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DISCUSSION ON THE 6 GHZ OPPORTUNITY FOR IMT

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1 Executive summary

The deployment of 5G will bring large benefits to mobile services and users over the next years. To ensure the full IMT vision, 5G will require spectrum in low frequency bands, in mid-bands from around 2 to 8 GHz, and in high (millimetre-wave) frequency bands above 24.25 GHz. This report discusses trends that support further study on possible 5G mid-band spectrum possibilities in the 6 GHz frequency. The goal of these studies would be to enable a decision to be made at WRC-23 on the possibilities of identifying further mid-band spectrum for 5G use, while taking account of the spectrum requirements for existing services in this frequency range and also non-IMT needs such as Wi-Fi usage.

Broadband networks bring economic growth and quality of life: 5G will extend this

There is clear evidence that mobile broadband deployment and usage has delivered substantial economic growth and prosperity. Increased broadband penetration yields GDP growth, and we are convinced that the Internet will remain one of the most important contributors to economic growth and improved quality of life. The deployment of 5G networks will further extend this growth. 5G will provide enhanced connectivity for mobile and home broadband, and the Internet of Things on a massive scale, as well as providing reliable and low latency communications that might be used for time-sensitive applications needing high network availability and reliability, such as might be needed in several industries.

Important drivers for 5G use of mid-band spectrum

Although mobile data usage has grown substantially in recent years, there is a high potential for further future growth. In particular, this report explores five areas where additional availability of mid-band spectrum will be beneficial:

Mobile broadband and citywide video consumption: Access to mid-band spectrum is especially useful for applications which involve citywide video consumption such as audio-visual communications, in-vehicle entertainment, streaming of high definition video content at popular locations, and enhanced mobile media experiences with high quality video for augmented or virtual reality (AR/VR).

Mobile networks for safe and smart cities: A number of high-bandwidth applications are being planned for safe and smart cities, such as video surveillance, real-time text translation, video-based sensor networks and applications for public safety and emergency response personnel.

Mobile networks for Industry 4.0: Enterprises and businesses will benefit from access to networks that can support Industry 4.0 applications such as 5G-based machine control, vehicle-to-network

(V2N) services, robot connectivity, "campus-wide" multimedia services, and AR overlays for remote maintenance or construction support.

Fixed wireless access (FWA): FWA based on 5G networks with access to adequate amounts of spectrum can bridge the digital divide within and between markets and can increase the level of competition among operators and access technologies providing high-speed internet services into homes and businesses.

National connectivity objectives: Many countries and regions have ambitious broadband goals that can realistically only be met by wireless networks as part of the solution. In urban areas, in particular, access to mid-band frequencies will be important to meet connectivity policies in an economically viable manner.

Future traffic growth scenarios

Mobile data usage has increased sharply in the recent years, although usage levels vary between countries and regions. In the coming years, it is expected that the peak traffic consumption per user will continue to grow substantially although the variability between countries and regions will remain. This report investigates two important trends that are likely to impact traffic growth and the associated spectrum needs:

The take up of price plans with unlimited data usage

Mobile data pricing has important consequences for usage growth. For example, Finland is one market where unlimited pricing has been in place for a long time, and the Finnish usage far exceeds any benchmarks in the region and is one of the highest in the world. With the continuity of unlimited pricing and an annual growth rate of 30%, the Finnish data usage per capita will be well above 150 GB per month in 2025. As other markets move towards unlimited usage plans, it is reasonable to expect that many of these will also see a sharp increase in usage levels.

Limited fixed line availability in many markets and Fixed Wireless Access

In many countries, a large share of households and businesses will not have very high speed (i.e. 100 Mbit/s or more) wireline broadband coverage in the foreseeable future. Their connectivity needs could be met with high-capacity mobile networks as part of wider solutions to provide connectivity to all locations where connectivity is needed. A 200 GB fixed broadband usage per month per household today, with an assumed annual growth rate of 30%, would mean a usage of around 1,000 GB per month in 2025. Household sizes vary around the world, but in most markets this means average traffic per user of more than 250 GB per month.

Although the global average is likely to be lower, these trends indicate data usage as high as 150 GB per user per month in some advanced markets with unlimited data pricing or the deployment of FWA networks.

Studies on the need for additional 5G mid-band spectrum at WRC-23

The availability of additional mid-band spectrum was a priority for several regional organizations and groups of countries at the World Radio Conference in November 2019. As a result, the Conference reached consensus on the inclusion of the 6425-7125 MHz band within the agenda for the next WRC in 2023 for the EMEA Region (ITU-R Region 1). The agreed agenda item requires studies to understand the possibilities to deploy IMT while protecting existing services in the band.

Based on the results of such studies, national administrations will be able to take informed decisions on the future identification of the band for IMT.

This wide range of frequencies has the advantage of mid-band propagation characteristics and is therefore suitable for high capacity citywide coverage.

Mid-band spectrum is especially valuable for 5G use since this spectrum offers higher capacity than low-band (sub-1GHz) and greater coverage, including indoor, than high-bands (millimetric waves). The 6GHz band is an attractive solution to complement the current mid-band spectrum for IMT and is of particular interest in the following types of countries:

- countries which require higher capacity to meet future data demand
- countries where millimetric waves are not an option
- countries where it has been difficult to re-farm sufficient wideband channels in the mid-band spectrum

2 Important drivers for mid-band usage

A much-cited ITU report[1] from 2012 found that "First and foremost, the evidence is fairly conclusive about the contribution of broadband to GDP growth." In 2018, ITU published an updated report[2] that included an analysis of data between 2004 and 2017 for 139 countries. With regards to the economic impact of broadband, the report concluded that:

- "[ ] fixed broadband has had a significant impact on the world economy during the last seven years (2010-2017). An increase of 1 per cent in fixed broadband penetration yields an increase in 0.08 per cent in GDP.
- [ ] an increase of 1 per cent in mobile broadband penetration yields an increase in 0.15 per cent in GDP"

The deployment of 5G networks is expected extend broadband's contribution to growth and quality of life. In 2018, Analysys Mason identified more than 50 use cases solving urgent business and societal problems in today's world which could see significant performance improvements when migrated from legacy 2G/3G/4G networks to 5G or which can only work with 5G[3]. Figure 1 depicts the many applications that could become available, and which could exploit mid-band (2 to 8 GHz) spectrum availability, through 5G citywide high capacity coverage in urban and suburban areas.

