Sustainability Benefits of 6 GHz Spectrum Policy

Study for Wi-Fi Alliance®

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1 Executive summary

1.1 Background

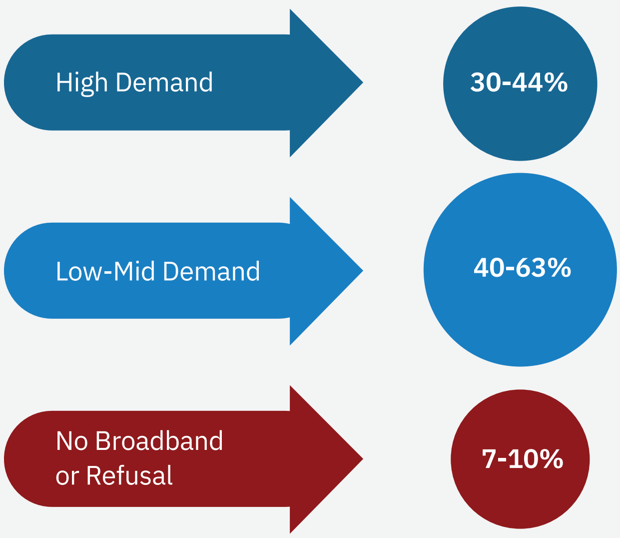
Spectrum policymakers in Europe and worldwide are considering whether to open the entire 6 GHz band for licence-exempt usage including Wi-Fi or to allocate the upper portion of the 6 GHz band (6.425-7.125 GHz) to licensed mobile (e.g., cellular/5G) networks.

In this study, drawing on demand models and scenario analysis based on literature, we elaborate why additional spectrum for Wi-Fi will be needed to meet consumer needs for indoor Gigabit connectivity and estimate the environmental impact of spectrum policies which favour mobile connections over Fibre-to-the-Home (FTTH) with Wi-Fi.

1.2 Europe's Gigabit broadband targets

The growing number of connected devices alongside the increasing popularity of services requiring high data transfer rates such as video is driving increasing demand for bandwidth across the EU and elsewhere. Demand models produced by WIK suggest that **by 2025, between 30% and 44% of European households will require more than 1 Gigabit per second (Gbps) download and 600 Megabits per second (Mbps) upload.**[1] The expansion of e-health and remote learning, alongside greater reliance on the cloud to support new use cases such as artificial intelligence (AI), automation, augmented/virtual reality (AR/VR) and other applications, is likely to further increase demand for bandwidth as well as higher quality connectivity in the home.[2]

Figure 1: Bandwidth demand in 2025 as a percentage of households



[1] In order to forecast future bandwidth needs, WIK developed a 'market potential' model which projects the future demand for residential bandwidth based on three parameters: 1) applications and their bandwidth requirements, 2) user profiles and 3) expected population and household structure. The underlying assumption is that there is no restriction to be considered in the access line so it provides the performance demanded by the applications at any time. The applications are allocated to the different user profiles, which vary from digital professionals to complete deniers. Thereafter, the aggregated demand of these profiles is further aggregated to household demand based on the population structure. This model has been applied to and validated in Germany, United Kingdom (UK), and the Flemish region in Belgium. The methodology for the model and results from the three regions are discussed in Strube Martins, S. and Wernick, W. (2021): Regional differences in residential demand for very high bandwidth broadband internet in 2025, in: Telecommunications Policy, Volume 45, Issue 1, February 2021.

[2] For example low latency and packet loss rates.

To support this increasing reliance on broadband services, **the European Digital Decade Programme has set a target that by 2030,[3] all Europeans should have access to fixed Gigabit connectivity up to the network termination point**. Significant amounts of EU funding as well as State Aid have been allocated towards achieving this target,[4] and **it is projected that by 2030, nearly 100% of EU households will be served with a FTTH connection**.

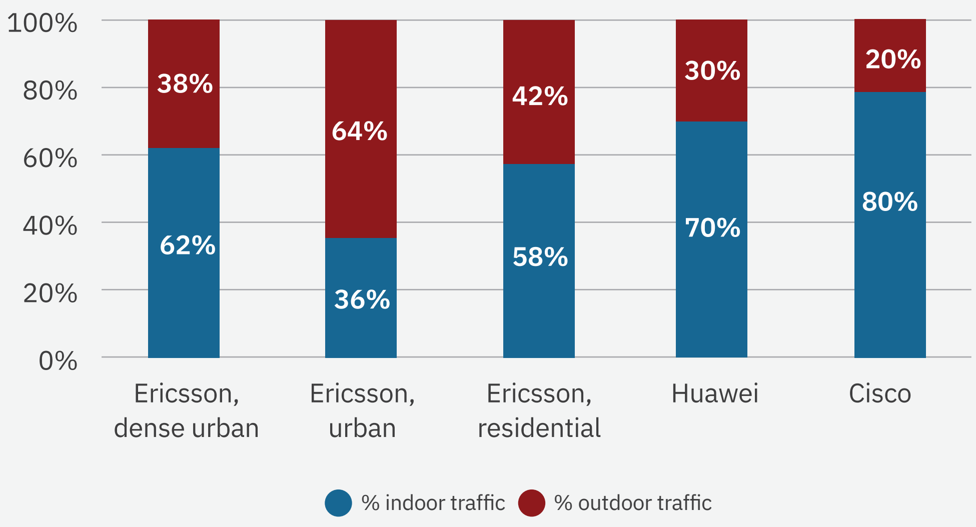
1.3 The role played by Wi-Fi

The prioritization of widespread FTTH deployment, despite the high installation cost,[5] reflects the fact that **most broadband traffic – even traffic on "mobile" devices – is consumed indoors**. Estimates of the proportion of indoor vs. outdoor mobile traffic vary, but available sources[6] suggest that up to 80% of all mobile traffic data worldwide is consumed indoors (see Figure 2).[7] As high-speed in-house cabling is costly to install and is not supported by all devices, Wi-Fi[8] is rapidly becoming an integral component of telecommunication infrastructure because it extends the network from the termination point down to the device level. Thus, Wi-Fi functionality and performance are essential for the realization of Gigabit connectivity.

1.4 The need for additional spectrum

In order to meet expanding demands for wireless connectivity, several countries including **Argentina, Brazil, Canada, Saudi Arabia, South Korea, and the US authorized Wi-Fi access to the entire 6 GHz band** (i.e., 5.925-7.125 GHz). However, **in the EU, only 480 MHz of additional spectrum has been made available in the lower 6 GHz band for Wi-Fi networks** (i.e., 5.945-6.425 GHz).[9]

Figure 2: Proportion indoor versus outdoor for mobile traffic



Source: Ofcom (2022)

[3] European Commission (2022).

[4] Around €19bln in EU funding has been committed towards achieving the Digital Decade connectivity targets.

[5] WIK-Consult estimates show that around €174bln in investment is still needed EU-wide to achieve the Digital Decade goals by 2030, the majority of which relates to FTTH deployment.

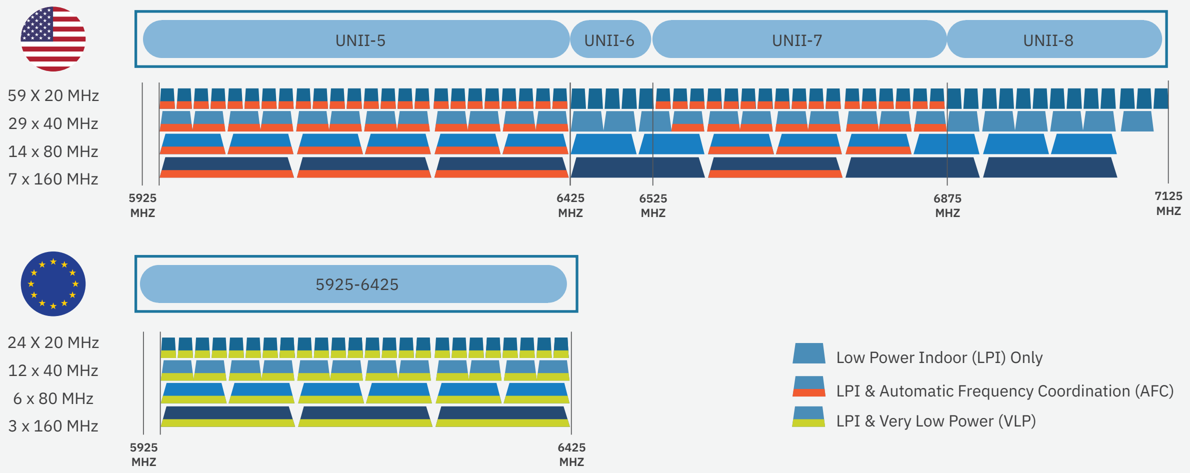
[6] Ericsson, Huawei and Cisco in Ofcom (2022a).

[7] Due to the availability of (non-paid) Wi-Fi versus paid mobile data combined with possible mobile coverage issues in buildings.

[8] Wi-Fi is a family of wireless network protocols based on the IEEE 802.11 family of standards, which are commonly used for local area networking of devices and Internet access, allowing nearby digital devices to exchange data by radio waves (Wikipedia).

[9] European Commission (2021) 6 GHz harmonisation Decision.

Figure 3: Available 6 GHz channels for Wi-Fi 6E in Europe versus the US



Source: HPE Aruba Networks

Tests[10] have shown that if the upper 6 GHz band is not made available for licence-exempt access (e.g., Wi-Fi) only a single 320 MHz or three 160 MHz channels would be available in Europe (see Figure 3) meaning that "...a significant number of moderate to demanding future applications will not function as intended and therefore, residential, enterprise, government, and industrial IoT users will not benefit from these applications".

1.5 The environmental impact of assigning additional spectrum for mobile

A choice to assign the upper part of the 6 GHz band for mobile as opposed to enabling its use for Wi-Fi could also have implications for the environment.

Specifically, if the upper part of the 6 GHz band is reserved for mobile and is not available for Wi-Fi, this could affect the relative quality of fixed compared with mobile connectivity, which could lead to a reduction in the amount of "mobile" traffic that is offloaded and result in a transfer in some of the traffic associated with indoor applications from Wi-Fi to mobile. Indeed, improving indoor coverage is one of the use cases cited by mobile operators for the upper 6 GHz band.[11]

However, literature confirms that 5G mobile networks are significantly less energy efficient for the same amount of data traffic than FTTH networks.[12] This remains the case, even when energy consumption from Wi-Fi routers is considered.[13]

Moreover, planned upgrades to 5G mobile networks could further increase the environmental footprint of the network. In China and Japan, where 5G deployment is the most advanced, the number of 5G base stations required is around 1.4 to two times higher than that of 4G base stations. Research suggests that increasing the number of small cells could strain the electric power infrastructure,[14] and the energy consumption of 5G access networks is higher for use cases that require ultra-low latency connectivity such as AR/VR.[15]

[10] Intel (2023)

[11] GSMA (2022). A significant proportion of MNO respondents to a GSMA survey said that they would use the additional (mid-band) spectrum to improve indoor coverage or outdoor to indoor coverage.

[12] Köhn et al.(2020) and Nuutinen (2021). Current FTTH access networks have been found to be two and a half times more energy efficient than current cellular/5G mobile.

[13] Köhn et al. (2020), Laidler (2019) and Andrae (2020). Current 5G access networks are estimated to consume between 0.05-0.09 kWh/Gigabit compared with 0.02 kWh/Gigabit for FTTH including Wi-Fi.

[14] Chih-Lin et al. (2020) and Cheng et al. (2022).

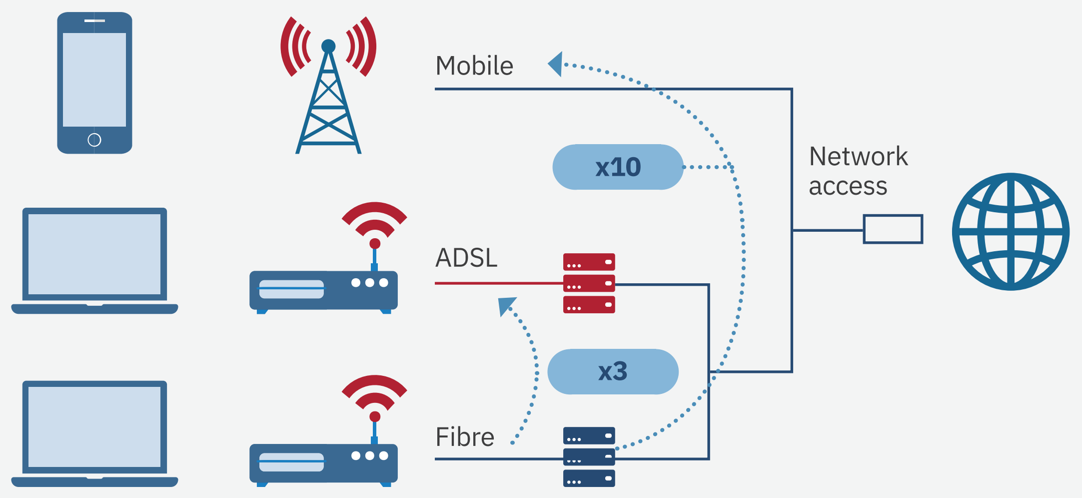
[15] Deepa, Beena and Girinath (2018).

In contrast, reduced energy consumption is a key benefit of Wi-Fi 6 – not only for access points, but also for client devices. Power saving for Wi-Fi 6 can save energy up to 51% compared to Wi-Fi 5 and is achieved through dedicated transmission characteristics such as improved and power dedicated beamformed radio signals and through a new and significant power saving feature called Target Wake Time (TWT).[16]

We have estimated that, as a result of insufficient spectrum availability for Wi-Fi, 15% of the data traffic would shift[17] from FTTH/Wi-Fi networks to 5G mobile networks. This shift would lead to around 16% more energy consumption, which translates to 3.2 megatons of additional CO_2 emissions in Europe per year. To put this into perspective, this is currently 4-6% of the overall CO_2 emissions of the European Information and Communications Technology (ICT) industry,[18] but this share is likely to increase towards 2030 as emissions from other elements of the ICT industry are planned to reduce (see Figure 4).

This study focused on the indirect additional energy costs of this traffic shift to mobile, but it did not consider the (additional) environmental impact of installing additional mobile network capacity required to handle the increased traffic.

Figure 4: Estimated energy consumption gaps between the different electronic communications across networks



Source: Arcep

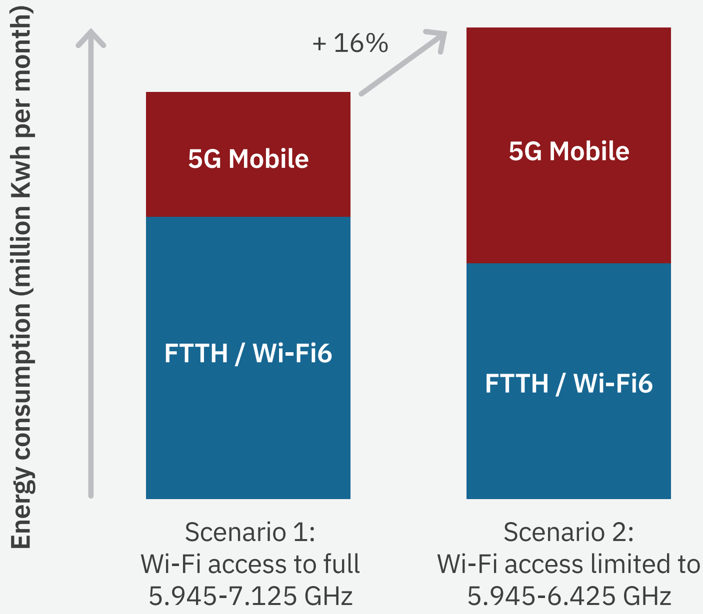
[16] WIK-Consult (2021a), Paragraph 4.2 and Silva et al. (2019).

[17] This estimate results from the applied assumption that the expected throughput of advanced applications is reduced with 50% based on Wi-Fi 7 tests using only the current allocated lower half of the 6 GHz spectrum (Intel 2023). These advanced applications are primarily used by the 'high demand' group, which are expected to make up between 30% and 44% of all broadband residential users in 2030 (WIK-Consult (2021a)). If the fixed connection can partly not support these applications, end users are expected to use the alternative mobile connection. Combining the reduced throughput (-50%) with 30% leads to the expected 15% decrease in data volume via the fixed connection at home which is therefore served via a mobile connection at home. This study focused on the indirect additional energy costs of this traffic shift to mobile, but it did not consider the (additional) environmental impact of installing additional mobile network capacity required to handle the increased traffic. Furthermore, the report did not consider the economic feasibility of this 15% shift (are end users willing to pay more for their mobile subscriptions?) or whether mobile networks have the capacity to accommodate additional data traffic.

[18] Statista: 2750 megatons CO_2 yearly emissions in Europe. Between 2-3% contributable to the ICT industry implies between 55 and 83 megatons CO_2 yearly. The estimated additional 3.2 megatons CO_2 yearly expressed as % thereof is between 4% and 6%.

Figure 5: Results of scenario analysis regarding energy consumption

Scenario 2 assumes reduced Wi-Fi delivered data indoors due to limited spectrum access in the 6 GHz band



Source: WIK-Consult

1.6 Results

These findings (represented in Figure 5) demonstrate that **allocating the complete 6 GHz band for licence-exempt access including Wi-Fi contributes to reducing the energy consumption and environmental footprint of telecoms networks** globally. In Europe, this is consistent with Europe's goal of becoming the world's first climate-neutral continent in 2050.[19]

Finally, to put these findings into a broader perspective, we note that both Wi-Fi 6 and 5G mobile are important in meeting increasing demand for wireless data. However, these technologies are complementary. Future mass market data-intensive applications such as artificial intelligence (AI), automation, AR/VR or high-resolution video will continue to take place indoors and can be supported by FTTH/Wi-Fi if sufficient 6 GHz spectrum is allocated, while 5G mobile connectivity is a key solution to support outdoor connectivity.[20] Importantly, European energy efficiency mandates for building construction will make outdoor-to-indoor mobile coverage even more challenging in the future.

[19] European Commission (2022).

