we can estimate the benefit of improved quality of service that additional spectrum would deliver. Our modelling estimates a total Net Present Value benefit for Europe of €12.3 billion (see Appendix D).

[40] An alternative approach, assuming benefits of faster broadband exceed the costs, is to estimate the incremental costs of meeting the Digital Agenda targets and annualise them (at a commercial discount rate). Based on the European Commission cost estimate of €270 billion to meet the Digital Agenda targets we calculate a cost per Mbps per month per household of €0.33.

5.3.2 Cost savings from increased mobile offload

Mobile data traffic is growing rapidly and must be met through a combination of more efficient technology (LTE carriers more data per unit of spectrum and capital expenditure than 3G[41]), additional spectrum and additional radio transmitters. To the extent that enhanced Wi-Fi carries additional data that would otherwise be carried over the mobile network the costs of meeting overall data demand can be reduced and the savings represent a social benefit. Enhanced Wi-Fi may reduce data demand that must be met over mobile networks in a number of ways:

- Enhanced quality of service may encourage consumers to time-shift file transfers and utilise Wi-Fi instead of cellular (a change that is not necessarily counted in estimates of “offload”).
- Enhanced Wi-Fi will also increase the capacity of public Wi-Fi access points and hybrid LTE/Wi-Fi small cells. In high traffic density locations, for example, transport hubs, this will reduce demand on the cellular network.[42]

It is difficult to know to what extent enhanced Wi-Fi capacity would lead to reduced traffic over mobile networks since both knowledge of how people’s behaviour would change and the extent to which the enhanced capacity would be supported by available backhaul to the fixed network will vary by time and place. We therefore estimate the benefit for a given increase in offload based on estimated avoided mobile network costs.

The Cisco VNI index estimates that Wi-Fi offload was 10% of cellular traffic or approximately 20 PB a month in 2011, this will grow to 860 PB or 25% in 2016. The proposed additional spectrum at 5 GHz roughly doubles the total capacity of Wi-Fi. However, a doubling of capacity is unlikely to double offload as some times and locations may have excess capacity for offload without additional spectrum whilst others may have constrained backhaul i.e. connectivity to the router rather than available spectrum for Wi-Fi constrains offload.

Assuming (perhaps somewhat conservatively) that doubling available spectrum increases mobile offload by 10% a month in 2016, growing to 25% in 2025 this would generate an estimated net present cost savings of €4.0 billion (see Appendix D).

5.3.3 Overview of benefits

We note that achieving the benefits estimated above do not involve any associated additional costs compared to a business as usual scenario as Wi-Fi equipment that can utilise additional spectrum is assumed to be deployed based on natural deployment and replacement cycles. Further, the opportunity cost of 5 GHz spectrum, assuming studies show that co-existence is feasible, is likely to be very low. The benefit estimate is therefore an approximate net benefit.

Table 5-1 summarises our findings in terms of benefits of additional spectrum for Wi-Fi.

[41] We note that whilst LTE is more spectrally and cost efficient than 3G, it also offers enhanced quality of service that will promote additional mobile data consumption. In markets where LTE has deployed there is evidence that this is the case.

[42] Increased capacity of Wi-Fi and small cells, cells which have much shorter range than mobile network macro cells, nevertheless increases the capacity of the macro cell over a wide area by allowing the overall capacity of the macro cell to be utilised elsewhere, now that local high density traffic is offloaded. Source: SCF “W-CDMA Open Access Small Cells”, paper -38 May 2012, http://www.smallcellforum.org/resources-white-papers

Table 5-1: Summary of estimated quantified benefits

Benefit	NPV (€)
Improved Wi-Fi quality of service in contested environments	€12.3 billion
Cost savings from increased mobile offload	€4.0 billion
Total estimated benefits	**€16.3 billion**

We do not quantify other potential benefits including time savings from faster Wi-Fi file transfers between devices, cost savings from a reduced number of routers in capacity constrained environments (e.g. at sports stadia), new applications, for example, in health care and industrial environments and competition benefits.

5.4 Action to make more spectrum available should be initiated now given the lead times

Spectrum reallocation can be costly and slow, particularly to new licensed applications where there are incumbent users (for example, the costs and delay associated with reallocation of 800 MHz spectrum from broadcasting to mobile are considerable). In the case of Wi-Fi there are grounds for optimism, but nevertheless hurdles that must be overcome in order that additional spectrum at 5 GHz is available and usable.

