Huawei response to the Ofcom discussion paper: Mobile networks and spectrum

Meeting future demand for mobile data

Summary

We thank Ofcom for the opportunity to comment on this discussion paper, where Ofcom summarises its views as follows:

> *"In summary we note:*
>
> - *Mobile data traffic has grown by an average of 40% year on year in recent years and we expect it to continue to grow. However, there is a high degree of uncertainty about the rate of future growth, particularly beyond 2030.*
> - *Mobile networks will need to evolve to meet future demand and deliver the quality of experience needed by consumers and businesses. There are a number of ways in which they might do this, including:*
>   1. *More extensive deployment of existing spectrum holdings and planned future spectrum for mobile e.g. in the millimetre wave (mmWave) bands. We will consult on our approach to making mmWave spectrum available shortly;*
>   2. *Using technology upgrades to increase the efficiency of the spectrum they use;*
>   3. *Network densification – deploying more cell sites – in particular using small cells to leverage the capacity offered by the large bandwidths available from mmWave spectrum."*

Furthermore, Ofcom states:

> *"We want to know what others think about the opportunities, options and solutions presented by a world where use of mobile data is so central, driving demand for additional capacity. We will take account of stakeholder inputs as we develop our future strategy for mobile spectrum. In particular, we invite stakeholder views on our initial thinking in the following areas:*
>
> - *Future demand for data through mobile networks (as opposed to demand for data more generally);*
> - *The potential opportunities and challenges associated with network densification in the UK;*
> - *Whether there are specific frequency ranges which should be considered for mobile access to support capacity provision in the future - including opportunities for more spectrum to be made available for mobile use on a shared or more localised basis."*

We broadly agree with Ofcom's view on the growth of mobile data traffic. Our own estimated projections suggest an annual growth of around 48% towards a consumption of 300 GB or more per use per month by 2030. We consider that this growth will be driven by demand for high-definition video communications for mobile broadband, a range of emerging industrial applications including advanced automotive use cases, and fixed wireless access.

However, we do not consider that the recognised growing demand for consistent high-capacity citywide "on the go" connectivity can be addressed through network densification of macro-cellular sites and/or the deployment of small cells at mid-bands, mmWaves or higher frequencies. This is because while small cells can readily meet user demand at specific geographic hotspots, such deployments cannot provide the required high-capacity citywide urban/suburban mobile coverage in an economically viable or environmentally friendly manner. Nor can the future outdoor mmWave deployments address outdoor-to-indoor coverage due to the prohibitive building penetration loss at these high frequencies.

Accordingly, we consider that additional **mid-bands** spectrum is required to meet the demand for high-capacity citywide urban/suburban mobile coverage based on the existing macro-cellular grids. The consensus among mobile operators and mobile network infrastructure vendors is that around 2 GHz of mid-bands spectrum is required to deliver downlink/uplink IMT-2020 target data rates of 100/50 Mbit/s cost-efficiently across the urban and suburban areas of cities and major towns. In the absence of the required additional mid-bands spectrum, the required densification would result in a doubling of power consumption, and a quadrupling of total network costs in a typical European city. This is in addition to the carbon footprint involved in the manufacture of the greater number of infrastructure equipment.

We have identified the upper 6 GHz band as a suitable candidate to support the evolution of 5G in the 2025-2030 timeframe in delivering user demand for mobile data. Our field tests indicate that by using a larger number of antenna elements and higher-order MIMO techniques in macro-cellular 5G base stations at 6 GHz (possible due to the lower wavelengths at this frequency), it is possible to achieve downlink and uplink spectral efficiencies that are comparable to those achievable in commercial macro-cellular 3.5 GHz deployments today, both for outdoor-to-outdoor and outdoor-to-indoor (shallow indoor) coverage.

Our studies – as well as those of other parties – also indicate that high-power macro-cellular 5G mobile networks can share the spectrum with incumbent services in the upper 6 GHz band (such as the fixed satellite service uplink), facilitated by base station active antenna systems which direct radiated power in favourable directions towards the users.

We note that the upper 6 GHz is also sought by some stakeholders for use by WAS/RLAN technologies such as Wi-Fi. However, we consider that the 2.4 GHz, 5 GHz and the lower 6 GHz bands are more than sufficient to satisfy the spectrum needs of Wi-Fi for the foreseeable future. Furthermore, we note that the authorisation of large swathes of spectrum for use by WAS/RLAN and other short-range communication networks – as is the case in the UK today – is not an efficient use of valuable frequencies that are optimum for the provision of high-capacity and wide-area communications. Should additional spectrum be required for WAS/RLAN, we recommend the use of mmWave frequencies such as the 60 GHz band available in the UK on a licence exempt basis, rather than additional mid-bands.

In closing, we note that there has been great focus in the UK in recent years on making licensed spectrum available for the deployment of low/medium power private local networks and for vertical use cases (including the 3.8-4.2 GHz band available since 2019 via shared access licensing). Such focus may have been justified, to the extent that this was a new area of interest to many national regulators. We consider that there is now an urgent need to re-focus on the spectrum needs of high-power public mobile communication networks for the delivery of both high-capacity wide-area coverage and local connectivity in the UK over the 2025-2030 timeframe. We consider that it is important for the UK to develop a roadmap for the availability of additional mid-bands spectrum in support of macro-cellular 5G networks and their evolution.

1. Future demand for data in national public mobile networks

In what follows, we describe the demand which we foresee from consumers, industries (so-called "verticals") and households for wireless connectivity as delivered by IMT 5G NR (5G for short).

- **Consumers (eMBB):** We expect that the premium experience delivered by 5G will continue to drive an increase in mobile data traffic. As video use grows and consumption of live broadcasts expands from PCs to mobile devices, we expect mobile high-definition (HD) video and augmented/virtual reality (AR/VR) services to become increasingly mainstream, making a data rate of 100 Mbit/s a basic requirement everywhere. Notably, ITU-R Report M.2370 projected that mobile data traffic consumed per subscription per month would exceed 250 GB globally by 2030[1]. And as an early indicator, in the first year of 5G deployments worldwide, 5G users on average communicated twice as much data per month as 4G users. Along with the increase of 5G adoption for various new services and a rising number of users, we expect the growth in the volume of data communicated to continue to maintain a strong momentum. This trend of rapid growth in mobile data traffic justifies the necessity for more spectrum – at the right frequencies – to meet the surging demand for network capacity.

- **Verticals:** 5G has been designed to enable industrial digitalization, in turn requiring networks to provide reliable connections of higher quality. Smart cities, automated transport, industrial manufacturing, agriculture, healthcare, and other vertical services will cause mobile data traffic to increase drastically. A prominent emerging example includes wide-area connectivity – as delivered by mobile networks and Cellular Vehicle-to-Everything (C-V2X) technologies – for advanced and automated driving use cases. Examples of such use cases include tele-operated driving, obstructed view assistance, infrastructure-assisted environmental perception, and high-definition map collection and sharing. An adequate amount of spectrum is key for economically viable delivery of such services, and only with licensed mid-bands spectrum can we ensure to meet the required stringent capacity and quality of service demanded by industrial mobile use cases across wide areas such as cities (urban/suburban), and along major transport routes[2].

