Nokia welcomes the opportunity to provide views on Ofcom's discussion paper "Meeting future demand for mobile data".

The need for ubiquitous availability of mobile data to serve businesses and end-users is already acknowledged by many Ofcom's stakeholders. While 4G provides a good geographical coverage in the UK's, the arrival of 5G – to the extent that it's already been deployed– has already significantly increased the consumption of mobile data, both indoors and outdoors. We anticipate such an upward trend to continue to be present on a year-to-year basis, and we believe it is likely to increase even more with the uptake of 5G.

5G technology aims to address not only residential use cases. Its industrial-oriented aspects and the flexibility in deploying its technology, has the potential to be adopted by even more businesses and become the basis for industrial automation and digitisation.

As such, we expect that 5G will play an even more important role in the mobile networks' evolution and deployment in the years to come.

Future demand for data through mobile networks

As 5G continues to roll-out in additional locations across the country, the opportunities for enhanced and more reliable mobile connectivity are being realised from an increasing number of consumers. The advancements, the new applications as well as the quality of experience introduced by current and earlier mobile generations (LTE, LTE-Advanced, 5G) lead to an average of 40% year-on-year growth in data demand for services provided over public mobile networks, as indicated in Ofcom's discussion paper[1].

Going into 2030/2035, future mobile technologies (5G Advanced, 6G) are expected not only to improve the user experience of existing applications by lowering latency, expanding bandwidth and improving reliability, but also to introduce new use cases, revolutionising future mobile networks to enable human augmentation and digital-physical fusion. We believe that those new applications will bring significant changes to the demands and the data consumption of mobile networks and therefore will require availability of additional spectrum in all types of bands: low, mid, and high.

Early stages of Augmented and Virtual Reality applications may already be available using 5G however, their future evolution will require and generate even larger amounts of bi-directional multimedia content in motion, utilising speeds at least 5 times higher than what 5G can offer.

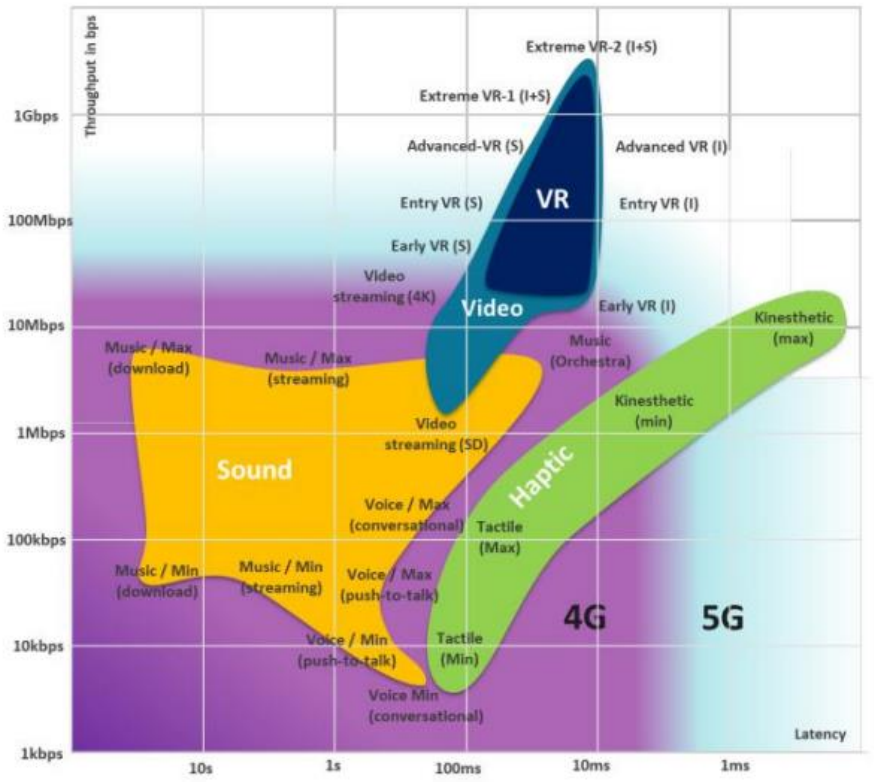
The full realisation of holographic telepresence and telemedicine, apart from the very low latency requirements, will also require 5-10 times higher spectral efficiency to meet the demanding QoS requirements and to provide a full sense of digitisation.

Furthermore, the greater degree of human-computer interaction, which future mobile generations promise to enable, will utilise autonomous operation of complex industrial robots for flexible and reliable manufacturing and will make extensive use of real time ultra-HD video streaming for faster and more efficient production lines in the factories of the future.