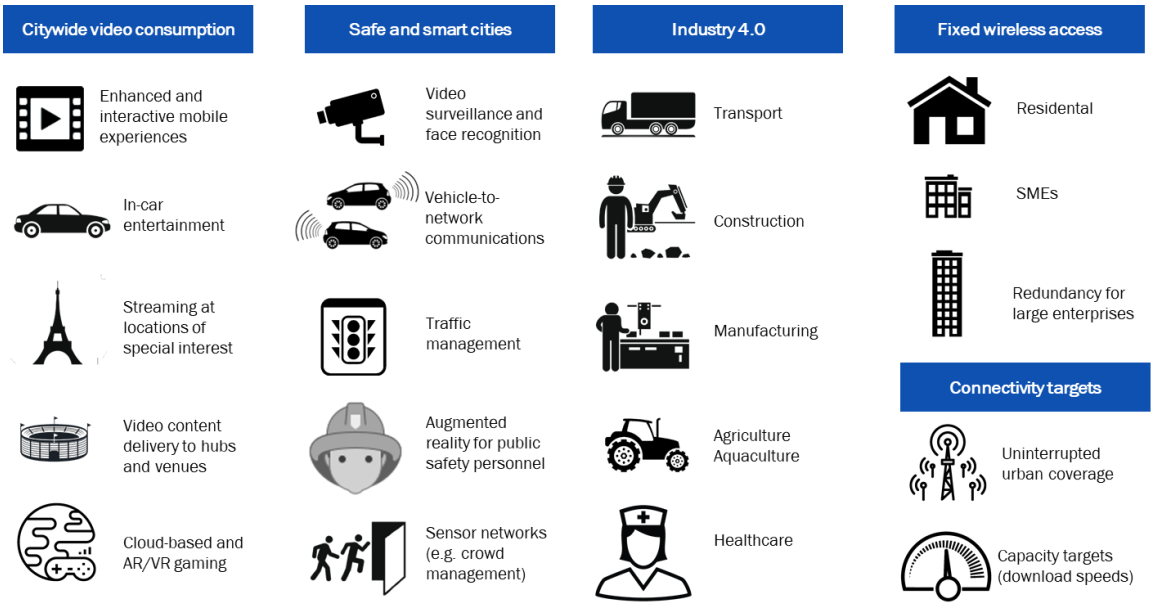

Figure 1. 5G applications for use of mid-band spectrum. Source: Analysys Mason, Icons8 Firefighter icon

1 R.Katz, "The impact of broadband on the economy" ITU, 2012.

2 R.Katz and F. Callorda, "The economic contribution of broadband, digitization and ICT regulation", ITU, 2018

3 See for example: "Unlocking digital opportunities with 5G: a GCC outlook", Analysys Mason, 2018

The remainder of this section identifies and discusses drivers for mobile data usage in general and 5G use of mid-band spectrum in particular. We have grouped the drivers into five areas:

- Mobile broadband and citywide video consumption.
- Mobile networks for safe and smart cities.
- Mobile networks for Industry 4.0.
- Fixed wireless access.
- National connectivity goals.

2.1 Mobile broadband and citywide video consumption

Access to mid-band spectrum – with its balance of favourable radio propagation and large contiguous bandwidths – is especially useful for the following variations of *citywide video consumption*:

- Enhanced and interactive audio-visual experiences for mobile users, where transfer of 4K/8K resolution video for multimedia communications and in AR/VR applications is made possible with high-capacity and low-latency mobile networks.
- In-vehicle entertainment, where better mobile network connectivity and edge-based deployments will enable passengers using private and public transport to consume high definition video and media services while travelling.
- Delivery of high definition video content in enterprises, campuses, and locations of special interest such as in transport hubs, malls, tourist attractions, sport stadiums, etc.
- Enhanced gaming experiences, such as cloud-based gaming and AR/VR gaming. The low latency in 5G networks means that game developers can offload most of the heavy computational work to data centres (leading to significant benefits including great simplification of end user devices and wearables). Players on 5G networks can stream their gaming content in a similar fashion as video streaming services Netflix or Amazon Prime. The new gaming platforms that companies like Microsoft (with Project xCloud) and Google (with Stadia) are developing will benefit from - and to a certain degree rely on - high capacity 5G networks.

2.2 Mobile networks for safe and smart cities

A number of high-bandwidth applications requiring large coverage are being developed for *safe and smart cities*, such as:

- Face recognition cameras and analytics for video surveillance (public safety).
- 5G-based Cellular V2X ("vehicle to everything") for public safety and traffic management.
- Augmented reality (AR) for real-time text translation.
- Digital signage for public venues.
- Data-aggregation of low-power wireless sensor networks:
  - Crowd management (wearables tracking).

- Public infrastructure stress monitoring.
- Smart streetlights.
- Smart waste management.
- Air quality monitoring systems.
- Smart parking systems.

In addition, several public safety and public transport networks (such as the UK Emergency Services Network) are moving or planning to move from dedicated, narrowband networks to IMT-based public networks. The 3GPP family of standards has already specified new features sought by these communities, including Mission Critical Push-To-Talk, Mission Critical Video, device-to-device communication and several others. This opens the opportunity for a move from private to public networks built with standard mobile network equipment, and using public mobile spectrum, with associated benefits related to costs, availability and service development. High capacity citywide networks, where the 6GHz-band can play an important role, can also enable several useful applications for public safety and utility professionals. For example, augmented reality applications can help firefighters and ambulance personnel with overlaying building designs and the location of important equipment such as defibrillators. In addition, the ability to offer network slicing, where operators can offer different classes of services across a common infrastructure, is an attractive opportunity for many public safety organizations and other users with high-priority needs.

2.3 Mobile networks for Industry 4.0

Enterprises will benefit from access to improved mobile networks as well. Technological innovations such as cloud and IoT are already creating new revenue opportunities by enabling the creation of new products and by improving businesses' access to new markets. Digital services such as artificial intelligence, analytics, virtual reality, and industrial IoT are expected to produce long-term gains in efficiency and productivity for several industrial sectors,

Within the *transport sector*, 5G-based cellular V2X (vehicle-to-everything) can allow vehicles to exchange data in real-time both among each other and with mobile networks. Aggregation of data collected from low-power wireless sensor networks can make aftermarket vehicle tracking and monitoring affordable and useful. Vehicle-to-network (V2N) applications can warn of hazardous situations and manage traffic jams and congestion charges. And at some point in the not too distant future, cellular V2X could enable self-driving and remotely controlled vehicles, possibly revolutionizing the transport of people and goods. A number of cities, such as Shenzhen, Paris and Montreal, are already testing self-driving buses and other tele-operated vehicles today.

There are similar applications in several other industries as well. The productivity in the *construction industry* can increase thanks to virtual property visits and increased use of wireless robots that require site-wide, high-capacity coverage. Progressive *manufacturers* are already looking into connectivity for robots, drones and augmented reality to support industrial operations. Augmented reality will help *tradespersons* (such as plumbers, carpenters and electricians) to receive remote support when needed and can be important in the *retail and energy production* sectors as well. Sensor networks and real-time video surveillance will increase productivity in *agriculture and*

aquaculture. In the *healthcare sector* we see a number of initiatives: Remote patient diagnosis and monitoring, and personal emergency response systems are already in place in some countries. Over time, we are likely to see even more high-connectivity applications such as remote surgery and variations of AR-assisted telemedicine.