- **Premises**: Fast growing fixed wireless access (FWA) technology is a cost-effective and convenient approach to overcoming the challenges of fibre connections and legacy wireline xDSL solutions in more rural areas outside cities, ensuring universal broadband access to bridge the digital divide. With 5G, FWA can ensure fibre-like Gigabit user experience and meet the broadband requirements of smart homes and SMEs for 4K video, and AR/VR services. Note that this is in addition to the traffic demand of consumers for mobile connectivity described earlier. In the past four years, FWA terminal shipment maintained a growth rate of 20%. Fuelled by 5G, new shipments are projected to reach 300 million from 2021 to 2025. Most FWA markets worldwide will see an average of more than 250 GB traffic per month. This strong momentum will only continue for FWA if operators obtain sufficient mid-bands spectrum in order to benefit from favourable radio propagation at these frequencies for economically sustainable FWA.

Figure (1) below illustrates the range of diverse use cases which can be supported by mobile communication networks based on IMT 5G NR operating specifically at mid-bands. It is important to note that the spectrum needs of a mobile communication network are the sum of the spectrum needs of each individual use case supported at any given place and time.

[1] Report ITU-R M.2370-0 (07/2015), "IMT traffic estimates for the years 2020 to 2030".

[2] We note that low-bands spectrum (sub 1 GHz frequencies) also has an important role to play in providing coverage along transport routes in rural and less densely populated areas.

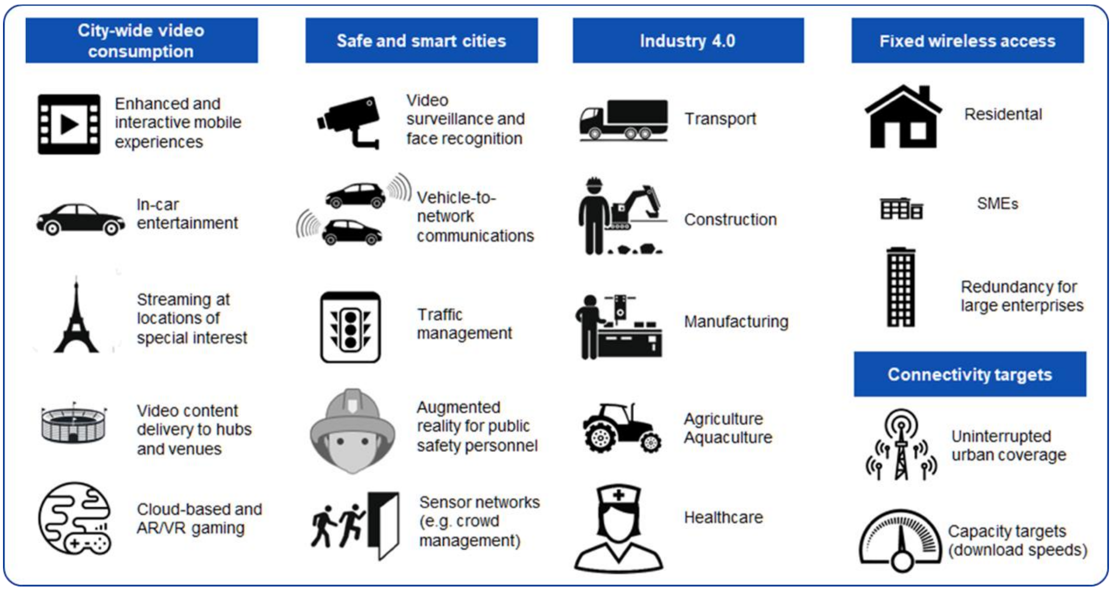


Figure 1: Use cases supported by 5G mobile communication networks at mid-bands
(*Source*: Analysis Mason, "The 6 GHz opportunity", 2019)

We note that Ofcom has considered low, medium and high growth scenarios up to the year 2035 corresponding to annual growth rates of 25%, 40% and 55% in mobile data traffic, respectively.

We agree with Ofcom that there is a high degree of uncertainty about the rate of future growth, particularly beyond 2030. Our own projections correspond to 300 GB or more of mobile data consumed per user per month by 2030, driven by high-definition video applications. Assuming a figure of around 9 GB per user per month in the UK in 2021, this corresponds to an annual growth rate of at least 48%.

As described later, we consider that spectrum needs for mobile communication networks are driven not only by the growth in the total volume of data consumed, but also by the required 5G (IMT-2020) data rates – as specified by the ITU-R – of at least 100 Mbit/s on the downlink and 50 Mbit/s on the uplink for the provision of high-capacity and/or low-latency citywide connectivity.

2. High bands (mmWaves) are important for hotspots but cannot meet the demand for citywide coverage

Ofcom's central proposition is that the future demand for mobile data can be met through "network densification – deploying more cell sites – in particular using small cells to leverage the capacity offered by the large bandwidths available from mmWave spectrum."

We agree that mmWave spectrum (e.g., the 26 GHz band and the 40 GHz band in the longer term) has a role to play in meeting outdoor and indoor demand at locations which are subject to very high geographic traffic densities (so-called "hotspots") through the deployment of small cells. Such hotspots may include busy train stations, stadiums and shopping centres.

However, due to poor signal propagation at these frequencies, especially in non-line-of sight (NLOS) scenarios, mmWaves deployments are not suitable to meet the demands of urban/suburban citywide mobile use cases in an economically feasible or environmentally friendly manner. This is due to the very large number of base station sites which would be required, and the costs associated with building, operating and maintaining these.

For example, existing macro-cellular mobile networks are typically deployed with an inter-site distance of 400 to 600 metres in major cities, whereas the high signal propagation losses at mmWaves would require inter-site distances of around 100 metres in cities. Therefore, mmWave coverage of a city would require roughly an order of magnitude greater (in this example, by a factor of $\times 16$ to $\times 36$) number of small cell sites at mmWave as there are existing macro-cellular sites. The required levels of investment in CAPEX and OPEX would simply not be justifiable. Furthermore, such small-cell sites would not be able to provide adequate outdoor-to-indoor coverage due to the prohibitively high building penetration loss at mmWave frequencies, not to mention the reduced spectral efficiencies and reduced call quality due to the required frequent handovers in high mobility scenarios.