As a result, following Ofcom's observation that 5G applications have started to be more and more integrated in the modern post-pandemic digital life and that the number of 5G subscribers continues to increase, we also expect that future use case scenarios will also see increased adaptation, especially considering the change of digital demographics and the experience revolution that those services will bring. Consequently, considering that significantly larger amounts of data will be produced as well as

[1] Discussion paper: Meeting future demand for mobile data (ofcom.org.uk)

that adaptation of existing services and new use cases will increase for end-users and businesses, we believe that Ofcom's estimate of 40% (medium) growth scenario is underestimating the expected demand for mobile data in the years up to 2030/2035, which in our view will be much higher.



Source: Ofcom

As an example, Ofcom's estimation of the minimum throughput requirement of sensory communications as shown in the figure above, indicates that the difference in throughput requirements for Extreme VR-2(I+S) is about 100 times more than Early VR (I). Analysis done by P&S Intelligence[2] predicts that there will be over 100 million XR users by 2025 and 1 billion by 2030, driven in part by the adoption of 5G and future technologies. Therefore, considering that the UK is among the countries with increased mobile phone penetration among its population (95%)[3], with continuous investments in new technology and upgrades in the mobile sites, we anticipate that the future mobile data demand will position the country at the top end of the list of countries in terms of data consumption, demonstrating high data growth over the next decade.

[2] PSM Market Research: https://www.psmarketresearch.com/market-analysis/extended-reality-xr-market-insights

[3] https://www.statista.com/statistics/289167/mobile-phone-penetration-in-the-uk/#statisticContainer

The potential opportunities and challenges associated with network densification in the UK

Densification of networks to deliver the growing mobile data capacity is essential in the 5G era. With the development of more data consuming applications, as the ones mentioned previously, it is expected that demand for mobile data will increase in both indoor and outdoor environments. Investments in densifying mobile networks can be one way to address increased mobile traffic. However, to sufficiently meet the increased demand of data in the future, especially in highly dense environments, additional spectrum in combination with micro/macro densification is required to provide an adequate coverage and capacity layer.

Nokia has the widest portfolio of small cell solutions which have proven to provide improved mobile connectivity and user experience where needed, in both indoor and outdoor environments, addressing the increasing number of spectrum bands. Although macro base stations provide excellent coverage and high-capacity, there are certain cases, for example dense-urban locations dominated by tall buildings, where providing the necessary coverage can be challenging. Furthermore, in busy city centres and transportation hubs, where there are high numbers of mobile users, providing enough capacity can also be challenging. Therefore, densifying the deployment of mobile networks can indeed address certain coverage and capacity limitations in highly-dense urban environments, however it also presents challenges which should not be ignored. Such challenges could be overcome if additional spectrum is authorised, to enable greater flexibility for operators to effectively improve their networks, satisfying the required coverage range and accommodating the high-capacity demand.

To effectively densify mobile networks, a significant increase of mobile sites needs to be deployed. Such site increase introduces limitations to operators which may or may not be always feasible to be addressed. Depending on the deployed frequency band, the distance between sites to prevent inter-site-interference can vary from few tens of meters to a few hundred meters before it reaches saturation. Maintaining the required inter-site distance over the entirety of the network can become ever more challenging and in the case of densification over large areas, it maybe not be always feasible. In addition, deploying suitable sites that could provide and maintain seamless high-throughput connectivity across a dense mobile network may not always be available, either due to location limitations (e.g., propagation environments) or due to not reaching an agreement in the negotiations between network operators and landlords. Nevertheless, even when such agreement is reached, the deployment of ultra-dense networks may create a negative impact on the aesthetics of city environments.

Focusing solely on small cell densification to deliver the service requirements of future mobile generations will also not be a cost-effective solution for operators in the long term, if no additional suitable spectrum is allocated. Studies[4] have shown that without additional spectrum, densification of networks in metropolitan cities, such as Paris, will result in approximately 4 times increased cost for network operators to deliver the 5G requirements, and this figure excludes the cost of site acquisition. It is likely that such increased deployment cost will, largely, need to be absorbed by users and this is an aspect which Ofcom would need to carefully consider. Higher cost per MB may delay 5G/6G adaptation by end-users and as a result, further investments in mobile networks are likely to be slowed down or even demotivated.

The scale of densification will also impact the network's overall power consumption. Depending on whether densification is deployed over macro or micro cells, as well as depending on which frequency band densification is considered, a network's energy consumption might present various savings if additional spectrum is utilised. As an example, in the same study[4], the power consumption of a dense small cell network without additional mid-band spectrum, was proven to consume more than two times more energy compared to the case when additional mid-band spectrum was utilised.

