The 6 GHz opportunity for IMT

5G area traffic demand vs. area traffic capacity supply

A whitepaper by

Coleago Consulting

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Content

1 Executive summary ................................................................. 1
  1.1 The 6 GHz band is essential to realise the 5G vision .......... 1
  1.2 Licensed vs. unlicensed use of spectrum ....................... 3
  1.3 Wi-Fi vs. IMT in developed and in developing countries .. 4
  1.4 Mid-bands and high bands complementarity ................. 4
  1.5 Sharing with incumbents ............................................... 4
  1.6 Key findings ................................................................. 5

2 The requirements for 5G drive the need for IMT spectrum ..... 6
  2.1 Spectrum to deliver the 5G vision .................................. 6
  2.2 Low, mid, and high frequency bands ......................... 7

3 Estimating spectrum requirements in the context of 5G ....... 8
  3.1 Data volume and speed .................................................. 8
  3.2 Growth in IMT spectrum in the 2020-2030 time-frame ...... 9

4 6 GHz band for citywide speed coverage ......................... 11
  4.1 Citywide speed coverage and high traffic density in hotspots 11
  4.2 Mid-bands spectrum availability .................................... 12
  4.3 6 GHz spectrum to deliver the 100Mbit/s user experienced data rate 13
  4.3.1 Spectrum demand model linked to the ITU IMT-2020 requirements .. 13
  4.3.2 The demand side: 100 Mbit/s experienced data rate ........... 14
  4.3.3 The supply side: Modelling 5G capacity in cities ............. 17
  4.4 Area traffic capacity demand and supply in five cities ...... 19
    4.4.1 Introduction ............................................................ 19
    4.4.2 Lagos, Nigeria ......................................................... 22
    4.4.3 Moscow, Russian Federation ..................................... 24
    4.4.4 Paris, France .......................................................... 25
    4.4.5 Sao Paulo, Brazil ...................................................... 26
    4.4.6 Tokyo, Japan ........................................................... 28
  4.5 The role of high bands in cities ...................................... 29
    4.5.1 High bands are no substitute for mid-bands ................. 29
    4.5.2 High bands are required to achieve 10 Mbit/s/m^2 .......... 30
  4.6 Key findings ............................................................... 31

5 The role of the 6 GHz band outside cities ....................... 31
  5.1 6 GHz spectrum for 5G FWA ......................................... 31
    5.1.1 Wireless is the fastest growing fixed broadband access technology .. 31
    5.1.2 5G FWA is used to close the digital divide in developed markets ..... 32
    5.1.3 Improving the economics of FWA with 6 GHz spectrum .......... 34
    5.1.4 5G FWA in developing countries ................................ 37
    5.1.5 Simultaneous FWA and mobile use of 6 GHz spectrum ....... 38
    5.1.6 High bands are not a good substitute for 6 GHz spectrum ...... 38
    5.2 6 GHz to deliver 100 Mbit/s along highways and transport paths ..... 39

6 IMT identification vs unlicensed use of 6 GHz spectrum ........ 41
  6.1 Unlicensed spectrum ..................................................... 41
  6.2 IMT identification and licenced spectrum ....................... 41
  6.3 IMT vs. Wi-Fi use of the 6 GHz band ......................... 42
  6.4 Wi-Fi offload vs. Wi-Fi onload ...................................... 42
6.5 Regional differences ................................................................. 43
6.6 Technical differences between 5G-NR and Wi-Fi 6 ...................... 44
6.7 Key takeaways ........................................................................... 44

7 Sharing with incumbents .............................................................. 45
7.1 Introduction and summary .......................................................... 45
7.2 Existing use of the 6 GHz band .................................................. 45
7.3 5G sharing with existing services ................................................. 46
7.3.1 Fixed service ........................................................................... 46
7.3.2 Fixed satellite service .............................................................. 47

Appendices .............................................................................................. 48
Appendix A: ITU definition of the user experienced data rate .............. 48
Appendix B: ITU definition of area traffic capacity .............................. 48
Appendix C: Selected use cases requiring citywide speed coverage ...... 49
Exhibit 1: Benefits of an IMT Identification of 6 GHz band ............................. 2
Exhibit 2: IMT 2020 requirements .................................................................. 6
Exhibit 3: Typical spectrum assigned to mobile in Europe by 2021............... 8
Exhibit 4: New use cases and applications drive 5G spectrum need .......... 9
Exhibit 5: Increase in mobile spectrum in 2020-2030 timeframe................. 10
Exhibit 6: Mix of spectrum for 5G ................................................................. 11
Exhibit 7: Low and mid-band spectrum used in the analysis ..................... 12
Exhibit 8: Traffic demand and capacity supply model .............................. 14
Exhibit 9: Key 5G modelling assumptions for future urban environment ... 19
Exhibit 10: Population and areas of sample cities...................................... 20
Exhibit 11: Spectrum available for IMT by 2030 ......................................... 21
Exhibit 12: Lagos, Nigeria: Population density and central region(s) .......... 22
Exhibit 13: Lagos, Nigeria: Traffic demand and capacity supply ............... 23
Exhibit 14: Moscow, Russia: Population density and central region(s) ...... 24
Exhibit 15: Moscow, Russia: Traffic demand and capacity supply ........... 25
Exhibit 16: Paris, France: Population density and central region ............... 25
Exhibit 17: Paris, France: Traffic demand and capacity supply ................. 26
Exhibit 18: Sao Paulo, Brazil: Population density and central region(s) ...... 27
Exhibit 19: Sao Paulo, Brazil: Traffic demand and capacity supply .......... 27
Exhibit 20: Tokyo, Japan: Population density and central region(s) ......... 28
Exhibit 21: Tokyo, Japan: Traffic demand and capacity supply ............... 29
Exhibit 22: Spectrum and area traffic capacity .......................................... 30
Exhibit 23: Growth of fixed broadband subscribers by technology in 2019 ... 32
Exhibit 24: FWA connections ..................................................................... 32
Exhibit 25: European broadband policy ....................................................... 34
Exhibit 26: Key variables in the FWA business case ................................. 35
Exhibit 27: 5G FWA modelling assumptions for future rural environment ... 35
Exhibit 28: Number of premises supported per 5G FWA site ..................... 36
Exhibit 29: FWA data rate depending on 6 GHz spectrum availability ....... 37
Exhibit 30: Comparison of 5G vs. Wi-Fi download speeds ......................... 43
Exhibit 31: Radio Regulation allocations in the 6 GHz band ..................... 46
Exhibit 32: Speed requirement for video ....................................................... 49
Exhibit 33: Data rates for car automation sensors ...................................... 50
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1 Executive summary

1.1 The 6 GHz band is essential to realise the 5G vision

The deployment of 5G will bring large benefits to mobile services and users over the coming years. Starting with the existing trends and anticipating further evolution in the longer term, this report elaborates on the importance of making more spectrum available for IMT as an essential means to achieve the 5G vision in developed and developing markets and considers the fact that the 6 GHz mid-band spectrum represents a very strong candidate band for this purpose.

Allocating spectrum in the 5925 – 7125 MHz band for 5G-NR and its evolution is a critical building block making it economically feasible to offer 5G services at a price point that is affordable to all income groups. There is therefore a clear link between the future use of the 5925 – 7125 MHz band for IMT and the United Nations’ Sustainable Development Goals. In this context, it is important to stress that all technical and regulatory decisions need to consider the paramount importance of lowering the cost associated with the transmission of each byte to ensure the long-term sustainability of 5G mobile networks.