The above shortcomings of mmWaves have been well understood by many mobile operators globally for some time, as exemplified by statements such as the following: “Millimetre wave (mmWave) spectrum has great potential in terms of speed and capacity, but it doesn’t travel far from the cell site and doesn’t penetrate materials at all. It will never materially scale beyond small pockets of 5G hotspots in dense urban environments.”[3] Moreover, many national administrations – including the FCC in the US, whose early actions saw the auction of large amounts of mmWaves for 5G in recent years – are now focussing on the availability of new mid-band spectrum for the enhancement and evolution of 5G.[4]

In short, while we agree that mmWaves can help meet demand in specific public hotspots scattered throughout towns and cities, we do not agree that Ofcom’s central proposition of network densification at mmWaves is the right approach for meeting the demands for high-capacity mobile urban/suburban coverage across cities.

3. Mid-bands are essential for high-capacity citywide coverage for mobile broadband and vertical use cases via macro-cellular public mobile networks

Mobile communication networks require access to spectrum at different frequencies, namely low-bands, mid-bands, and high-bands.

Low-bands refer to frequencies below 1 GHz. Signals at these frequencies are subject to favourable propagation conditions, and are therefore best suited for very wide-area and deep-indoor coverage. However, they suffer from narrow bandwidths, and cannot deliver very high data rates.

High-bands refer to frequencies above 24 GHz, or so-called “mmWaves”. These bands have very wide bandwidths and can therefore deliver very high data rates. However, signals at these frequencies suffer from poor propagation and indoor penetration. For this reason, high-bands are best suited for short-range, low-mobility, hotspot coverage at locations with very high demand.

Mid-bands typically refer to frequencies between 2-7 GHz and represent a sweet-spot between high bandwidths and favourable radio signal propagation conditions. As such, mid-bands can support a diverse variety of use cases, including high-capacity small cells in urban hotspots, citywide urban/suburban high-capacity wide-area coverage, coverage along major transport routes, communications within industrial complexes, factories and campuses, and fixed wireless access for rural premises/households. This is illustrated in Figure (2) below.

[3] Blogpost by Neville Ray, CTO of T-Mobile USA, April 22, 2019.

[4] Light Reading, “Rosenworcel's MWC appearance hints at shifting spectrum policy,” 1 March 2022.

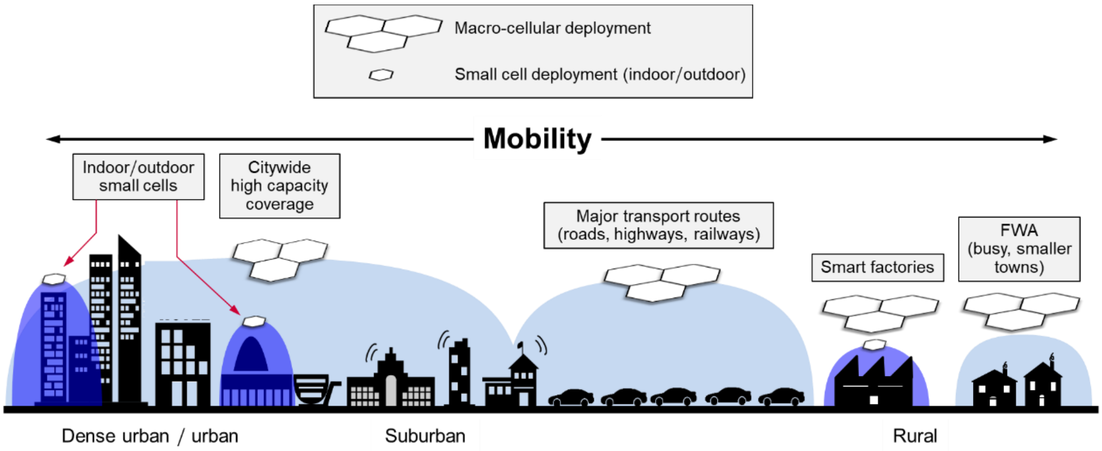


Figure 2: The versatility of mid-bands spectrum in addressing diverse use cases and environments.

We also consider that mid-band spectrum will serve as an important component of the *Metaverse*, by enabling economically viable high-capacity citywide mobile communications implemented through macro-cellular networks.

We consider that the Metaverse will involve high data rate AR/VR/XR both in indoor and outdoor scenarios. Accordingly, wide-area outdoor mobility is expected to play an important role in the Metaverse, whereby smartphones and XR headsets would need to connect to 5G macro-cellular mobile networks with sufficient bandwidth at mid-bands. Short-range connections (e.g., between smartphones and XR headsets) can be addressed with either Wi-Fi/WiGig/IMT-sidelink @ 60 GHz, or with Wi-Fi @ 5 GHz and the lower 6 GHz. This is illustrated in Figure (3).

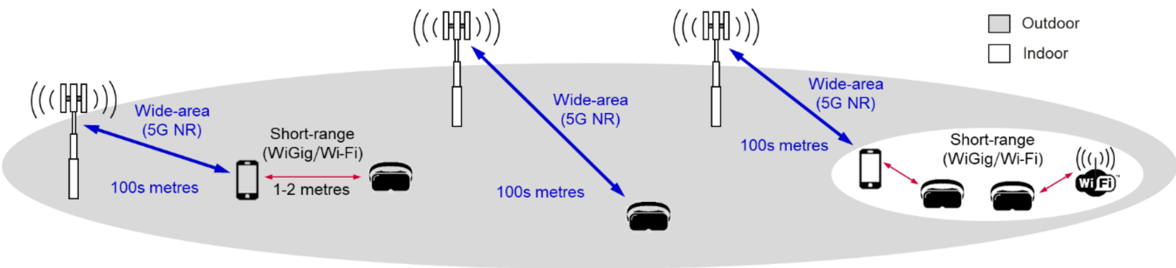


Figure 3: Outdoor communications will play an important role in the Metaverse facilitated by high-capacity wide-area connectivity in mid-bands spectrum.

The versatile nature of mid-bands, and the key role which they play in the provision of services via mobile communication networks is well-recognised by the mobile industry and spectrum regulators.

3.1. Demand for additional mid-bands (GSMA)

Considering the tremendous demand for connectivity by consumers, households, businesses, and industries, the GSMA recently published a report on its vision of the future needs for mid-bands spectrum[5].

The study examined 36 cities globally, and quantified their mid-bands spectrum needs accounting for factors such as population density, existing spectrum available for IMT, inter-site distance between macro-cellular IMT base stations, 5G spectral efficiency, massive MIMO upgrades, offload to high

5 GSMA, "5G Mid-Band Spectrum Needs – Vision 2030," July 2021.

bands, indoor small cells and Wi-Fi, and end users' activity factor. Figure (4) shows a sample of the results.