Some private, dedicated networks are likely to remain private for many years ahead, and some organizations may want to build new, private networks. This will require spectrum resources, and some administrations are considering dedicated spectrum assignments for localized industrial applications. A mix of national, regional and local licences means a more fragmented approach to spectrum authorisation and an increased difficulty to release 100 MHz of contiguous spectrum for each operator in the current mid-bands.

The timing and communications requirements for these applications will vary, but one thing is clear: the more capacity that is available at an affordable price, the easier it will be to realize such services.

2.4 Fixed wireless access

The last decade has seen a remarkable expansion of fixed broadband networks where increased speeds and service quality has resulted in a high uptake among businesses and households. However, there are large differences between regions with respect to broadband availability.

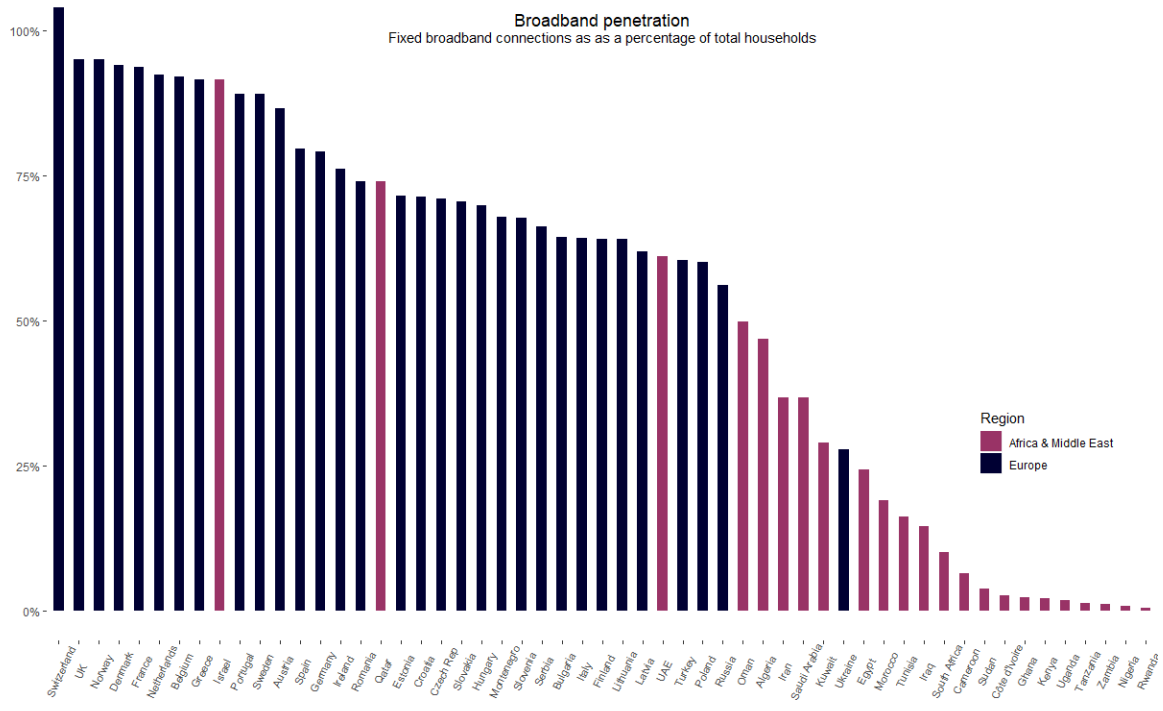

Figure 2. Fixed broadband penetration 2017: Europe, Africa & Middle East. Source: Analysys Mason

Figure 2 shows fixed broadband penetration in 2017. The penetration is particularly low in Sub-Saharan Africa, where fixed wireless access (FWA) based on 5G mobile networks with access to appropriate amounts of spectrum can help bridge the difference in penetration. In addition, the

delivered speeds with FWA can be comparable to the wireline broadband networks with a deployment cost that is significantly lower in urban and suburban areas. In rural areas, 5G in lower (sub-1 GHz) frequency bands could improve current broadband capacities and help connect those with no wireline broadband access today.

In markets with high wireline broadband penetration, mobile networks can increase the level of competition in the provision of broadband services to homes and businesses among operators and access technologies. This is especially important in markets where xDSL services will eventually disappear due to the switch-off of copper networks. But again, such mobile networks if used as part of an internet to the home solution will require the right amount of spectrum in feasible frequency bands to operate effectively. Also, as the importance of Internet access grows, business users will increasingly demand more than one Internet connection to avoid downtime. FWA could be an attractive solution for such users.

2.5 Nationwide connectivity goals

Many countries and regions have ambitious broadband goals that can realistically only be met by wireless networks as part of the solution. For example, the European Union's three main broadband objectives for 2025 are:

A. Access to 1 Gbit/s for all schools, transport hubs and main providers of public services and digitally intensive enterprises.
B. Access to download speeds of at least 100 Mbit/s to be upgraded to 1 Gbit/s for all European households.
C. Uninterrupted 5G wireless broadband coverage for all urban areas and major roads and railways.

With reference to objective C, more mid-band spectrum will be needed to allow for high-quality, high capacity and wide coverage in urban areas. In many markets, it is not realistic to deploy wireline networks - in most cases FTTH networks - to 100% of households within 2025. In these markets, mobile networks with access to sufficient mid-band frequencies would be in a strong position to help countries achieve objective B.

3 Analysis of growth in mobile data usage

In the previous section we identified important drivers for 5G in mid-band frequencies. This section investigates the likely impacts that the identified drivers could have on the end users' data usage and on the corresponding future traffic growth.

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3.1 The strong mobile data traffic growth in recent years

For consumers, digitalization of the economy has already significantly transformed the way people access and consume products and entertainment services while providing increased choice and access to information and significant time savings. The growth in mobile data usage during the last years demonstrates the contribution of mobile connectivity towards achieving this digitalization and the value of mobile connectivity for end-users.

We have used Analysys Mason's data on mobile data usage in 166 countries and divided these by the number of inhabitants between 15 and 64 years of age to estimate the average use per adult. Figure 3 shows the median usage and growth factor for various regions:

	Mobile data usage per adult (MB per month)		
Region	2013	2017	Growth factor
Sub-Saharan Africa	37	420	11
Emerging Asia	60	1,310	23
Latin America	180	1,530	8
Mid-East & North Africa	320	2,580	8
Central & East Europe	340	2,650	8
Western Europe	540	4,760	9
North America	920	4,010	4
Developed Asia	1,680	5,370	3

Figure 3. Mobile data usage growth 2013 - 2017 by region. Source: Analysys Mason, EIU, World Bank

Figure 3 shows that the median usage in Sub Saharan Africa was more than ten times higher in 2017 – a little over 400 MB - than in 2013, when the median usage was less than 40 MB per month. The median usage in Western Europe increased by a factor of nine during the period.