5.4.1 The spectrum opportunity cost is expected to be low

One of the key factors that enabled the release of 5 GHz spectrum for RLAN use was the mandatory use of Dynamic Frequency Selection (DFS) in those bands shared with radars. There were some early incidents of interference to radars in spite of the mandatory DFS requirement. These incidents were for two main reasons; devices performing out of specification and the fact that early versions of the RLAN standard did not specify all types of radar signal that had to be detected and avoided (in particular weather radars operating around 5600 MHz). The standard has since been modified and it has been proven that satisfactory sharing with radars is possible provided equipment complies with the modified standard. More recent incidents were all due to non-compliance or unlawful operation of equipment.

The proposed additional spectrum covers 5350 – 5470 MHz and 5725 – 5925 MHz. In the case of the higher frequency band (5725 – 5925 MHz) this is largely available in European countries for Broadband Fixed Wireless Access (BFWA) services (up to 5875 MHz), although it can be noted that it is not extensively used. Most of this higher band (up to 5850 MHz) is also shared with radars and the requirement for DFS already applies here for BWFA. In the case of the lower band (5350 – 5470 MHz) this is currently used by radars the main type of which is forward looking airborne weather radar. When the original 5 GHz spectrum was made available for RLANs this part of the spectrum was considered but put on one side for safety reasons and in any event the amount of spectrum required at the time was able to be satisfied by designating other parts of the 5 GHz spectrum for RLAN use (ERC Report 72).

A number of other systems also use or are planning to use this higher band. These systems support Road Transport and Traffic Telematics (RTTT) in the band 5795 – 5815 MHz largely used for RFID based road tolling, Intelligent Transport Systems (ITS) above 5855 MHz and Direct Air-to-Ground Communications (DA2GC) which is seeking to use 5855 – 5875 MHz.

The technical compatibility of RLANs in relation to airborne weather radar needs to be studied in detail to ensure compatibility. There is no obvious reason why DFS cannot be applied to prevent interference from occurring. However, one possible effect of the elevated nature of airborne radars is that RLANs over a large area visible from the aircraft would have to avoid using the spectrum which defeats the point of having the additional spectrum in the first place. The extent of this effect will depend on the number of aircraft, the geometry of the radar coverage and the impact of interference on these radars. Such an analysis would be undertaken within CEPT (Spectrum Engineering Working Group and ratified by the Frequency Management Working Group) before it is decided that this spectrum could be released for RLAN use.

Consideration would also need to be given to compatibility aspects relating to those services currently using or planning to use the upper band including Intelligent Transport Road Systems and Transport and Traffic Telematics (ITS/RTTT) and Direct Air to Ground Communication (DA2GC).

In conclusion, since additional spectrum for Wi-Fi at 5 GHz would be utilised on a licence exempt shared basis, assuming compatibility can be demonstrated, there would be no opportunity cost in terms of existing uses and users (though sharing may limit the benefit in terms of Wi-Fi use to somewhat less than the amount of additional spectrum made available, to the extent that detect and avoid limits usable spectrum).

5.4.2 Additional benefits should flow quickly from enhanced Wi-Fi once spectrum is made available

Whilst new routers would be required to utilise additional spectrum at 5 GHz this does not necessarily involve any incremental cost if they are deployed as part of normal deployment and replacement cycles (end user devices such as smart phones etc. that can utilise 5 GHz today will be able to utilise additional 5 GHz spectrum, but only if the router they connect to is authorised to utilise the spectrum).

The need for new routers in order to utilise additional 5 GHz spectrum does however introduce a delay in achieving the full benefits of additional spectrum. These lags, perhaps around two years or more for 50% of routers to be able to utilise additional spectrum, are one reason for initiating analysis of compatibility ahead of demand (both in terms of capacity and speed, though improving the latter would offer some benefit even today).

The regulatory approval process also takes time to perform coexistence studies, to develop appropriate regulatory environment and to modify the existing European Harmonised Standard. The overall lag from initiation of work to achieving half of the potential full benefit of additional spectrum may therefore be around four years. Anticipated demand from 2016 is therefore strong grounds for initiating the required studies now.