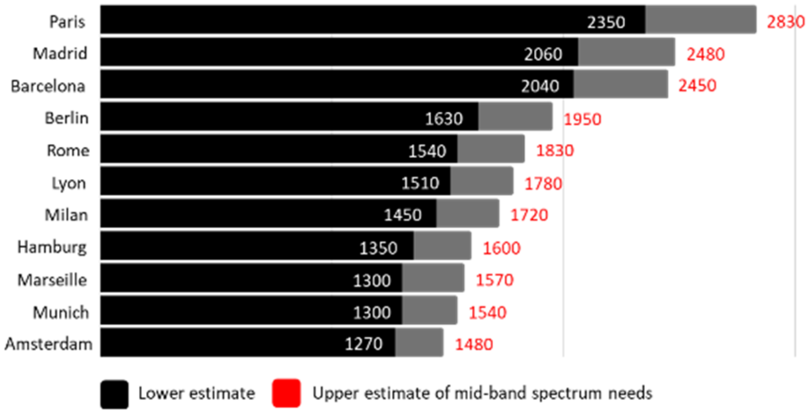


Figure 4: Mid-band spectrum needs for a sample of cities studied by the GSMA. (*Source: GSMA*)

The report concludes that "The GSMA recommends governments and regulators to plan to make 2 GHz of mid-band spectrum available in the 2025-2030 timeframe. This is the average value needed to guarantee the IMT2020 requirements for 5G", and that "…spectrum is required to deliver the 5G vision of downlink user experienced data rate of 100 Mbit/s across the city, i.e. citywide "speed coverage", and also to satisfy the 50 Mbit/s uplink target."

The report clarifies that mid-bands spectrum is required in addition to the mid-bands that are available to mobile networks today (which the study assumed will eventually be re-farmed for use by 5G), and that this is necessary to achieve the IMT-2020 5G data rates specified by the ITU-R for the delivery of high-capacity coverage across cities and along major transport routes in the 2025-2030 timeframe in support of mobile broadband, smart city, automotive and industrial use cases.

Network densification cannot meet the demand economically

Importantly, the GSMA report shows that in the absence of the required additional mid-band spectrum, the mobile radio networks would need to be substantially densified (numbers of base station sites increased) in order to deliver the 5G data rate targets, and that this would lead to a significant increase in energy consumption and radio network cost. Specifically, for a typical large European city, the implication would be a doubling of power consumption, and a four-fold increase in total network costs. This is in addition to the carbon footprint involved in the manufacture of the greater number of equipment.

Further analysis was carried out by the authors of the report to quantify the reduction in downlink and uplink data rates in cities in the absence of the required additional mid-bands spectrum and in the absence of the "extreme" network densification that would be unsustainable citywide. The results show that in the absence of additional mid-bands spectrum, and given the economic and technical limits to extreme network densification, MNOs would only be able to achieve 20% of the 5G data rate requirements of 100 Mbit/s downlink and 50 Mbit/s uplink in densely populated European cities.

3.2. Demand for additional mid-bands (5GAA)

In its roadmap[6] published in 2020, the 5GAA sets out a consolidated view of the automotive and telecommunications industries on the evolution of communication technologies, their application to

[6] 5GAA, "A Visionary Roadmap for Advanced Driving Use Cases, Connectivity Technologies, and Radio Spectrum Needs," September 2020.

automotive connectivity, and the deployment of advanced driving use cases up to 2030, which include advanced safety and automated driving.

In this roadmap, the 5GAA identifies a number of promising advanced driving use cases, which can be supported by Cellular Vehicle-To-Everything (C-V2X) technologies [7] for direct communications (between road users) and/or mobile network-based communications. These two modes of communications are illustrated in Figure (5).

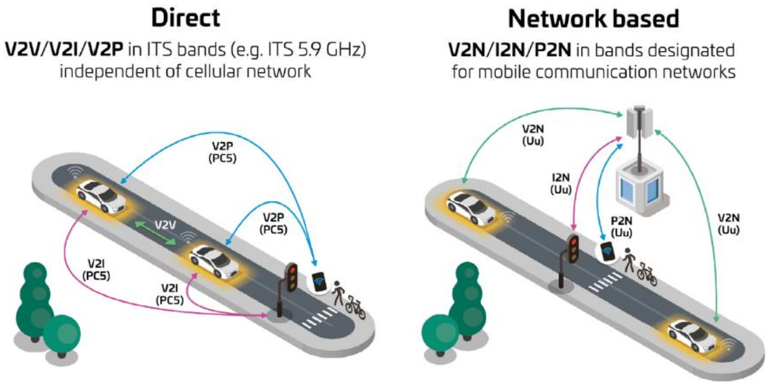


Figure 5: Direct and mobile network-based communications modes supported by C-V2X.
(*Source: 5GAA*)

As explained in 5GAA's spectrum needs study[8], the identified use cases can be classified as:

- "use cases which involve direct communications among road users or between road users and ITS roadside infrastructure (so-called V2V, V2I, V2P) as supported by the C-V2X (PC5) interface in the 5.9 GHz band harmonised globally for ITS, and
- use cases which involve network-based communications between road users and mobile network base stations (so-called V2N) as supported by the C-V2X (Uu) interface in bands designated and licensed for use by mobile communication networks, where the term "road user" includes vehicles and pedestrians."

Based on the results of its spectrum needs study, the 5GAA concludes that:

"The current spectrum allocations available to mobile operators are not sufficient to support the advanced mobile network-based communications anticipated by the automotive industry. It is the view of the 5GAA that national and regional administrations address this with the following complementary actions:

- At least 500 MHz of additional service-agnostic mid-band (1 to 7 GHz) spectrum be made available for mobile network operators to provide high capacity city-wide advanced automotive V2N services.

In the above, the term "additional" means availability of spectrum in addition to the bands that are currently identified for IMT use by mobile communication networks."

[7] C-V2X is an umbrella term which encapsulates all 3GPP V2X technologies, including both direct (PC5) and mobile network communications (Uu), and includes LTE-V2X and 5G-V2X. LTE-V2X mobile network communications start with Rel. 8 for LTE. LTE-V2X direct communications start with Rel. 14. 5G-V2X relates to the combination of LTE-V2X and 5G radio access technology (NR). 5G-V2X mobile network communications start with Rel. 15. 5G-V2X direct communications start with Rel. 16.

[8] 5GAA, "Study of spectrum needs for safety related intelligent transportation systems – day 1 and advanced use cases," June 2020.

Accordingly, the 5GAA states that it "… places a high value on the importance of communications between road users and mobile network infrastructures in enabling future advanced driving use cases, as supported by the Uu interface of C-V2X. Accordingly, the 5GAA recommends that national and regional administrations ensure the availability of sufficient spectrum for mobile communication networks in the so-called low-bands and mid-bands for the support of services, including ITS, in the coming decade." [6]

4. Supply of mid-bands spectrum: the opportunity at upper 6 GHz for mobile networks

As described above, mid-bands are essential for cost-effective and economically viable and environmentally friendly provisioning of high-capacity wider-area urban/suburban mobile network coverage across cities. Insufficient spectrum at mid-bands would imply extreme densification to meet mobile demand. Extreme densification imposes unsustainably high costs (ultimately borne by users) and increases overall power consumption, not to mention issues with site availability. Moreover, the required extent of extreme densification may not even be feasible from a radio planning perspective due to increased likelihood of co-channel inter-cell interference.