The report provides an analysis of the future spectrum need based on area traffic density demand for the 2025-2030 timeframe, accounting for the 5G target minimum performance requirements as agreed by the ITU for IMT-2020 and considering the expected deployment scenarios in cities and rural areas in both developed and developing countries. The report also supports stakeholders in assessing the most suitable authorisation scheme for the 6 GHz band.

With the introduction of 5G, mobile communications are entering a new era; we are currently in the early growth phase of the 5G life cycle. In the 1990s, when the first consumer orientated mobile phone services were launched, it was hard to imagine that virtually all people in the world would eventually use a mobile phone. In the same way it may be hard to imagine that 5G mobile broadband delivering a user experienced downlink data rate of 100 Mbit/s will be available to everyone, with predictable QoS, citywide and beyond.

Our analysis shows that there are significant benefits in identifying the frequency band 5925-7125 MHz for IMT in support of 5G-NR and its evolution.

Using the 6 GHz for 5G would enable mobile operators to deliver the ITU IMT-2020 requirements, notably the user experienced data rate of 100 Mbit/s in urban areas in an economically feasible manner.

Using the 6 GHz for 5G would enable mobile operators to deliver the ITU IMT-2020 requirements, notably the user experienced data rate of 100 Mbit/s in urban areas in an economically feasible manner. This is relevant in cities with a population density of 6,000 people per km² or more. This report provides an analysis for five cities, namely Lagos, Moscow, Paris, Sao Paulo and Tokyo, which clearly shows that 6 GHz spectrum is required to deliver the 5G vision of near guaranteed user experienced data rate of 100 Mbit/s, i.e. citywide “speed coverage”. The selected cities have characteristics that also apply to a broad number of other larger cities.

While the 6 GHz band could allow for 100 Mbit/s user experienced data rate citywide (in both developed and developing markets), in rural areas the 6 GHz band spectrum can be used for FWA thus optimising the spectrum usage of the band and enabling operators to deliver 100 Mbit/s (or more) rural broadband without recourse to subsidies. Furthermore, in sub-urban areas the same spectrum could serve both mobile broadband and FWA.

In developed countries, which in principle have a good urban and suburban broadband infrastructure, there is a lack of broadband in many rural areas. FWA using 6 GHz spectrum in addition to other mid-bands spectrum would make it possible to overcome the urban-rural digital divide in a time-frame consistent with national broadband development plans. Using the 6 GHz for 5G FWA would materially reduce or potentially even eliminate the need for rural broadband subsidies. Importantly, the 6 GHz band
In developing countries, FWA is the fastest growing method of bringing fixed broadband to the unconnected. 6 GHz spectrum has a key role to play in providing fibre like access at a cost that makes it affordable even for lower income groups.

In developed countries, high speed connectivity along highways and transport paths will facilitate the inevitable introduction of more sophisticated use cases for the intelligent transport systems revolution, cost effectively.

would provide sufficient bandwidth to ensure that FWA will also be able to address the needs for fixed connectivity as a long-term solution for rural areas.

In developing countries where affordability is a major issue, the economic implications associated with a possible IMT identification of the 6 GHz mid-band are even more apparent. FWA is the fastest growing method of bringing fixed broadband to the unconnected. 6 GHz spectrum has a key role to play in providing fibre like access at a cost that makes it affordable even for lower income groups. There are 1.1 to 1.2 billion households without broadband access and the vast majority of these are in developing countries.

The Broadband Commission for Sustainable Development 2025 Targets make this explicit: “By 2025, entry-level broadband services should be made affordable in developing countries, at less than 2% of monthly gross national income per capita.” Using the 6 GHz spectrum for IMT would make a key contribution towards attaining the United Nations Sustainable Development Goals and the Broadband Commission 2025 targets.

The development of automated driving systems and connected vehicles is still in its infancy. The safety and environmental benefits that automated driving and connected vehicles will bring to society are significant but, to realise this vision, reliable high speed connectivity and capacity is required. IMT use of 6 GHz spectrum to provide 5G capacity along busy highways and transport routes will significantly reduce the cost of providing the required data rate for people and connected vehicles.

Exhibit 1 summarises the benefits of using the 6 GHz band for IMT for a) developed countries with good fixed wired broadband and b) developing countries with poor fixed wired broadband. While developing countries’ demand for 5G capacity from smart city applications and connected vehicles may be less than in developed countries, the lack of wired broadband in developing countries adds an additional layer to demand for spectrum.

Exhibit 1: Benefits of an IMT Identification of 6 GHz band

<table>
<thead>
<tr>
<th>Benefit of using 6 GHz spectrum for IMT</th>
<th>Developed countries with good wired broadband</th>
<th>Developing countries with poor wired broadband</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic delivery of a consistent 100 Mbit/s user experienced data rate, citywide, urban and suburban</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Ensures that FWA broadband is a long-term solution</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Lower cost for urban FWA overcomes lack of fibre or xDSL broadband access</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Improves rural FWA broadband economics to bridge the digital divide</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Helps to deliver United Nations Sustainable Development Goals</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Economic delivery of a consistent 100 Mbit/s user experienced data rate on busy highways</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Contributes to reaching the ITU and UNESCO Broadband Commission 2025 targets</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Source: Coleago Consulting
Aiming at a realistic estimate for spectrum needs in the 2025-2030 timeframe, the report accounts for the following conservative assumptions:

- While assessing the future spectrum needs having the 2025-2030 timeframe in mind, the paper assumes a significant amount of spectrum is made available in low bands, lower mid-bands, upper mid-bands and high bands; it is to be noted that not all that spectrum might actually become available in all countries/cities in practice.

- The report assumes that all the available spectrum is used at all available sites. This is a simplified assumption and appropriate for the purposes here because it maximises the use of spectrum and is therefore a conservative assumption in the context of assessing the spectrum needs for 5G-NR.

- We use population density in cities as a proxy for traffic density when estimating the capacity requirement. This is appropriate because traffic generated by connected vehicles, cameras and video based sensors occurs where people are and is incremental to the traffic generated by human users.

- The capacity calculations do not include any network loading factor for the sake of simplicity. Including it would reduce available capacity and magnify the need for additional spectrum.

1.2 Licensed vs. unlicensed use of spectrum

The need for additional license exempt spectrum is recognised. Both licensed and unlicensed authorisation regimes for the use of spectrum have their strengths and weaknesses. It is clear that administrations will need to strike the right balance between the two regimes across all frequencies and within the mid-bands in particular.

5G-NR is designed to operate subject to licensed authorisation regimes in order to deliver a near guaranteed 100 Mbit/s data rate, anytime and anywhere, which is central to the IMT 2020 vision. To deliver this an operator must have control over the spectrum resources at its disposal. In contrast, unlicensed spectrum does not guarantee that a 5G operator will have access to the required spectrum resources as and when needed. For this reason, it is not possible to ensure delivery of ultra-reliable and low latency using unlicensed spectrum.

Furthermore, with licensed authorisation regimes, the known numbers and locations of 5G base stations will allow for efficient coordination with fixed links, providing the necessary protection.

In summary, licensed spectrum makes coordination on a case-by-case basis with incumbent systems such as the Fixed Service easier. License conditions can include provisions to ensure incumbents’ protection, with oversight from regulators.
1.3 Wi-Fi vs. IMT in developed and in developing countries

There is a fundamental difference between Wi-Fi and 5G IMT. In contrast to 5G, Wi-Fi 6 is only an access technology, albeit a very useful one, but which cannot deliver the benefits of 5G. Wi-Fi cannot serve mobile use nor deliver a guaranteed QoS. In contrast 5G is designed to deliver both. Nevertheless, Wi-Fi and 5G IMT are complementary.