[20] Mobile is also an important solution to support certain indoor applications with specific security and / or quality and reliability requirements, but these are likely to be relevant for certain industrial use cases. The adoption of these services has however been slower than anticipated. See https://www.berec.europa.eu/en/document-categories/berec/reports/study-on-wholesale-mobile-connectivity-trends-and-issues-for-emerging-mobile-technologies-and-deployments

Making the full 6 GHz band licence-exempt is the sustainable choice

1 Massive demand for connectivity

By 2025, about 1/3 of European households may have a Gigabit broadband connection, which they will use to access immersive cloud-based services, such as e-health, remote learning, HD video, and gaming and augmented/virtual reality.

The European Digital Decade Programme has set a target that by 2030, all Europeans should have access to fixed Gigabit connectivity up to the network termination point, meaning that nearly 100% of EU households are set to be served with a fibre-to-the-home (FTTH) connection.

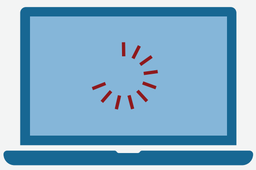
2 Wi-Fi is the default solution for indoor connectivity

The EU's prioritization of FTTH, despite the high installation cost, reflects the fact that most broadband traffic is consumed indoors.

While most household devices can't use mobile or cables to connect to the Internet, many are equipped with Wi-Fi.

3 In the EU, Wi-Fi doesn't have sufficient spectrum

While Argentina, Brazil, Canada, Saudi Arabia, South Korea, US, and several other countries have enabled Wi-Fi access to the entire 6 GHz band, the EU has opened less than half of the band for Wi-Fi – insufficient spectrum to meet the demand for high quality broadband connectivity in the home.

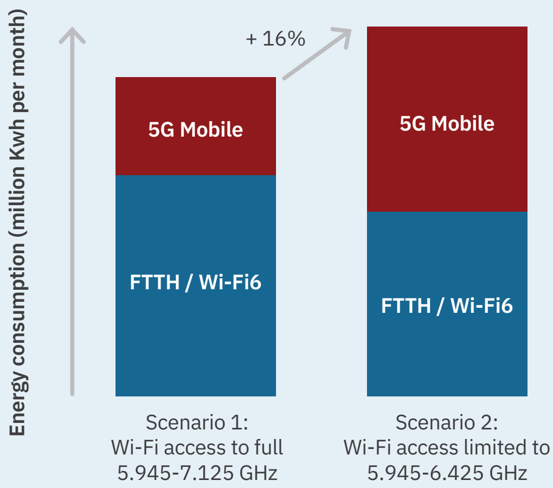


4 Implications for the environment

A shortage of spectrum for Wi-Fi may mean more indoor traffic goes mobile.

But FTTH networks are 2.5x more energy efficient per megabyte transmitted than 5G.

A 15% transfer of traffic from fixed to mobile networks could result in 16% higher energy consumption which would lead to 3.2 megatons of additional CO_2 emissions in Europe per year by 2030 – that's currently 4-6% of the overall CO_2 emissions of the European ICT industry or equivalent to Democratic Republic of Congo's fossil CO_2 emissions in 2020.



5 How to reduce greenhouse gas emissions from connectivity

Making the full 6 GHz band licence-exempt will contribute to reducing the environmental footprint of telecom networks; and support Europe's goal to become the world's first climate-neutral continent.

2 Introduction

The EU Digital Decade Programme seeks to achieve universal coverage of fixed Gigabit technology up to the network termination point (primarily Fibre-to-the-Home (FTTH)) with populated areas served by wireless technologies equivalent to 5G performance. The programme also focuses on the potential of digital transformation as critical enablers for attaining the sustainability goals of the European Green Deal. This requires a "...digital sector that puts sustainability at its heart...ensuring that digital infrastructures become verifiably more sustainable, renewable and energy- and resource-efficient...".[22] This is consistent with the European Commission's target to reduce the EU's greenhouse gas (GHG) emissions by at least 50% compared to the levels of 1990. The ICT sector as a whole is currently responsible for 2-4% of GHG emissions across its lifecycle,[23] but some forecasts suggest that this amount could increase as a proportion of the total.[24]

WIK's models show that in the coming years, demand for Gigabit connectivity in the home as well as increased requirements regarding reliability and response time will become commonplace. Delivering on these needs will be crucial as up to 80% of data is estimated to be consumed indoors. However, while the Digital Decade Programme establishes targets for fixed Gigabit connectivity, this is limited to the network termination point. Less attention has been given to ensuring that consumers, enterprises, and institutions can actually make use of the broadband capability delivered by FTTH and receive high quality of service levels indoors, *beyond* the fixed network termination point. This connectivity is mainly distributed through Wi-Fi connections. However, the capabilities of Wi-Fi are affected by the available spectrum capacity. Lack of accessible spectrum results in congestion among the multitude of Wi-Fi devices streaming data while contending for the same spectrum resource.

The European Union (EU) has opened the lower portion of the 6 Gigahertz (GHz) band (i.e., 5.945-6.425 GHz) to Wi-Fi, however, the upper portion of the band remains inaccessible. The upcoming World Radio Conference (WRC)-23 will debate designation of the upper 6 GHz band for licensed mobile deployments (e.g., 5G or International Mobile Telecommunications "IMT"). Identifying the upper part of the 6 GHz band to IMT would be at the expense of Wi-Fi performance needed to support the broadband FTTH connectivity. Spectrum policy decisions about the 6 GHz band will thus affect the balance in delivery of broadband capability by the FTTH vs mobile networks.

This report explores the practicality and environmental impact of using 5G mobile networks versus FTTH/Wi-Fi for indoor broadband coverage and makes recommendations to policymakers.

[21] European Parliament (2022). Article 4.

[22] Recital 6.

[23] WIK-Consult (2021b).

[24] For example, Cheng et al. (2022) found that based on a medium demand scenario, the electricity consumed by the 5G radio access network alone will account for more than 2.1% of the total electricity generation in 2030 in the UK.

3 Future needs for wireless connectivity

In this chapter, we analyse the evolution of broadband applications and assess what this means for future needs for wireless connectivity in the home and the implications for spectrum assignment.

3.1 Drivers of broadband demand

The increasing availability of very high capacity FTTH infrastructure coupled with continued growth in the number of connected devices, data-intensive applications and greater reliance on the edge-computing is driving a progressive increase in demand for connectivity in homes, businesses, and institutions such as schools and hospitals.

Applications with growing data rates requirements include progressive Television (TV)[25]/Virtual Reality, Virtual Private Networks (VPN), cloud computing and gaming. In the area of progressive TV, a significant increase in data traffic is expected due to the introduction of new technologies such as 8K as well as Augmented and Virtual Reality (AR/VR) that demand higher data transmission rates, low latency, and low packet loss rates.[26] The Meta Oculus Quest 2 is an example of a VR headset that targets the streaming and gaming market. The volume of data and quality of service requirements of future applications also impact the spectrum requirements for Wi-Fi, particularly since many devices depend on wireless connections.[27]

The connectivity requirements of home office/VPN as well as remote education are driven by a strongly increasing share of high-definition audio-visual content transmitted by home office/VPN users. The COVID-19 pandemic has led to a structural shift in the number of employees working from home, which underlines the importance of high data rates and reliable connections to support the effective use of remote working. Remote work further supports sustainability efforts as it is an important contributor to the reduction of CO_2 emissions (see chapter 4.3).

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

Cloud computing includes the storage of high-resolution images, movies, and data as well as the use of software in the cloud. The growing need for connectivity in this area results from the increasing amount of data that is transferred via the Internet. While only a few kilobytes of data are needed to transmit a text message, a full high definition (HD) video requires several gigabytes (GB) of data and high data rates to complete the transmission without major delays.

The increasing use of e-health and smart home applications may also generate additional data volumes, potentially in conjunction with cloud computing. While today's data volumes and speed requirements associated with many telemedicine and telecare solutions are relatively limited, emerging e-health applications are becoming increasingly complex. For example, virtual reality technology is being used to treat certain medical conditions, such as dementia and phobias, and will likely require increased data rates as well as a higher quality of service for enhanced reliability.[28]

[25] Technique in which every line of the screen is refreshed instead of only the odd lines as done with traditional (interlaced) technology. In effect this doubles the vertical resolution and prevents line flickering. See Was ist eigentlich Progressive Scan? - channelpartner.de.

[26] Mangiante, S. et al. (2017): CAICT and HUAWEI Technologies Co. Ltd (2017): Huawei iLab (2017).

[27] See Quotient Associates (2017): and Qualcomm (2016).

[28] Godlovitch, I et al. (2019).

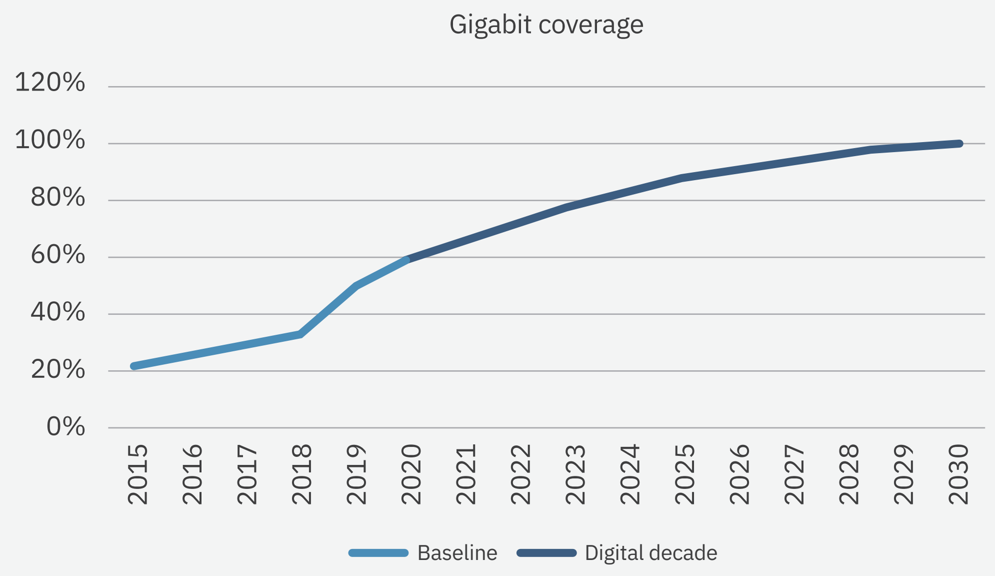
Moreover, interactivity, virtual reality, and tactile internet are likely to be increasingly used in the area of e-learning. For example, music teachers and coaches that provide remote instruction could give real-time guidance to students, correcting their movements instantly. However, these types of applications will only work correctly when the data is transmitted in a manner that enables human sensory reactions, meaning that latency of less than 5 milliseconds may be required.[29] Low response times might also be needed when transmitting lessons or university lectures that involve live participation from remote students. The same applies to virtual and augmented reality applications that will be relevant in education.[30]

Services that are widely used today are also expected to experience moderate increases in connectivity requirements. For instance, requirements for basic internet and communication will expand as high-resolution images and videos are increasingly transmitted via the Internet.

It is also important to note that many of the applications forecast not only require high data rates, but also low latency, and low packet loss rates as well as reliable connections. Applications such as e-health and video communications may not require data rates as high as gaming and progressive audiovisual content, but they may still require specific access technologies to satisfy their demand for low packet loss rates and low latency.

In order to support access to the expanding range of applications, the recently agreed European Digital Decade Programme has set a target that by 2030, all Europeans should have access to fixed Gigabit connectivity up to the network termination point (see Figure 4).[31] Significant amounts of EU funding as well as State Aid have been allocated to support the achievement of this target[32] and it is projected that by 2030, 100% of households will be served with a FTTH connection.[33]

Figure 6: Targets for Gigabit coverage from the Digital Decade program



Source: EC, Digital Decade

[29] ITU (2014):The Tactile Internet. ITU-T Technology Watch Report, p.10-11.

[30] Godlovitch, I et al. (2019).

[31] European Parliament (2022).

[32] €19 billion is estimated to have been allocated EU funding for (primarily fixed) digital connectivity. See also national state aid allocations for fixed broadband at https://op.europa.eu/en/publication-detail/-/publication/d6b8368d-f3dd-11ea-991b-01aa75ed71a1/language-en

[33] European Commission (2021b).

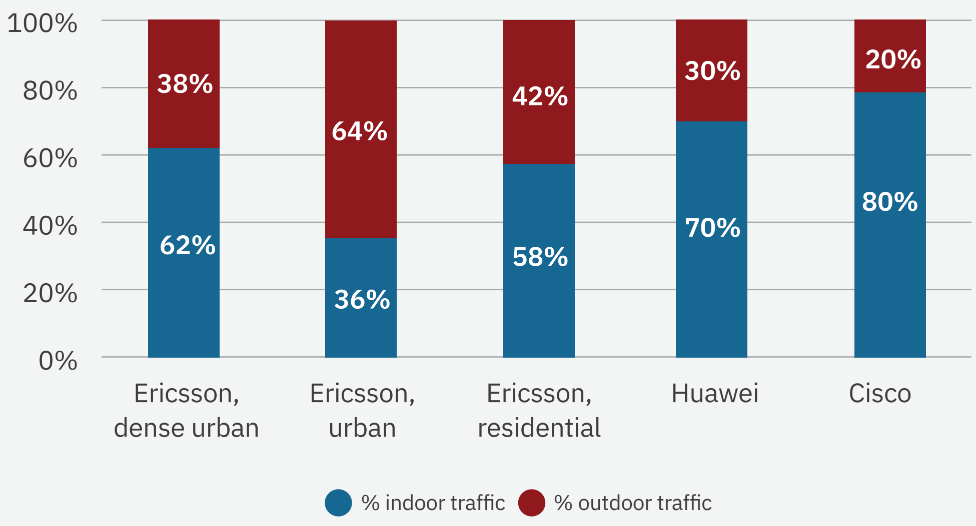
3.2 How much is wireless?

FTTH and technologies like TV-cable provide a fixed wireline connection for indoor connectivity. However, most devices are not equipped to connect to a built-in socket for a wired ethernet connection or they may be used in locations where no fixed direct connection is available. Wi-Fi routers are therefore indispensable to FTTH connections. According to a representative survey conducted by Kantar for Vodafone in 2022,[34] European homes possess up to nine Wi-Fi enabled devices, and three-quarters of householders agreed that the provision of reliable Wi-Fi was their number one requirement. 80% of households where someone works from home regarded Wi-Fi to be as important as electricity and gas, with the same number of home workers reporting that they couldn't work at all without Wi-Fi. Moreover, four in five households also said that their use of Wi-Fi is expanding, while 50% said they expect Wi-Fi to be available in every room of the house.

Available data suggests that even devices such as mobile phones, certain tablets, and laptops that also offer mobile connectivity are typically connected via Wi-Fi when indoors. For example, the UK telecoms regulator Ofcom noted in its 2022 annual report that in 2021 "…more than 70% of connections from mobile devices are through Wi-Fi." And that "…mobile operators are also increasingly giving consumers the choice to use Wi-Fi for voice calls and SMS."[35] Ofcom also noted that most UK broadband traffic takes place indoors. Its research showed that indoor Wi-Fi traffic averaged 453 GB per month in 2021 versus 5.3 GB for an average mobile subscription.[36]

Estimates of the proportion of indoor vs. outdoor mobile traffic vary, but as noted in Figure 7,[37] available sources suggest that most of the mobile data traffic is delivered by Wi-Fi indoors.

Figure 7: Proportion indoor versus outdoor for mobile traffic



Source: Ofcom (2022)

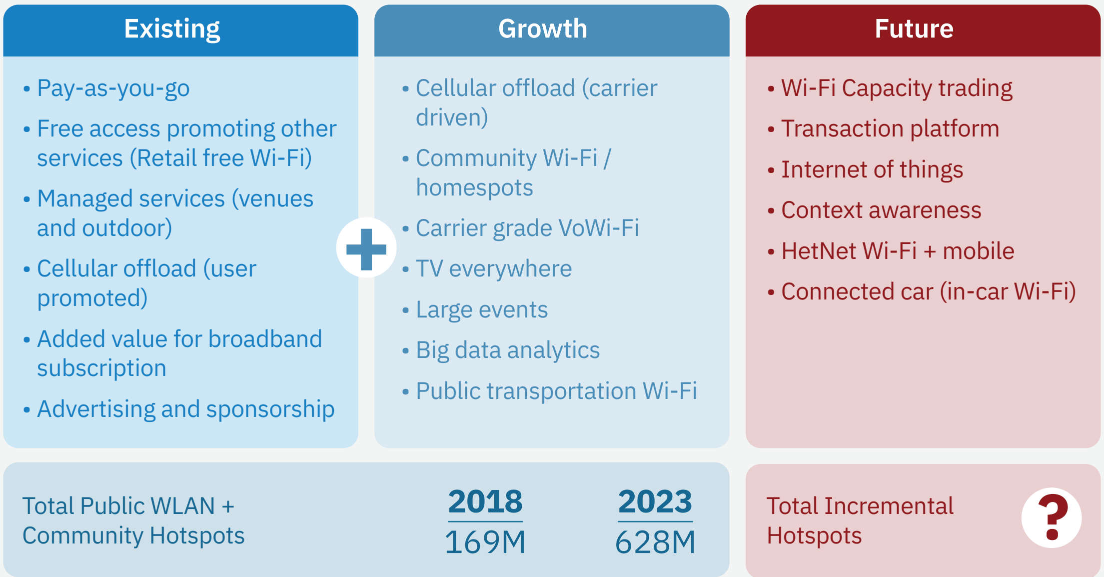
[34] https://www.vodafone.co.uk/newscentre/press-release/research-reveals-transformation-of-home-wifi-usage-in-europe/

[35] Ofcom collected data between 1 January and 31 March 2021 from around 280,000 Android devices showing that 73% of active connections were made on Wi-Fi and 27% made on mobile networks.

[36] Ofcom (2022a). Paragraph 2.18.

[37] From Ofcom (2022a). Figure 2.3 proportion of indoor and outdoor mobile traffic, several sources.