However, we observe that there is today a substantial anomaly in the way mid-bands are assigned for use in the UK. This is in the sense that there is significantly more mid-bands spectrum assigned for use by low/medium-power equipment for short-range communications, as opposed to use by high-power licensed macro-cellular mobile networks using IMT technologies such as 4G/5G which can support both wide-area and local connectivity. This is illustrated in Figure (6) below.

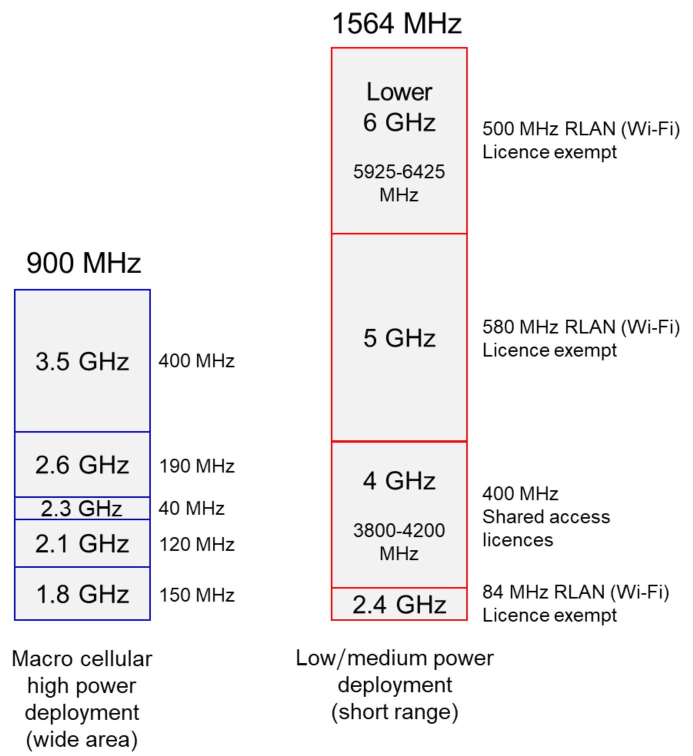


Figure 6: Mid-bands spectrum currently authorised for use in the UK
for high-power wide-area and low/medium-power shorter-range communications.

We certainly acknowledge that there is a need for short-range connectivity. However, it must be recognised that the assignment of large swathes of mid-band spectrum for low/medium power short-range connectivity is a mis-use of precious and limited spectrum resource[9], especially when viewed in terms of the high opportunity cost of the mid-bands not being used for wider-area connectivity. This is even more puzzling given that large amounts of spectrum are available at mmWaves for short-range communications (e.g., 26 GHz for licensed IMT equipment, or 60 GHz for licence-exempt equipment).

Accordingly, we consider that there is a need for a road-map for the availability of additional harmonised mid-bands spectrum in the UK over the next decade for use by macro-cellular public mobile networks to deliver high-capacity wide-area coverage – as well as local connectivity – to consumers, enterprises, industries and households.

A key mid-bands spectrum is the so-called “upper 6 GHz” band (6425-7125 MHz) which is currently subject to compatibility studies by ITU-R towards potential identification of the band for IMT under Agenda Item 1.2 of the World Radio Conference in 2023 (WRC-23).

The upper 6 GHz band is the only remaining spectrum of sufficient contiguous bandwidth in the mid-bands range to meet the demands placed on mobile communication networks in the 2025-2030 timeframe, and WRC-23 is an important and critical opportunity to ensure that the upper 6 GHz is harmonised for IMT to meet the spectrum needs for both wider-area and local deployments (“hetnets”) via IMT 5G NR and its evolution.

We recommend that the UK takes a proactive and positive approach towards this WRC-23 Agenda Item in support of the IMT identification of the upper 6 GHz band for use by 5G evolution in the coming decade.

We note that Ofcom is currently proposing to authorise the use of the upper 6 GHz through shared access licensing for indoor local networks ahead of the WRC-23 outcome. We urge Ofcom not to proceed with such authorisation of the upper 6 GHz as this would further exacerbate the inefficient imbalance in spectrum assignment illustrated in Figure (6) by making even more spectrum available for low/medium power short-range networks, as opposed to high-power wide-area macro-cellular networks (see also our response to Ofcom’s consultation on this specific matter).

4.1. Suitability of 6 GHz for macro-cellular deployments

As outlined earlier, due to the fact that radio signals suffer from increasing propagation path loss and building penetration loss at higher frequencies, mmWave 5G deployments can only target small-cell coverage in hotspots at specific locations, rather than macro-cellular citywide coverage.

This poses the question of whether 5G deployments in the 6 GHz band would be suitable for macro-cellular coverage in order to address high-capacity citywide demand.

To answer this, we performed a number of field tests in 2021 to compare the performance of macro-cellular IMT deployments at 3.5 GHz and 6 GHz. These tests involved two 5G NR base stations operating at 3.5 GHz and 6 GHz, respectively, both co-sited at an existing commercially deployed rooftop macro-cell site[10].

Importantly, we investigated the enhancements provided by active antenna systems (AAS) and MIMO at the 5G NR base stations. The 3.5 GHz base station used 64Tx/64Rx MIMO, whereas the 6 GHz base station used 128Tx/128Rx MIMO, on account of the smaller inter-element antenna spacings possible at the higher frequency (lower wavelength). The user equipment in both bands used 2Tx/4Rx MIMO.

9 Low/medium power deployments – whether using licensed or licence-exempt spectrum – do not need as much mid-bands bandwidth as wider-area mobile networks. This is because low/medium power deployments with small cells capture fewer users and traffic per cell, and due to the shorter communication range, experience higher wanted signal power levels.

10 Inter-site distances in the areas are 350 to 600 metres.

Downlink and uplink spectral efficiencies were measured for outdoor-to-outdoor (O2O) and outdoor-to-indoor (O2I) scenarios. Apart from the higher-order MIMO used at 6 GHz, the two base stations used the same bandwidth and total radiated power (TRP) at 6 GHz and 3.5 GHz, respectively.

Figure (7) shows the route taken by the user equipment for the O2O measurements. With an average building height of around 20 metres, this implied non-line-of-sight (NLOS) propagation between the rooftop base stations and the user equipment at street level in over 80% of the route. Figure (8) shows the distributions of the measured uplink and downlink spectral efficiencies along the route.