5.5 Conclusion

ICT is recognised as a key driver of productivity and income growth, as is the growth of connected computing as a key driver within ICT. Computers are increasingly connected via wireless – either via mobile or Wi-Fi (with Wi-Fi carrying far more traffic than mobile and, in the near term, anticipated to carry more than direct fixed wired connections).

Higher speed and higher capacity Wi-Fi supported by additional spectrum will facilitate the continued development of wireless connected computing supporting high end-to-end connectivity speeds, improved quality of service in contested environments, higher mobile traffic offload and support the development of cloud computing applications.

The estimated benefits for Europe, in net present value terms, are €12.3 billion and €4.0 billion respectively. Other potential benefits, which we did not quantify, include time savings from faster device-to-device file transfers, cost savings in capacity constrained environments such as sports stadia, potential new applications in health care and industry and competition benefits between public Wi-Fi and mobile service providers.

Potential benefits must be considered alongside potential costs, which can be substantial where there are potentially competing spectrum uses, clearance costs and/or interference issues that must be addressed. However, Wi-Fi has a detect and avoid technology. Nevertheless, a study undertaken by CEPT is required before it is decided that additional 5 GHz spectrum could be released for Wi-Fi use. We propose, given the potential benefits and lead times that such a study is undertaken now.

Appendix A: 5 GHz device and access point forecast

A.1 Device forecast

Table A-1 shows the assumptions underlying the device forecasts for Western Europe.[43]

Table A-1: Device forecast assumptions

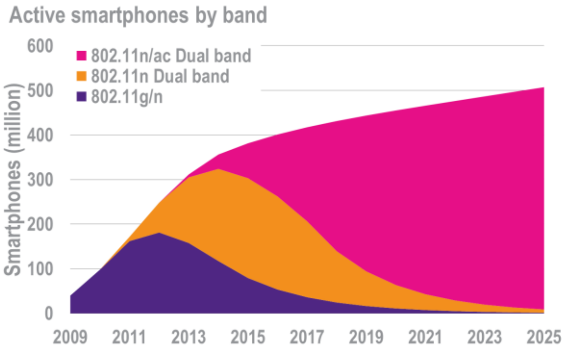
Device	2009 stock (million)	Shipments in 2010 (million)	Shipments in 2015 (million)	Devices scrapped per year, 2010	Devices scrapped per year, 2018
Smartphone	40	66	141	20%	32.5%
Tablets	0	6	58	5%	25%
Other devices	300	60	90	20%	20%

Other assumptions:

- Devices are shipped with different Wi-Fi technologies:
  - 802.11n/ac devices begin shipping in 2013
  - by 2017 all devices are shipped with 802.11n/ac
- By 2017 the market has reached an equilibrium, thereafter all devices grow at 2% per annum
- 'Other devices' includes all other devices e.g. PCs, Laptops, TVs
- We ignore M2M and other low bandwidth devices

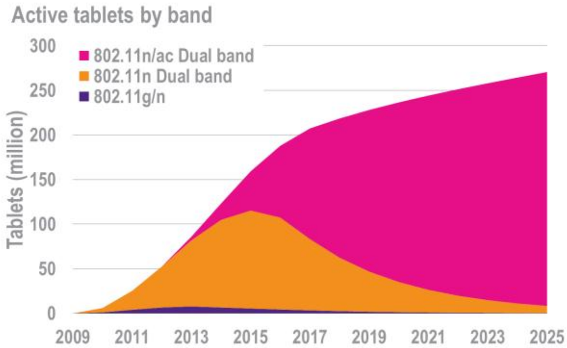
Figure A-1 to Figure A-3 show the forecasts for the different device classes.