[4] Estimating-Mid-Band-Spectrum-Needs.pdf (gsma.com)

Energy efficiency of mobile networks has always been a priority in Nokia's agenda. We believe that the technology we create plays a vital role in the fight against climate change. The solutions we create are keeping people connected and enable sustainable industries. Sustainable solutions are at the heart of our decision-making process, and we are being ranked #4 in the Wall Street Journal's top 100 most sustainably managed companies[5]. This year we recalibrated our own climate targets in line with the latest science and committed to cutting emissions across our business by 50% by 2030 compared to 2019. We have now delivered zero-emission products to over 150 customers globally. Moreover, the base station sites we modernised in 2020, are now using 54% less energy on average, and together with our business partners we introduced the world's first 5G liquid cooled mobile network base station[6], which uses up to a third less energy, reducing carbon dioxide emissions by up to 80% per site.

Specific frequency ranges that should be considered for mobile access to support capacity provision in the future

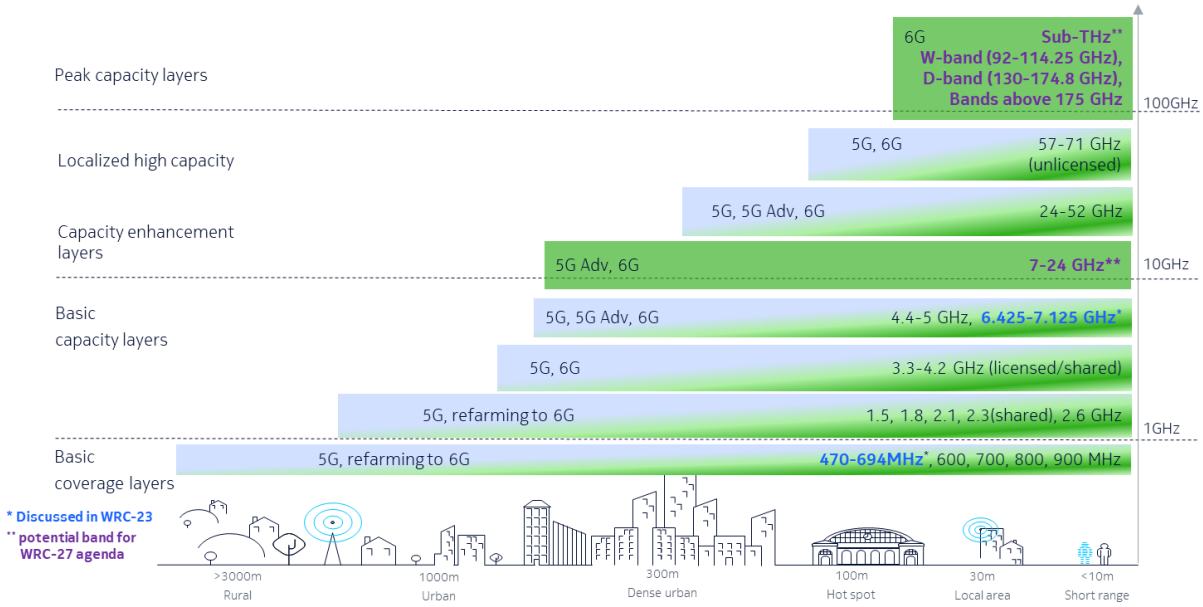
To address the increasing data demand generated by the use cases and the applications of current and future mobile generations, it is important to utilise all the means and technology innovations from the mobile industry. As mentioned in Ofcom's discussion paper, network densification and small cells can improve coverage and capacity in metropolitan cities and dense environments, but this is not the single solution. Furthermore, applications of innovative solutions in antenna technology can also improve flexibility and performance of mobile networks. Nokia's unique Massive MIMO approach, using modular arrays and advanced algorithms, enables a set of devices to be served simultaneously with many more dynamically controllable antenna elements than the number of devices. Our world's first distributed massive MIMO system can offer significant efficiency gains both in the uplink and the downlink directions[7]. Nevertheless, we believe that those strategies and technology advancements alone, would not be sufficient to fully address the future mobile data demand and thus, we strongly believe that additional, suitable and affordable spectrum in multiple frequency ranges should be authorised by Ofcom to accommodate the needs of the industry in the future. This approach is applicable whether we consider 5G developments or the upcoming 6G deployments.

In the figure below, we provide our views on the potential frequency bands for future mobile generations alongside the types of areas they can be utilised to serve.