Figure 8: Growing number of public Wi-Fi hotspots from 2018 to 2023



Source: Maravedis, Cisco Annual Internet Report, 2018-2023

Wi-Fi is also one of the most significant technologies for Internet of Things (IoT) devices and made up 31% of all IoT connections worldwide in 2022.[38] Key applications for Wi-Fi enabled IoT devices include smart homes, buildings, and healthcare. This compares with around 20% of IoT devices which were supported by mobile IoT, many of which are connected using specialized lower data rate technologies such as LTE for Machine communication (LTE-M) and narrow band IoT (NB-IOT). However, analysts note that the growth rate of 5G IoT shipments has been slower than many expected.[39]

Wi-Fi is playing an increasing role in connecting public venues such as stadiums, smart cities, and on public transport. Cisco (2020a) estimated that there will be almost 628 million public Wi-Fi hotspots by 2023 across industry segments, which is a fourfold increase compared to 2018. In Figure 8, Cisco describes the different applications of Wi-Fi hotspots in 2018, 2023, and in the future. Importance of Wi-Fi in public spaces is evidenced by various policy initiatives such as WiFi4EU.[40]

3.3 Increasing demand for Wi-Fi performance

As previously noted, connectivity requirements are increasingly driven by applications such as progressive media and entertainment, including AR/VR and HD video, cloud computing, AI, as well as demanding office and industrial automation. Table 1 illustrates how data rate and other requirements such as latency and packet loss are likely to evolve by 2025.

[38] https://iot-analytics.com/number-connected-iot-devices/
[39] https://iot-analytics.com/number-connected-iot-devices/
[40] See https://wifi4eu.ec.europa.eu/

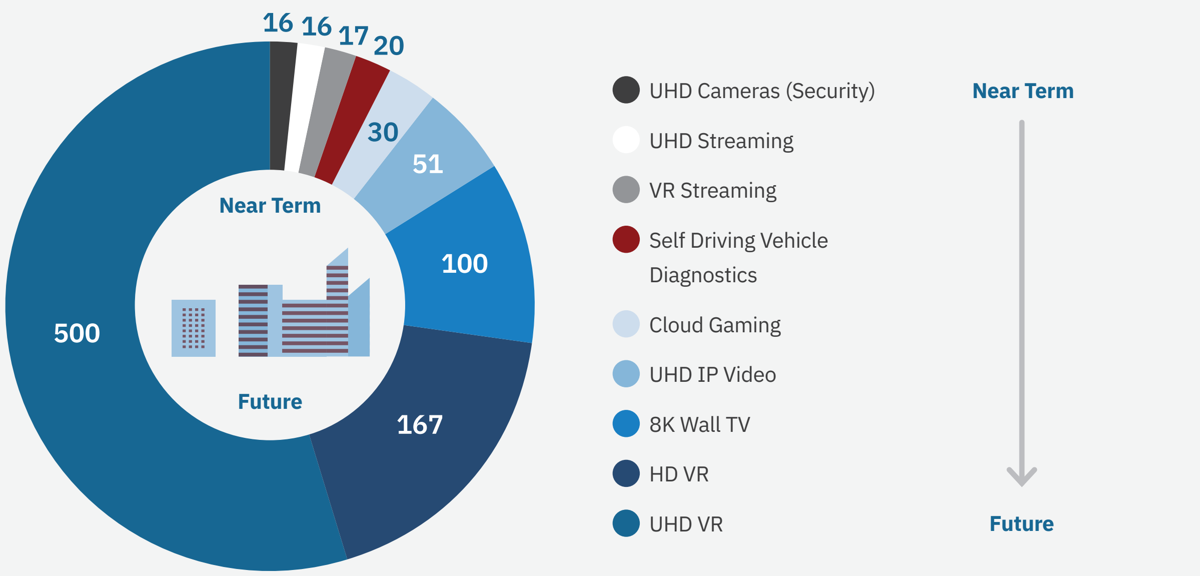
Table 1: Application categories with projected capacity and quality requirements

Application category	Downstream (Mbps) in 2025	Upstream (Mbps) in 2025	Packet loss	Latency
Basic Internet	≈30	≈16	0	0
Home office/VPN	≈250	≈250	+	+
Cloud Computing	≈250	≈250	+	++
State of the Art Media and Entertainment	≈150	≈30	++	+
Progressive Media and Entertainment (8k, AR/VR/)	≈300	≈60	++	+
Video Communication (HD)	≈25	≈25	++	++
Gaming (including VR)	≈300	≈150	++	++
E-health	≈50	≈50	++	+
E-home/E-facility	≈50	≈50	0	0
E-learning	≈50	≈50	0	0
Mobile Offloading	≈15	≈12	0	0

Notes:
0 = Low specific importance
\+ = High importance
++ = Very high importance

Source: Strube Martins, S. and Wernick, W. (2020).[41]

Figure 9: Growing demand by innovative applications – Cisco 2018-2023



Application requirements in Mbps

Source: Cisco Annual Internet Report, 2018-2023

[41] Strube Martins, S., and Wernick, W. (2020): Regional differences in residential demand for very high bandwidth broadband internet in 2025, in: Telecommunications Policy, Volume 45, Issue 1, February 2021.

These estimates have also been confirmed by industry experts, which noted that time-sensitive applications like AR/VR solutions for residential or enterprise usage, industry 4.0, collaborative robotics, and existing applications like remote working and cloud computing will benefit from higher reliability and lower response time of the combined fixed/ wireless internet connection. Cisco (2020a) also confirmed in its Annual Internet Report 2018-2023 that "...innovative applications such as Augmented Reality and Virtual Reality are likely to drive increased requirements for data rates and quality in indoor infrastructure".

Figure 9 from the Cisco report shows the growing demand for these applications by 2023.[42]

The use of multiple devices in parallel by different individuals in a household as well as home IoT is another important driver of overall data traffic.

In order to forecast future bandwidth needs, WIK has developed a 'market potential' model[43] which projects the future demand for residential connectivity based on three parameters: 1) applications and their bandwidth requirements, 2) user profiles, and 3) expected population and household structure.[44] The underlying assumption is that there is no restriction to be considered in the access line allowing it to provide the performance demanded by the applications at any time. The applications are allocated to the different user profiles, which vary from digital professionals to complete deniers. Thereafter, the combined demand of these profiles is further aggregated to household demand based on the population structure. This model has been applied to and validated in Germany, United Kingdom (UK), and the Flemish region in Belgium (see Table 2 for the results).

The main findings of the WIK model show:

- By 2025 between 30% and 44% of European households will need more than 1 Gigabit per second (Gbps) download and 600 Mbps upload speed (bandwidth demand).
- Demand is likely to further increase towards 2030 as a result of the FTTH deployment and growing acceptance of emerging applications such as e-health and e-learning.
- The main demand drivers for data, as well as the need for higher quality (low latency and packet loss rates) are immersive experiences use cases (e.g., artificial intelligence, VR/AR, industrial automation, telepresence, 3D-video, and other applications).

The authors also noted that considerable focus has been given to providing fibre access lines to end users to support the anticipated demand, but that it is also important to ensure that the wireless indoor infrastructure is capable of satisfying their current and future demand.[45]

Table 2: Forecasted residential connectivity demand in 2025 (% of households)

Region / Download capacity	Gigabit	500 Mbps – Gigabit	150-500 Mbps	Up to 150 Mbps	Deniers
Germany	30	45	10	8	7
UK	40	34	11	8	7
Belgium -Flemish region	44	22	15	9	10

Source: Strube Martins, S. and Wernick, W. (2021): Regional differences in residential demand for very high bandwidth broadband internet in 2025, in: Telecommunications Policy, Volume 45, Issue 1, February 2021.

[42] Cisco (2020a).

[43] This model was developed in 2011 (See Doose, A.-M., Monti, A., Schäfer, R. (2011) and Monti, A., Schäfer, R. (2012)) and updated in 2017 (See Strube Martins, S., Wernick, C., Plückebaum, T., Henseler-Unger, I. (2017) and Godlovitch, I., Plückebaum, T., Strube Martins, S., Gantumur, T., Elixmann, D., Tas, S., Arnold, R., Wernick, C. (2018)) to reflect emerging and future applications, related bandwidth requirements, as well as developments in household usage patterns for broadband.

[44] See for more details on the model, WIK-Consult (2021a), paragraph 3.2.

[45] WIK-Consult (2021a)

3.4 Suitability of wireless technologies

In principle, wireless devices can be supported by either Wi-Fi or mobile technologies, but in reality, they are not perfect substitutes. Some devices are designed such that they can only be connected via Wi-Fi or mobile networks. The different technologies also have advantages or disadvantages in specific settings. Differentiating factors include performance, cost, indoor coverage, and outdoor mobility.

Performance

From the perspective of performance, 5G offers a theoretical peak downlink rate of 10 Gbps. In principle, this should meet future connectivity needs, but the peak speeds envisaged are rarely achieved in practice,[46] and peak performance will be further reduced if more traffic is relayed over mobile as opposed to fixed infrastructure due to the shared nature of the medium.

Table 3: An overview of the performance of wireless technologies

Transmission technology	Year of specification release/ introduction	SDO – Specification	FttX	Data rate downlink peak in Mbps	Data rate uplink peak in Mbps	VHC BB upgrade to 1G
Radio waves	Licensed access					
NB-IoT	2017/2018	3GPP Rel. 13/14	-	0.025/ 0.079	0.062 /0.010	n.a.
LTE-M	2017	3GPP Rel. 13	-	0.3/0.8[1]	1.0/0.37	n.a.
4G-LTE Adv.	2011	3GPP Rel. 10	Fbackhaul	3,000	1,500	N
4G FWA	2009/11	3GPP	Fbackhaul	50-150	20-40	N
5G NSA NR Rel. 15	4Q2017	3GPP TR 21.915	Fbackhaul	5,000	2,500	N
5G Rel. 15	2Q2019	TR 21.915	Fbackhaul	10,000 50[2]	5,000 25[2]	Y
5G Rel. 16	2Q2020	TR 21.916	Fbackhaul			
5G Rel. 17	2Q2021	TR 21.917	Fbackhaul			
IMT2020	2020	ITU		20,000 100[3]	10,000 50[3]	
Radio waves	Licence-exempt access					
Wi-Fi	1997	IEEE802.11	-	2[4]		N
Wi-Fi	2000	IEEE802.11b	-	11		N
Wi-Fi	2000	IEEE802.11a	-	54		N
Wi-Fi 4	2009	IEEE802.11n	-	600		N
Wi-Fi 5	2013	IEEE802.11ac	-	1,300[5] / 6,936		Y
Wi-Fi 6	2019-2020	IEEE802.11ax	Fbackhaul	9,600		Y
LoRaWAN	2015	Release 1.0	-	0.05	0.05	n.a.

Note 1: Cat-M1 devices using HD-FDD respectively FD-HDD.

Note 2: IMT2020 ratio applied for peak to user experienced data rates.

Note 3: User experienced data rate.

Note 4: Aggregate data rate.

Note 5: Current product max.

Source: WIK-Consult and Ramboll (2021).[47]

[46] Opensignal (2022).

[47] https://www.berec.europa.eu/en/document-categories/berec/reports/external-sustainability-study-on-environmental-impact-of-electronic-communications.

Wi-Fi 6 supports peak data rates of up to 9.6 Gbps. Performance is further optimized with access to 6 GHz by Wi-Fi 6E and subsequent generations of Wi-Fi technologies. This means that, with access to the 6 GHz band, Wi-Fi implementations can extend the full capabilities of FTTH access connections to the device level, surpassing 1 Gbps.

Indoor coverage

While 5G (under certain usage assumptions) and Wi-Fi should in theory be capable of supporting the data rates and quality of service requirements of future applications, a key difference relates to indoor coverage. Indoor wireless connectivity is vital as the vast majority of data is consumed indoors. For example, Cisco estimates that over 80% of mobile data is consumed indoors and only 4% of mobile data is consumed when 'on the go'.[48]

Currently, for indoor coverage mobile networks rely on outdoor base station deployments. This is a challenge as radio signals need to propagate into buildings which can have varying structural characteristics (building materials, insulation, etc.) that make it difficult or impossible to do so.

Mobile network operators manage to overcome these indoor propagation challenges with higher transmit power levels and in lower frequencies that have favourable propagation characteristics. Ofcom (2022) indicated that in the UK "...overall indoor coverage sits between 90% and 95% across mobile operators, but only between 68% and 80% for rural areas." It further described that mobile network operators "...have to a large extent relied on an 'outdoor in' solution to this problem, using their lower frequency spectrum to provide indoor coverage from outdoor cells."[49] These lower frequencies are below 1 GHz, meaning they employ the traditional 500 and 700 Megahertz (MHz) bands. As explained in section 3.5, lower frequencies can travel further and as such, mobile operators can cover a large area including indoor. However, Ofcom also notes that "...there is not enough of this spectrum to address capacity demand in future, even if more were made available."

In addition to the limited availability of low frequency spectrum, there are two other issues. First, mobile operators also use much higher frequencies in the mid-band (2-6 GHz) and plan to use even higher frequencies (26-114 GHz) in the near future in combination with 5G to cater to the increased connectivity requirements. These higher radio frequencies (hence, shorter radio waves) are by nature more sensitive to reflection and absorption, so they will have a harder time passing through walls and obstacles in general to reach customers indoors.

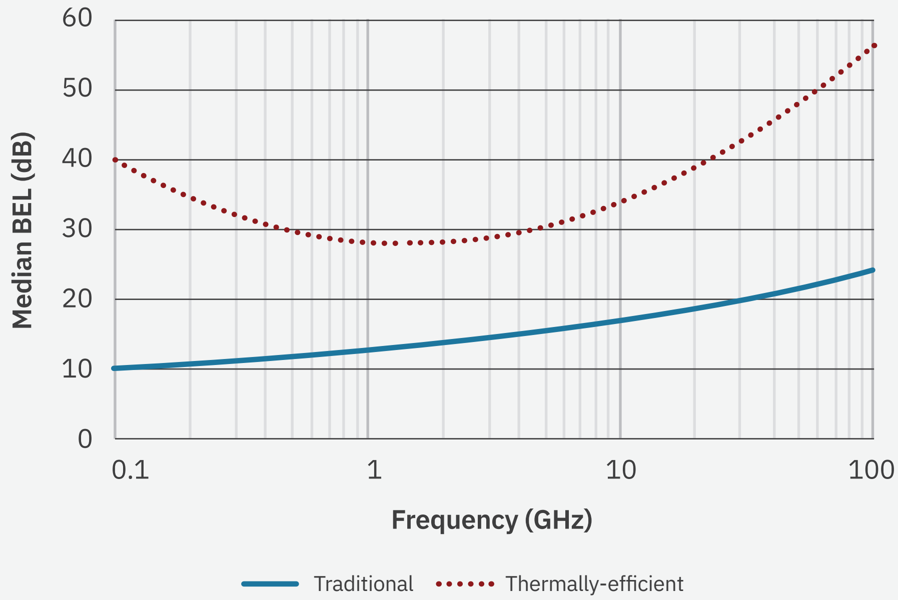
The second issue is that over time, buildings will become more energy efficient and have thicker, more insulated walls and windows. Figure 10 from the ITU shows the predicted building entry loss (BEL) on the vertical axis versus the used radio frequency on the horizontal axis. It shows not only the increased BEL for higher radio frequencies above 1 GHz, but also clearly the much higher BEL for thermally efficient buildings (red dashed line) versus the older buildings (blue line).[50]

[48] CISCO (2020c), Cisco Vision white paper: 5G – thriving indoors.

[49] Ofcom (2022b), paragraphs 5.71-77, table 1.1.

[50] ITU (2017). Figure 1.

Figure 10: The impact of radio frequency on building entry loss



Source:ITU

It should be further noted that the described BEL apply for horizontal transmission, whereas in reality many mobile cells are located either higher than the surrounding buildings (or in the case of high-rise buildings, lower) leading to even higher losses. IDATE (2023) noted that indoor coverage is challenging for buildings higher than 50 meters (around 10 floors), where it found that for 5G operating at 3.5 GHz and 80 MHz of spectrum, 23% have poor indoor coverage and 77% have almost non-existing coverage.[51]

In 2020, The European Commission announced its strategy for "A Renovation Wave for Europe – Greening our buildings, creating jobs, improving lives". Its Climate Target Plan 2030 contains the objective to at least double the annual energy renovation rate of residential and non-residential buildings by 2030 and to foster deep energy renovations. This will lead to 35 million building units being renovated by 2030, which is 16% of the current total European building units.[52]
Overall, it is expected that it will become even more challenging for mobile operators to provide indoor coverage with high capacity 5G operating on higher frequencies as BEL increases significantly. Challenges will increasingly occur, not only in existing buildings, but especially in renovated and new high-rise[53] building units. Hence, the 5G indoor connectivity will increasingly depend on wireless technologies such as Wi-Fi.

Alternatively, neutral third-parties or mobile operators could install small cells, low power mobile radio access points (AP) outside and inside buildings,[54] to complement their existing large cell towers, the so-called macro cells. Small cells can be microcells, picocells or femtocells. See Table 4 below for the different coverage areas and applications.

[51] iDate (2023), paragraph 4.2.

[52] European Commission (2020).

[53] iDate (2023).

[54] Small cells are low powered mobile radio access points used for voice, video, and data transmission designed to provide network coverage to smaller areas compared to traditional large cell towers or macro cells. Small cells could be micro cells, pico cells and femto cells. See Small Cells: Microcell, Picocell and Femtocell Comparison - Dgtl Infra.

Table 4: Key differences of small cells – Microcell, Picocell, Femtocell

Small cells types	Microcell	Picocell	Femtocell
Location	Outdoors	Indoors (large areas)	Indoor (small areas)
Range	180 to 900 meters	90 to 300 meters	Less than 30 meters
Users	100 to 2,000	30 to 100	1 to 32
Power	2 to 20 watts	250 milliwatts to 2 watts	100 to 200 milliwatts
Cost	$$$	$$	$

Source: Amended table based on Small Cells: Microcell, Picocell and Femtocell Comparison - Dgtl Infra

Ofcom noted in this respect that "...network operators may be willing to supply additional technology like femtocells and picocells which create mobile hotspots from a fixed broadband connection. Most existing femtocells rely on 3G mobile technology, but the market is now also producing a range of 4G and 5G femtocells."[55]

From a performance and initial purchase price perspective, indoor picocells seem only economically feasible for large enterprises, airports, large railway stations, sport arenas etc., but not for mass market (e.g. residential deployment). Femtocells are less costly and may be feasible for the consumer market as their purchase price is comparable with Wi-Fi routers. However, femtocell deployments require additional expenditures on the mobile data package from a mobile operator. In contrast, comparably priced Wi-Fi 6E router in combination with the existing internet connection can deliver similar connectivity for a fraction of the cost.