Figure A-1: Smartphones



Source: Plum Consulting

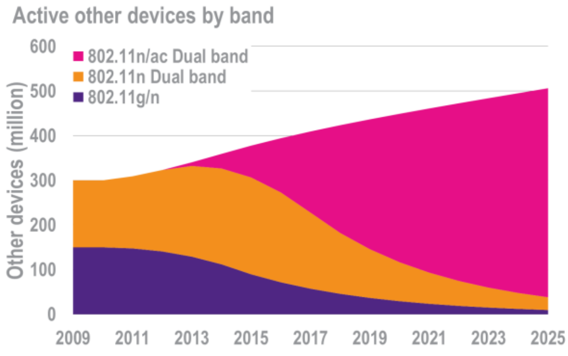
Figure A-2: Tablets



Source: Plum Consulting

[43] Device forecasts out to 2016 are based on IDC, Morgan Stanley and Analysys Mason

Figure A-3: Other devices



Source: Plum Consulting

A.2 Access point forecast

The main assumptions underlying the access point forecast are as follows:[44]

- In 2009 there were 100 million Wi-Fi access points in western Europe, approximately 40% of the global figure
- In 2010 48 million access points were shipped, this grows to 110 million by 2018
- From 2019 the market is in equilibrium and access points grow at 2% per annum
- Every year 30% of installed access points are replaced
- We differentiate between 802.11n dual band access points and simultaneous dual band access points, we assume that all 802.11n/ac access points will be simultaneous
- In 2009 20% of access points were 2.4 GHz only, the remainder were dual band but not simultaneous dual band
- The share of access points that are shipped shifts from primarily dual band in 2009 to only 802.11ac by 2017

A.3 Devices using the 5 GHz band

Combining device and access point forecasts we can estimate the number of devices that will be using the 5 GHz band. Possible permutations of access points and devices include the following five groups which are illustrated in a decision tree in Figure A-4.[45]

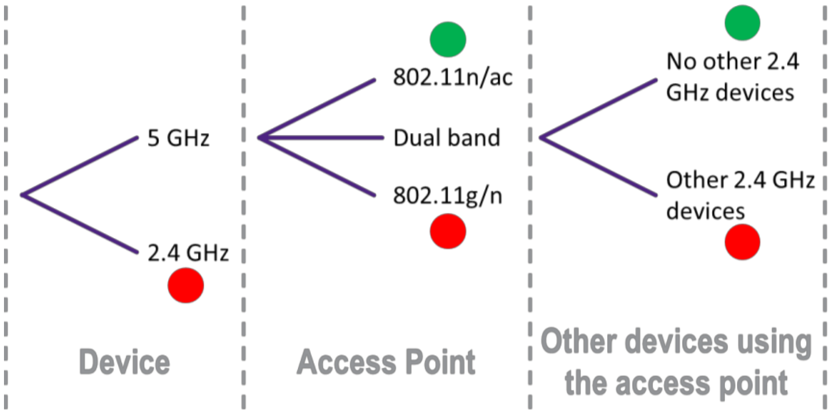
- 2.4 GHz only client devices – these use the 2.4 GHz band
- Dual band devices connected to a 2.4 GHz only access point – these use the 2.4 GHz band

[44] Access point forecast out to 2015 are based on Informa Telecoms and Media

[45] This estimate is a snapshot as it assumes each device only connects to a single AP, over the course of a day an individual device may connect to a number of APs which will increase the chance of the device using the 5 GHz band. We estimate the number of devices on each branch of the decision tree using probability, e.g. in the final branch the probability of "No other 2.4 GHz devices" = (probability that a device is 5 GHz)^(average number of devices per access point)

- Dual band client devices connected to a dual band router but there are other 2.4 GHz devices connected – these use the 2.4 GHz band
- 5 GHz client devices, connected to a dual band router and there are no other active 2.4 GHz client devices connected – these use the 5 GHz band
- 5 GHz client devices connected to an 802.11n/ac or simultaneous access point – these use the 5 GHz band

Figure A-4: Whether or not a device uses the 5 GHz band



Appendix B: Wi-Fi capacity forecast

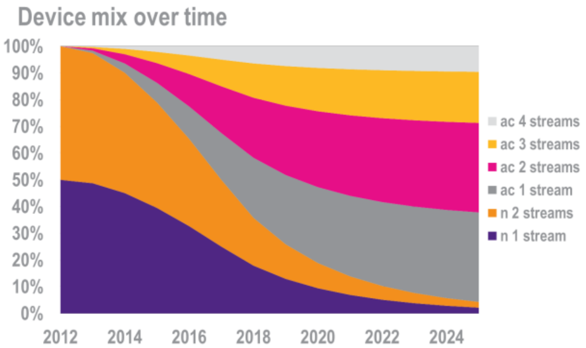
The capacity forecast models the total headline capacity available assuming a certain device mix. This device mix evolves over time as more devices include greater numbers of spatial streams and users purchase new devices. Table B-1 shows the spectral efficiency of different technologies.