"Wi-Fi offload" is the traditional way in which the complementary nature of mobile (IMT) and Wi-Fi is described. However, this complementarity exists only if there actually is a fixed broadband network to which Wi-Fi access points can be connected. In reality we are seeing the reverse: "Wi-Fi onload". Wireless routers connected over the mobile network are the fastest growing method of connecting devices to the network and the default in developing countries. Therefore, while the availability of the 6 GHz band for 5G macro base station coverage layer would produce socio-economic benefits in countries with less developed fixed broadband, in such countries the unlicensed (Wi-Fi or other) access to the 6 GHz band would not solve the connectivity problem.

The Wi-Fi onload phenomenon is of course present in places with poor or non-existent wired access networks, but it is also present in developed markets. Indeed, much of the high mobile usage in Finland, for example, is explained by households going mobile only.

1.4 Mid-bands and high bands complementarity

We have also examined the use of high bands (e.g. 26, 28, 40, 66 GHz, also referred to as mmWave spectrum) and considered their possible role as substitutes for 6 GHz spectrum. Our analysis shows that high bands are not an economically feasible substitute to 6 GHz spectrum, either to provide area traffic capacity citywide or broadband FWA in rural areas. However, high bands are required to deliver the ITU IMT-2020 (5G) requirement to deliver an area traffic capacity of 10 Mbit/s/m² in hotspots.

1.5 Sharing with incumbents

An important consideration around the future use of 6 GHz by 5G is the current uses of the band and how coexistence could be managed to facilitate 5G use.

Both the Fixed Satellite and Fixed (fixed links) services currently use the 6 GHz band. Studies on coexistence, and the conditions that might be required, are in their early stages. They are expected to provide some initial outcomes in the coming months and some final conclusions within the next couple of years.

The WRC-23 offers an excellent opportunity for the global or regional harmonization of the 6 GHz band. WRC-23 agenda item 1.2 will consider, among others, the identification for IMT of the frequency bands 6425-7025 MHz in EMEA (ITU Region 1) and 7025-7125 MHz globally in accordance with Resolution 245 (WRC-19). During WRC-23, countries outside EMEA will also have the opportunity to join in the IMT identification of the whole 6425-7125 MHz band. Depending on the Region and country, outside the WRC process it may be possible to also use the 5925-6425 MHz for 5G and its future evolution. Hence, between 700 and 1,200 MHz of additional mid-bands spectrum could be made available for IMT in the 6 GHz band. The final part of this report includes initial views in relation to the possibility of sharing spectrum between 5G and the incumbent users.

Work in ITU-R is currently focused on defining the technical and operational parameters of both the incumbent users and 5G-NR at 6 GHz. The relevant ITU-R technical groups are expected to provide a stable set of incumbents’ parameters for sharing studies by June 2021. Similarly, 3GPP will develop the required studies of the characteristics of 5G-NR covering the 6 GHz range and communicate these to the ITU-R in the same timeframe. It is considered very important that future sharing studies are
based on the same set of agreed typical parameters, so as to make the results directly comparable.

Nevertheless, some initial sharing studies between 5G and incumbents at 6 GHz based on typical parameter values which are currently being carried out by the IMT industry, indicate that coexistence is likely to be achieved – particularly in the 10 year timeframe for 5G at 6 GHz considered in this paper. In particular, it is believed that certain technology developments and suitable regulatory frameworks could facilitate the co-existence, including:

- Active Antenna Systems (AAS) using beamforming;
- Propagation model enhancements; and
- Lower spectral power density of 5G signals.

1.6 Key findings

The analysis of future needs clearly shows the importance of the 5925-7125 MHz band for 5G-NR and its evolution. The findings of our study point towards the following conclusions:

- Use of 6 GHz spectrum in addition to 3.5 GHz spectrum (and/or 4.5 GHz in some cases) would deliver the required citywide “speed coverage” with a 100 Mbit/s user experienced data rate. In areas with a population density greater than 6,000 per km², being able to use the 6 GHz spectrum for IMT would enable mobile operators to deliver 5G user experience economically.

- Areas with a population density of more than 6,000 per km² can be found in almost all countries and in areas with a population density below 6,000 per km², using 6 GHz spectrum in addition to 3.5 GHz spectrum would still deliver benefits. The benefit would either be a lower site density or a higher experienced data rate. A lower site density translates into a lower cost per bit which in turn will translate into lower retail prices. The latter point is particularly relevant for developing countries.

- The economics of rural FWA are driven by how many premises can be served by one cell-site: using 6 GHz spectrum in addition to other available mid-bands spectrum for 5G FWA in the future ensures that FWA is a long-term solution. The same 6 GHz spectrum that will be used in cities can therefore be used outside cities with clear added value for society.

- Given the propagation characteristics of high bands, it is not economically feasible to cover an urban area with high bands. In contrast, it is economically feasible to cover an urban area with 6 GHz spectrum. To build an area traffic capacity of 10 Mbit/s/m² for indoor and outdoor traffic hotspots, high bands are required.

- While high bands are important for delivering the IMT-2020 area traffic capacity requirement in hotspots (10 Mbit/s/m²), from a business case perspective they are not suitable for citywide speed coverage, rural FWA or for high speed coverage along highways and transport paths due to their reduced coverage properties.

- The 5925-7125 MHz range is a strong candidate to address the expected need for more mid-bands spectrum in the 2025-2030 timeframe. The band is key for fulfilling the minimum performance requirements defined by the ITU for IMT-2020 in terms of the user experienced data rate.

- Countries with a well-developed fibre, cable, or DSL broadband access network should make the 6425-7125 MHz band available for 5G to deliver the IMT-2020 requirements whereas the range 5925-6425 MHz needs special attention and consideration on a country-by-country basis.

- In countries which overwhelmingly rely on wireless for connectivity, the future use of the entire 5925-7125 MHz for 5G and its evolution would produce the greatest socio-economic benefit.
2 The requirements for 5G drive the need for IMT spectrum

2.1 Spectrum to deliver the 5G vision

One of the pillars in the vision for 5G is to provide ubiquitous fibre-like wireless connectivity. “IMT-2020 is expected to provide a user experience matching, as far as possible, that of fixed networks”\(^1\). The need for IMT spectrum is driven by the requirements for 5G as set out in the ITU-R requirements for IMT-2020\(^2\).

Exhibit 2 shows the IMT 2020 (5G) requirements compared to LTE-A. The requirements for 5G compared to LTE-A are not just an incremental percentage improvement but a multiple improvement, i.e. a revolution rather than an evolution. In assessing the need for additional IMT spectrum we are focusing on two of these new 5G requirements:

- The user experienced data rate jumps from 10Mbit/s to 100Mbit/s - a factor 10 increase (see Appendix A: for a more detailed description); and
- Area traffic capacity moving from 0.1Mbit/s/m\(^2\) to 10Mbit/s/m\(^2\) – a 100 fold increase (see Appendix B: for a more detailed description).

Exhibit 2: IMT 2020 requirements

Radio frequencies are the key ingredient to deliver these requirements. Therefore the step change in the IMT requirements means there is also a step change in the need for IMT spectrum. Of course improved spectral efficiency associated with higher orders of MIMO and the 5G radio interface will enable mobile operators to squeeze more capacity out of spectrum resources, but this is not remotely sufficient to deliver the capacity requirements of 5G.