[5] Nokia sustainability approach: https://www.nokia.com/about-us/sustainability/our-approach/

[6] Nokia AisScale MWC22 Nokia adds Liquid Cooling technology to latest AirScale Base Station portfolio outlining commitment to sustainability #MWC22 | Nokia

[7] Nokia Massive MIMO, MWC22 https://www.nokia.com/about-us/news/releases/2022/02/28/nokia-and-att-collaborating-to-improve-5g-uplink-with-distributed-massive-mimo-mwc22/

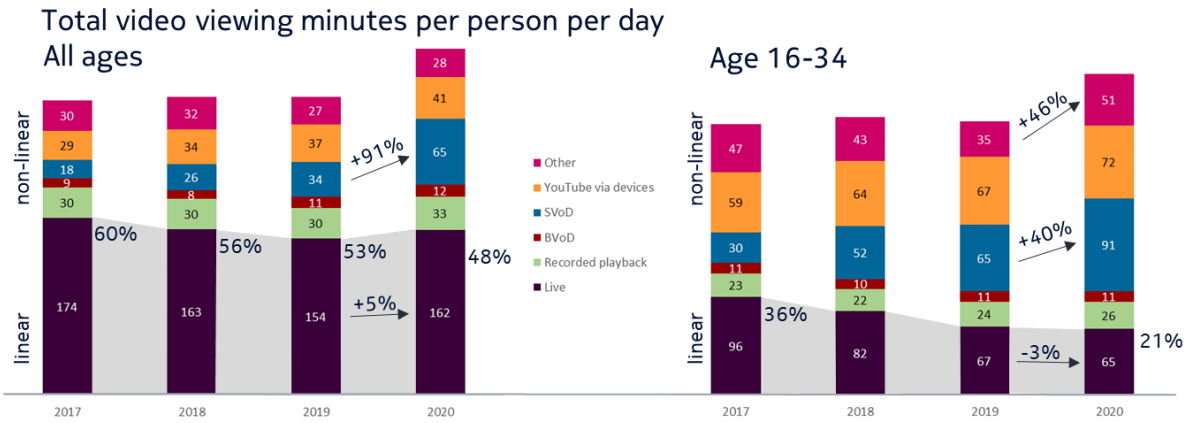


Source: Nokia

Sub-GHz frequencies are essential for rural coverage, they can provide deep indoor penetration and become the basic layer of wide-area coverage for IoT. While basic coverage is reached for very large percentages of the UK population and geography, to avoid the technology divide there is a growing need for the performance levels of rural networks to be comparable to the experience in the densely populated areas. The WRC-23 AI1.5 and the subsequent planned UHF review in the European Union as well as the discussions in CEPT offer opportunities for discussions on shaping the future use of UHF in an efficient way responding to latest technology developments and users demands. Nokia supports a co-primary allocation to mobile and welcomes administrations promoting the case of the mobile allocation and IMT identification in ITU-R, as appropriate .

Cost-efficient performance improvements of rural networks are best supported by more sub-GHz spectrum for the existing site grids. As such, consumers could increasingly use in-car and in-train audio and video entertainment, requiring substantial capacity and bandwidth for video along all traffic paths. While DTT can be expected to stay for many years to come, there is a clear trend in decreasing use of linear and a strong increase in non-linear video consumption. The UK Media Nations Report 2021 seems to indicate that – when considering self-recorded video as non-linear consumption - non-linear video minutes have passed linear video minutes for all audiences[8].

[8] Ofcom's Media Nations report: https://www.ofcom.org.uk/__data/assets/pdf_file/0023/222890/media-nations-report-2021.pdf



Source: Ofcom

DTT frequency planning leaves large parts of the spectrum in 470-694 MHz unused for that service in any given location, which allows for additional use, such as very localised PMSE application and TV white space use. Nokia believes that another option could be also the additional mobile downlink use in rural areas as it can co-exist with DTT and PMSE as e.g., proven in Finland in 2017[9]. The definition of a 3GPP band in the 470-694 MHz range with 8 MHz carrier bandwidth for 5G Broadcast may trigger a global ecosystem for receivers in that frequency range in mobile devices, which then could also be used for additional mobile DL capacity. A recent report[10] by Plum Consulting outlines both the needs and the possibilities for more flexibility in the regulation of the 470-694 MHz range.

Nokia suggest to Ofcom to analyse the potential of additional sub-GHz spectrum for mobile use in the range 470-694 MHz for improving network performance in rural areas as well as for deep indoor penetration.