Table B-1: Device efficiency

Wi-Fi standard	Spatial streams	Headline speed (Mbps)	Channel Width (MHz)	Headline device efficiency (Mbps/MHz)
802.11n	1	150	40	3.75
802.11n	2	300	40	7.50
802.11ac	1	325	80	4.06
802.11ac	2	870	80	10.88
802.11ac	3	1300	80	16.25
802.11ac	4	3467	160	21.67

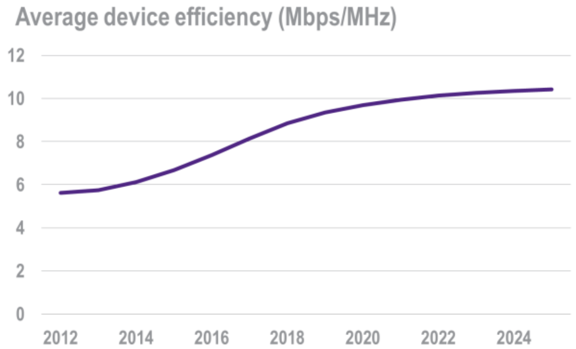
The share of 802.11n and 802.11ac devices is based on the previous device forecast; the device split by number of spatial streams is based on further assumptions.[46] This device mix, shown in Figure B-1, is then used to calculate average device efficiency in each period, shown in Figure B-2.

Figure B-1: Device mix over time



Source: Plum Consulting

Figure B-2: Average device efficiency



Source: Plum Consulting

The average device efficiency is then multiplied by the total amount of available spectrum:

- In the base case there are 3 x 20 MHz channels at 2.4 GHz and 19 x 20 MHz channels at 5 GHz
- In the additional spectrum scenario there are 3 x 20 MHz channels at 2.4 GHz and 35 x 20 MHz channels at 5 GHz

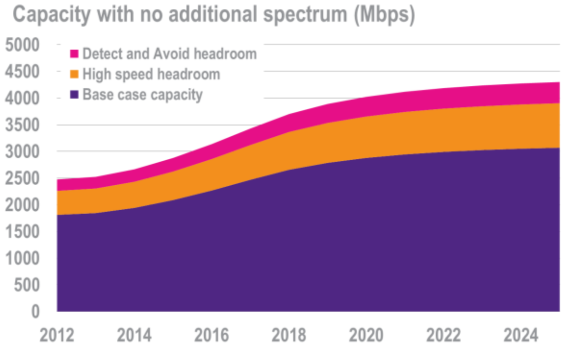
However not all of this spectrum is available because:

[46] 802.11n devices are split equally between 1 stream and two streams. 35% of 802.11ac devices are single stream, 35% are 2 stream devices, 20% are 3 stream devices and 10% are 4 stream devices.

- High speed transfer headroom – we have assumed 80 MHz of 5 GHz spectrum is reserved for high speed transfers. 80 MHz was assumed because this is enough to provide high throughputs but is also the largest contiguous block of non-DFS spectrum available.
- Detect and avoid headroom – we have assumed that 10% of the 5 GHz spectrum is unavailable because radar is detected in part of the band

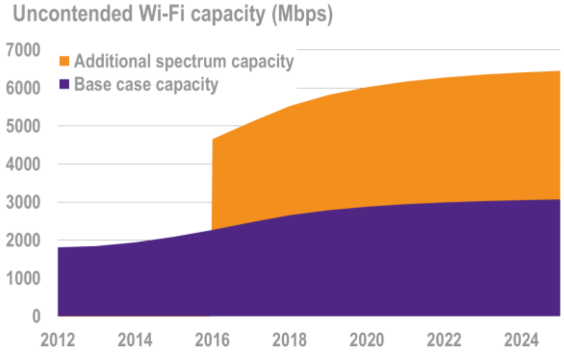
The impact of these two assumptions is shown in Figure B-3. The total uncontended capacity for the base case and the additional spectrum scenario are shown in Figure B-4.[47]

Figure B-3: Impact of headroom assumptions on base capacity



Source: Plum Consulting

Figure B-4: Potential uncontended Wi-Fi capacity



Source: Plum Consulting

[47] Capacity of the 2.4 GHz band is assumed to remain constant as 802.11ac is restricted to the 5 GHz band, in future the 2.4 GHz band is likely to be primarily used by Wi-Fi Direct, low bandwidth applications and devices far from the access point.