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\(^1\) Report ITU-R M.2441-0 (11/2018), “Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT)"

For simplicity, this report considers the spectrum needed to fulfill the experienced data rate requirement in downlink direction only (100 Mbit/s), the uplink requirement defined by the ITU-R\(^3\) (50 Mbit/s) is likely to trigger additional spectrum needs.

### 2.2 Low, mid, and high frequency bands

Spectrum in the range of 450MHz to above 24GHz is used for IMT and band plans exist in many frequency ranges. Depending on the frequency range and the amount of spectrum in the range, different frequency bands serve different purposes. The large number of frequency bands can be categorized into four groups: sub-1GHz, lower mid-bands, upper mid-bands, and high bands.

- **Low bands** (e.g. 600, 700, 800, 900, 1500 MHz) are effective at addressing very wide area coverage and deep indoor coverage given their good propagation characteristics. However, there is very little spectrum available and hence the channel bandwidth does not provide much capacity.

- **Lower mid-bands** (e.g. AWS, 1800, 1900, 2100, 2300, 2600 MHz) are already used for IMT for 2G, 3G, 4G and 5G. The lower mid-bands are the capacity layer for 4G data traffic and in most countries the spectrum is used in FDD mode. China is an exception to this, with the world’s biggest 5G deployment in the 2600MHz band with a TDD band plan. The use of this band for 5G will certainly grow over time.

- **Upper mid-bands** (e.g. 3.3-4.2 GHz, 4.5-4.99 GHz, 6 GHz) are newer to IMT and offer a much wider bandwidth. This is a key 5G capacity resource. As of mid 2020, upper mid-bands spectrum used in most countries is in 3.4-3.8GHz but in future more spectrum in the range of 3.3-4.2GHz will be made available and this report looks at additional mid-bands spectrum in the 5.925-7.125GHz (the 6 GHz band). Upper mid-bands offer a good combination of propagation and capacity for urban areas. Whilst lower mid-bands have better propagation characteristics, lower mid-bands have limitations in regard to available bandwidth. By contrast, the upper mid-bands have significant bandwidth and reasonable propagation characteristics. The larger amount of spectrum available in upper-mid bands corresponds to larger channel bandwidth supported by 3GPP standards, currently allowing for a 100 MHz wide channel and for maximum bandwidth of 400 MHz in carrier aggregation mode.

- **High bands** (e.g. 26, 28, 40, 66 GHz, also referred to as mmWave) are effective at addressing areas with extreme traffic density and with very high peak data rates. With their limited cells radius, especially in cases of non-line of sight propagation, and limited outdoor to indoor propagation properties, high bands are not suitable for wide area eMBB coverage given the large number of sites this would require and the cost associated with building, operating, and maintaining them.

5G will be introduced in legacy bands, namely low bands and lower mid-bands 6 GHz. However, the introduction of 5G is inseparable from making large amounts of new spectrum available for mobile in upper mid-bands, as well as high-bands. Exhibit 3 below shows the typical spectrum used by mobile networks in a European country in mid 2021. Upper mid-bands and high-bands each serve distinct purposes and hence both are required:

- **Upper mid-bands** are key to make available a citywide 100 Mbit/s user experienced data rate.

- **High bands** are required to create the area traffic capacity of 10 Mbit/s/m\(^2\) at selected locations (hotspots).

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3 Estimating spectrum requirements in the context of 5G

3.1 Data volume and speed

The ITU methodology for calculating spectrum requirements is set out in the report “Recommendation ITU-R M.1768-1(04/2013), Methodology for calculation of spectrum requirements for the terrestrial component of International Mobile Telecommunications”. Input parameter values to be used in this methodology have been updated from those employed in Report ITU-R M.2078 in order to reflect the developments in mobile telecommunication markets. The ITU “Report ITU-R M.2290-0 (12/2013) Future spectrum requirements - estimate for terrestrial IMT” applies this methodology to arrive at a forecast for 2020. This methodology proved to be useful to forecast spectrum requirements in the medium term in the context of WRC-15 and WRC-19.

The methodology was driven by traffic volume which was a reasonable approach because LTE is essentially used for “best effort” smartphone connectivity. In contrast the 5G vision is for a ubiquitous fibre-like user experience and connectivity for a wide range of new uses coupled with new features. Therefore a key factor in driving the demand for capacity is the vision that 5G should provide the 100 Mbit/s user experienced data rate any time, anywhere, while “on the move”. While fundamentally in a mobile network a particular speed cannot be guaranteed, there is a quasi guarantee which translates into a high probability of experiencing this data rate. This means networks will be designed to deliver a data rate (Mbit/s) rather than data volume (Gbytes / month). As a result, as we transition to 5G, the need for capacity will grow faster than traffic volume.

Exhibit 3: Typical spectrum assigned to mobile in Europe by 2021

<table>
<thead>
<tr>
<th>Legacy bands</th>
<th>New “5G” bands</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low bands</strong></td>
<td><strong>Upper mid-bands</strong></td>
</tr>
<tr>
<td>190 MHz FDD</td>
<td>400MHz TDD</td>
</tr>
<tr>
<td>700MHz 2x30 MHz</td>
<td>3.5GHz 400 MHz</td>
</tr>
<tr>
<td>800MHz 2x30 MHz</td>
<td></td>
</tr>
<tr>
<td>900MHz 2x35 MHz</td>
<td></td>
</tr>
<tr>
<td><strong>Lower mid-bands</strong></td>
<td><strong>High bands</strong></td>
</tr>
<tr>
<td>410 MHz FDD, 50 MHz TDD</td>
<td>1600MHz TDD</td>
</tr>
<tr>
<td>1800MHz 2x75 MHz</td>
<td></td>
</tr>
<tr>
<td>2100MHz 2x60 MHz</td>
<td></td>
</tr>
<tr>
<td>2600MHz 2x70 MHz</td>
<td></td>
</tr>
<tr>
<td>2600MHz 50MHz</td>
<td></td>
</tr>
</tbody>
</table>

Based on typical situation in Europe in 2021

Source: Coleago Consulting
5G enables the Internet of Things (IoT) with Massive Machine Type Communications (mMTC) and Ultra Reliable and Low Latency Communications (uRLLC). 5G end to end features such as making available a slice of the network for specific use cases bring a new dimension to how wireless communications can be used. Exhibit 4 illustrates that 5G spectrum need is driven by a vastly expanded set of applications and use cases, all enabled by the enhanced capabilities of 5G compared to 4G. With these capabilities 5G is an enabling platform for what has been described as the “4th industrial revolution”. While appearing futuristic today, connected vehicles, smart deliveries with drones and robots and smart cities will generate traffic volumes far higher compared to today’s smartphone driven data usage rates.

Not only are there many new applications and use cases, but many future applications require higher speeds. These developments show that there is a need for “speed coverage”. The 100 Mbit/s requirement of 5G is a reflection of this. For applications and use cases which require a minimum speed, not having the required speed is the same as not having coverage at all.

Given the step change from 4G to 5G, forecasting spectrum based on the historic trend in traffic per smartphone is no longer useful. With 5G the focus is on user experienced data rates and area traffic capacity as set out in the ITU’s IMT 2020 requirements. Driven by these requirements, we have based our analysis of the need for 6 GHz spectrum on delivering a near guaranteed user experienced data of 100 Mbit/s anytime, anywhere “on the move”. Additionally, we also examine how the requirement to deliver the area traffic capacity of 10 Mbit/s/m² can be delivered.

Compared to the existing IMT spectrum, the quantity of new 5G specific spectrum is substantial but not when compared to the 5G requirements uplift vs. LTE-A.