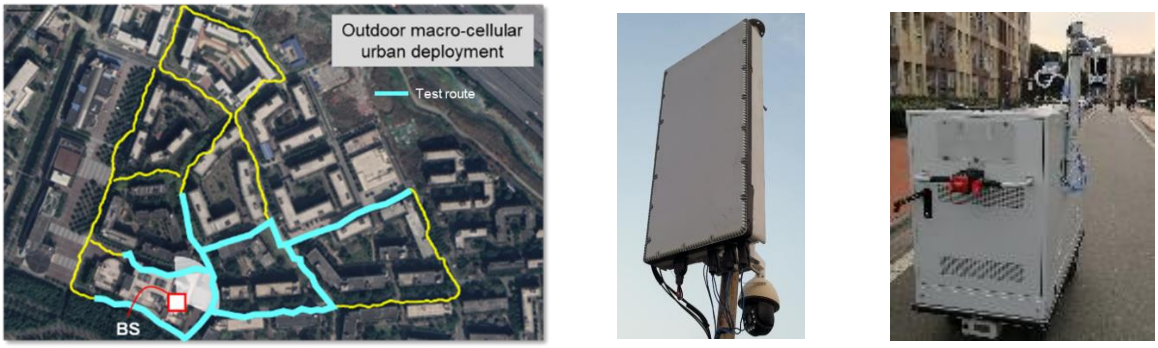


Figure 7: O2O field test scenario.

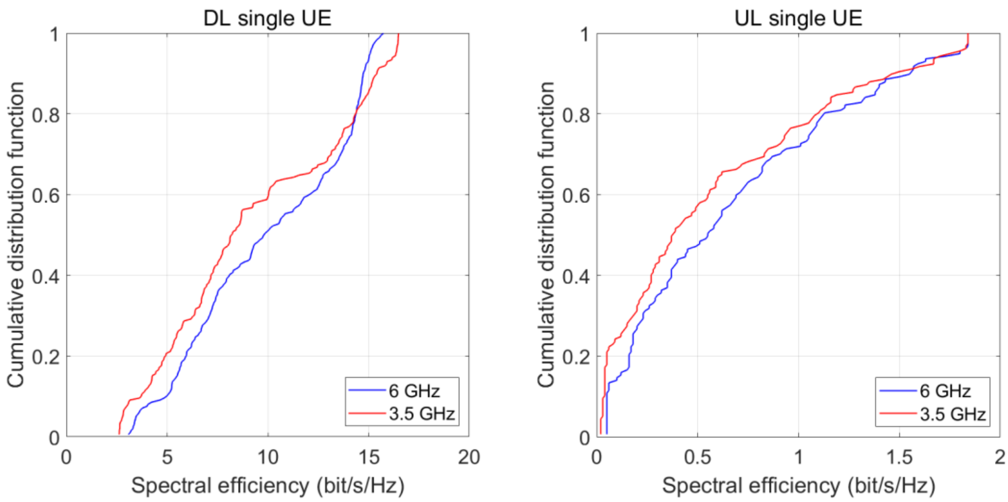


Figure 8: Cumulative distributions of measured O2O spectral efficiencies.

Figure (9) shows measurements of uplink and downlink spectral efficiency with the user equipment located indoors and in the proximity of a window, in what we refer to as a “shallow” rather than “deep” indoor environment. The 5G NR base stations were located a distance of 150 metres outside the building and in non-line-of-sight.

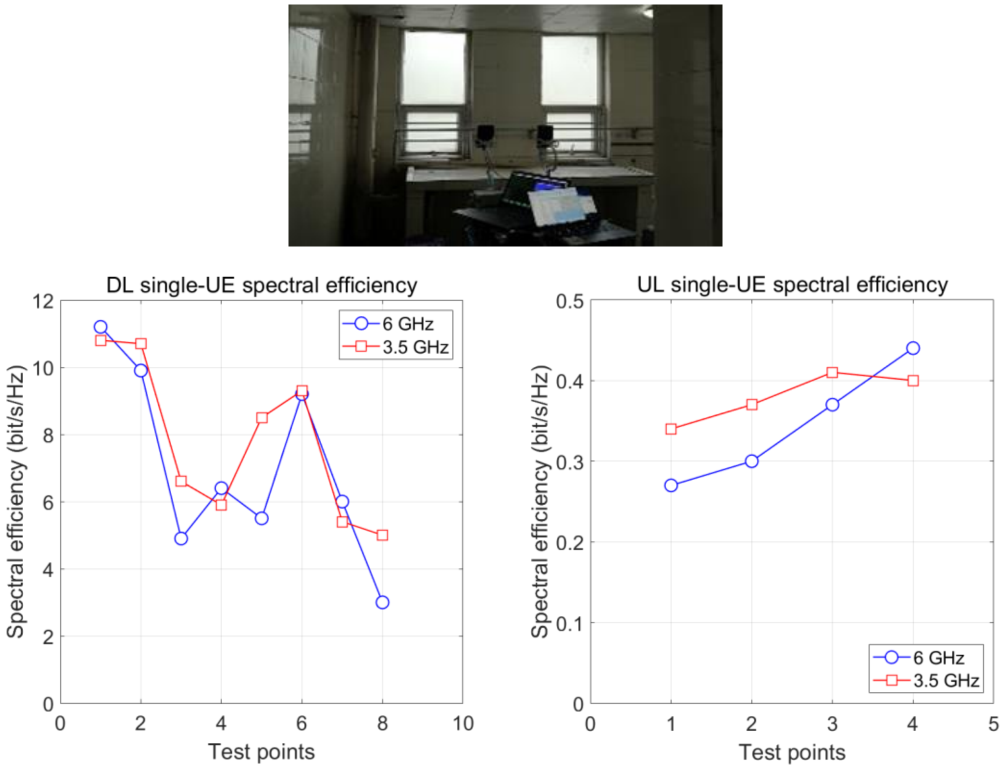


Figure 9: Measured O2I spectral efficiencies.

Figure (10) shows measurements along a corridor, and how the downlink throughout reduces with distance from a door at the end of the corridor.

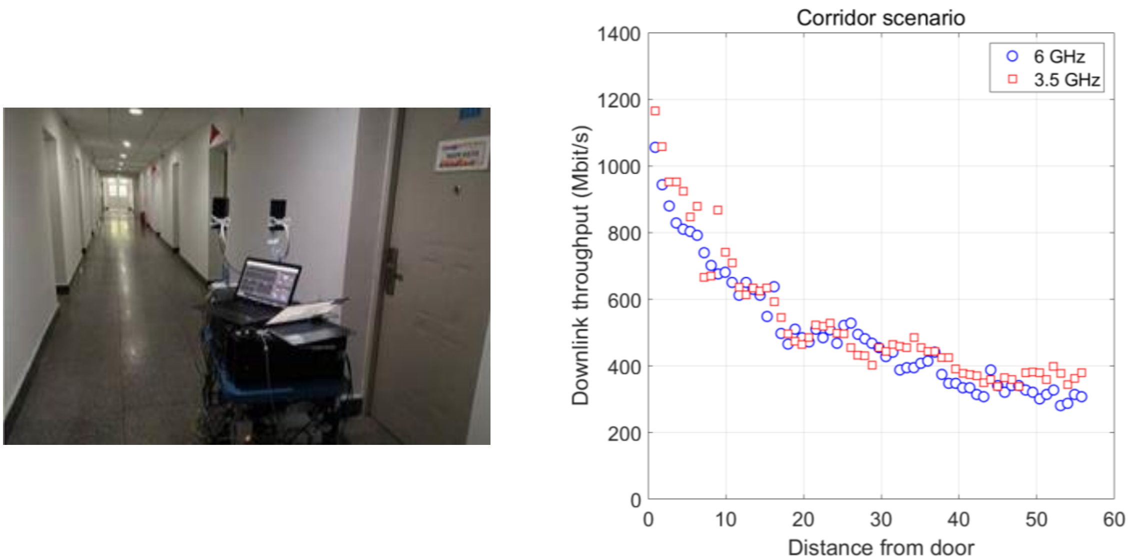


Figure 10: Measured O2I throughput as a function distance from a door at the end of a corridor.