Regarding the frequencies above 1 GHz, the 1.5-2.6 GHz spectrum can assist in expanding the performance of the coverage layers of 6G in settlements in rural, sub-urban and urban environments. Mid band frequencies such as the 6 GHz band provides a suitable range for capacity on a macro cell basis for urban environments. While Ofcom is of view that the spectrum in the upper 6 GHz band can be used, as of now, under the shared-access licensing framework, Nokia is of view that such an approach will not lead to substantial volumes of licence applications, since the awaiting period for the outcomes of WRC-23 does not provide certainty for investments.

To accommodate the increased capacity requirements, while providing coverage in dense urban environments, frequencies in the upper mid band (7-24 GHz) can provide the necessary bandwidth to create the new high-capacity layers, opening up opportunities for 6G use. The challenging propagation conditions of higher frequency bands (e.g., mmWave and sub-THz frequencies) make the coverage of wide areas very expensive. Therefore, upper mid band spectrum, offering bandwidth allocations of 400MHz carriers needed for 6G, is the sweet spot for simultaneously providing extreme capacity and competitive coverage.

Even though utilising the above-mentioned frequency bands offers a basic as well as an expanded layer of capacity and coverage for 5G Advanced and 6G, the higher the adaptation of new applications, the more bandwidth will be required. In dense and highly dense urban environments, applications such as VR, AR and 3D gaming as well as increased capacity requirements in highly populated venues

[9] https://www.nokia.com/about-us/news/releases/2016/09/02/qualcomm-nokia-and-yle-announce-worlds-first-demonstration-of-lte-supplemental-downlink-in-a-tv-broadcast-band/

[10] Plum consulting report: https://plumconsulting.co.uk/the-future-use-of-uhf-in-itu-region-1/

and events, will require even stricter constraints on throughput, reliability and latency requirements. Consequently, mmWave frequencies can be utilised to accommodate localised high-capacity requirements. Furthermore, to support the more capacity demanding services and applications indoors, mmWave frequencies can be utilised by FWA in urban environments to provide 5 to 10 times more capacity. It is expected that over the next 5 years, the mmWave-enabled 5G customer premise equipment will significantly increase[11]. At Nokia, we have validated and started trials of our 360 High Gain 5G mmWave FWA technology, which can pick up direct and reflected signals from any direction (both indoors and outdoors) and can adapt to changing environments through advanced analytics. As technology evolves, the sub-THz spectrum (~ 90 - ~300 GHz) is expected to open a new frontier in wireless communications. Access to the large bandwidths of sub-THz frequencies will provide the 6G peak capacity layer which will enable the implementation of emerging new cases as well as the enhancement of existing ones. Its wavelength characteristics will require new radio system concepts and architectures, utilising Ultra-massive MIMO antennas to provide enhanced beam forming strategies for even better network performance and user experience. Such miniaturisation of antenna apertures will also lead to reduced base station power consumption. Even though the use cases and technologies for sub-THz frequencies are still evolving, there is extensive academic and industrial research currently undergoing to identify in detail the applications characteristics and performance requirements. Therefore, it is crucial for Ofcom to ensure appropriate allocation of sufficient bandwidth for mobile networks in sub-THz frequencies to avoid creating a barrier to technological innovation and development of future applications in the UK.

Spectrum is a fundamental enabler of wireless communications. At Nokia we believe that making use of licenced, shared and unlicenced spectrum is necessary to satisfy the growing mobile data demand. Access to licenced spectrum for individual use is the preferred option to meet the expected QoS demand from current and future mobile networks, as well as to provide certainty for further investments. Authorising spectrum on a technology neutral basis, allows spectrum users to move from one technology to another in the same frequency band, depending on market demand, enabling smooth refarming of spectrum from an earlier generation to a more recent one. Furthermore, allocating contiguous blocks of spectrum offers significant benefits in mobile network deployments allowing operators and consumers to fully benefit from technology evolution. Use of contiguous spectrum is also found to be a more energy efficient approach, compared to the when carrier aggregation is applied[12].

Therefore, we would like highlight to Ofcom's the importance for a thorough assessment of the most suitable spectrum authorisation regimes for new spectrum bands. Future spectrum authorisation should enable the full realisation of benefits from new generation technologies, without imposing compromises in performance requirements but instead, with the objective of bringing new opportunities to innovate, opening new frontiers in the future of the wireless communications industry.

[11] Nokia FWA 5G mmWave: https://www.nokia.com/about-us/news/releases/2021/10/12/nokia-gives-fixed-wireless-access-a-boost-by-enabling-5g-mmwave-indoor-installations/

[12] Table 4, ECC Report 287: https://docdb.cept.org/download/1363