3.2 Growth in IMT spectrum in the 2020-2030 time-frame

Compared to the existing IMT spectrum, the quantity of new 5G specific spectrum is substantial but not when compared to the 5G requirements uplift vs. LTE-A.

- In countries which have assigned most IMT spectrum, around 650 MHz of spectrum in low bands and lower mid-bands is available for mobile use.

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4 Klaus Schwab, The Fourth Industrial Revolution, Magazine of Foreign Affairs, 12 Dec 2015

© copyright Coleago 2020 9
• Adding upper mid-bands spectrum will make 200 to 700 MHz available for 5G mobile in the range 3.3-4.2GHz (and / or 4.4-4.99GHz in some cases). For example, in several European and Middle Eastern countries already a harmonised 300 to 400 MHz has been assigned to mobile operators. In the 6 GHz band a further 700 to 1,200 MHz could be made available for mobile. In total upper mid-bands could amount to 900 to 1,900 MHz, depending on the circumstances in a particular country.

• In addition, several GHz of high bands are gradually becoming available in the most advanced markets and high bands will eventually be used for 5G mobile. High bands have already been assigned in the US, Japan, Korea and some countries in Europe. We assume that, depending on the region, 5 to 6 GHz of high bands may eventually become available for IMT.

Exhibit 5 below summarises the amount of spectrum available in legacy bands (low bands and lower mid-bands), new upper mid-bands spectrum and high bands. Adding the upper mid-bands, which will be used to deliver the 5G-NR experienced data rate of 100 Mbit/s, increases available spectrum for mobile by a factor of 3.8. However, as shown in Exhibit 2, the 5G requirements in terms of the user experienced data rate is a factor of 10 increase compared to LTE-A. This means that even if, within the upper mid-bands, 700MHz in the 3.3-4.2 GHz range (and/or in the 4.4-4.99 GHz range in some cases) are added as well as 1200MHz in 6 GHz, the increase in the amount of spectrum is still well below the increase in demand that will be made from the spectrum, i.e. there will still be a spectrum gap.

The spectrum gap will be filled by technological advances such as higher orders of MIMO and investment in network densification in the form of small cells. If 6 GHz spectrum cannot be used for 5G mobile, the challenge of delivering 5G services consistent with IMT-2020 requirements at a price that consumers and businesses are willing to pay, may become unsurmountable.

Exhibit 5 below also shows that adding high bands, which will be used to provide area traffic capacity, increases (relatively to the typically available legacy low bands and lower mid-bands) the amount of spectrum used by mobile by a factor of 11.5. However, as we will explain in more detail below, high bands are not a substitute for mid-bands, i.e. it is not useful in the context of achieving a consistent user experienced data of 100 Mbit/s.

Exhibit 5: Increase in mobile spectrum in 2020-2030 timeframe
4 6 GHz band for citywide speed coverage

4.1 Citywide speed coverage and high traffic density in hotspots

As mentioned above, one of the pillars in the vision for 5G is to offer a fibre-like wireless experience, any time, anywhere, while “on the move”. This is extremely challenging in urban areas where 5G traffic densities will be high. In this context two 5G requirements are relevant, firstly the user experienced data rate of 100 Mbit/s and secondly the area traffic capacity of 10 Mbit/s/m².

As regards the user experienced data rate of 100 Mbit/s this needs to be delivered at least in all populated areas. This is economically feasible, even in the high density cities we have analysed provided that, in addition to the available mid-bands 3.5 GHz spectrum, 6 GHz spectrum is made available for IMT. Without 6 GHz spectrum, the number of cell sites required in those cities to provide the “speed coverage” is extremely large and would increase network cost to a point where it may not be possible to offer a wireless broadband service at a price point that is affordable to the vast majority of the population and businesses. The issue is particularly acute in cities which lack wired (FTTH, xDSL, cable) broadband connectivity. This includes almost all of Africa, emerging Asia, much of Latin America and also many cities in Eastern Europe.

Secondly, 5G is designed to cater for extremely high traffic densities of 10 Mbit/s/m². These occur in hotspots, outdoors and indoors. Legacy spectrum and new upper mid-bands are not sufficient to deliver this requirement. The 10 Mbit/s/m² goal can only be reached if high bands are deployed. However, the propagation characteristics of the high bands are such that high bands cannot be a citywide coverage solution, because the number of cell sites required would be too high from an economic perspective. High bands are therefore a complement to upper mid-bands and not a substitute.

Exhibit 6: Mix of spectrum for 5G

<table>
<thead>
<tr>
<th>Low-bands (600, 700, 800, 900, 1500 MHz)</th>
<th>Deep indoor and rural coverage layer, legacy technology and 5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower mid-bands (AWS, 1800, 1900, 2100, 2300, 2500 MHz)</td>
<td>Basic capacity layer, legacy technology and 5G</td>
</tr>
<tr>
<td>Upper mid-bands (3.3-4.2, 4.5-4.9, 6 GHz)</td>
<td>Citywide speed coverage layer, 5G only</td>
</tr>
<tr>
<td>High-bands (26, 28, 40, 66 GHz), super high capacity hotspots, 5G only</td>
<td></td>
</tr>
</tbody>
</table>

Note: In China the 2.6 GHz TDD band is the key resource for citywide speed coverage

Source: Coleago Consulting

Below we provide an analysis of these issues for several cities which all lead to the same conclusions:

5 “For wide area coverage cases (e.g. in urban and suburban areas), a user experienced data rate of 100 Mbit/s is expected to be enabled. In hotspot cases, the user experienced data rate is expected to reach higher values (e.g. 1 Gbit/s indoor).” Source: Report ITU-R M.2441-0 (11/2018), Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT), page 7.
The 6 GHz Opportunity for IMT

- Using 6 GHz spectrum in addition to the available upper mid-bands spectrum (3.5 GHz and/or 4.5 GHz in some cases) spectrum would deliver the required citywide “speed coverage” with a 100 Mbit/s user experienced data rate.

- Given the propagation characteristics of high bands, it is not economically feasible to cover an urban area with high bands. In contrast, it is economically feasible to cover an urban area with the 3.5 GHz (and/or 4.5 GHz) and 6 GHz spectrum using a combination of macro sites and small cells. In other words, high bands cannot be used as a substitute for 6 GHz spectrum. This is discussed in detail in chapter 4.5 below.

4.2 Mid-bands spectrum availability

As stated above, for our analysis we have divided the mid-bands into the lower mid-bands (e.g. AWS, 1800, 1900, 2100, 2300, 2600 MHz) and the upper mid-bands (e.g. 3.3-4.2, 4.5-4.99, 6 GHz).

Depending on the region, around 400-500 MHz of lower-mid bands are used for IMT with the vast majority of this spectrum used in FDD mode. In most regions, this spectrum is used by 2G, 3G and 4G systems and, in some cases, already 5G. In 10 years’ time, we can anticipate that the vast majority of this will have been refarmed to 5G. Since we are considering spectrum needs over a 10 year time-frame, for simplicity we have assumed that the totality of the spectrum is used for 5G at that point. This assumption maximises the capacity available from existing low and lower mid-bands.

In the upper mid-bands, 3.3-4.2GHz and the 4.4-4.99 GHz range in some cases are already included in 3GPP specifications for 5G-NR and 200 to 700 MHz is anticipated to be available on a TDD basis with some national variation.

To augment the upper mid-band, 6425-7025 MHz in EMEA (ITU Region 1) and 7025-7125 MHz (globally) have been selected as potential bands for IMT with a decision due at the next World Radio Conference (WRC-23). Up to 700 MHz may therefore become available in Region 1.