Our field tests indicate broadly similar downlink and uplink spectral efficiencies for both outdoor-to-outdoor and outdoor-to-indoor (shallow indoor) scenarios in the 6 GHz and 3.5 GHz bands. This is justified by the higher-order MIMO implemented in the 6 GHz base station.

In addition to AAS and MIMO, further user equipment and base station physical layer enhancements are being investigated and developed.

4.2. Coexistence between IMT (5G NR) and incumbents at 6 GHz

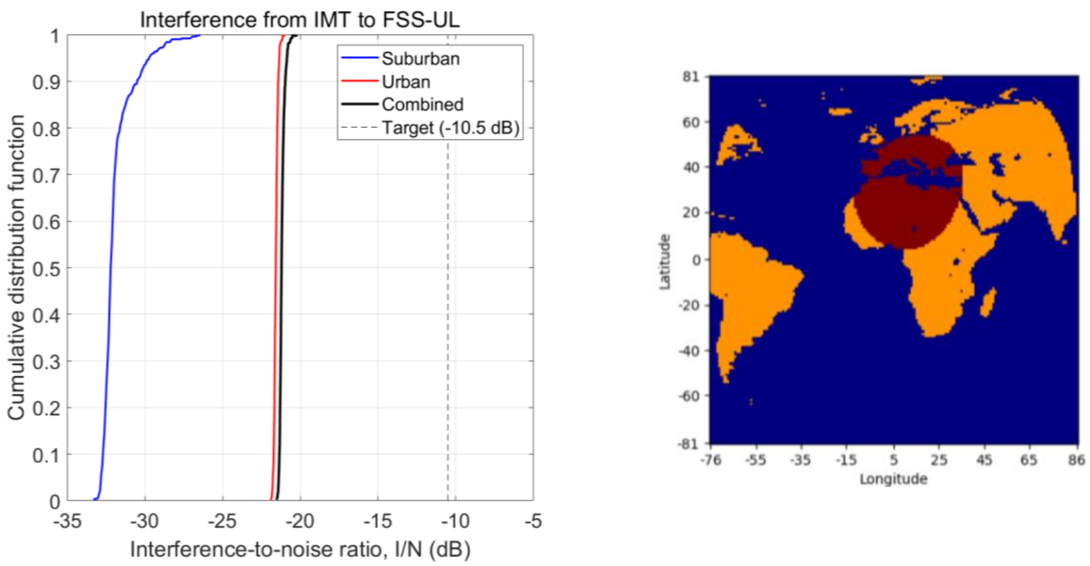
We acknowledge that the upper 6 GHz band is used by a number of incumbents. We are working at various international forums to identify appropriate and least-restrictive technical conditions for the sharing of the 6 GHz band between IMT and the incumbents.

Specifically, we are actively engaged in ITU-R sharing studies for the upper 6 GHz band towards WRC-23, and are committed to assist administrations to ensure a realistic modelling of harmful interference from IMT networks to incumbent services in the band, accounting for:

- ability of active antenna systems (AAS) to mitigate interference towards geostationary satellites;
- realistic models of clutter loss of signals from IMT base stations to satellites;
- realistic modelling of the numbers and locations of IMT base stations at 6 GHz.

The sharing between IMT networks and the uplink of the Fixed Satellite Service (FSS) is – by the nature of the incumbent – an international matter and is the subject of extensive studies at ITU-R. Our studies indicate that sharing with FSS UL is feasible with a reasonable margin when accounting for key parameters including a) the realistic geographic density of IMT base stations, b) the influence of clutter loss in mitigating interference, c) the impact of IMT base station active antenna systems (AAS) in directing interference towards desired directions (rather than towards satellites), and d) realistic satellite receiver antenna characteristics. Similar conclusions have been derived by other parties, including Ericsson and the French administration[11].

Figure (11) below shows an example of our studies[12] indicating an 80th percentile interference-to-noise ratio (I/N) of -21 dB at the satellite receiver, compared to a target I/N of -10.5 dB.



IMT scenario	80th percentile I/N (dB) experienced at satellite receiver
Suburban	-31.6
Urban	-21.5
Combined	**-21.1** (protection target as agreed at ITU-R: I/N = -10.5 dB)

Figure (11): Interference from IMT deployments falls below the agreed protection threshold.

[11] See contributions to ITU-R WP5D, 5D/1032 and 5D/1042.

[12] See Huawei contribution to ECC PT1, ECC PT1(21)225, September 2021.

Co-existence with the Fixed Service (FS) is a national matter and is to be addressed on a case-by-case basis due to different usage across Europe, and where a toolbox of solutions can help administrations address their specific circumstances[13]. Notably, the individual licensing associated with IMT networks is always preferred when co-existing with the FS.

While sharing with the Radio Astronomy Service is not within the scope of WRC-23 AI 1.2, protection zones can be specified at a national level to reduce the likelihood of harmful interference to this service.

Sharing with passive microwave sensors over oceans is also not within the scope of AI 1.2, but is important for Europe. Mitigation measures and techniques are already in place on the passive sensors side. Considerations by administrations and industry are on-going on this topic.

4.3. Spectrum is not a bottleneck for Wi-Fi

We note that while the lower 6 GHz band (5925-6425 MHz) has been available in the UK since 2020 for use by technologies such as Wi-Fi for WAS/RLAN on a licence exempt basis, some parties are also advocating for licence-exempt authorisation of the upper 6 GHz band (6425-7125 MHz) for Wi-Fi.

However, we do not consider that Wi-Fi requires any additional mid-bands spectrum in the foreseeable future. By using advanced MIMO radio technologies (16 spatial streams), our own high-end Wi-Fi products can deliver data rates of up to 10.75 Gbit/s using the 2.4 GHz and 5 GHz bands alone[14]. We consider that such data rates are more than sufficient to deliver user demand for Wi-Fi – not to mention the availability of the lower 6 GHz band which is also available for Wi-Fi. We elaborate on this next.

Figure (12): Wi-Fi equipment can already deliver very high data rates by using the 2.4 GHz and 5 GHz bands. We do not foresee a need for additional mid-bands.