Appendix C: Wi-Fi use case and demand scenarios

We have modelled four separate demand scenarios by estimating the number of devices, throughput per device and growth over time. Data rate per device grows at a fixed rate in 2012, this declines at a set rate until 2020 and then a faster rate until 2025 e.g. growth in 2012 is 15%, growth in 2013 is 14.25%, growth in 2020 is 8.38% and growth in 2021 is 6.70%. The main assumptions for each of the scenarios are shown in Table C-1.

Table C-1: Scenario assumptions

	Apartment block	Terraced House	Office block	Transport hub
Average data rate per device in 2012 (Mbps)	10	10	5	1
Growth in average date rate in 2012	15%	15%	15%	15%
Annual decline in growth rate until 2020	5%	5%	5%	5%
Annual decline in growth rate after 2020	20%	20%	20%	20%
Average number of people per network	1.5	4	10	2,500
Average no. devices per person in 2012	1.5	1	1.5	1
Growth in devices	5%	2%	5%	2%
Share of users active simultaneously	75%	75%	20%	5%
Mesh networking factor[48]	1	2	1	2[49]
Number of networks	9	3	10	1

We use the user throughput to estimate the total user demand i.e. the capacity required at the device summed across all devices. This is then adjusted to account for the three overheads present in Wi-Fi use:

- Wi-Fi protocol efficiency – Wi-Fi does not deliver the headline speeds, we assume this is 60%
- Network protocol overhead – applications often use small packets and therefore don't achieve the maximum feasible speeds when testing with very large packets, we assume this is 65%
- Wi-Fi range overhead – as distance from the access point increases, throughputs fall, we have assumed on average you are half way between the maximum feasible distance and the access point therefore this overhead is 50%

[48] The mesh networking factor is one if there is no mesh networking and 2 if there is mesh networking. Mesh networking increases the total data rate required because data has to travel across the air multiple times.

[49] Here we have assumed a single network with a mesh infrastructure, however you could also have multiple networks which overlap in which case the overall capacity required will likely be lower

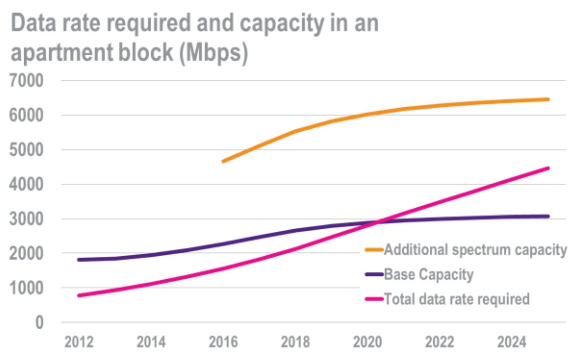
By comparing the demand with the capacity estimates we can estimate when additional spectrum will be needed in each scenario. The main results for each scenario are shown in

Table C-2: Scenario results

	Apartment block	Terraced House	Office block	Transport hub
Year demand exceeds current capacity	2021	2022	2021	2016
User data rate per network in year demand exceeds capacity (Mbps)	68	100	61	253
Devices per person in 2025	2.83	1.29	2.83	1.29
User data rate per network in 2025 (Mbps)	97	118	86	491

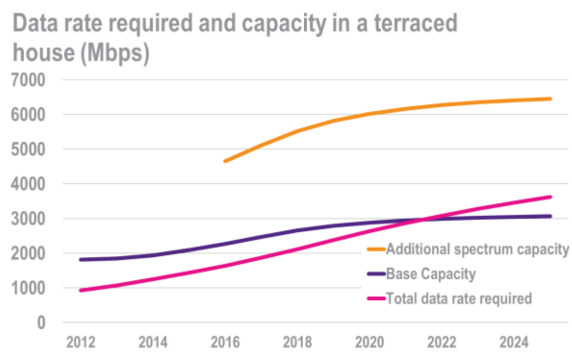
Figure C-1 to Figure C-4 show the total data rate required and capacity for each of the scenarios.