3.2 High usage variability

In addition to the strong growth in data usage, Figure 4 shows there is a high variability between regions and countries. The figure includes mobile data usage from 2013 (the blue boxes) to 2017 (the red boxes) in every world region.

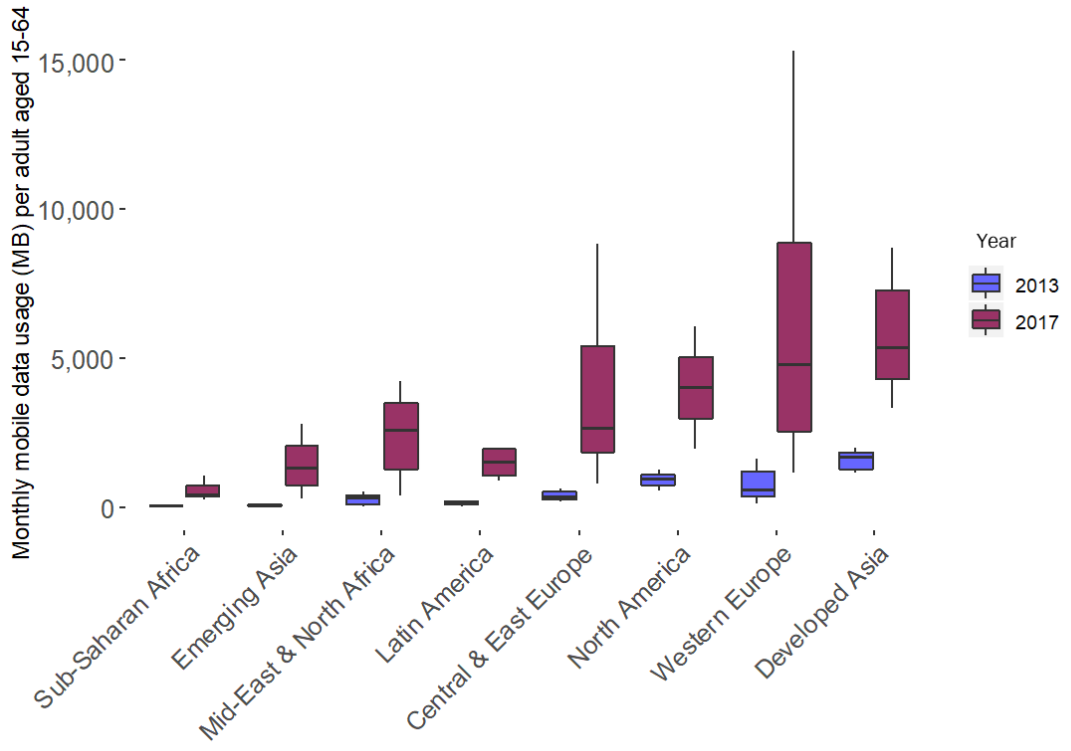

Figure 4. Mobile data usage growth 2013 - 2017 by region. Source: Analysys Mason, EIU, World Bank

The horizontal black line inside each box represents median usage, the upper and lower range of the boxes show the 75th and 25th percentiles, and the vertical lines show the upper and lower range for the countries in each region[4]. As can be seen, the usage variability can also be high among countries within a region. Figure 5 shows that in Western Europe this varies from more than 30 GB per adult per month (Finland) to less than 2 GB in Belgium and Greece.

4 We have excluded a few outlier countries with very high or very low usage to make the graph easier to read.

	Mobile data usage per adult (MB per month)		
Country	2013	2017	Growth factor
Finland	4,000	35,900	9
Sweden	3,700	11,200	3
Austria	1,600	15,400	10
Denmark	1,600	12,000	8
Ireland	1,100	8,100	7
Norway	900	5,700	6
Italy	800	4,800	6
UK	600	3,800	6
Portugal	500	2,500	5
Switzerland	500	6,300	13
Germany	420	2,140	5
Spain	360	2,860	8
France	320	4,750	15
Netherlands	260	2,520	10
Greece	170	1,170	7
Belgium	120	1,440	12

Figure 5. Mobile data usage in Western Europe. Source: Analysys Mason

We expect that in the coming years, further digitalization will enable more ubiquitous, convenient and personalized access to higher quality (higher definition video) mobile broadband services, while fostering innovation and the development of new products (e.g. augmented reality and virtual reality-based entertainment).

The mobile industry's traffic forecasts are usually based on assumptions regarding services and service usage as we see them today. Such forecasts are by their nature uncertain, since services sometimes take longer to develop and take hold than envisaged. It is also possible to overlook other emerging applications and sectors that turn out to be important for the forecasts in future. While the normal growth in the average usage for an already-installed base of devices is estimated to be about 30–35% per annum, it is possible that higher patterns of growth could also be achieved for some uses – such as through the introduction of new classes of devices (such as VR/AR) or new hyper-scale services such as Netflix[5].

Figure 6 shows how various amounts of mobile video consumption per day can impact monthly data usage. For applications such as 4K video and VR/AR[6], even relatively modest amounts of daily usage could theoretically result in requirements which exceed 150 GB/month/user.

5 S. Wilson, "Wireless network data traffic", Analysys Mason, 2019

6 We used the following Mbit/s requirements: 2K HD Video – 5.5 Mbit/s, 4K video - 20 Mbit/s, VR/AR - 49 Mbit/s

Example usage	Minutes of daily use HD Video	4K video	VR/AR	GB usage per month
HD video (2K)	120	0	0	149
HD and 4K video	30	30	0	172
VR/AR	0	0	15	169
Mix	15	15	10	199

Figure 6. The impact of video consumption on monthly mobile data usage. Source: Analysys Mason, third party estimates.

3.3 Mobile networks with unlimited data plans

Mobile data pricing has important consequences for usage growth, and we notice a large increase in mobile data use when the whole mobile market shifts to unlimited plans. Finland is an example of this: rather than having usage caps on data, the competition is based on different speeds. This creates an incentive to use mobile data at home on individual smartphones, and it is already clear that larger data bundles have caused a relative decline in the use of local Wi-Fi networks available for general use in public spaces[7].

As Figure 7 shows, the mobile data usage in Finland exceeds that in other countries in the region and is one of the highest in the world. Many households in Finland use only mobile broadband. This mobile-centric model is still uncommon, but the occurrence could grow in other markets with the introduction of 5G networks. Other markets also offer unlimited data plans, but traffic in the networks are often throttled after a certain usage level.