The significant advantage of cellular technology is that it provides ubiquitous mobile connectivity. But as previously noted, the proportion of data consumed outdoors (e.g., 'on the go') is significantly smaller compared with data requirements indoors. It is reasonable to anticipate that most of bandwidth-intensive use cases such as AR/VR and high-resolution video will continue to take place indoors and can be supported by Wi-Fi with the exception of certain critical applications, which are unlikely in a residential context but could include business applications requiring 5G campus networks. Moreover, many of the IoT applications that require mobility will not necessarily require the high data rates or low latency and may not comport with the higher power consumption entailed by 5G implementations.

In short, connecting indoor devices with Wi-Fi is more energy efficient and affordable to deploy than 5G indoor solutions.

3.5 The impact of available spectrum

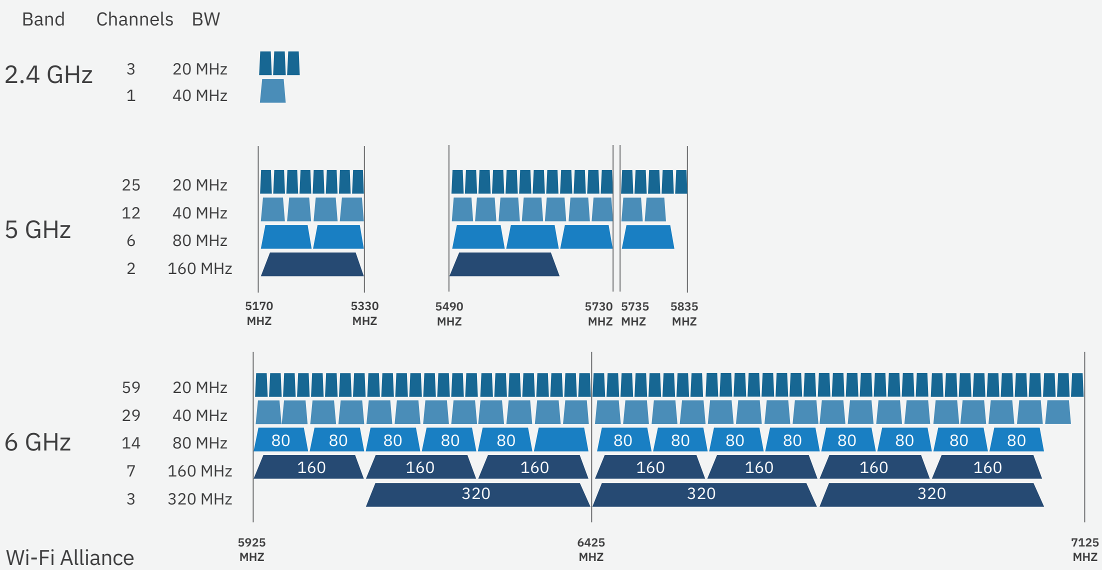
All wireless networks depend on access to radio frequency spectrum. In general, radio signal propagation decreases with increase in frequency. This reduction of the amplitude of radio waves is called attenuation. Thus, lower frequencies are utilized to achieve more widespread coverage. Overall, the available width of the applied frequency block determines the capacity (e.g., for mobile use there are 20 blocks of 5 MHz between 700 and 800 MHz and 2000 between 1 and 3 GHz). However, the frequency blocks in the higher frequency range offer more capacity (see Figure 11 below).

[55] Ofcom (2022a).

3.5.1 Mobile networks

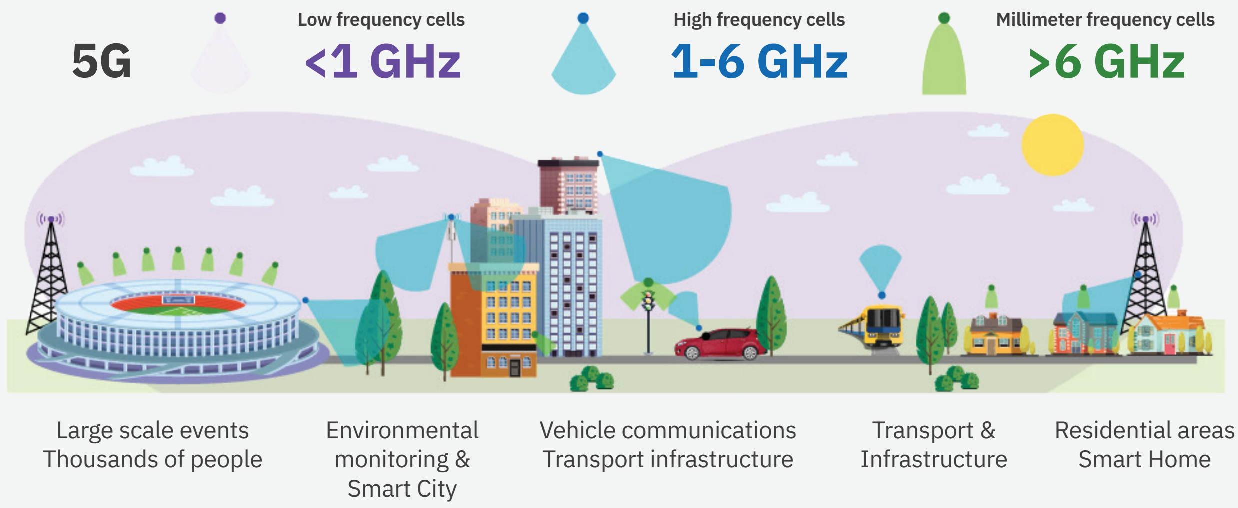
Traditionally the 500-700 MHz bands were used for mobile networks, allowing for coverage of a wide area with a limited number of large, powerful mobile towers above rooftop level, known as macro cells (see Figure 12 below). Due to the scarcity of spectrum and demand for higher throughput, less powerful small cells operating on the mid and higher spectrum bands (2-5 GHz and above 26 GHz) have been added to enable mobile operators to increase capacity in localised dense urban and urban areas. These small cells are typically sited below rooftop level (e.g., on road signs, mailboxes, etc.) or in indoor locations.[56] Network densification using small cells can support significantly higher speeds due to the use of higher radio frequencies and new modulation techniques in 5G networks. However, the effects are limited to the local area, in contrast with the large areas covered by the macro cells using the lower frequencies.

Figure 11: Number of Wi-Fi channels per spectrum band



Source: Wi-Fi Alliance

Figure 12: The different coverage areas of radio frequencies



Source: 5G Antenna for Next Generation Networks| E-shop SECTRON

[56] See https://5gobservatory.eu/observatory-overview/5g-scoreboards/ and https://www.ctia.org/news/2021-annual-survey-highlights

Up until this point, 5G has mainly been deployed by mobile network operators (MNOs) on the basis of lower frequency bands on a "non-standalone" basis, overlaying the 5G core network on the previously deployed 4G network.[57] This has achieved rapid and widespread coverage of 5G, but without the significantly higher throughput that was envisaged when 5G was conceived.

Various studies by WIK-Consult[58] and others including Ofcom (2022b)[59] show that network densification will be needed alongside the deployment of standalone 5G core networks to meet future connectivity needs. This is likely to be through a combination of more macro cells in rural areas with additional small cells in dense urban/urban areas. Small cells are likely to make use of the 3.5 GHz and 26 GHz spectrum that has been assigned for mobile use, but surveys of MNOs suggest that there has been limited deployment of small cells in Europe thus far.[60] As small cell deployment is yet to begin on a widespread basis and is expected to be gradual, it seems unlikely that mobile operators in Europe will exhaust the mid-band (3.5 GHz) frequencies already assigned to them and be in a position to utilize additional frequencies in the mid-band in the near term.

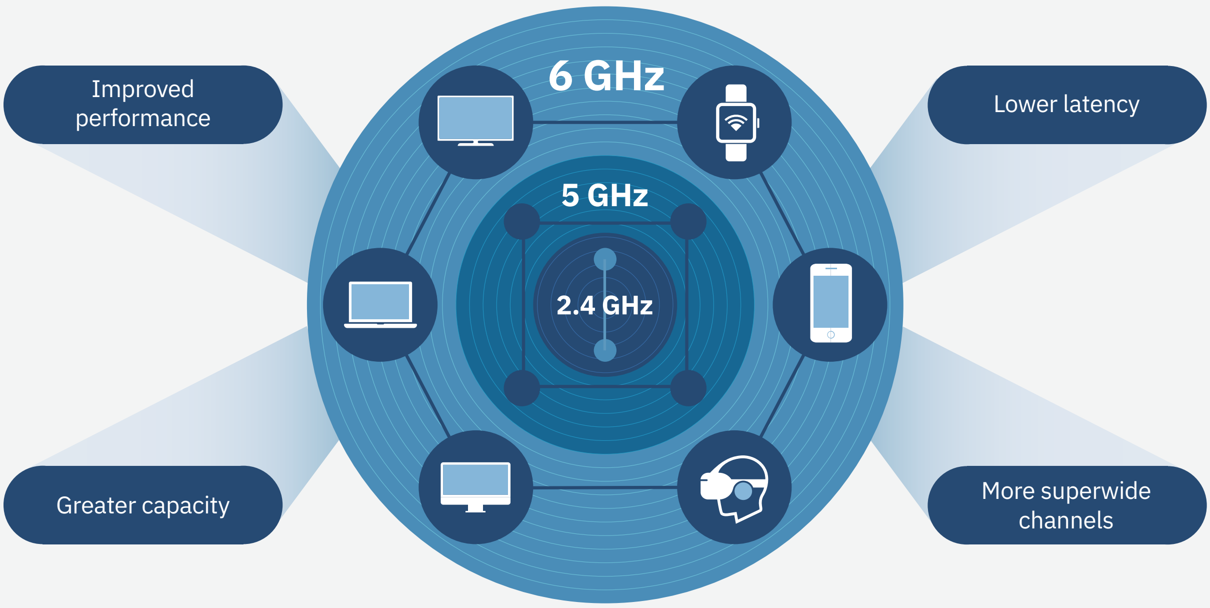
Higher frequencies will be needed to support the deployment of fixed wireless access (FWA). However, the mm Wave (26 GHz and higher) band, which has been allocated to mobile operators in a few countries including Italy, has proven to be well suited to FWA connections in very rural areas. In a survey conducted by the GSMA, FWA was the second most cited use case for 6 GHz (after enhanced mobile broadband (eMBB) services).[61] However, as the EU has placed significant focus on supporting FTTH technologies, the need for FWA as a complement to FTTH is likely to be limited to the most rural households, significantly reducing spectrum requirements for this use case.

The use case that was highlighted by GSMA members as the main application for the 6 GHz band was to support eMBB services (i.e., to increase capacity for mobile broadband).[62] However, a high proportion of mobile broadband use is expected to be indoors. Thus, the demand for mobile connectivity and the associated amount of spectrum that mobile operators will need to meet this demand will also depend on the degree to which wireless traffic passes over mobile (as opposed to over FTTH/Wi-Fi) networks. This could be influenced by spectrum assignment policies which affect the relative quality and reliability of mobile and Wi-Fi networks. This is further discussed in relation to Wi-Fi (see section 3.5.2).

Furthermore, there are mechanisms in place which should ensure that the existing spectrum in the 3.5 GHz and 26 GHz bands is efficiently used – including the potential for spectrum trading or leasing if certain MNOs are underutilizing the spectrum they have been granted. Mobile operators have also acknowledged that further network densification could be used to increase capacity as an alternative to using additional spectrum in the 6 GHz band.[63] Although they observe that this could be more costly, it should be noted that measures have been introduced in the EU Electronic Communications Code (Article 57) to limit site leasing costs and permit requirements for small cells, and further measures to reduce the cost of deploying 5G small cells have been put forward in the draft Gigabit Infrastructure Act.[64] In any event, it should be recalled that if the 6 GHz band is used as an alternative to network densification for mobile network operators, this would be associated with licensing costs for the spectrum, which must be considered when comparing the costs and benefits of a 6 GHz assignment to mobile vs the need for network densification.

57 WIK-Consult and Ramboll (2021).
58 https://op.europa.eu/en/publication-detail/-/publication/7f14b774-b71a-11ed-8912-01aa75ed71a1/language-en/format-PDF/source-287144955
59 Paragraph 5.38 and onwards.
60 WIK-Consult (2023a).
61 GSMA (2022). p.13.
62 Idem.
63 GSMA (2023).
64 https://digital-strategy.ec.europa.eu/en/library/gigabit-infrastructure-act-proposal-and-impact-assessment

Figure 13: Benefits of Wi-Fi operating on 6 GHz spectrum



Source: Wi-Fi Alliance

3.5.2 Wi-Fi networks

Unlike mobile networks, Wi-Fi accesses spectrum on licence-exempt basis. Thus, implementation of new Wi-Fi technologies depends only on the availability of devices and spectrum access.

Available spectrum access directly impacts performance of Wi-Fi networks. European regulations allow Wi-Fi access only to the lower portion of the 6 GHz band, while the US, Canada, most of South America (including Argentina, Brazil, Colombia), and some countries in the Middle East and Asia allow for Wi-Fi to operate across the entire 6 GHz band.[65]

Wi-Fi Alliance® introduced the new Wi-Fi 6E brand[66] to distinguish the latest generation Wi-Fi 6 devices that are capable of 6 GHz operation. Wi Fi 6E brings a common industry name for Wi-Fi users to identify devices that offer the features and capabilities of Wi Fi 6 – including higher performance, lower latency, and faster data rates – extended into the 5925-7125 MHz frequency band ("6 GHz band"). As the 6 GHz regulatory landscape evolves, Wi-Fi Alliance member companies continue to expand the Wi-Fi 6E ecosystem even further. Current deployments in the band include Wi-Fi 6E enterprise-grade and consumer access points, smartphones, computers, and televisions. Industrial environments are also expected to see strong adoption of Wi-Fi 6E to deliver applications including machine analytics, remote maintenance, and virtual employee training. Wi-Fi continues its rapid rate of innovation with work underway within Wi-Fi Alliance to define the next generation of Wi-Fi (i.e., Wi-Fi 7).[67] Wi-Fi 7 is intended to deliver unprecedented quality of service (QoS) at higher data rates and lower latencies necessary for a growing set of demanding applications and use cases such as AR/VR/XR, Industrial IoT, automotive, telepresence, and immersive 3-D. Based on the IEEE 802.11be standard, Wi-Fi 7 will support channel

[65] See https://www.wi-fi.org/countries-enabling-wi-fi-in-6-ghz-wi-fi-6e
[66] See https://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-delivers-wi-fi-6e-certification-program
[67] See Wi-Fi 7: https://www.wi-fi.org/who-we-are/current-work-areas#Wi-Fi%207

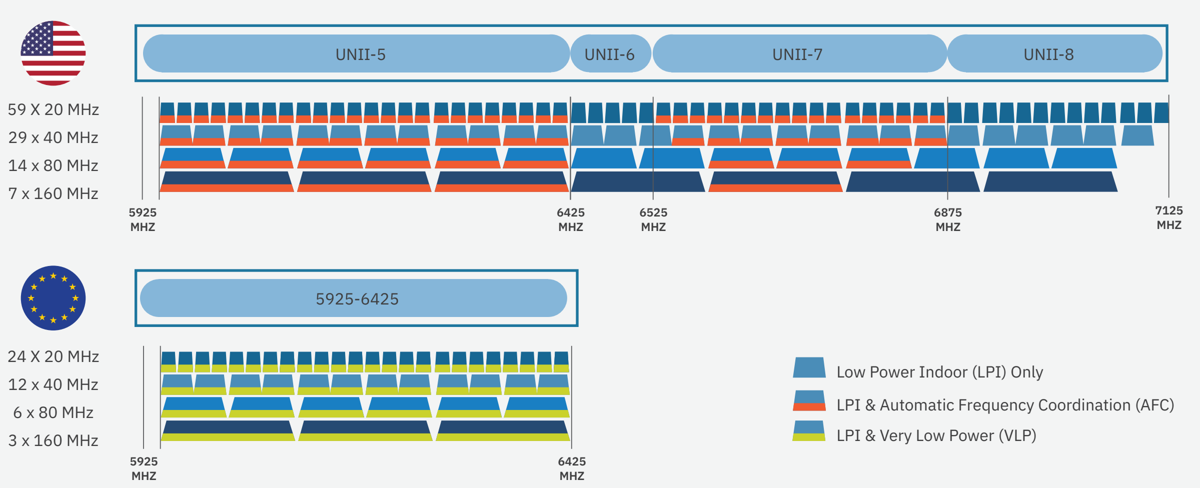
bandwidths of up to 320 MHz, Multi-link Operation, 4096 Quadrature Amplitude Modulation (QAM), improved power consumption with Target Wake Time, and other features. It is important to emphasize that optimal performance of Wi-Fi 7 will depend on access to multiple wider (e.g., 320 MHz) channels in the 6 GHz band. Without Wi-Fi access to the 6425-7125 MHz band, consumers and enterprises cannot realize the full benefits of Wi-Fi 6E, Wi-Fi 7, and future generations of Wi-Fi technologies.

In contrast to the US, as shown in Figure 14 below, Wi-Fi spectrum access in Europe is insufficient to support multiple wider channels needed for multi-device, high-density deployments.

Studies have shown that this could limit the potential for Wi-Fi to support the range of applications that would be possible with a Gigabit (and in future multi-Gigabit) FTTH connection. For example, Intel (2023) conducted an extensive simulation of parallel usage of expected applications in households and enterprises, testing a variety of situations with Wi-Fi 6 and Wi-Fi 7 access points. It tested the consequences of different channelisation in 160 MHz and 320 MHz and various overlap between 0% and 75% in combination with a varying amount of spectrum to compare the effect of having only the lower half of the 6 GHz band or the whole 6 GHz band available for licence-exempt access.
Intel concluded that if the upper 6 GHz band is not made available for licence-exempt access (e.g., Wi-Fi), only a single 320 MHz or three 160 MHz channels would be available in Europe, meaning that "…a significant number of moderate to demanding future applications will not function as intended and therefore, residential, enterprise, government, and industrial IoT users will not benefit from these applications."

Furthermore, it concluded that "…in moderate to high traffic load environments, e.g., enterprises, industrial plants, homes, hotspots, the availability of a single 320 MHz channel is insufficient to meet the KPI of these emerging applications." and "In particular the latency goals cannot be met while maintaining the required reliability." Intel concluded that "…only when three non-overlapping 320 MHz channels are available can the latency performance and reliability be kept at acceptable levels…".