Figure C-1: Apartment block



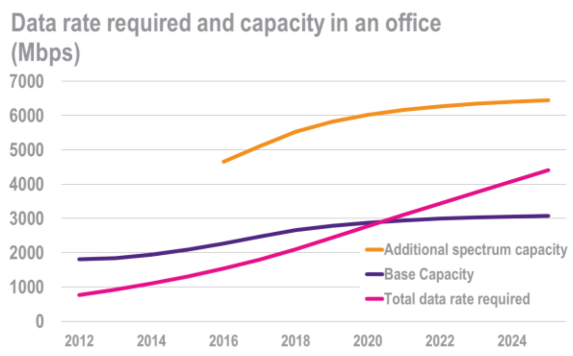
Source: Plum Consulting

Figure C-2: Terraced housing



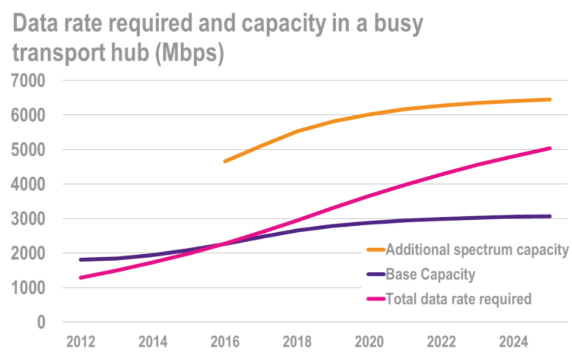
Source: Plum Consulting

Figure C-3: Office block



Source: Plum Consulting

Figure C-4: Busy transport hub



Source: Plum Consulting

Further information on each of the scenarios is available below:

C.1 Scenario 1 – Apartment in a block of flats

- A small one-bedroom apartment in a multi-floor block of flats, in total there are nine apartments:
  - two adjacent flats where Wi-Fi contention is possible on the same floor
  - three adjacent flats where Wi-Fi contention is possible on the floor below
  - three adjacent flats where Wi-Fi contention is possible on the floor above
- On average 1.5 people per apartment, using on average 1.5 devices each in 2012
- During the busy hour 75% of people use Wi-Fi
- 100 Mbps fixed broadband connection
- Radio LAN for all data streams in the flat
- Use includes video streaming HD content, Wi-Fi direct and possible some background use (i.e. not user initiated) in 2012 this averages 10 Mbps per device.

C.2 Scenario 2 – Terraced house

- Big terraced house (four-bedroom) on three floors, in total three households, including:
  - two adjacent houses with potential Wi-Fi contention
- Mesh network, one hop to the bottom floor, one hop to the top floor
- Four occupants of the house, using on average 1 device each, devices per person is lower than in scenario 1 because young children are less likely to have as many devices.
- During the busy hour 75% of people use Wi-Fi
- 100 Mbps fixed broadband connection
- Radio LAN for all data streams in the house
- Use includes video streaming HD content, Wi-Fi direct and possible some background use (i.e. not user initiated) in 2012 this averages 10 Mbps per device.

C.3 Scenario 3 – Open plan office floor

- Block of shared offices with a total of 10 companies
- Each office has 10 people, 10 desks and one meeting room
- A single high-speed broadband fixed connection 1 Gbps going into the building
- Radio LAN distribution throughout the floor for:
  - Standard wide area office applications
  - LAN applications e.g. printing, connections to local servers

- Tele-presence for meeting rooms
- Some Wi-Fi Direct however wireless docking not likely to be possible due to lack of non DFS spectrum (160 MHz channels not possible)
- High speed data transfers

In 2012 this averages 5 Mbps per device.