Exhibit 7 summarises the spectrum bands and bandwidths that our analysis uses in various scenarios around their availability for 5G.

<table>
<thead>
<tr>
<th>Type of spectrum</th>
<th>Bands (depending on country)</th>
<th>MHz available depending on country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legacy spectrum, low bands and lower mid-bands</td>
<td>600, 700, 800, 900, 1500 MHz and AWS, 1800, 1900, 2100, 2300, 2600 MHz</td>
<td>650</td>
</tr>
<tr>
<td>Upper mid-bands excl. 6 GHz</td>
<td>3.3-4.2, 4.5-4.99 GHz</td>
<td>200 to 800</td>
</tr>
<tr>
<td>6 GHz scenario 1</td>
<td>6425-7125 MHz</td>
<td>700</td>
</tr>
<tr>
<td>6 GHz scenario 2</td>
<td>5925-7125 MHz</td>
<td>1200</td>
</tr>
</tbody>
</table>

Source: Coleago

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6 WRC-23 Agenda Item 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 245 (WRC-19);
4.3 6 GHz spectrum to deliver the 100Mbit/s user experienced data rate

4.3.1 Spectrum demand model linked to the ITU IMT-2020 requirements

We have developed a concise and easily verifiable model to examine the impact of 6 GHz spectrum in an urban environment to deliver the ITU requirement for 5G of a 100 Mbit/s user experienced data rate in downlink.

The advantage of focusing on the 5G requirements for a minimum data rate is that the model is easy to validate because it relies on a small number of key assumptions.

The need for spectrum is driven by traffic density. Therefore to examine future spectrum needs for IMT, we need to analyse traffic demand in areas with high population densities, i.e. cities. With this in mind, we have developed a concise and easily verifiable model to examine the impact of 6 GHz spectrum in an urban environment to deliver the ITU requirement for 5G of a 100 Mbit/s user experienced data rate in the downlink.

“Traditional usage” models employ individual user consumption figures coupled with various factors to derive overall capacity needed. Instead our model examines the capacity needed over a wide area in an urban environment consistent with the ITU 5G capacity focussed requirements, notably the requirement to deliver a user experienced data rate of 100 Mbit/s.

In the development of the ITU’s IMT-2020 requirements, the user experienced data rate relates to human users but this will account for only part of the traffic. Connected cars, cameras, and IoT devices will generate substantial amounts of traffic in their own right. Hence one of the requirements of 5G is to support 10 million devices per km².

The uncertainty over how much simultaneous capacity will be required for all of these use cases in a given area is very large and bottom up-models of future traffic are speculative. Our approach is to use population density in cities as a proxy for traffic density to estimate the minimum or floor capacity requirement. This is conservative, since traffic generated by connected vehicles and video based sensors could be a multiple of traffic generated by human users. Hence tying traffic demand per capita to the 100 Mbit/s requirement generates a conservative estimate for future spectrum needs.

The advantage of this approach is that the model is easy to validate because it relies on a small number of key assumptions around typical cell sizes and average spectral efficiencies that are representative of future 5G deployments.
4.3.2 The demand side: 100 Mbit/s experienced data rate

With regards to the demand for capacity in a city with a particular population density, the four drivers in our model are listed below and described in the following paragraphs:

- the IMT-2020 requirement for a user experienced data rate of 100 Mbit/s;
- the population density;
- an assumption of concurrent demand from human users and new use cases (the activity factor); and
- an assumption of how much of the traffic demand would be satisfied by high bands (24GHz and above) sites.

These assumptions are applied to population densities. The objective is to compare the traffic demanded in a city with the capacity delivered, comparing the with- and without 6 GHz spectrum case.

100 Mbit/s user experienced data rate

The ITU requirement is that 5G must deliver a user experienced data rate of 100 Mbit/s. This is the starting point for the demand analysis. The ITU requirement is that 5G must deliver a user experienced data rate of 100 Mbit/s. This is the starting point for the demand analysis. This requirement was developed some time ago in 2013 and may therefore increase. However, as it stands the IMT 2020 requirements have been agreed globally as that which 5G mobile networks should seek to deliver.

The ITU requirement is that 5G must deliver a user experienced data rate of 100 Mbit/s. This is the starting point for the demand analysis.
The user experienced data rate of 100 Mbit/s needs to be delivered across an entire city, i.e. any time anywhere fibre-like experience. Our starting point is that mobile operators must cater for “speed coverage” across the entire city area. This implies that the traffic per square kilometre over an entire city area is a function of the population density in that city. This results in an average traffic demand per square kilometre (Mbit/s/km²).

Citing an average implicitly assumes that traffic demand is evenly distributed across the city area. In reality traffic is not evenly distributed across a city area, but for our approach to demand modelling, the simplified assumption that traffic which would be carried by low bands and lower / upper mid-bands can be treated as relatively evenly distributed is reasonable, considering the following:

- As explained below, data usage and the duration of usage is increasing and hence traffic demand becomes more distributed over time and location.
- Today’s traffic distribution relates largely to traffic demand from smartphones. In future traffic demand by new use cases and new applications – such as automotive infotainment or automated driving – will occur in locations within a city where previously there may not have been a need for much capacity, for example on urban transport routes. This tends towards a more even demand for capacity across a city area.
- There are always areas with a very high area traffic capacity requirement, i.e. hotspots. Our model takes account of this by assuming that high bands will provide hotspot capacity. This will effectively take care of localised peaks in area traffic demand thus leaving traffic demand in the remaining area more evenly distributed. In other words, localised traffic demand peaks are offloaded to high band sites.

**Population density**

Our approach is to use population density in cities as a proxy for traffic density to estimate the minimum or floor capacity requirement. This is very conservative, since traffic generated by connected vehicles and video based sensors could be a multiple of traffic generated by human users. Hence tying traffic demand per capita to the 100 Mbit/s requirement generates a conservative estimate for future spectrum needs.

From a network dimensioning perspective administrative city boundaries are irrelevant. What matters are areas with a high population density. Population density should be looked at over a reasonably large urban area which may or may not be within the administrative boundaries of a city or encompass the whole city. Given that population density is an average over an area, one must define the level of analysis and it is appropriate to look at population density clusters rather than dividing a city’s population by the area within its administrative boundary. The area considered needs to be reasonably large, i.e. not just a 1 km² hotspot, for the issue to be material. From a materiality perspective, Coleago considers the minimum size is 25 km² in a single area or several such areas within an urban area.

Demand for area traffic capacity is of course only a problem in areas with a high population density. In our analysis (based on publicly available data⁷) of specific cities we focussed on areas within a city with a population density of at least 15,000 people per km². In principle, the higher the density, the greater the demand per km².

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⁷ https://sedac.ciesin.columbia.edu/data/set/grump-v1-urban-extents
Concurrent demand for capacity - the activity factor

As stated above, the key driver to determine the traffic demand per km² within a city area is population density. However, not all users would require 100 Mbit/s at the same time. We need an assumption with regards to the concurrent or simultaneous demand for capacity during the busy period. In our model this is captured in the form of an “activity factor” to represent concurrent use in a cell from human users with smartphones and other devices, and new use cases such as connected cars, sensors, and cameras.

It is reasonable to use population density as a proxy for demand from human users with smartphones and other devices as well as new use cases because many new use cases occur where people are. Traffic from new use cases occurs in additional to traffic generated by human users. In other words it adds to the human activity factor. As an illustration, let’s consider the case of 5G enabled cameras. Most cameras are where people are. The higher the population density, the higher the density of cameras is likely to be.