Figure 14: Available 6 GHz channels for Wi-Fi 6E in Europe versus the US



Source: HPE Aruba Networks

The UK regulator Ofcom (2023) highlighted in its 2023 preparation document for the WRC that various stakeholders noted that licence-exempt access of the upper 6 GHz band would allow several, non-overlapping 320 MHz channels in the entire 6 GHz band, which would boost throughput, and enable very low latency communication links supporting the rendering of high-resolution graphics like AR/VR and other future use cases. Suppliers for both mobile and licence-exempt equipment have also voiced their preference for licence-exempt access due to availability of higher bandwidth.[68]

3.6 Conclusions regarding most efficient use cases for spectrum

In conclusion, Wi-Fi and 5G are both necessary to meet the increasing demand for wireless connectivity. However, the technologies are likely to play different roles. While Wi-Fi (in conjunction with FTTH) is best suited to meet indoor broadband connectivity needs, licensed mobile is the preferred solution to support outdoor connectivity. Mobile solutions such as indoor pico- and femtocells may support indoor coverage, but their usage is most feasible in industrial setting where a guaranteed quality of service is required.

A majority of wireless devices is expected to be used indoors. The EU has set a target to achieve universal fixed Gigabit connectivity, creating a strong case to assign the full 6 GHz band to Wi-Fi, thus ensuring that Gigabit connectivity (and higher) can be effectively achieved in the coming years and support the increasing number of Wi-Fi devices that will be used in homes, offices, enterprises, and institutions. Experience suggests that network densification and the related use of midband frequencies for 5G deployment in Europe is likely to be gradual. Based on current 5G networks, population data of Germany, and spectrum characteristics, WIK-Consult (2022) analysed that until 2032, network densification of existing 5G mobile networks in Germany is only needed where the demand is very high.[69] This is already witnessed today with 3.6 GHz frequencies only being used for meeting high demand in hot spots combined with sub 1 GHz spectrum covering larger areas. Only from 2030 onwards, based on the assumed traffic growth, relatively few (10,500, which is 24% of the existing 5G antenna locations) additional antennas have to be set up per operator. This supports the statements that further densification of mobile networks is only intended for additional indoor coverage.

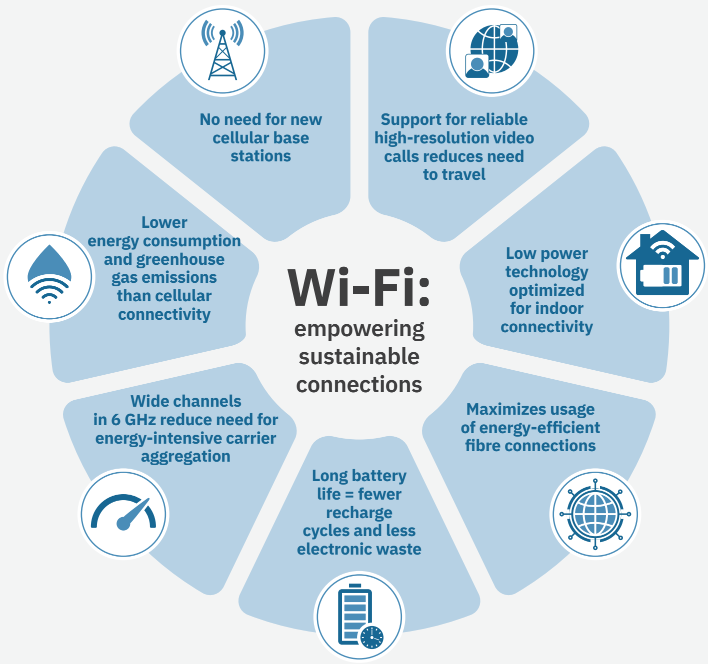
This further supports the idea that assignment of the full 6 GHz band to Wi-Fi, which could be exploited without delay, is likely to deliver more benefits than assigning the spectrum to mobile, which in addition to questions around demand, would require a significant time (i.e., years) and investments (i.e., billions of euros) to develop, implement, deploy, and operate 5G networks in the upper 6 GHz band.

[68] Ofcom (2022a), paragraphs 2.11, 2.12, 2.13.

[69] This is based on the following assumptions: reuse of existing antenna mast locations, full use of the existing frequencies for 5G new radio, additional 3.6 GHz antennas on more or less all existing mast locations. Indoor coverage by low frequencies and Wi-Fi use.

4 Developments in energy requirements for telecommunication networks

Figure 15: Sustainability benefits of Wi-Fi



Source: Wi-Fi Alliance

The energy efficiency of all networks and their components have improved over the years as their capabilities have evolved. However, mobile networks typically consume significantly more energy than fixed networks for a given bandwidth, which impacts the sustainability of a solution in varying situations. In this chapter we provide an overview of the energy efficiency of fixed access networks, including FTTH/Wi-Fi 5 and Wi-Fi 6, and compare these with mobile access networks, including 4G/LTE and 5G. Finally, drawing on these insights, we estimate the possible environmental impact of a certain amount of indoor internet traffic shifting from the FTTH/Wi-Fi network to the mobile 5G network. This traffic shift could arise if a lack of adequate spectrum prevents FTTH/Wi-Fi 6 networks from delivering the performance required to meet future demand.

4.1 Energy consumption of fixed access networks versus mobile networks

Available literature shows that while energy efficiency tends to improve with successive mobile network upgrades, fixed networks like FTTH are more energy efficient for a given amount of bandwidth than mobile or wireless technologies. Thus, a sustainable communications policy should limit the conveyance of data over mobile or wireless access to situations where it is necessary for outdoor mobility or to achieve quality requirements that can only be met via mobile technology.

4.1.1 Energy consumption of FWA vs FTTH

Mobile network operators have cited fixed wireless access (FWA) as one application that could be relevant for the 6 GHz band.[70] However, this would not be the most environmentally efficient solution. In a study comparing cost, energy consumption, and performance of fibre vs 5G fixed wireless access based on three scenarios (existing commercial macro cells, newly installed millimetre (mm)Wave small cells, and hybrid macro and small cells) in Sweden, Forzati (2019)[71] found that solutions using macro cells have significantly higher levels of energy consumption in terms of the total consumed electricity over 10 years than the pure fibre-based solution. For the FWA hybrid solution, the total energy consumption is expected to be nearly five times higher in urban areas and more than three times higher in rural areas than the pure fibre-based solution.

4.1.2 Energy consumption of 5G mobile vs FTTH

FTTH networks have also been found to be two and a half times as efficient as mobile 5G when streaming a video for one hour.[72] Specifically, Köhn, Gröger and Stobbe (2020) found that FTTH emits 2 grams of GHG, whereas 5G networks emit around 5 grams.

Bieser and Hilty (2018)[73] reach the same conclusion and note that they expect around 4.5g CO_2 emission per GB for 5G networks in 2030. Although 5G is widely considered to be as much as 85% more energy efficient per Gigabit transmitted than previous generations of mobile technology,[74] another study by Deepa, Beena and Girinath (2018),[75] notes that the energy efficiency of 5G is reduced for use cases that require ultra-low latency, which would make it less suitable in supporting recreational or non-critical AR/VR applications indoors.

Further supporting this argument, Nuutinen (2021) notes that although the numbers reported vary and are not always completely comparable due to different network boundaries, it is plausible that mobile access networks consume several times more energy per gigabyte than FTTH access networks. This is due to the physical advantage of light typically not requiring intermediate active network elements in the access networks (the only active elements are CPE and optical network termination[76]). Nuutinen (2021) reports the following values (Figure 16) for fixed and mobile energy consumption based on the results of academic research.

Figure 16: Overview of collected energy consumption factors per access network technology

Year	2020	2030
Mobile (Ussa, 2020)	0.22	
Mobile (Andrae, 2020, p.28)	0.18	0.014
Fixed (Andrae, 2020, p.28)	0.07	0.017
VDSL2 (Breide et al., 2021)	0.002	
FTTP (Breide etc al., 2021)	0.00002	

Energy intensity (kWh/GB) of different network technologies

Source: Nuutinen (2021)

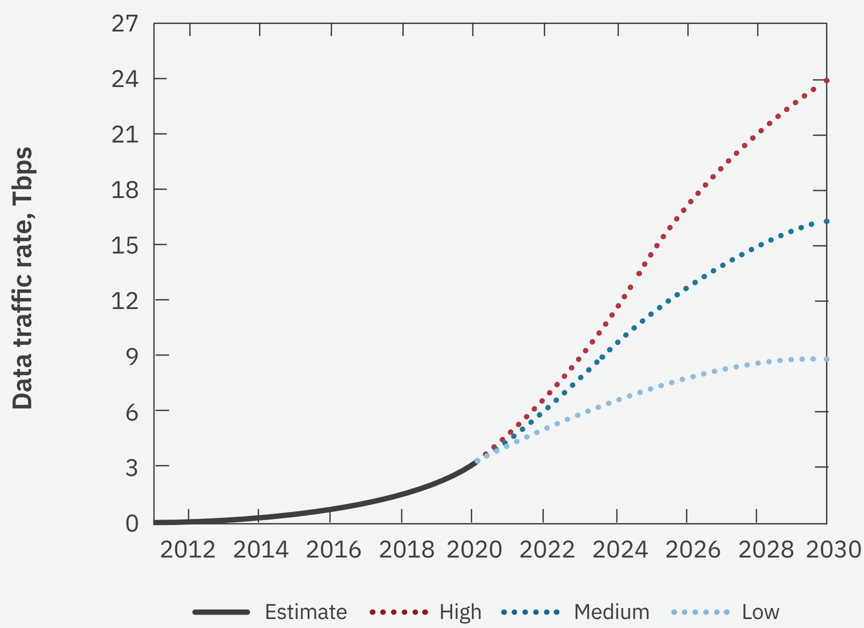
[70] GSMA (2023).
[71] Forzati (2019).
[72] Köhn et al. (2020).
[73] Bieser, Jan & Hilty, Lorenz. (2018).
[74] See chart in Nuutinen (2021) based on Ussa E. (2020) and Pikhola et al. (2018).
[75] Deepa, Beena and Girinath (2018).
[76] For longer Fibre lines amplification and signal regeneration is required too, but at a significantly lower extent.

The energy consumption in 2020 for fixed access networks seemed to be between 0.00002 kilowatt-hours per gigabyte (kWh/GB) (Breide et al. (2021)) and 0.07 kWh/GB (Andrae (2020)). However, Andrae's figure was an average for the different fixed access networks and as can be seen from Figure 16, there are significant differences between VDSL2, HFC, and FTTH. Considering the migration to FTTH, Andrae (2020) forecast that by 2030 the energy consumption of fixed access networks would decrease to 0.017 kWh/GB. The authors rebutted Andrae's suggestion that mobile access networks would become more energy efficient in 2030 than fixed access networks, noting that wireless antennas consume energy in addition to the wired (fibre) core network of mobile operators. Nuutinen (2021) concluded that a consumer can significantly reduce the energy consumption of their Internet usage by avoiding mobile data connections when a fixed (Wi-Fi) network is available.

These findings also call into question suggestions from the GSMA (2023)[77] which show 5G energy consumption decreasing from 0.05 in 2022 to 0.005 Watthour per Mbit (Wh/MB) in 2031 based on a 2020 short article from Orange.[78] In this article, Orange states that overall 5G technologies are expected to lower the energy consumption per GB by a factor 10 compared to 4G by 2025 and then by a factor 20 by 2030. This is based on assumptions around Sleep Modes, but limited independent evidence is provided.[79]

In contrast with these findings, more concerning evidence of trends towards increasing bandwidth consumption due to 5G has been provided by Cheng et al. (2022), who developed a model to explore the future deployment of non-stand-alone 5G networks and used the UK as a real-life example to analyse energy consumption and carbon footprint. The simulation showed that 700 MHz and 26 GHz will play an important role in the 5G deployment in the UK as it enables base stations to respectively meet short and long-term traffic demands.

Figure 17: Total estimated demand for mobile data capacity in the UK by 2030



Source: Figure 14, Cheng et al. (2022)

[77] GSMA (2023).

[78] Orange (2020).

[79] Orange noted that energy consumption will go down by a factor of 20 compared to 4G in particular by so-called Sleep Modes. It refers to test cities, where the new 5G network is already twice as energy efficient as 4G. Further, Orange noted greater traffic flows for energy consumption of the same order of magnitude resulting in a reduction per bit transported. Eric Hardouin, Director, Orange Labs Research is quoted that "While a 5G antenna consumes three times more energy on average today than a 4G antenna, this ratio is expected to drop to 50% by 2021 and 25% by 2022. In addition, a 5G antenna manages five times more bandwidth and serves more users simultaneously."

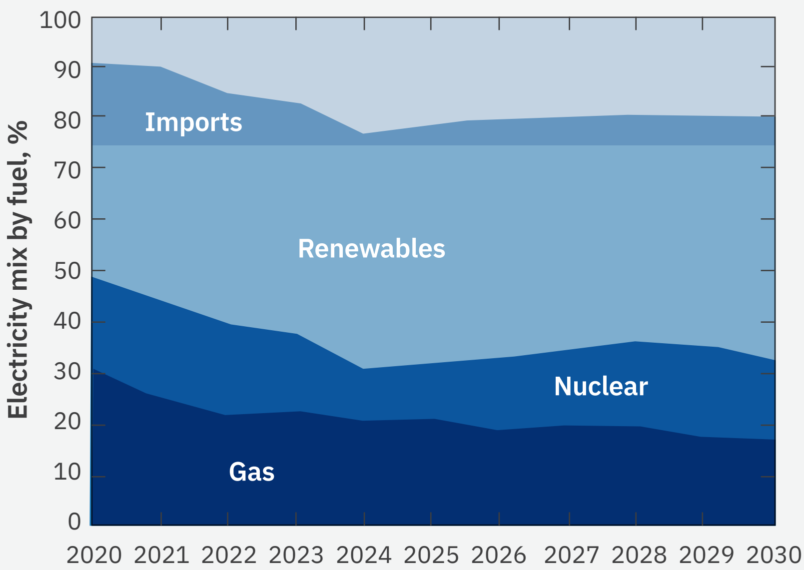
Chih-Lin et al. (2020) previously found that the total power consumption of a single 5G base station is about four times that of a single 4G base station and considering the high density, the overall power consumption of 5G networks may be 12 times that of 4G networks. This was confirmed in a study by Cheng et al. (2022).

In this study the total mobile data traffic in the UK up to 2030 was estimated for different scenarios. Using the medium demand scenario, by 2030, the authors concluded that there would be sufficient capacity to transport 16.5 Terra Bit per second (Tbps) of mobile data (see Figure 17). This amounts to 59.4 e6 GB data in one hour.[80]

Combined with the estimated aggregated energy consumption of 8.4 Terra Watt hour (TWh), this level of data consumption would amount to a very high energy consumption of 141 kWh/GB.[81]

Lastly, this energy consumption was transferred into (indirect) Green House Gasses (GHG) from the generation of purchased electricity. For this purpose, the projected electricity mix (see Figures 18 and 19 below) was used and the below CO_2 emission per kWh per fuel type.

Figure 18: Electricity mix in the UK by 2030



Source: CarbonBrief (2019)

Figure 19: CO_2 emissions per fuel type

CO_2 emissions from electricity generation by fuel (source Moro and Lonza, 2018)

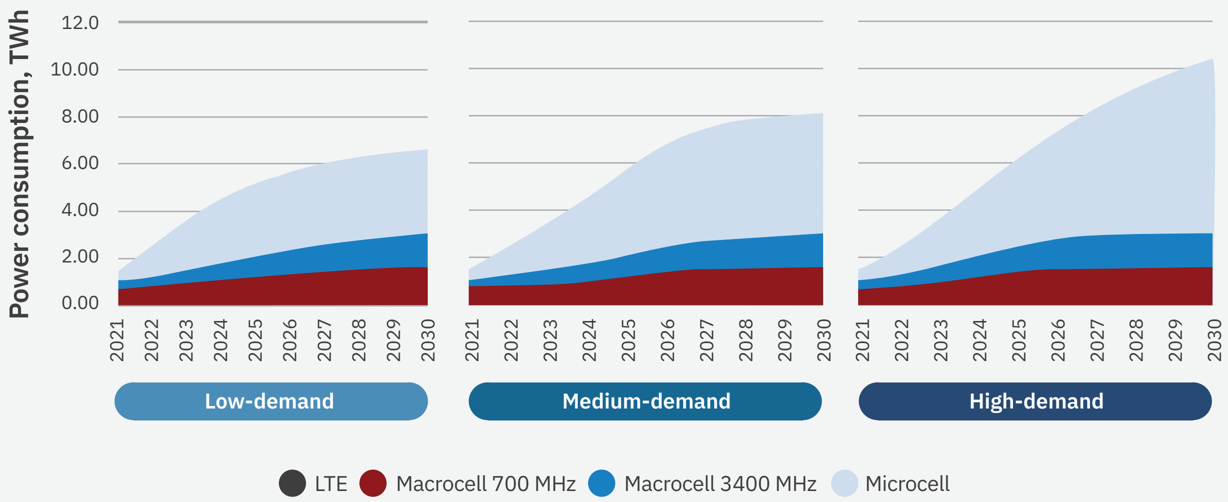
Fuel type	CO_2 emission g/kWh
Gas	500
Nuclear	29
Renewables	26
Import	93

Source: Table 8, Cheng et al. (2022)

[80] 16.5 Tbps = 16.500 Gbps. Multiplied by 3600 seconds (1 hour) implies that 59.4 e6 GB data is transported over the mobile network per hour.

[81] 8.4 TWh/59.4 e6 GB = 8.4 e3 kWh/59.4 = 141 kWh/GB.

Figure 20: Estimated energy consumption future 5G networks in the UK



Source : Figure 19, Cheng et al. (2022)

Cheng et al. note, as shown in Figure 20, that most of the power consumption in 5G networks is linked to small cells rather than the macro cells.