C.4 Scenario 4 – Busy transport hub (Wi-Fi/mobile offload)

- There is a single networking covering the entire area, some access points don't have fixed access therefore there is mesh network infrastructure
- Clutter from kiosks, partitions, mezzanine floors
- Total area covered by the network is approximately 4,000 m^2
- During busy hour approximately 2,500 people
- On average 5% of people using devices at once
- On average 1 device per person
- Fixed broadband connection of 1 Gbps or more
- Use varies from streaming video on portable devices, to downloading movies to watch on the go, to browsing the internet, there is limited Wi-Fi direct use, in 2012 this averages 1 Mbps per device

Appendix D: Quantifying the benefits

D.1 Benefits of higher speed connectivity

We assume that all high density housing in Europe is potentially congested. We estimate that 40% of total households are in high density areas; this is based on the fact that approximately 40% of the population of Europe live in flats.[50] Although not all flats will be in high density areas, there will be some additional households that are not flats but still may experience congestion e.g. terraced housing. This gives a total number of households that may benefit from improved Wi-Fi quality of service, 83 million in 2012. The average data rate demanded by each household is based on the modelling in Scenario 1. The population of households is distributed as follows:

- 25% of households demand 75% of the average data rate
- 50% of households demand 100% of the average data rate
- 25% of households demand 125% of the average data rate

The benefit of improved quality of service in each year is the difference between the data rate demanded and the data rate Wi-Fi can deliver (estimated from Scenario 1) multiplied by the value per Mbps. The value per Mbps per month is €0.15 in 2012 and grows at 2% per annum in real terms.[51]

Discounting the benefits out to 2025 at a social discount rate of 4%[52] we obtain a Net Present Value (NPV) benefit estimate for Europe of €12.3 billion in terms of gains in speed.

D.2 Savings from additional mobile offload

The savings estimates are based on Cisco VNI offload forecasts extrapolated out to 2025 and a (perhaps conservative) assumption that doubling available spectrum for Wi-Fi increases mobile offload by 10% i.e. to 946 PB a month in 2016 growing to 25% in 2025. We multiply the difference in mobile network traffic with and without additional spectrum for Wi-Fi by the estimated incremental cost of mobile data to obtain an estimate of cost savings.

We utilise an incremental cost estimate for mobile data of €0.24 in 2012 falling to €0.08 in 2025.[53] This estimate is based on a number of assumptions in the Plum Nomad model.[54] The spectrum efficiency assumption is based on the assumption that incremental offload from 2016 relates entirely to LTE (which has lower incremental costs than 3G). We assume a spectral efficiency of 1 bit per

[50] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Housing_statistics

[51] We note in relation to the value per Mbps that whilst many consumers have not adopted fast broadband where it has been made available (i.e. their revealed willingness to pay is less than the price differential) that we are in an early phase of the transition from current to next generation broadband and that those who have adopted next generation broadband value it at least as highly as the price differential. The estimate is necessarily approximate.

[52] Guide to Cost-Benefit Analysis of investment projects. EC DG Regio. Annex B. http://ec.europa.eu/regional_policy/sources/docgener/guides/cost/guide2008_en.pdf

[53] Broadly in line with the following estimates: Greger Blennerud, 2011, "In search of the sweet spot." *Ericsson Business Review: no. 01, 2011.* http://www.ericsson.com/ericsson/corpinfo/publications/ericsson_business_review/pdf/111/111_in_search_of_the_sweet_spot.pdf

[54] Brian Williamson. January 2012. "Mobile data growth – too much of a good thing?" http://www.plumconsulting.co.uk/pdfs/Plum_Insight_Jan2012_Mobile_data_growth_-_too_much_of_a_good_thing.pdf

second per hertz in 2012, rising to 3 Bps / Hz in 2025.[55] We also assume an annual base station cost including capital recovery of €30,000.[56]

Combining the estimated change in offload with the estimated cost per GB and discounting the benefits out to 2025 at a social discount rate of 4% we obtain an NPV benefit estimate for Europe of €4.0 billion from cost savings due to additional mobile offload.

---

[55] Drawing on the following:

Real Wireless. January 2011. "4G capacity gains." http://stakeholders.ofcom.org.uk/binaries/research/technology-research/2011/4g/4GCapacityGainsFinalReport.pdf

Real Wireless. 2011. "Techniques for increasing the capacity of wireless broadband networks: UK, 2012-2030." http://www.ofcom.org.uk/static/uhf/real-wireless-annex1.pdf

[56] Ofcom, 2007, "Application of spectrum liberalisation and trading to the mobile sector" http://stakeholders.ofcom.org.uk/binaries/consultations/liberalisation/summary/liberalisation.pdf