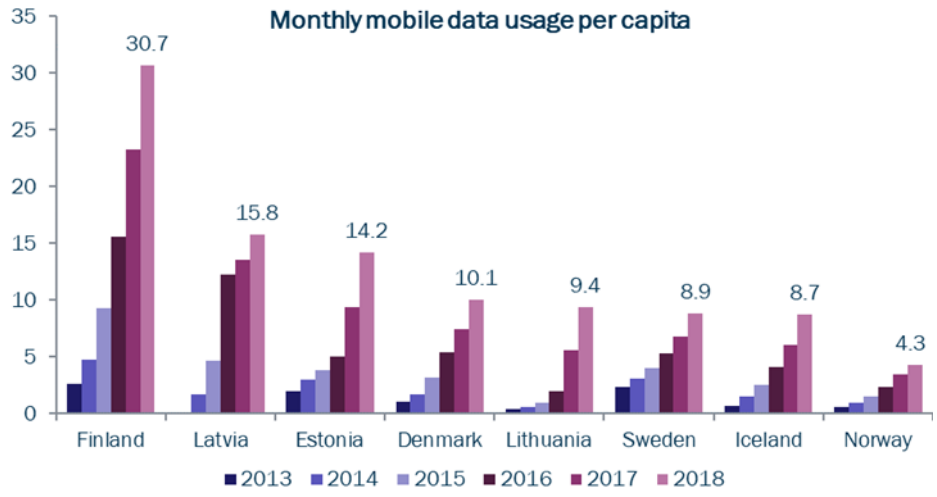

Figure 7. Mobile usage (GB) per capita per month. Source: Nordic-Baltic Telecom Statistics

With the continuity of unlimited pricing and an annual growth rate of 30%, the Finnish data usage per capita will be well above 150 GB per month in 2025. As other markets move towards unlimited usage plans, it is reasonable to expect that many of these will also see a sharp increase in usage levels.

7 R. Wood and W. Nagy, "Fixed network data traffic: worldwide trends 2018-2024", Analysys Mason, 2018

3.4 5G usage - experience from South Korea

South Korea is among the leading 5G markets, and South Korean mobile operators have offered 5G services to consumers and businesses since April 2019. So far, we have observed the following data points for 5G in South Korea:

- 5G is popular with end users: It took 69 days to reach 1 million 5G subscribers while the same figure for the 4G launch in 2011 was 80 days[8].
- The smallest 5G data package from the mobile operator SKT includes 150 GB per month, for KRW75 000 (USD65).
- 5G subscribers use a lot of data: In June 2019, the average traffic per 5G subscriber was around 24 GB/month - 2.6 times higher than the 9 GB average for all 4G users[9].
- Some of the large difference between 5G and 4G usage can be attributed to early adopters and technology enthusiasts whose 4G usage may also have been high. But according to SK Telecom's analysis on 5G subscribers, the average monthly data usage of customers who switched devices from LTE to 5G has increased about 65 percent[10].

Although it is still early days, the 5G launches seem to have a significant impact on data usage, just like the 4G networks had when compared to 3G data. Figure 8 shows that within 2 years of launch, 4G smartphones generated at least 3 times more traffic than for 3G.

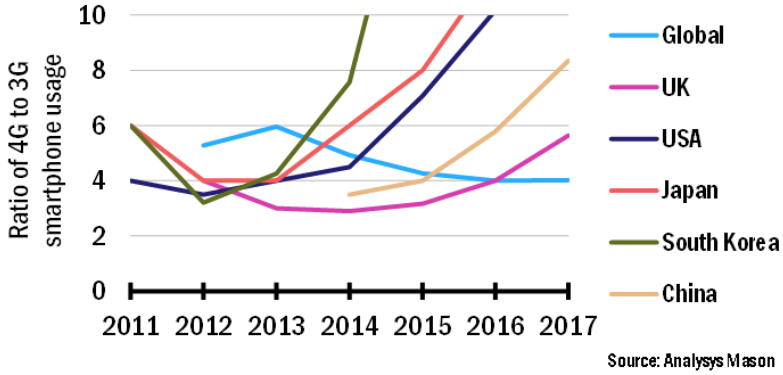

Figure 8. Ratio of average 4G and average 3G smartphone data usage. Source: Analysys Mason

So far, we have primarily investigated demand for mobile broadband and found that we can expect a large increase in future mobile broadband usage from new pricing plans and the launch of 5G networks. In addition, fixed wireless access services, which are likely to be based on 4G and 5G networks, will drive demand beyond mobile broadband alone.

8 Source: Venturbeat.com, June 2019

9 Source: South Korea Ministry of Science and ICT

10 Source: Light Reading, August 2019

3.5 Fixed wireless access: impact on mobile data usage

As we have already discussed, several countries have limited availability of wireline broadband technologies such as xDSL, cable or fibre. In addition, other countries are phasing out the use of copper networks. Fixed wireless access delivered over 4G and 5G networks could provide a cost-efficient alternative to wireline broadband services and could also be the dominant broadband access method in some emerging markets. As Figure 9 shows, users in emerging markets consume broadly equivalent amounts of data to those in developed economies.

An indication of the future level of traffic that can be expected on new FTTH networks can be garnered from their fair-use policies: The Indian operator You Broadband offers 12 TB per line per year, and Jio GigaFiber has hinted that it will offer 1.1 TB per month. In Indonesia, the development of FTTx by Telkom and competitors has allowed average fixed data traffic per line to explode: one operator offered 240 GB per month on FTTx by mid-2018[11].