As regards the activity factor for human users, in non-urban environment, this is likely to be in the range of 5 to 10%. This estimate is based on Coleago’s work with mobile operators in the context of spectrum auctions world-wide. In other words, up to 10% of the population present in a cell may be using their devices simultaneously in that cell.

Today’s mobile network usage is dominated by smartphones and is increasing rapidly. In 2019, the average usage per smartphone was 7.0 Gbytes/month. In Finland average usage is already nearly five times higher than this: "Mobile data usage grew to 34 gigabytes per Finn per month during the first half of 2019, which is 21 per cent more than the year before". Looking specifically at 5G users in South Korea, monthly data usage is already higher than average usage in Finland. This is driven by the fact that the majority of 5G plans offer unlimited data usage and do not throttle speed above a certain limit. Increased use means people are using more data for longer periods. The higher the usage, the more concurrent use there will be. This is evident from FTTH, xDSL, and cable broadband which have a busy period lasting several hours rather than the peaky traffic pattern associated with today’s mobile use. The high concurrent usage for FTTH, xDSL and cable is in no small part due to the fact that unlimited use plans are common. As noted above, from the launch of 5G plans it is now clear that unlimited data plans are also becoming common for 5G mobile. This translates into a higher activity factor for human users, i.e. more people use their devices in the same period in the same cell. The activity factor for human users is anticipated to reach 20%.

Not only is average usage per smartphone increasing rapidly, but traffic demand from non-human usage is just at the beginning of the growth curve. Therefore when assessing the activity factor, we need to take account of new use cases.

In the development of the ITU’s IMT 2020 requirements, the user experienced data rate relates to human users. However, as shown in Exhibit 4 above, 5G enables new use cases and has features not available in 4G, all of which increase the demand for capacity and this is discussed in chapter 3 above. Connected cars, cameras, and a high density of IoT devices will generate substantial amounts of new data traffic.

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8 Source: Ericsson Mobility Report, June 2020
9 Source: Traficom, Finish Transport and Communications Agency, 2.11.2019
There is considerable uncertainty over how much of the demand for the new use cases in a given area will be simultaneous. Our approach is to use population density in cities as a proxy for traffic density in order to estimate the minimum or floor capacity requirement. This approach is very conservative, since traffic generated by connected vehicles, cameras, and video based sensors could be a multiple of traffic generated by human users. For example, connected cars today generate hardly any traffic. However, over a 10 year time-frame a connected car may generate about as much data as 3,000 people as explained in chapter 5 of this report. On this basis Coleago estimates that today’s average data usage per capita from smartphones, IoT, smart city, connected cars and other use cases is less than 5% of what we will see once 5G is mature.

It is with this in mind that we have provisioned a range for the activity factor, with an expectation that 15% to 20% is likely to be representative, taking account both of human users and other uses such as connected vehicles, smart city, cameras, network slices, etc.

**High bands hotspot offloading factor**

In traffic hotspots, high bands will be used to deliver the required area traffic capacity of 10Mbit/s/m². In those hotspots, high bands sites will carry some of the traffic and this will reduce traffic demanded from sites with mid-bands. High bands will only cover a small percentage of a city, i.e. only indoor and outdoor locations with an extremely high traffic density.

While the number of high bands sites will vary substantially from city to city, coverage and hence traffic capture will be limited. “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.”

Despite the small percentage of a city’s area that will be covered by high-bands, in order not to underestimate the role of high band sites, we have assumed that as much as 20% of the total traffic in a dense urban area may be carried by high bands sites.

### 4.3.3 The supply side: Modelling 5G capacity in cities

The variables in the urban capacity per km² availability model are:

- the number of cell sites per km², driven by the inter-site distance;
- the role of mid-bands small cells;
- the site sectorisation;
- the amount of spectrum deployed on those sites; and
- the spectral efficiency.

#### Number of cell sites

A key assumption is the number of sites per km² across a city at which the spectrum is used. In this we did not make operator specific assumptions, but for the sake of simplicity we model this as if all operators share the same sites. Since not all physical sites are multi-tenant, the real number of physical sites would be higher but not all spectrum would be used at each site. The capacity calculation does not depend on this issue because total capacity is the number of sites multiplied by the amount of spectrum on each site. Our simplified approach is therefore representative.

In a typical city, sub-1 GHz and lower mid-bands are deployed mostly on macro sites with an inter-site distance of ca. 400 m. In cities, the inter-site distance is driven by the need to provide capacity rather than range. We validated this assumption by comparing the number of macro sites predicted by the model with the number of actual sites.

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10 Blogpost by Neville Ray, CTO of T-Mobile USA, April 22, 2019
The role of mid-bands small cells

We need to take account of future site build with 2025-2030 in mind. In cities where it is difficult for operators to acquire new sites for macro base stations, 5G densification will rely on small cell deployment and hence the number of cell sites is expected to increase substantially. In our model we assume 3.5 GHz spectrum and 6 GHz spectrum would be used at macro sites as well as in small cells.

Small cells would not provide contiguous coverage but would be deployed to fill in “speed coverage holes”. These speed coverage holes are locations where, for example due to blockage by buildings, upper mid-bands used at macro sites do not provide coverage. In other words, small cells provide consistency of area traffic capacity by infilling any speed coverage holes at the macro layer.

The precise number of small cells required to fill in speed coverage holes depend on the topology of a particular city. Various estimates predict that small cells might double the number of cells sites in a city or even exceed the number of macro sites by a factor of 3. We assume that the number of small cells in cities would grow to exceed macro sites by a factor of 1.8.

For example, the macro site raster in Paris consists of 616 sites (assuming 100% co-location) and we assume that 1,094 small cells will be added (assuming 100% co-location). While this is a large number, in order of magnitude the assumption is consistent with industry estimates. For example, CTIA (the cellular operator association of the US) stated “To keep pace with the increased use of wireless data … and build out 5G networks, wireless providers will need to deploy roughly 800,000 small cells in the next few years”.\(^\text{11}\)

Site sectorisation

A typical urban macro-cell deployed uses three sector sites which increase the capacity per site. However, small cells will be predominantly omnidirectional, i.e. have only one sector. Our model is consistent with these assumptions.

Spectrum used

We assume that all available low-bands and all available lower mid-bands are used at the existing macro sites. With some regional variation this typically amounts to 650 MHz of spectrum in total, with the vast majority of this being FDD spectrum.

As regards the upper mid-bands, we assume that both the 3.5 GHz (and/or 4.5 GHz in some cases) and 6 GHz bands will be used at all macro sites and also small cells. Depending on the country, the amount of 3.5 GHz spectrum (and/or 4.5 GHz in some cases) available varies from less than 200 to 700 MHz. For each city, our model looks at the availability in 8 to 10 years’ time. As regards the 6 GHz band, we have modelled three scenarios to examine the essential role of 6 GHz spectrum to deliver the experienced data rate of 100 Mbit/s in a typical urban environment:

1. No 6 GHz, which represents the worst case scenario.
2. Adding 700 MHz of spectrum at 6 GHz which is consistent with WRC-23 agenda item 1.2 which will consider, among others, the identification for IMT of the frequency bands 6425-7025 MHz in EMEA (600 MHz) and 7025-7125 MHz globally (100 MHz).
3. Adding an additional 500 MHz of spectrum at 6 GHz (i.e. 1.2 GHz in total), an option which might be available in certain countries.