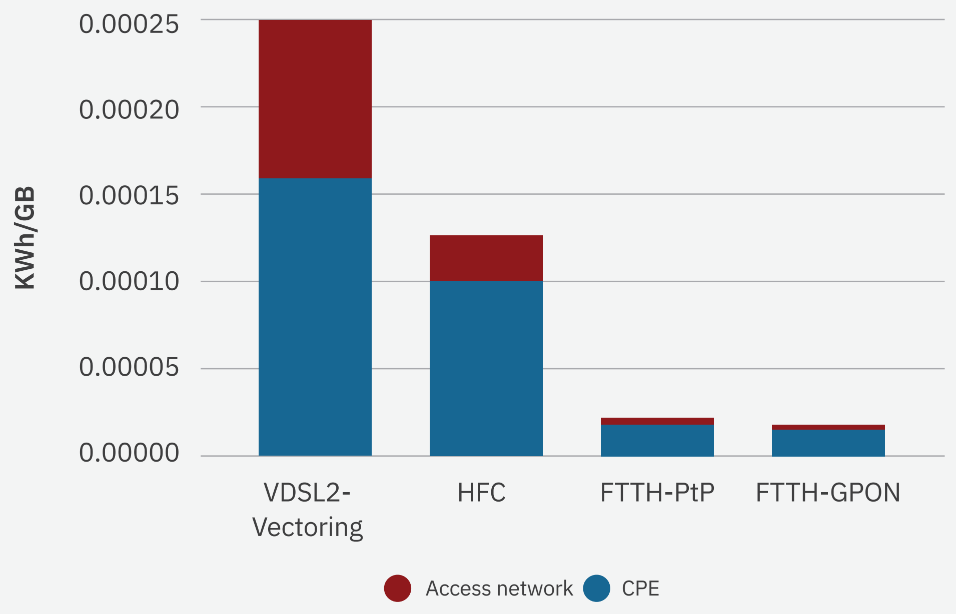
Cheng et al. posit that up to 2030, the power consumption of mobile networks will increase with the densification of small (micro)cells and the upgrading of macrocells. This will cause aggregate energy consumption to increase from 1.8 TWh in 2021 to 8.4 TWh in 2030 in the business-as-usual scenario (medium-demand), accounting for approximately 2.1% of total electricity generation in the UK by 2030. They expect even that this increased energy demand poses a risk for the (local) energy supply. In addition, the ever-increasing energy costs brought about by 5G networks are so large that it can also significantly impact MNOs' profitability.

4.1.3 Efficiency improvements in Wi-Fi equipment

As shown in Figure 21, the largest electricity consuming component in FTTH access networks has been found to be the Customer Premises Equipment (CPE), including a Wi-Fi modem router and a possible optical network termination.

However, the introduction of new Wi-Fi technology should further limit the energy consumption of Wi-Fi routers compared with previous generations, providing positive trends for energy consumption in the future. Specifically, reduced energy consumption is a key benefit of Wi-Fi 6 – not only for the access points, but also for connected devices.

Figure 21: Energy consumption for access network and CPE



Source: Breide et al. (2021)

Power saving for Wi-Fi 6 is achieved through dedicated transmission characteristics such as improved beamforming radio signals, as well as through a new and significant power saving feature called Target Wake Time (TWT). This feature offers three receive states for Access Points and terminals. Besides the full operational on-mode, it offers the already well known idle-mode and the newly introduced deep sleep mode, which does not monitor to the radio during idle times but rather wakes up at predefined intervals and listens. If there is a requirement to communicate, the device fully wakes up, but otherwise returns to deep sleep.

Another feature of Wi-Fi 6 is that 'target wake times' between APs and clients can be agreed, meaning that devices can exchange data in predefined periods. This not only increases spectral efficiency as channel access contention is reduced, it also saves battery life of devices and thus energy. Hence, this is an ideal power saving method for mobile and IoT devices as these remain connected for long periods of time but transmit little information and with a low frequency. Wi-Fi 6 has already seen strong growth for battery-powered applications, driven by increased adoption of Wi-Fi devices. The emergence of IoT-centric Wi-Fi 6 chipsets that can efficiently and reliably address smart home, industrial, and other IoT market requirements support the next generation of low power Wi-Fi networks.
WIK-Consult (2021a) has collected and analysed data regarding the power consumption of the highest performing Wi-Fi 4, Wi-Fi 5, and Wi-Fi 6 access points from the same producer (Aruba) to provide a like-for-like comparison. The resulting table below (Table 5) confirms that the main energy efficiencies from Wi-Fi 6 APs arise from the TWT feature, which supports the deep sleep mode and is exclusive to this generation of Wi-Fi. This deep sleep mode can save up to 51% energy in addition to the idle mode.[82]

[82] WIK-Consult (2021a), paragraph 4.2.

Table 5: Comparison between different APs performance in terms of power consumption

Wi-Fi Generation	AP Model	AP technical specifications	Power per device (W)		
			on-mode *	idle mode*	deep sleep*
Wi-Fi 4 + Wi-Fi 5	Aruba 340	Dual Band, 4x4 MIMO in 5 GHz and 2x2 MIMO in 2.4 GHz	20.4	11	N/A
	Aruba 310	Dual Band, 4x4 MIMO in 5 GHz and 2x2 MIMO in 2.4 GHz	12.7	5.9	N/A
Wi-Fi 6	Aruba 550	Dual/tri-radio, 5 GHz and 2.4 GHz with 4x4 MIMO in all bands	32.6	15.1	3.6
	Aruba 530	Dual Band 5 GHz and 2.4 GHz with 4x4 MIMO in both	23.3	14.3	3.6
	Aruba 510	Dual Band, 4x4 MIMO in 5 GHz and 2x2 MIMO in 2.4 GHz	16	9.7	1.5
	Aruba 500	Dual Band, 2x2 MIMO for both 5 GHz and 2.4 GHz	8.9	4.3	1.7
Wi-Fi 6E	Aruba 615	Tri-band, 2x2 MIMO for 2.4 GHz, 5 GHz, and 6 GHz bands	12.5	5.6	1
	Aruba 635	Tri-band, 2x2 MIMO for 2.4 GHz, 5 GHz, and 6 GHz bands	20.7	8.7	1.1
	Aruba 655	Tri-band, 4x4 MIMO for 2.4 GHz, 5 GHz, and 6 GHz bands	36	14.3	2.4

*For model with DC and without USB. Models with Power over Ethernet and USB have a higher energy consumption.

Source: WIK-Consult, composed of Aruba Networks datasheets, 2020, checked 2023

In addition, WIK-Consult (2021a) compared the energy efficiency of Wi-Fi 6 versus Wi-Fi 5 access points as the absolute power consumption might slightly rise in newer APs due to more radios and/or antennas, but this is offset by increased throughput. This was already noticed by Silva et al. (2019), who conducted an experimental study, comparing enterprise Wi-Fi APs up to generation 5 of the three different vendors. One result they found was that the rationale that higher data rates always use more power was not verified; according to their study, in some configurations, higher data rates for some IEEE 802.11 standards use the same power level or even less power than lower data rates. Due to this, higher data rates are always more energy efficient configurations.[83]

To verify these claims, WIK used the power consumption figures from a 2019 real-life test, which compared a Wi-Fi 5 Fritz!Box 7590 and the Wi-Fi 6 Asus RT-AX88U under the same conditions.[84] It found that the overall power consumption of both devices were almost similar. Where the Wi-Fi 5 device had a power input of 8 W (without data traffic), the

[83] Silva et al. (2019).
[84] https://www.computerweekly.com/de/feature/80211ax-Test-Wi-Fi-5-FritzBox-versus-Wi-Fi-6-Asus-Router

Wi-Fi 6 device consumed 9 W in the same mode. This was consistent with the manufacturer's indication and input from expert interviews.[85] Comparing the two devices with respect to their data rates, the Wi-Fi 6 device performed significantly better than the Wi-Fi 5 device (4,804 Mbps versus 1,733 Mbps in the 5 GHz range respectively and 1,148 Mbps versus 800 Mbps in the 2.4 GHz range).[86] This implied that the real-life energy needs (required energy input in Joule per GB of data) for the Wi-Fi 6 device was less than 50% of that required by the Wi-Fi 5 device. As noted by Liu et al. (2023), energy efficiency for Wi-Fi 6 can be less than Wi-Fi 5 in certain circumstances.[87] Specifically, there seem to be trade-offs between throughput and energy consumption.

4.2 Environmental impact of transferring indoor traffic from FTTH/Wi-Fi 6E to 5G mobile

Precluding Wi-Fi access to the 6.425-7.125 GHz spectrum will result in performance degradation of FTTH/Wi-Fi solutions and consequent shifting of certain users and applications towards 5G mobile networks, which also provide indoor coverage. In this context, we note that a significant proportion of MNO respondents to a GSMA survey said that they would use the additional (mid-band) spectrum to improve indoor coverage or outdoor to indoor coverage.[88]

In this section, we consider the potential impact on energy consumption and greenhouse gas emissions if a certain proportion of the current indoor broadband traffic handled by the FTTH/ Wi-Fi networks is shifted to 5G mobile networks Conservatively, this study did not consider the impact of additional mobile network capacity required to handle the increased traffic. We define two scenarios for the year 2030:

- **Scenario 1: Assigning the entire 6 GHz band to Wi-Fi:** Under this scenario, FTTH capacities are not constrained by limitations on the available spectrum for indoor wireless solutions. Forecast for FTTH/Wi-Fi and 5G mobile broadband matches those prepared by WIK-Consult in the 2022 study on the review of the Broadband Cost Reduction Directive.[89]

- **Scenario 2: Assigning the upper portion of 6 GHz band to mobile**. In this scenario, by 2030, FTTH combined with Wi-Fi 6E ("FTTH/Wi-Fi") can only support a certain number of concurrent users and required quality of AR/VR streams. Consumers who are not adequately served through their fixed connection will then use the alternative, 5G mobile provided inter alia by picocells or small cells operating in the 6 GHz spectrum bands (in addition to other available spectrum bands).

As previously discussed, the logic behind scenario 2 is that mobile operators are arguing that they need access to the upper 6 GHz band inter alia to improve indoor coverage and outdoor to indoor coverage. Consumption of applications indoors is assumed to remain unchanged, but under scenario 2, the quality of mobile indoor coverage would be improved relative to fixed and Wi-Fi, leading to a shift in traffic from one to another, which may have consequences for energy consumption as described further below.

Parameters used for the scenario analysis
Based on the literature review, parameter values have been collected regarding energy consumption of FTTH, Wi-Fi access points, and mobile networks. The following table presents an overview of the values provided for mobile networks at the time of publication and (where available) in 2030.

[85] These figures correspond with the indication of the manufacturers. While AVM states an average power consumption of 9 to 10 W for its Fritz!Box, the Asus router consumes 9.8 W on average. See https://www.techstage.de/test/wlan-6-router-asus-rt-ax88u-im-test-schnell-und-teuer/mh6v8wy

[86] https://www.computerweekly.com/de/feature/80211ax-Test-Wi-Fi-5-FritzBox-versus-Wi-Fi-6-Asus-Router

[87] Liu et al. (2023) tested with the support of Nokia Bell Labs among others Wi-Fi 6 performance and energy efficiency in a comprehensive test bed with a focus on multi-user performance. They tested multiple parameters, which impact the energy efficiency (channel approach (ODFMA, TWT, CSMA/CA), OFDMA Ru size, traffic characteristics, modulation, and code schemes). They found that OFDMA can improve the overall throughput but can incur severe energy consumption costs. For short transmission traffic, OFDMA improves the aggregated throughput up to 11 times at the cost of 2,5-8,4 times the energy consumption. For intensive traffic, OFDMA improves the aggregated throughput up to 2.3 times at the cost of 18 times more energy consumption. Authors advise to consider the trade-off depending on the characteristics of the application. Throughput of Wi-Fi 6 increased from 10 Mbps to 129 Mbps but energy consumption increases from 141 nJ/bit to 355 nJ/bit. This test was done on 80 MHz channel size due to limitations in Ethernet backhaul (1 Gigabit port on the Access Point). Throughput will increase with large channel blocks as described before, but the issue of trading-off throughput versus energy consumption remains according to authors.

[88] GSMA (2022).

[89] WIK-Consult (2023b).

Table 6: Overview of collected values for energy consumption – mobile networks

Energy consumption mobile networks from literature		
Author	At publication time: 2018-2023	2030
Andrae (2015)	0.6 kWh/Gb for LTE-4G	
Bieser and Hilty (2018)	3G – 30 g CO_2/GB in 2018	5G – 4.5 g CO_2/GB in 2030 expected, so 85% less than in 2018. Assuming 120 gCO_2/kWh, this implies 0.0375 kWh/GB
Laidler (2019)	0.069 kWh/GB for basic 5G 0.039 kWh/GB 3.5 GHz 5G cells	0.0252 kWh/GB – full 5G (average mmWave and 3.5 GHz cell)
Forzati (2019)	5G FWA is up to 5 × more energy consuming than FTTH (urban area), and 3 times in rural area.	
Köhn, Göger and Stobbe (2020)	5G networks consume 2.5 × less energy than 4G (so 40%) but still consume 2.5 × more energy than FTTH networks (5 gram GHG for 1 hour video (SD) versus 13 versus 2). Resulting in 0.0595 kWh/GB *	
Ussa (2020)	4G – 0.22 kWh/GB	
Andrae (2020)	4G – 0.18 kWh/GB	5G – 0.014 kWh/GB
Chih-Lin et al. (2020)	5G overall consumer 12 × energy compared to 4G.	
GSMA (2023) based on Orange (2020)	4G – 0.1 kWh/GB 5G – 0.05 kWh/GB (50% of 4G)	5G – by 2031 – 0.005 kWh/GB

* Assuming SD quality of the video stream, this implies 700 MB for 1 hour. Based on a CO_2 emission for a certain energy mix of 120 gCO_2/kWh, this implies that 0.0416 kWh are used for 0.7 GB, which is 0.0595 kWh/GB.

Source: WIK-Consult and various authors, see literature list.

According to available literature, the current energy consumption of 4G mobile networks lies between 0.1 and 0.22 kWh/GB. The lower value comes from the GSMA based on Orange data, while literature from multiple resources suggests that energy consumption may be on the higher side, between 0.18 and 0.22 kWh/GB (see Table 6).

For current 5G networks, there are three data points: 0.05 kWh/GB from the GSMA (2023), the indirectly calculated higher value of 0.0595 from Köhn et al., and the 0.069 value for current (basic) 5G by Laidler (2019). For verification, we applied the relationship between 4G and 5G energy consumption referred to by Köhn et al. and GSMA; which is between 40% to 50%. Applying this to the chosen value for 4G results in a range between (0.4-0.5 x 0.18) and implies that current 5G energy consumption is between 0.072 and 0.09 kWh/GB.

Looking at the expected energy consumption of 5G by 2030 shows larger differences: Laidler (2019) estimates 0.0252 kWh/GB, while Andrae (2020) estimates that 5G networks will consume even less energy than FTTH networks (0.014 versus 0.017 kWh/GB), which is strongly challenged by

Nuutinen (2021), as the largest part of energy consumption is from active devices, like base stations and antenna of which 5G has more compared with FTTH. The GSMA (2023), based on rough estimations of Orange in 2020, believes that 5G will become 20 times more efficient than current networks, leading to a value of 0.005 kWh/GB in 2031, which is almost three times lower than the already low estimation from Andrae (2020).

The GSMA's estimates also run counter to the findings of real-life tests like Chih-Lin et al. (2020) and Cheng et al. (2022), which warn about increasing energy consumption of 5G base stations based on experience in China and Japan where 5G deployment is the most advanced. Chih-Lin notes that the power consumption of a single 5G base station is about four times that of a base station in 4G network and that considering the high density of future 5G networks, the overall power consumption may reach as much as 12 times that of 4G networks. Similarly, Israr et al. (2021) note that "Due to the high radio frequency and limited network coverage of 5G base stations, the number of the 5G base stations are 1.4~2 times than that of the 4G base stations, and thus the energy consumption is also 2~3 times."

We thus disregard the low value of the GSMA (2023) for the purposes of the estimation. Instead, the estimate is based on the lowest value for the current energy consumption of 5G networks (0.072) with the expectation that this will further decrease by 2030 to 0.0252 kWh/GB for the larger, more efficient small cells operating on the mid-range spectrum (2-6 GHz) and to 0.0356 kWh/GB for the less energy efficient small cells operating on the very high frequencies (26 GHz). This is however, compared to current 5G networks which is still a decrease of 50% and 65%, respectively. Table 7 provides an overview of the findings from the literature of energy consumption for FTTH/Wi-Fi 6E.

Table 7: Overview of collected values for energy consumption – FTTH/Wi-Fi 6E

FTTH / Wi-Fi networks		
Author	At publication time: xx- 2023	2030
Forzati (2019)	FTTH is up to 5 x more energy efficient than 5G FWA (in urban areas, in rural areas 3 x)	
Köhn, Göger and Stobbe (2020)	FTTH consumes 2.5 x less energy than 5G (5-gram GHG versus 2). Resulting in 0.0238 kWh/GB*	
Andrae (2020)	Average fixed -2020 – 0.07 kWh/GB	FTTH - 2030 – 0.017
Breide et al. (2021)	FTTH – 0.00002 (95% CPE)	
WIK-Consult (2021a)	Wi-Fi 6 router requires 13.16 J/GB versus 30 for Wi-Fi 5 router. Converted to kWh/GB:** Wi-Fi 6: 0.00000365 / Wi-Fi 5: 0.0000083	
Liu et al. (2023)	Wi-Fi 6 – factor 0.22 up to 0.76 better energy efficiency (short transmission) or 7.8 times worse (intensive traffic). Overall: Wi-Fi 5 – 141 nJ/bit and Wi-Fi 6 - 355 nJ/bit (2.5 x more) Converted to kWh/GB:*** Wi-Fi 6: 0.000789 / Wi-Fi 5: 0.00031	

* Assuming SD quality of the video stream, this implies 700 MB for 1 hour. Based on a CO_2 emission for a certain energy mix of 120 gCO_2/kWh, this implies that 0.01666 kWh are used for 0.7 GB, which is 0.0238 kWh/GB.

** 13.16 J/GB = 3.65 e-6 kWh/GB. 30 J/GB = 8.3 e-6 kWh/GB

*** 141 nanoJoule/bit = 3.92 e -14 kWh/bit = 31.4 e -14 kWh/byte = 31.4 e-5 kWh/GB = 0.00031 kWh/GB. 355 nanoJoule/bit = 9.86 e-14 kWh/bit= 78.9 e-14 kWh/byte = 78.9 e-5 kWh/GB = 0.000789 kWh/GB.