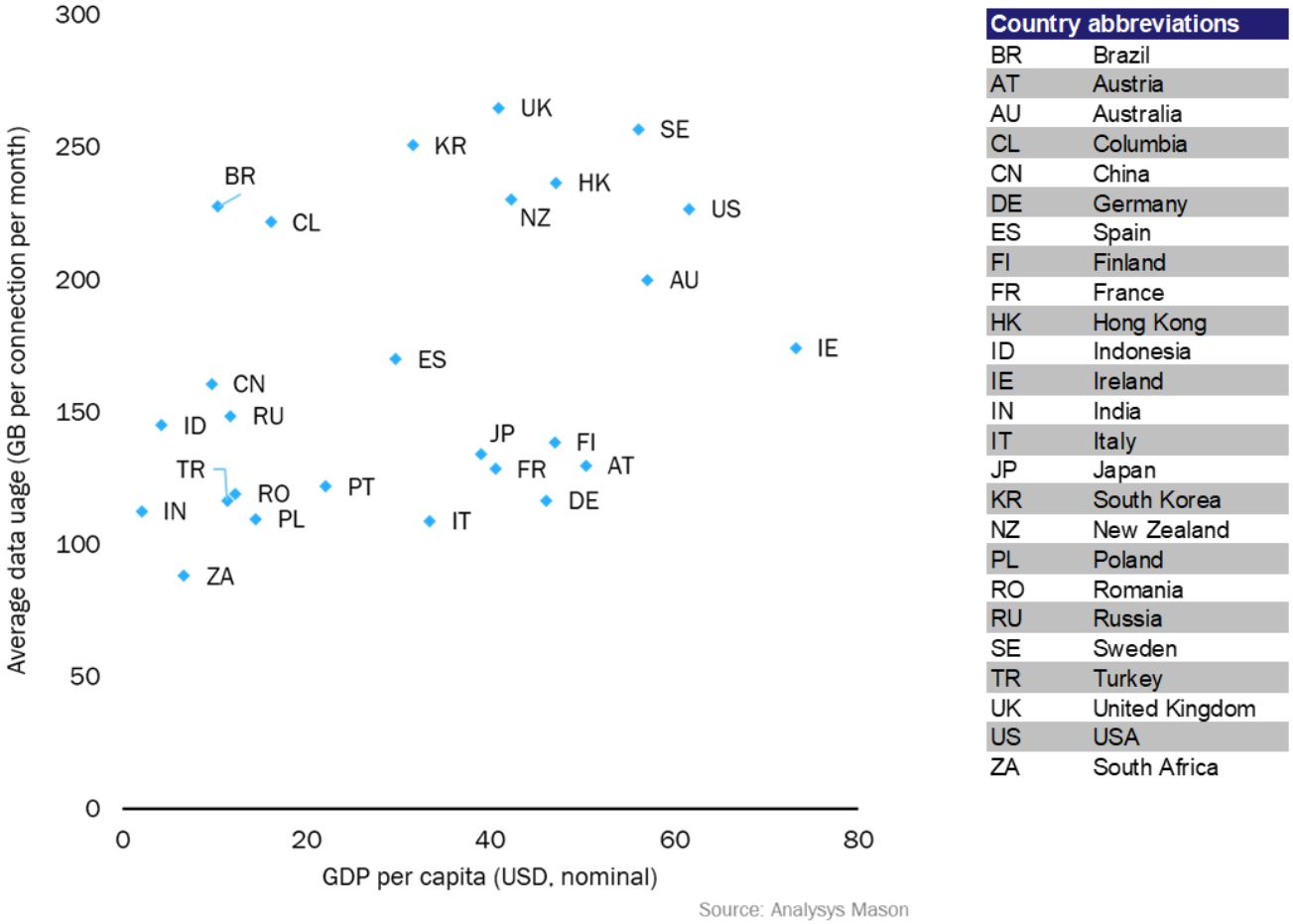

Figure 9. Average wireline broadband data usage and GDP per capita, end of 2018

11 Source: R. Wood and W. Nagy, "Fixed network data traffic: worldwide trends 2018-2024", Analysys Mason, 2018

Even though usage among connected customers is high, a large share of households and businesses in many countries will not have access to wireline broadband in the foreseeable future. Their connectivity needs could therefore be met with fixed wireless access.

With a 200 GB usage per household per month, a conservative traffic estimate would be around 1,000 GB per household per month in 2025. Household sizes vary around the world, but in most markets, this means average traffic per user of more than 250 GB per month.

4 Calculation of future mid-band mobile spectrum needs

To enable commercial success of 5G deployments, harmonized frequency bands and large continuous bandwidths are necessary. 5G networks may need to support aggregation of frequency bands both below and above 8 GHz.

Around the world, mid-band 5G spectrum plans have been developed, with several countries at an advanced stage with their plans. Parts of the 3 GHz band have been licensed in several countries. By 2025, a typical country with a mature mobile market that has assigned the most common IMT bands (in ITU Region 1 this would be the 700, 800, 900, 1400, 1800, 2100, 2300 and the 2600 MHz bands in addition to the 3400-3800 MHz band) will only have a total spectrum portfolio of 1230 MHz[12]. In a 4-player market with equal spectrum distribution among operators this will amount to 307 MHz per operator being available across the different frequency bands.

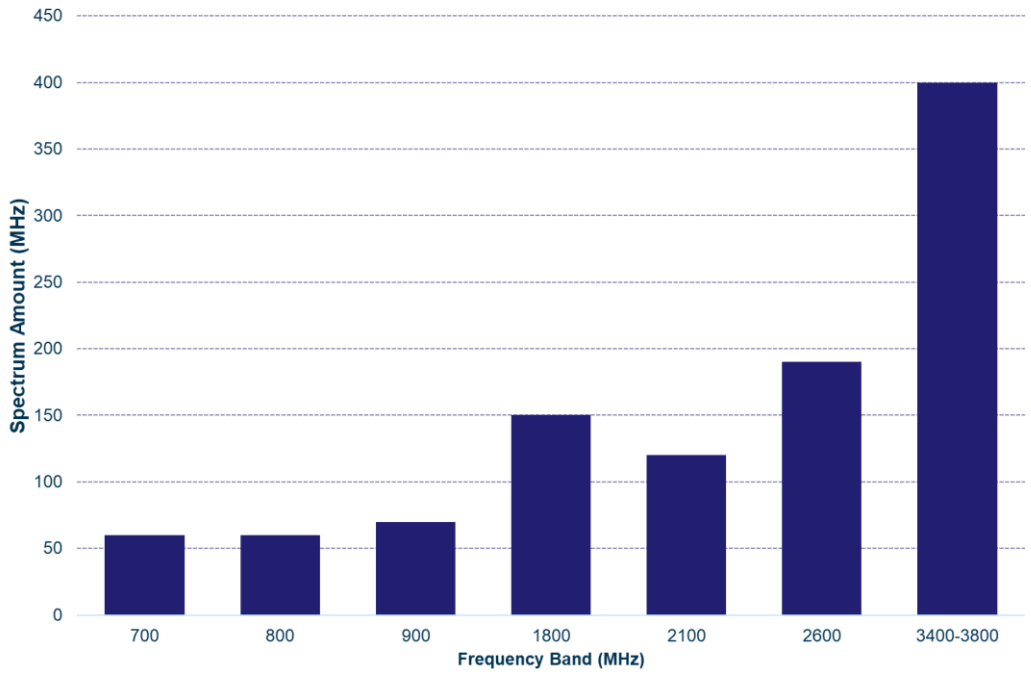

Figure 10. Current typical total spectrum inventory (2G, 3G, 4G, 5G) in an advanced European market. Source: Analysys Mason

By 2025, the majority of this spectrum will be used for 5G, but a significant amount of spectrum will continue to be used for 4G and, in some cases, even for 2G/3G.