Access to fixed broadband in households and enterprises

As noted above, Wi-Fi 6 equipment can today deliver data rates of 10 Gbit/s or more by only using the 2.4 GHz and 5 GHz bands, and not even having to rely on the lower 6 GHz band which has been available in the UK since 2020. Yet, we see that in many developed countries the provision of fibre to premises by 2030 is expected to result in fixed broadband speeds of typically up to 1 Gbit/s at most.

As such, we do not consider that the availability of additional spectrum for Wi-Fi will be a bottleneck for the provision of fixed broadband services to homes and enterprises.

Short-range communications indoors and outdoors

Notable examples include the wireless connection of XR headsets (e.g., in the form of AR/VR glasses) to access points or to smartphones and other smart devices. See earlier in relation to the Metaverse.

Such wireless connections typically require very high data rates for the low-latency communication of high-definition (4K/8K) video over several metres, and can use the lower 6 GHz band. In principle, these

[13] For example, see industry contribution to ECC PT1, ECC PT1(21)227r1 (Sept. 2021), or Huawei contribution to ECC PT1, ECC PT1(22)073r1 (Jan. 2022).

[14] https://e.huawei.com/en/products/enterprise-networking/wlan/wifi-6/new-products-launch

short-range communications can be much better served at mmWave frequencies than at mid-bands, the latter being the sweet-spot for wider area mobile use cases. Specifically, these use cases can be supported through the use of the 60 GHz band (57-71 GHz) which is harmonised in Europe and has been available in the UK on a licence-exempt basis.

Some chipset suppliers have developed 60 GHz products targeting AR/VR headsets[15,16] and there are already WiGig VR headsets available on the market.

Use by consumers in public spaces

We expect Wi-Fi to continue to play an important role for delivery of broadband in public spaces such as train stations, airports and shopping malls. That said, there is growing evidence of changes in user behaviour in relation to reduced offload of traffic from mobile communication networks to Wi-Fi.

As indicated in a study by Coleago[17], "Where the capacity and speed of mobile networks is low and / or prices for mobile data are high, smartphone users often log onto a Wi-Fi network rather than using the mobile network. This is referred to as "*Wi-Fi offload*". This is the traditional way in which people look at the complementarity of mobile (IMT) and Wi-Fi."

Coleago then goes on to say:

"Wi-Fi offload is declining. The key factors in the trend away from Wi-Fi offload are the better 4G and 5G mobile user experience in terms of speed, the proliferation of unlimited data plans, and user convenience: […]

- The launch of 5G has ushered in a trend for unlimited data plans, with South Korea, one of the world's most advanced 5G nations, being a prime example. This means smartphone users no longer ration their mobile data usage and stay connected to a mobile network even when free of charge Wi-Fi access is available.

- Mobile broadband networks provide ubiquitous connectivity and allow users to move around without logging onto location-specific Wi-Fi access points. This is extremely convenient to users. In other words, 5G delivers a level of user convenience which Wi-Fi cannot."

- In short, Wi-Fi offload will remain important, however, there is qualitative evidence that suggest that it may not grow significantly:

- The cost per bit of mobile broadband provisioning is going down[18,19,20], which may make the business case of operator offloading less appealing.

- As unlimited (or >100 GB) data packages and high speed networks become widespread[21], consumer demand for Wi-Fi off-loading may decrease."

15 www.intel.com/content/www/us/en/products/docs/wireless-products/wigig-overview.html

16 https://www.fiercewireless.com/wireless/qualcomm-unveils-60-ghz-wi-fi-chipsets-for-wigig-devices

17 Coleago, "The 6 GHz opportunity for IMT," August 2020.

18 Ericsson, "The 5G consumer business case".

19 Boston Consulting Group, "A playbook for accelerating 5G in Europe".

20 Cisco, "Building the 5G business case".

21 Pelephone (Israel), O2 and Vodafone (UK), Vodacom (South Africa), SK Telecom (South Korea), Sprint and T-Mobile (US), NTT DoCoMo (Japan), Swisscom (Switzerland).

Use in industrial applications

Wi-Fi has been used in the past for communications in industrial applications, and we expect this to continue going forward, well-supported by the 10 Gbit/s data rates achievable by Wi-Fi 6 in the 2.4 GHz and 5 GHz bands.

However, we do not expect a huge growth in Wi-Fi use for emerging industrial use cases which require very high data rates, high reliability and low-latency communications. This is because Wi-Fi's robust medium access control (MAC) protocol is specifically designed and optimised for operation in the uncertain interference environment of licence-exempt spectrum, and therefore cannot match the performance of 5G NR which is designed to deliver extremely high quality of service in the managed interference environment of licensed spectrum[22].

In any case, should demand for Wi-Fi in industrial applications grow beyond our expectations, we consider that the lower 6 GHz band available in the UK since 2020 would be more than sufficient to meet such demand.

4.4. Socio-economic benefits of IMT at 6 GHz.

A recent report[23] by GSMA Intelligence presents a cost-benefit analysis of options for authorisations at 6 GHz that will maximise the social and economic value of spectrum in 12 specific markets over the 2022-2035 time period:

- Looking at expected traffic demand and supply for 5G and Wi-Fi, whereby supply is partly determined by the amount of spectrum available.
- Relative to the baseline scenario of unassigned 6 GHz spectrum.
- Comparing the socio-economic benefits of three different allocations of the 6 GHz band (5G only, Wi-Fi in the lower 6 GHz and 5G in the upper 6 GHz, and Wi-Fi only).

The study concludes that

a) licensing the entire 6 GHz for 5G will deliver the largest benefits in countries where fixed broadband provides maximum user speeds of up to 10 Gbps and if a portion of Wi-Fi traffic is offloaded to the 60 GHz band, and

b) licensing the upper 6 GHz for 5G, with licence-exemption of the lower 6 GHz for Wi-Fi, will deliver the largest benefits if FTTH/B and cable broadband adoption is widespread, they support maximum user speeds of 10 Gbps and the 60 GHz band is not utilised by Wi-Fi.

Notably, licence exemption of the entire 6 GHz band was not found to be the most beneficial authorisation in any of the considered analyses.

■

[22] As part of our research into industrial applications, we have demonstrated an implementation of *distributed MIMO* with 5G NR in a warehouse of dimensions 104 m × 32 m × 9.7 m. The distributed MIMO involved the reception of signals from 96 UEs (each with a 2Tx/4Rx antenna configurations) by a network of 16 coordinated 5G NR small-cell base stations (each with a 4Tx/4Rx antenna configuration) deployed with a separation of around 12 m throughout the warehouse, all using the same 100 MHz channel (frequency re-use of 1) in the 4.9 GHz band. The distributed MIMO – possible due to the deterministic medium access control protocols of 5G NR – achieved an astounding overall uplink spectral efficiency of around 115 bit/s/Hz.

[23] GSMA Intelligence, "*The socioeconomic benefits of the 6 GHz band considering licensed and unlicensed options*," January 2022.