Source: WIK-Consult and various authors, see literature list.

There are a number of data points available for current FTTH access networks ranging from a very low value of 0.00002 kWh/GB (Breide) to 0.0238 (Köhn) and 0.07 (Andrae). Andrae's highest value is explained as this is an average of all fixed access networks. As a realistic reference, we have therefore used 0.0238 kWh/GB for the estimation.

Regarding the energy consumption of FTTH networks by 2030, there is only the figure from Andrae (2020) of 0.017 kWh/GB, which constitutes an improvement of around 30% on the current 0.0238. We assume the reason is that FTTH networks have been further developed than the new 5G networks, for which we applied a 50% and 65% improvement by 2030 compared to current networks.

Regarding Wi-Fi access points, WIK-Consult (2021a) estimated more than 50% decrease in power consumption compared to Wi-Fi 5 routers. However, recent tests (Liu et al. (2023)) show that this depends on the type of traffic and that Wi-Fi 6 can also lead to increased power consumption per GB. To remain conservative, we have used the higher energy consumption for Wi-Fi 6E access points from Liu. However, it is important to note that the higher consumption figure of Liu (0.000789 kWh/GB) is still 63 times smaller than the energy consumed by a 5G small cell per transported GB of data.

Assumptions underlying the shift of indoor data from FTTH/Wi-Fi to 5G mobile under scenario 2
Projections by WIK regarding bandwidth consumption in the context of the review of the Broadband Cost Reduction Directive[90] suggest that if the EU achieves its goal of a full transition to fixed Gigabit technology by 2030 (i.e., all fixed broadband connections are based on FTTH or technologies offering equivalent capabilities), 85% of all data in the EU would flow over fixed access networks. We have used this figure in the base case scenario where the full spectrum in the 6 GHz band is assigned to Wi-Fi. However, in the case where Wi-Fi 6E is based on 500 MHz of 6 GHz spectrum and thus may not be able to support all demand over fixed FTTH networks by 2030, we assume that the proportion of traffic carried over FTTH and Wi-Fi networks would be less – at 70% of all traffic. In this case, the capacity available on 5G mobile networks will be further expanded to meet additional demand through the use of the 6 GHz band to provide better outdoor-to-indoor coverage. The underlying justification for the assumption behind the shift in traffic is that:

- WIK has found in various applications of its broadband demand model[91] that a substantial proportion of households will require downstream data rates of more than 1 Gbps in the period from 2025 onwards. Based on recent research by WIK-Consult, two-thirds of households could require these connections to make use of a range of applications by 2033.

- Intel has tested a variety of existing and emerging AR/VR applications and found that existing applications had an aggregated data rate requirement of around 90 Mbps and each of the 20 AR/VR streams had 100 Mbps.

- In the situation where the complete 6 GHz band is allocated to licence-exempt access, seven 160 MHz channels or three 320 MHz channels are available for Wi-Fi. This would result in the potential to support 790 Mbit/s including up to seven simultaneous AR/VR streams at the required quality while also supporting existing applications.

- However, when only the lower half of the 6 GHz band is available, only three 160 MHz channels are available for Wi-Fi, resulting in a maximum throughput of 390 Mbps supporting up to three simultaneous AR/VR streams while adhering to the quality requirements combined with the existing applications. This is roughly 50% less due to the restricted 6 GHz spectrum amount.

[90] WIK-Consult (2023b).

[91] Strube Martins, S. and Wernick, W. (2020): Regional differences in residential demand for very high bandwidth broadband internet in 2025, in: Telecommunications Policy, Volume 45, Issue 1, February 2021.

- 10% of mobile traffic will still be transported in 2030 over 'basic 5G' operating on sub 1 GHz in line with the assumption taken in the Broadband Cost Reduction Directive. This distinction is made as there is a different energy cost related to the use of the macrocells combined with sub 1 GHz spectrum compared to the additional small cells using mid-band spectrum.

It seems reasonable to assume that the reduced quality of fixed broadband in relation to mobile broadband in the scenario where 6 GHz is not assigned to Wi-Fi will lead to the increased use of mobile networks relative to fixed. This is also compatible with observations that there has been more usage of mobile relative to fixed networks (including for household traffic consumption) and greater use of fixed wireless access in comparison with fixed wireline in countries where the fixed network quality is low relative to mobile.[92]

Other assumptions

- It is assumed that in line with the aspirations of the Digital Decade targets, all fixed broadband connections (173 million) will be provided over FTTH in the EU by 2030.

- It is assumed that 100% of FTTH subscribers will have a Wi-Fi 6E modem/router in 2030. Thus, the energy consumed for each FTTH connection will include the energy associated with the Wi-Fi 6E modem/router. In fact, by 2030, a significant portion of Wi-Fi deployments will be Wi-Fi 7.

- For the conversion of energy consumption (kWh/GB) to tons of CO_2 emission (GHG), we have used an estimation of the energy mix in the UK by 2030 (Cheng et al. (2022)). The mixture is 17% Gas, 16% Nuclear, 47% Renewable, and 20% Import. This combined with the CO_2 emissions from electric generation by fuel from Moro and Lonza (2018) results in a value of 120 gCO_2/kWh used in the calculation.

- It is assumed in line with the Digital Decade targets that by 2030 all personal mobile connections will be based on 5G. Per the forecast deployment and uptake of 5G in the WIK-Consult study on the review of the BCRD,[93] it is assumed that there will be 477 million 5G mobile connections in Europe by 2030.

- In scenario 2, more traffic will be handled by small cells operating on the mid-range spectrum band (2-6 GHz) due to the allocation of additional licensed 6 GHz spectrum. This translates into the assumption that in scenario 1, 45% of full 5G traffic is distributed over mid-band small cells and 45% over 26 GHz small cells. In scenario 2, this is 50% and 40% due to increased mid-band spectrum.

4.2.1 Results of scenario analysis

For scenario 1 (Wi-Fi access to 5.925-7.125 GHz), the energy consumption of the future fixed access FTTH/Wi-Fi network in Europe is calculated by multiplying the number of expected FTTH subscriptions by the expected data consumption per FTTH subscriber and adding energy consumption associated with the Wi-Fi router. In addition, the expected mobile data consumption in Europe is distributed over basic 5G (operating on sub 1 GHz), and full 5G (over the existing mid-range spectrum) as these have different energy consumption characteristics. The total energy consumption is estimated by adding the FTTH/Wi-Fi and mobile energy consumption estimates.

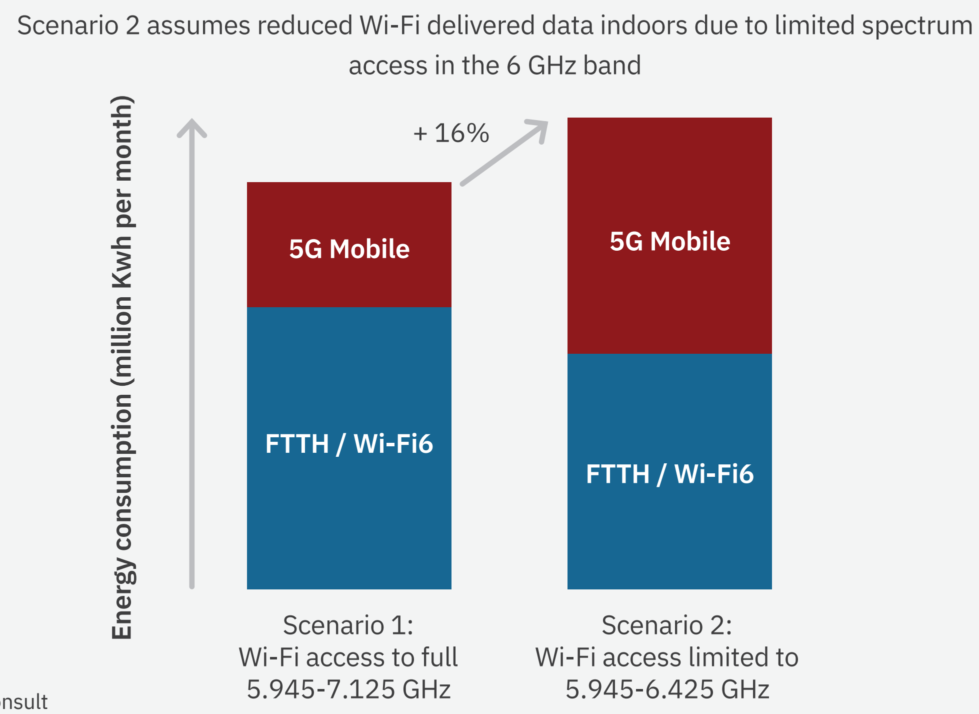
For scenario 2 (upper 6 GHz spectrum allocated for mobile usage), the same calculation is performed but with a 15% shift of traffic from the FTTH/Wi-Fi network to mobile reflecting reduced fixed quality and improved mobile indoor coverage. The increased amount of mobile data traffic is then redistributed accounting for small cells with access to the upper 6 GHz spectrum.

[92] WIK-Consult (2020).
[93] WIK-Consult (2023b).

The result of comparing the scenarios is that diverting 15% of indoor internet traffic from FTTH/ Wi-Fi 6E access points onto the 5G mobile networks leads to 16% higher energy consumption. This translates to an additional 2230 million kWh of energy consumption per month and based on the estimated future energy mix,[94] an additional 3.2 megatons of CO_2 emissions per year (which corresponds to 4-6% of the current CO_2 emissions by the complete ICT sector in Europe).

This study focused on the indirect additional energy costs of this traffic shift to mobile, but it did not consider the (additional) environmental impact of installing additional mobile network capacity required to handle the increased traffic.

Figure 22: Results of scenario analysis regarding energy consumption



Source: WIK-Consult

[94] Consisting out of 20% import, 47% renewables, 16% nuclear, and 17% gas, based on UK 2030 expectation. See Cheng et al. (2022).

The future of the 6 GHz band: Two scenarios

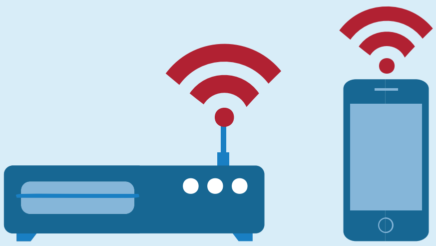
Without licence-exempt access to the full 6 GHz band, overall energy consumption will be considerably higher

Scenario 1: Assigning the entire 6 GHz band (5.945-7.125 GHz in Europe) to Wi-Fi

Fibre-to-the-home (FTTH) capacity is not constrained by a lack of spectrum for Wi-Fi – the default wireless technology of choice for connectivity indoors.

By 2030, Europe will see:

- Total FTTH/Wi-Fi energy consumption of **9,518 million kWh/month**
- Total mobile energy consumption of **4,088 million kWh/month**
- Total connectivity energy consumption would therefore be **13,606 million kWh/month**

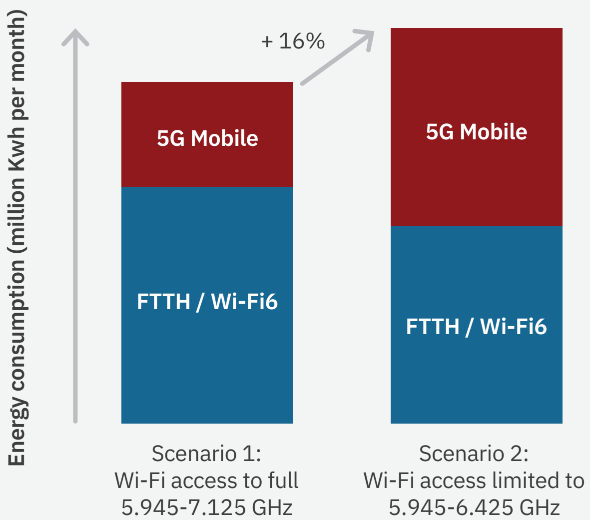


Scenario 2: Assigning the upper 6 GHz band (6.425-7.125 GHz) to mobile

The spectrum available to Wi-Fi is limited. Consumers who are not adequately served through their fixed connection will use 5G mobile. That could lead to a 15% shift of traffic from FTTH/Wi-Fi to mobile.

By 2030, Europe will see:

- Total FTTH/Wi-Fi energy consumption of **7,849 million kWh/month**
- Total mobile energy consumption of **7,988 million kWh/month**
- Total connectivity energy consumption would therefore be **15,837 million kWh/month**



In summary, scenario 2 would result in a 16% increase in overall energy consumption compared to scenario 1.

Based on the estimated future energy mix, that would mean an additional 3.2 megatons of CO_2 emissions per year (which corresponds to 4-6% of the current CO_2 emissions of the entire ICT sector in Europe).

These additional emissions would hamper efforts to deliver the EU's Green Deal, which aims to make the region climate neutral by 2050.

4.3 Knock-on effects in other sectors

In addition to maximizing the data delivered over more energy efficient FTTH networks, Wi-Fi enabled applications ("use cases") can also help to limit GHG emissions in a range of other sectors, with significant potential particularly in the fields of remote working and learning, e-health, buildings, and transport. This means that, when the knock-on effects are also considered, Wi-Fi 6, Wi-Fi 6E, and Wi-Fi 7 could have a significant net positive effect on the environment. Key use cases which can be supported by fibre connectivity complemented by Wi-Fi include support for remote working, smart building solutions, e-health, e-learning, and certain smart city applications.

Regarding teleworking, a study in the UK market, SQW (2013)[95] estimated that achieving faster broadband by 2024 could lead to a reduction of 2.3 billion kilometers in annual commuting distance. This translated into an annual net carbon dioxide equivalent savings of around 0.24 million ton for the UK alone. Giovanis (2018)[96] explores the relationship between teleworking, air quality, and traffic in Switzerland. He found that teleworking could reduce traffic by an average of 2.7% and thus air pollution by 2.6-4.1%. The impact EU-wide could be significant as passenger cars are responsible for about 12% of total CO_2 emissions in the EU.[97]

Buildings are responsible for around 40% of all energy consumption in the EU as well as 36% of CO_2 emissions,[98] meaning the potential for saving energy and CO_2 emissions in the buildings sector is huge. One solution for greater energy efficiency can be the use of Smart Buildings. The scope of Smart Buildings includes energy, lighting, and water applications, which can all contribute to increased energy efficiency and environmental sustainability. According to the ACEEE (American Council for an Energy-Efficient Economy), smart technologies could reduce the energy consumption of buildings by about 20%. This may be achieved by interconnected technologies, occupancy sensors, or complex energy management systems. The estimated average energy savings range between 18% for offices, 14% for retail stores and hospitals, and 8% for hotels.[99]

In the context of Smart Cities, Cisco estimated that moving from traditional street lighting to smart street lighting could reduce CO_2 emissions in the city of Copenhagen by 23,000 tons per year, while implementation of traffic management systems in Copenhagen were estimated to permit a reduction of 18 tons in CO_2 emissions.

[95] SQW (2013). UK Broadband Impact Study. Study conducted for the European Commission.

[96] Giovanis, E. (2018). The relationship between teleworking, traffic, and air pollution. Atmospheric Pollution Research, 9(1), 1-14.

[97] See EC (2019). Reducing CO_2 emissions from passenger cars, available at: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en

[98] See EC (2019). Energy performance of buildings, available at: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/overview

[99] See ACEEE (2017). Smart buildings save energy and improve occupant comfort, available at: https://aceee.org/blog/2017/12/smart-buildings-save-energy-and

5 Conclusions

A very significant proportion of data is currently consumed indoors. This proportion is expected to increase as use cases requiring high-rates, low-latency and reliable connectivity continue to emerge. FTTH/Wi-Fi offers the most energy efficient solution for the expanding indoor broadband connectivity requirements. Wireless distribution of the FTTH connections will require Wi-Fi access to the 6 GHz spectrum.

Wide area (cellular) licensed mobile network implementations will experience signal attenuation and degradation due to building standards that impede signal propagation through walls and windows. Such networks significantly underperform FTTH/Wi-Fi implementations in terms of energy consumption and GHG emissions.

Wi-Fi can also contribute to energy efficiency in other sectors, such as reducing traffic through supporting remote working and by reducing energy consumption in buildings, which is a significant source of greenhouse emissions today.

Allowing licence-exempt access to the entire 6 GHz band (i.e., 5.925-7.125 GHz) would result in substantive reductions in energy consumption of telecommunication networks, advancing environmental policy goals and objectives.

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Annex

Table A1 shows the evolution in Wi-Fi standards including the available channels.

Table A1: Wi-Fi Evolution

	Wi-Fi 4	Wi-Fi 5	Wi-Fi 6	Wi-Fi 6E
Operating frequency bands	2.4 GHz, 5 GHz	5 GHz	2.4 GHz, 5 GHz	6 GHz
Modulation scheme	OFDM	OFDM	OFDMA	OFDMA
Channel width	20 MHz, 40 MHz	20 MHz 40 MHz, 80 MHz 160 MHz	20 MHz 40 MHz, 80 MHz 160 MHz	20 MHz 40 MHz, 80 MHz 160 MHz
Number of non-overlapping channels	**2.4 GHz band:** 3 x 20 MHz or 1 x 40 MHz **5 GHz band:** 25 x 20 MHz or 12 x 40 MHz	25 x 20 MHz or 12 x 40 MHz or 6 x 80 MHz or 2 x 160 MHz	**2.4 GHz band:** 3 x 20 MHz or 1 x 40 MHz **5 GHz band:** 25 x 20 MHz or 12 x 40 MHz or 6 x 80 MHz or 2 x 160 MHz	**In the US (1200 MHz):** 59 x 20 MHz or 29 x 40 MHz or 14 x 80 MHz or 7 x 160 MHz **In Europe (500 MHz):** 24 x 20 MHz or 12 x 40 MHz or 6 x 80 MHz or 3 x 160 MHz
Highest modulation order	64-QAM	256-QAM	1024-QAM	1024-QAM
MIMO streams	Up to 4x4	Up to 8x8	Up to 8x8	Up to 8x8
MU-MIMO	No	Downlink MU-MIMO	Downlink and Uplink-MU-MIMO	Downlink and Uplink-MU-MIMO
Target Wake Time (TWT)	No	No	Yes	Yes
BSS Coloring	No	No	Yes	Yes
Extended Range Improvements	No	No	Yes	Yes

Source: Litepoint (2020)

Wi-Fi 5

IEEE 802.11ac, or Wi-Fi 5, is a standard for a local radio network that was adopted in November 2013. This standard provides for a transmission speed in the Gigabit range. Strictly speaking, the standard defines a theoretical maximum calculated data rate of 6,936 Mbps.[100] Wi-Fi 5 is an evolution from Wi-Fi 4 and not a revolutionary technology or standard. Many of the techniques used to increase speed in Wi-Fi 5 are familiar after the introduction of MIMO, with one exception. Rather than using MIMO only to increase the number of data streams sent to a single client, Wi-Fi 5 involves a multi-user form of MIMO that enables an access point (AP) to send to and receive from multiple clients at the same time.