12 This 1230MHz represents an upper limit since the listed harmonized bands may still not be fully available to operators by 2025.

We have developed a simple high-level model to estimate the amount of mid-band spectrum that could be needed, in addition to spectrum already identified and assigned, in order to cope with a theoretical traffic demand of 150GB per user per month.

The model involves a high-level calculation based on the following:

- A theoretical peak traffic level of 150 GB/user/month (in line with the examples given in Section 3).
- The operator's market share and number of macro sites.
- Distribution of traffic across sites according to logarithmic curves based on data from mobile networks.
- Calculation of a capacity per site based on the expected spectrum holdings13 per operator by 2025.
- Calculation of the proportion of sites by year in which traffic exceeds capacity.

Furthermore, we assume:

- A 1% annual growth in the number of macro sites.
- A 5% cap on the proportion of congested sites.
- The use of Massive MIMO in several frequency bands by 2025
- An assumption that the following spectrum is used: 700 MHz, 800 MHz, 900 MHz, 1400 MHz, 1800 MHz, 2100 MHz, 2300 MHz, 2600MHz and 3GHz (for a mixture of 4G and 5G and also a mixture of AAS and non-AAS).

Based on this we have estimated the amount of additional mid-band mobile spectrum required in Helsinki and London by 2025. The Finnish example is based on the largest operator (DNA) with a 40% market share. In the UK we have used a typical operator with an assumed 25% market share. The figure below shows the results:

Market	Helsinki	London
Operator	DNA	Typical
Subscribers (est)	240,000	2,113,000
No of sites (est)	525	2,500
Additional mid-band spectrum needed per operator (MHz)	**130**	**467**

Figure 11. Estimated additional mid-band spectrum required per operator to meet a theoretical traffic level of up to 150 GB/month/user. Source: Analysys Mason

The amount of additional spectrum needed per operator varies significantly between the two cities. The main reason for this is that the number of sites in relation to population is higher in Finland than in the UK. The Finnish operators will also have more spectrum in 2025 than operators in the UK, given that Finland is a three-player market while the UK has four mobile networks.

13 The current typical spectrum inventory in the mobile market in a country is shown in Figure 10. The model uses spectrum per operator as the input.

5 Current uses of spectrum around 6GHz

Section 4 established that additional mid-band spectrum is needed to achieve a data usage of 150 GB per user per month. This section deals with the suitability of the 6425-7125 MHz band to accommodate such a demand. In order to identify appropriate mid-band spectrum, it is important to consider the coexistence between IMT and incumbent services as well as the operating needs of incumbent services.

Figure 12 shows the Table of Frequency Allocations in the ITU Radio Regulations for the 6-7 GHz band. The frequency band 5925-7125 MHz has a primary allocation to mobile services in all Regions in the Radio Regulations. The other services with primary allocation in the band, the Fixed Service (FS) and Fixed Satellite Service (FSS), need to be considered for coexistence with IMT.

Frequency range MHz	Allocations		
	Region 1	Region 2	Region 3
5 925 - 6 700	FIXED 5.457 FIXED SATELLITE (Earth-to-space) 5.457A 5.457B MOBILE 5.457C 5.149 5.440 5.458		
6 700 - 7 075	FIXED FIXED SATELLITE (Earth-to-space) (space-to-Earth) 5.441 MOBILE 5.458 5.458A 5.458B		
7 075 – 7 145	FIXED MOBILE 5.458 5.459		

Figure 12. ITU Table of Frequency Allocations for services in the range 5925 – 7145 MHz. Source: ITU

The 5925-7125 MHz band also presents several other promising characteristics:

- There is a good balance between coverage and capacity in the band (comparable to the 3-5 GHz band).
- The outdoor to indoor coverage is comparable to the 3-5 GHz range.
- The band can support large contiguous blocks.

5.1 Fixed-satellite service (FSS) in the 6 GHz Band

C-band satellite communications is used in portions of the spectrum between 3 and 8 GHz. The uplink and corresponding downlink frequencies in the 6 GHz band are shown in the figure below:

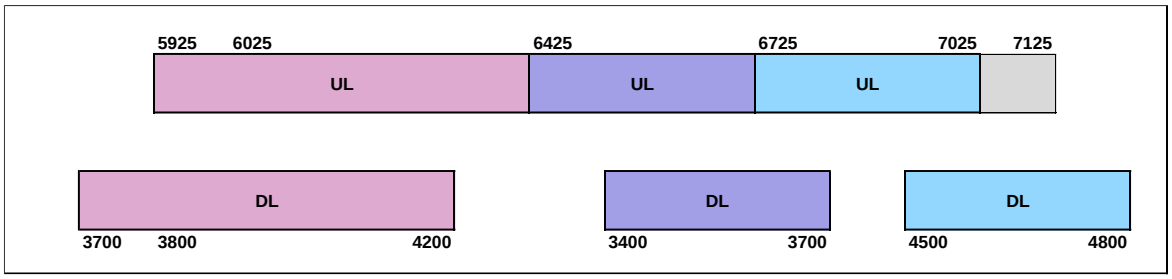

Figure 13. FSS UL and DL pairings in the 5925-7125 MHz and 3400-4800 MHz bands. Source: Analysys Mason

As spectrum in the 3400-4800 MHz range is being progressively assigned for mobile operators use, the use of the same frequencies for FSS is being decreased in many countries and ceased in others. Correspondingly, given the FSS DL and UL pairings described in Figure 13, the FSS uplink usage in the 6 GHz range is expected to decrease over time.

Where both IMT and FSS uplink need to operate in the band, the studies to be carried in the next WRC study period should determine the conditions under which the two services can coexist.

Such studies might consider potential IMT co-existence issues based on current satellite deployment. However, it is also noted that any potential IMT coexistence conditions are likely to become less restrictive over time due to the expected gradually decreasing use of the band by FSS; e.g. due to the corresponding 5G take-up in the paired C-band (FSS downlink) and due to increased use of the Ku/Ka bands.

5.2 Fixed Service (FS) in the 6 GHz Band

The Fixed Service also uses spectrum in the 6 GHz band. It is expected that co-existence between IMT and fixed links will be possible through coordination. Furthermore:

- The number of fixed links in the 6 GHz band is less than in other major FS bands.
- Coexistence in urban areas will be less of an issue if the FS deployments using the 6GHz band are mostly for long-hop links in rural and suburban areas.
- Fixed links are deployed at known locations with known characteristics (per-link licensing): interference can be managed on a case-by-case basis by network planning.
- Many fixed links are deployed in areas that would fall outside of the 5G mid-band service area, which is expected to be mainly in urban areas and cities.

5.3 The next 4-year WRC study period

The sharing studies conducted during the WRC-15 study period for the 5925-6425 MHz range did not account for important factors relating to propagation models and technology advances in 5G

(Report ITU-R S.2367[14]). New studies should be performed during the upcoming WRC study period to re-valuate IMT-FSS coexistence in the 6 GHz band, taking into account the characteristics of 5G (including lower power spectral density and the mitigating effects of Active Antenna Systems / beamforming) and the more recent and accurate ITU-R recommendations (on clutter loss, building entry loss and propagation).

5.4 Discussions on future use of the 6 GHz band around the world

Discussions about the future of the 6 GHz band are taking place around the world. Some countries have proposed license-exempt[15] in the band (United States), others have decided to move towards licensed IMT use (China), while others may decide to split the band for licence-exempt and licensed operation. It is therefore important to consider the pros and cons of licence-exempt and licensed spectrum authorisation in the context of the 6 GHz band.

It is important to strike a right balance between licence exempt and licensed use of spectrum in the mid-bands. The advantage of licence exempt authorisation is that users can deploy their communication systems and radio equipment without the need to apply for licences or to pay the accompanying licence fees. This represents a reduced barrier to entry which can be very beneficial in many use cases. However, licence exempt spectrum cannot meet the requirements for large scale network deployments due to the high risk of mutual harmful interference with other licence exempt users of the band and due to the technical restrictions applying to licence exempt use, which would typically limit deployments to using low power transmitters. In addition, the lifetime costs of IMT networks in licensed bands can be expected to be significantly lower than for networks in licence exempt bands, simply by virtue of the fact that nationwide IMT networks and infrastructures are already in place and will be maintained long into the future.

By comparison, some important features of licensed IMT networks are:

- *Oversight.* Administrations can – if needed – have full oversight over IMT network deployments in licensed spectrum because the identities of the licensees are known. This is an important feature, especially in the context of the ability to manage any harmful interference between the IMT networks, and between IMT networks and other services. This is contrary to the case in licence exempt spectrum where the identities of the users of equipment are not known.

- *Interference*. Deployments in licence exempt radio frequency bands can cause harmful interference to, and receive harmful interference from, other licence exempt deployments. IMT networks operate in licensed bands, which means that interference to and from other uncoordinated systems operating in the same frequency band is not an issue.

[14] Sharing and compatibility between International Mobile Telecommunication systems and fixed-satellite service networks in the 5 850-6 425 MHz frequency range.

[15] By license exempt spectrum we mean spectrum that can be used by radio equipment without the need for a license but still subject to regulatory technical conditions. License exemption is sometime referred to as general authorisation or unlicensed use of spectrum.

- *Quality of Service*. Many eMBB and verticals applications require guaranteed and enhanced QoS, security and robustness which can only be met with licensed spectrum.
- *Mobility management and handover*. There are various ways of implementing handover functionality in licence exempt networks. However, licensed IMT networks are – by design – inherently better suited for mobility support than their licence exempt counterparts.

6 IMT at WRC-23

6.1 Introduction

The availability of additional mid-band spectrum was a priority for several regional organizations and group of countries at the World Radio Conference 2019 (November 2019). As a result, the Conference reached the following consensus on RESOLUTION COM6/1 (WRC-19) which includes the following mid-band related agenda items for the WRC-23:

"1.2 to consider identification of the frequency bands 3 300-3 400 MHz, 3 600-3 800 MHz, 6 425-7 025 MHz, 7 025-7 125 MHz and 10.0-10.5 GHz for International Mobile Telecommunications (IMT), including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution COM6/2 (WRC-19);"

According to RESOLUTION COM6/2 (WRC-19) :

"…resolves to invite ITU-R…

2) to conduct and complete in time for WRC-23 the sharing and compatibility studies, with a view to ensuring the protection of services to which the frequency band is allocated on a primary basis, without imposing additional regulatory or technical constraints on those services, and also, as appropriate, on services in adjacent bands, for the frequency bands:

- 3 600-3 800 MHz and 3 300-3 400 MHz (Region 2);
- 3 300-3 400 MHz (amend footnote in Region 1);
- 7 025-7 125 MHz (globally);
- 6 425-7 025 MHz (Region 1);
- 10 000-10 500 MHz (Region 2),"

"1.3 to consider primary allocation of the band 3 600-3 800 MHz to mobile service within Region 1 and take appropriate regulatory actions, in accordance with Resolution COM6/3 (WRC-19);"

The agreed agenda item requires studies to understand the possibilities to deploy IMT while protecting existing services in the band. Based on the results of such studies, national administrations will be able to take informed decisions on the future availability of the band for IMT.

Current specifications call for 80-100 MHz of contiguous spectrum per operator in the mid-bands in order to realize the full potential of 5G. However, as shown in Section 4, additional contiguous spectrum in mid-bands from 2025 onwards is needed to support citywide high capacity use cases.

The combination of favourable propagation characteristics and the opportunity for wide channelization makes the 6 GHz band uniquely well suited for IMT. The band will offer much higher capacity than low bands and better coverage than millimetric-wave spectrum.

6.2 The concept of tuning range

While decisions on the future identification of the 6425-7125 MHz band will be taken at WRC-23, there is an ongoing debate on the broader 5925-7125 MHz range.

The People's Republic of China and five other countries in the Asia Pacific region have promoted the IMT identification for the 5925-7425 MHz[16] during the WRC-19. Europe is making 5925-6425 MHz available under a licence-exempt regime[17] targeting deployments from 2020 onwards. In the US, the FCC has proposed 5925-7125 MHz for license-exempt.

The agreed WRC-23 agenda item and associated studies for the 6425-7125 MHz should not prevent countries from proceeding with their respective regulatory actions on the 5925-7125 MHz frequency range, according to their preferences.

Given the current usage in this band, and

- the fact that spectrum usage is different in different parts of the world, and
- the fact that some parts of the world may wish to use different mobile applications within the band,

the concept of a "tuning range" for IMT in the band should therefore be explored.

The term "tuning range" would mean a range of frequencies over which radio equipment is envisaged to be capable of operating. Within this range, the use of IMT will be limited to the range of frequencies identified nationally in any one country for IMT and will be operated in accordance with the related national circumstances and requirements following the studies. A tuning range will accommodate regional differences and provide flexibility for both regions and administrations to meet future spectrum demands.

The benefit of this approach is to provide international harmonization even when different countries use different segments of the frequency range for IMT. Harmonized spectrum and tuning ranges lead to a larger ecosystem for technologies, resulting in economies of scale and lower costs

[16] R16-WRC19-C-0110!R1!MSW-E.

[17] The license-exempt regime enables 3GPP-based and other technologies such as Wi-Fi.

for deployment. Devices will be able to operate within the tuning range. However, they will only operate within the subsets of spectrum assigned within an individual country.