Unlike Wi-Fi 4, which operated across 2.4 GHz and 5 GHz licence-exempt spectrum bands allocated to wireless LANs, Wi-Fi 5 is restricted to 5 GHz operation only, so that Wi-Fi 5 clients could operate in the (at that point in time) less crowded 5 GHz band.

Wi-Fi 5 is designed to be compatible and coexist efficiently with existing previous generation Wi-Fi devices. Wi-Fi 5 achieves its raw speed increase by achieving improvements in three different dimensions:

- More channel bonding
- More spatial streams and denser modulation scheme
- Beam forming and multi-user MIMO (MU-MIMO)

Wi-Fi 5 introduced two new channel sizes: 80 MHz and 160 MHz. Just as with Wi-Fi 4, wider channels increase speed. In some areas, 160 MHz of contiguous spectrum is hard to find, so Wi-Fi 5 introduced two forms of 160 MHz channels: a single 160 MHz block, and an “80+80 MHz” channel that combines two non-contiguous 80 MHz channels and gives the same capability of spectrum.

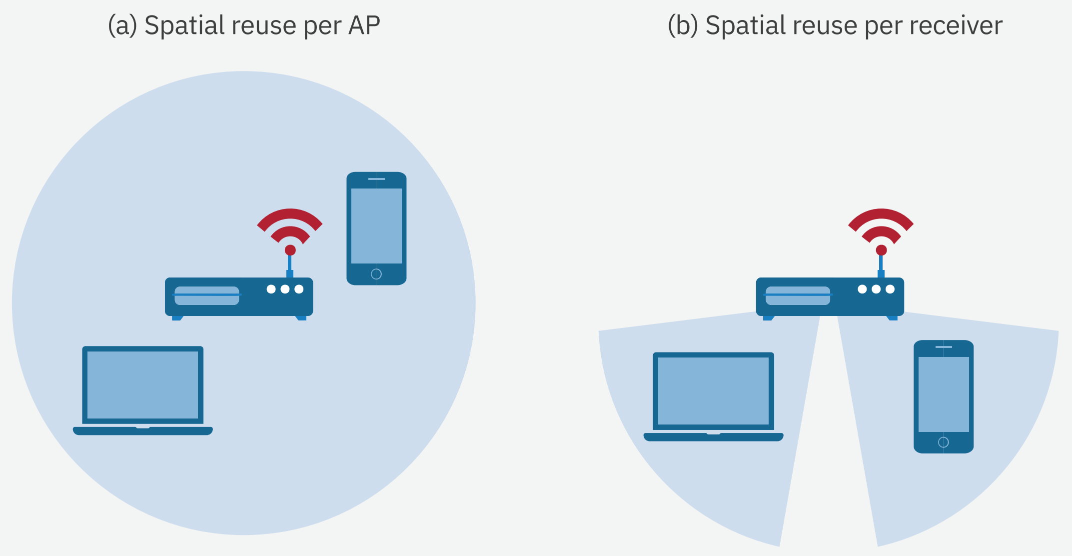
By using a more complex modulation that supports more data bits, it is possible to send eight bits per symbol period (256-QAM) rather than 6 bits in a symbol period (64 QAM), which leads to a gain of 30%. Wi-Fi 5 specifies up to eight spatial streams, compared with Wi-Fi 4’s four spatial streams, at the AP. The extra spatial streams can be used to transmit to multiple clients at the same time.

Beamforming is a process by which the sender of a transmission can direct its energy toward a receiver to increase the Signal-to-Noise Ratio (SNR), and hence the speed of the transmission. Although Wi-Fi 5 significantly simplified the beamforming specifications, it still required two devices to implement mutually agreeable beamforming functions and very few vendors implemented the same options, and as a result, there was almost no cross-vendor beamforming compatibility.

Multi-User MIMO (MU-MIMO) represents the greatest potential of Wi-Fi 5. Prior to Wi-Fi 5, all 802.11 standards supported only Single-User MIMO (SU-MIMO), and every transmission sent was sent to a single destination only. The main advantage of MU-MIMO is that the spatial streams can be transmitted to multiple separate devices. See Figure A1.

[100] Elektronik Kompendium (2020).

Figure A1: Spatial reuse per Access Point versus Spatial reuse per receiver



Source: Emami (2013)

One of the keys to building a Wi-Fi network of any type is reusing the same channel in multiple places. On the left of Figure A1, the radio channel transmitted by the Access Point (AP) is received by both the laptop and the smartphone, and the channel may be used to communicate with only one of the devices at any point in time. The picture on the right shows the reuse of the same radio channel for certain areas. As a result, the AP can send independent transmissions within its own coverage area. Just like Ethernet switches reduced the collision domain from a whole broadcast segment to a single port, MU-MIMO reduces the spatial contention of a transmission.

Wi-Fi 6

Wi-Fi 6 or the IEEE 802.11ax standard will improve high-density performance and provide faster throughput. Additionally, this new generation of Wi-Fi will augment customary speed and density improvements with new capabilities designed for the technology trends of the future. This is required as the number of connected devices driven by the Internet of Things (IoT) is significantly growing. It is estimated that this will increase from 20.4 billion IoT devices in 2020 to 75 billion devices by 2025. IoT connections will represent more than half of all global connected devices by 2022.[101] Furthermore, the variety of applications and traffic being generated is evolving quickly, from more video to virtual and augmented reality and higher quality requirements.

Wi-Fi 6 adds additional spatial streams by supporting both the 2.4 and 5 GHz bands. In addition, Wi-Fi 6 operates in 20, 40, and 80 MHz channels, similar to Wi-Fi 5. The added 2.4 GHz spectrum provides several benefits for longer range outdoor use cases and improved coverage for IoT devices. While the spectrum is noisy and congested, the better propagation abilities of 2.4 GHz combined with efficiency improvements of Wi-Fi 6 should help maximize the potential of the 2.4 GHz band.

Wi-Fi 6 is designed to meet increased user needs. Its performance will exceed Wi-Fi 5 Wave 2 by over three to four times, support higher density with more efficient airtime, support a higher scale of client devices, and provide significant savings in battery usage. While Wi-Fi 6 will be able to deliver

[101] Review42 (2020).

theoretical data rate growth of around 37%, its largest benefit is the ability to deliver high efficiency performance in real-world environments. As the number of clients increases, Wi-Fi 6 will be able to sustain far more consistent data throughput than previous Wi-Fi standards. There are controlled environments with a very small number of clients where previous generations of Wi-Fi may provide higher throughput. However, this is due to the longer frames and wider guard intervals of Wi-Fi 6, which help provide resilience.

Essentially, there are two technologies that make a real difference in Wi-Fi 6 which are orthogonal frequency division multiple access (OFDMA), and spatial reuse, which is also referred to as Basic Service Set (BSS) coloring. Additionally, Wi-Fi 6 provides a slew of new features to address performance improvements and optimizations across multiple dimensions.

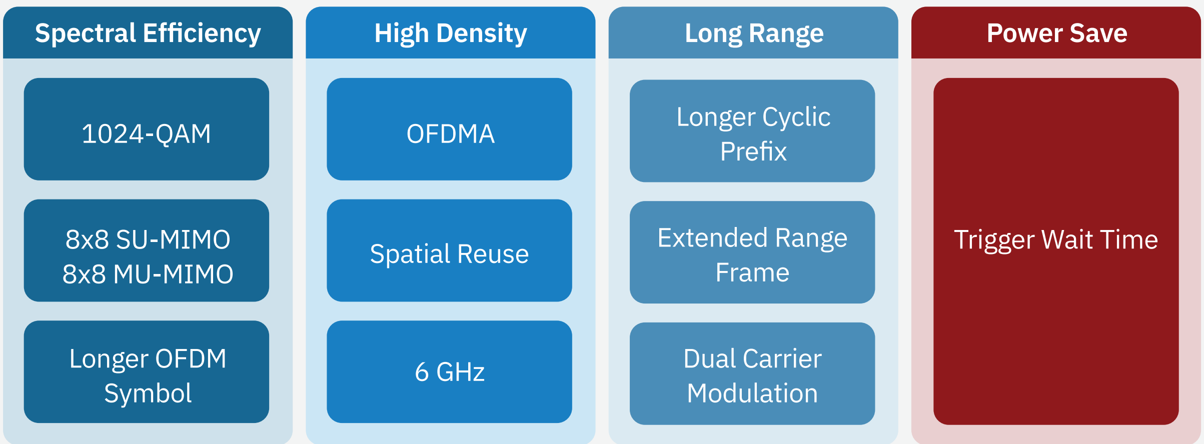
Wi-Fi 6 introduces a more efficient data transmission mode, Orthogonal Frequency Division Multiple Access (OFDMA). Since Wi-Fi 6 supports the uplink and downlink Multi-User (MU) mode, this mode can also be referred to as MU-OFDMA. Thus far, this technology has been used by many wireless technologies, such as LTE in mobile networks. OFDMA allows more efficient transmission of data to multiple devices, allowing for a 20 MHz channel to be split into small sub-channels. At the same time, OFDMA decreases the spaces between the subcarriers from 312.5 Kilohertz (KHz) to 78.124 KHz, packing in even more resource units. The advantages are:

- **More efficient channel resource allocation**: The transmit power can be allocated based on the channel quality, especially when the channel status of some nodes is not good. This can help allocate channel time-frequency resources in a more refined manner.

- **Better Quality of Service (QoS)**: earlier Wi-Fi generations occupy the entire channel to transmit data. If a QoS data packet needs to be sent, it must wait until the current sender releases the complete channel. Therefore, a long delay exists. In OFDMA mode, one sender occupies only some resources of the entire channel. Therefore, data from multiple users can be sent at a time. This reduces the access delay of QoS nodes.

- **More concurrent users and higher user bandwidth**: OFDMA divides resources of the entire channel into multiple subcarriers (subchannels). The subcarriers are further divided into several groups by RU type. Each user may occupy one or more groups of RUs to meet different bandwidth requirements.

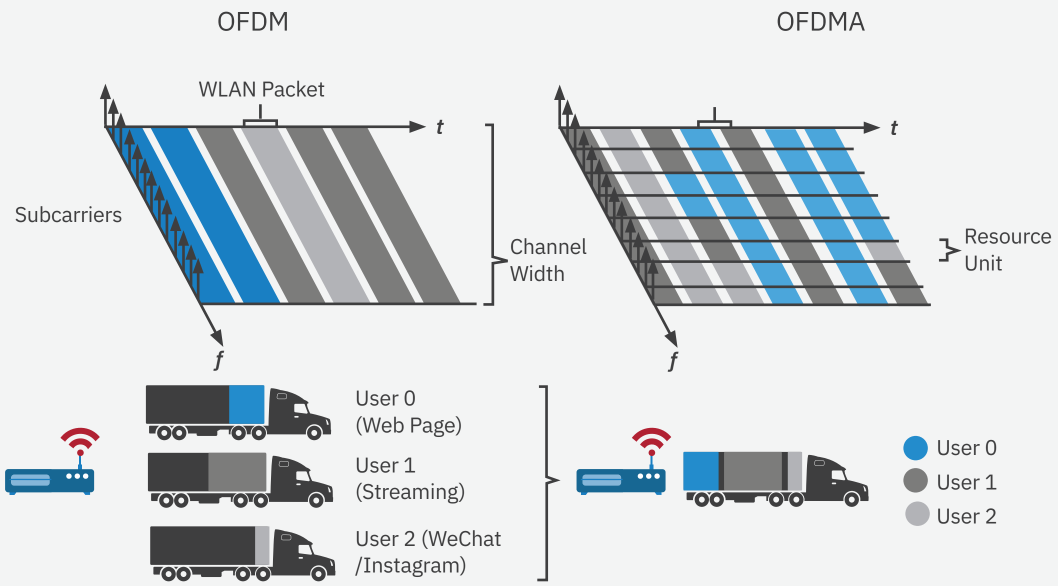
Figure A2: Key features of Wi-Fi 6



Source: Arista (2020)

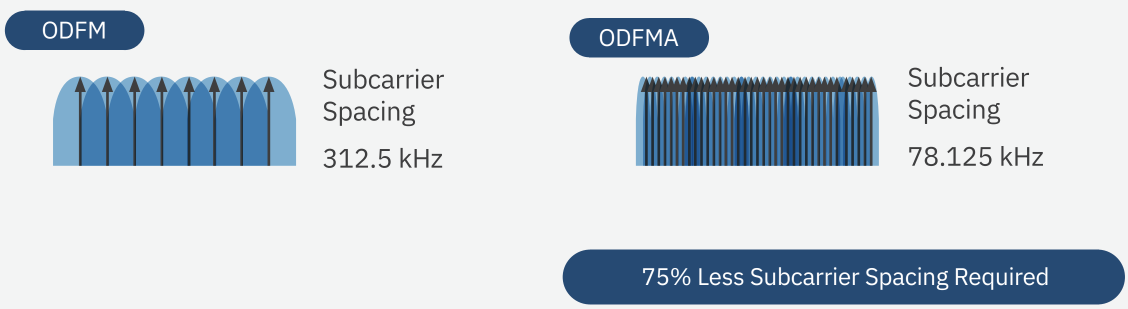
Figures A3 and A4 show these principles:

Figure A3: OFDM versus OFDMA



Source: Oorvo (2017)

Figure A4: Subcarrier spacing change in Wi-Fi 6

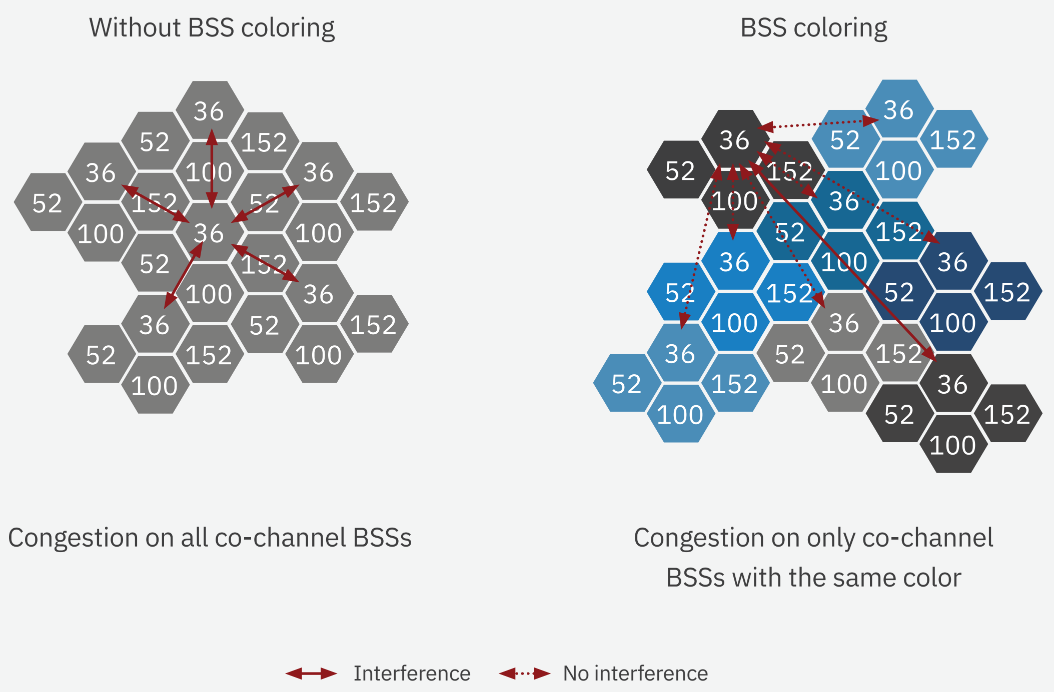


Source: Oorvo (2017)

The second important improvement in Wi-Fi 6 is "Basic Service Set" or "BSS" coloring, which is a new co-frequency transmission identification mechanism. This feature aims at optimizing data transmission in dense and therefore possible interference environments. The BSS color field is added to the packet header between the access point and the STA to color data from different BSSs and allocate a color to each channel. The color identifies a BSS that should not be interfered with. The receiver can identify co-channel interference signals (interference in the same channel) and stop receiving them at an early stage, thereby avoiding collisions and high response and transmission times. If the colors are the same, the interference signals are considered to be in the same BSS, and signal transmission is delayed. If the colors are different, no interference exists between the two Wi-Fi terminals. They can then transmit data on the same channel and at the same frequency. Figure A5 depicts the advantage of considering the BSS coloring in Wi-Fi networks.

With this feature, the channels with the same color are kept far away from each other to avoid interference and hence better performance as shown in Figure A5.

Figure A5: Advantage of BSS Coloring



Source: Huawei (2020)

Wi-Fi 6E

Wi-Fi 6E is the industry name for users to identify Wi-Fi 6 devices that will operate in 6 GHz frequency band. Wi-Fi 6E offers all the features and capabilities of Wi-Fi 6 including higher performance, lower latency, and faster data rates extended into the 6 GHz band. Rapid development of products has already begun, with Wi-Fi 6E devices expected to become available quickly following 6 GHz regulatory approvals.

The additional spectrum capacity offered by Wi-Fi 6E enables more Wi-Fi innovation and delivers valuable contributions to consumers, businesses, and economies. Wi-Fi 6E has been strongly advocated for by many innovation drivers in the Wi-Fi industry. From chipset and equipment manufacturers to service providers and end users, all agree that more than doubling the available spectrum will revolutionize the Wi-Fi user experience. Chipset manufacturers (e.g., Qualcomm, and Broadcom) have already announced new products capable of supporting the 6 GHz band.[102]

[102] Qualcomm (2020).

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