\(^{11}\) Blog, Making the U.S. 5G Ready with Infrastructure Reform, Scott Bergmann, Senior Vice President, Regulatory Affairs, CTIA, 5 Sep 2018
Spectral efficiency

We have used appropriate assumptions with regards to the downlink spectral efficiency for the different types of spectrum in an urban environment. While currently 2G, 3G and 4G are deployed in low bands and lower mid-bands, in time these will all be reformed to 5G. Therefore we used the higher spectral efficiency for 5G with an appropriate MIMO configuration. The following average 5G spectral efficiency is assumed for the different frequency ranges and base stations types:

- 4 bit/s/Hz for low bands and for mid-bands indoor small cells (no massive MIMO / beamforming deployed)
- 8 bit/s/Hz for mid-bands macro base stations and outdoor small cells (micro base stations)
- 5 bit/s/Hz for high bands small cells

The values for these key assumptions have been aligned with published trial and simulation results.

Exhibit 9: Key 5G modelling assumptions for future urban environment

<table>
<thead>
<tr>
<th>Band</th>
<th>Category</th>
<th>Average Inter-Site Distance (m)</th>
<th>Number of sectors</th>
<th>Aver. DL spectral efficiency (bit/s/Hz)</th>
<th>Amount of available spectrum (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1.6 GHz</td>
<td>Macro site; Low bands</td>
<td>400</td>
<td>3</td>
<td>4</td>
<td>Typically 190</td>
</tr>
<tr>
<td>1.6-2.6 GHz</td>
<td>Macro site; Lower mid-bands</td>
<td>400</td>
<td>3</td>
<td>8</td>
<td>Typically 460</td>
</tr>
<tr>
<td>3.5 GHz / 4.5 GHz</td>
<td>Macro site; Upper mid-bands</td>
<td>400</td>
<td>3</td>
<td>8</td>
<td>200 to 800</td>
</tr>
<tr>
<td>6 GHz</td>
<td>Macro site; Upper mid-bands</td>
<td>400</td>
<td>3</td>
<td>8</td>
<td>Zero or 700 or 1200</td>
</tr>
<tr>
<td>3.5 GHz / 4.5 GHz</td>
<td>Small Cell; Upper mid-bands</td>
<td>300*</td>
<td>1</td>
<td>8</td>
<td>200 to 800</td>
</tr>
<tr>
<td>6 GHz</td>
<td>Small Cell; Upper mid-bands</td>
<td>300*</td>
<td>1</td>
<td>8</td>
<td>Zero or 700 or 1200</td>
</tr>
</tbody>
</table>

* The inter-site distance in an average. For small cells this does not assume contiguous coverage because small cells are deployed to fill in speed coverage holes rather than providing contiguous coverage.

Source: Coleago Consulting

4.4 Area traffic capacity demand and supply in five cities

4.4.1 Introduction

Without practical examples, the population density figures can be somewhat academic. We have therefore used several city examples to illustrate the impact more specifically: Lagos, Moscow, Paris, Sao Paulo and Tokyo.

In these examples, we assume all the available spectrum is used across all available sites. This removes issues around differences in numbers of mobile operators, co-location, and the amount of spectrum held by individual operators. Whilst this is a simplifying assumption, it is appropriate for the purposes here because it maximises the use of spectrum and is therefore a conservative assumption in the context of assessing the spectrum need for 5G.
Below we show the analysis for individual cities with maps illustrating the resulting specific high population density regions identified. The urban extent of each city is also shown on each map to give some context to the size of regions identified. Urban extents and population densities are sourced from SEDAC. As stated above, when looking at population density it is appropriate to look at population density clusters rather than dividing a city’s population by the area within its administrative boundary.

In each city, we have identified a similar reasonably sized central region containing the highest population densities as shown in Exhibit 10. For Lagos, Moscow, Sao Paulo, and Tokyo a contour of 17,500 people/km² has been used to identify the region. In Paris, we have captured the region contained by the Boulevard Périphérique.

Exhibit 10: Population and areas of sample cities

<table>
<thead>
<tr>
<th>City</th>
<th>Population (million)</th>
<th>Size of urban area (km²)</th>
<th>Avg. pop density in the urban area</th>
<th>Size of city centre area (km²)</th>
<th>Avg. pop density in the city centre (pop/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagos</td>
<td>17.0</td>
<td>1,171.28</td>
<td>14,514</td>
<td>193</td>
<td>28,356</td>
</tr>
<tr>
<td>Moscow</td>
<td>13.2</td>
<td>2,511</td>
<td>5,257</td>
<td>204</td>
<td>21,000</td>
</tr>
<tr>
<td>Paris</td>
<td>2.1</td>
<td>105</td>
<td>20,382</td>
<td>85</td>
<td>25,018</td>
</tr>
<tr>
<td>Sao Paulo</td>
<td>12.3</td>
<td>1,521</td>
<td>8,055</td>
<td>266</td>
<td>21,542</td>
</tr>
<tr>
<td>Tokyo</td>
<td>13.5</td>
<td>2,191</td>
<td>6,169</td>
<td>174</td>
<td>19,440</td>
</tr>
</tbody>
</table>

Sources: 
(2) For Lagos: https://worldpopulationreview.com/world-cities/lagos-population/

On the supply side, we assumed that, by 2030, approximately the same quantity of low-bands and lower mid-bands will be available. However, the difference between the five cities we analysed is the amount of 3.5 and 4.5 GHz spectrum that is likely to be available as shown in Exhibit 11 below.

12 From SEDAC: “Urban extents distinguish urban and rural areas based on a combination of population counts (persons), settlement points, and the presence of night-time lights. Areas are defined as urban where contiguous lighted cells from the night-time lights or approximated urban extents based on buffered settlement points for which the total population is greater than 5,000 persons”


YEAR

The 6 GHz opportunity for IMT

Exhibit 11: Spectrum available for IMT by 2030

<table>
<thead>
<tr>
<th>City</th>
<th>Low &amp; lower mid bands MHz</th>
<th>3.3-4.2 GHz / 4.4-4.99 GHz</th>
<th>6 GHz scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagos</td>
<td>650</td>
<td>400</td>
<td>0, 700, 1200</td>
</tr>
<tr>
<td>Moscow</td>
<td>650</td>
<td>200 ¹</td>
<td>0, 700, 1200</td>
</tr>
<tr>
<td>Paris</td>
<td>650</td>
<td>600</td>
<td>0, 700, 1200</td>
</tr>
<tr>
<td>Sao Paulo</td>
<td>650</td>
<td>400</td>
<td>0, 700, 1200</td>
</tr>
<tr>
<td>Tokyo</td>
<td>650</td>
<td>800</td>
<td>0, 700, 1200</td>
</tr>
</tbody>
</table>

Source: Coleago Consulting  
Note 1: in 4.4-4.99 GHz

For each of the five cities we present charts (see individual city analysis below) showing area traffic capacity (the supply) and area traffic demand. Area traffic demand increases proportionally to population density.

Our model shows that the use of additional spectrum at 6 GHz would enable the 5G user experienced data rate of 100 Mbit/s to be delivered in an economically feasible manner in the cities we examined, any time, anywhere, citywide.

For each of the five cities we present charts (see individual city analysis below) showing area traffic capacity (the supply) and area traffic demand. Area traffic demand increases proportionally to population density.

The chart shows that, depending on the city, the line which represents an activity factor of 20% crosses the lowest capacity supply line at between 6,000 (Moscow) and 11,000 (Tokyo) people per km². This indicates that, depending on the city, in areas with a population density greater than 6,000 per km², being able to use the 6 GHz spectrum for IMT would deliver benefits in terms of delivering the 5G user experience. Areas with a population density of more than 6,000 per km² can be found in almost all countries¹⁵.

The higher the population density the greater the need for 6 GHz spectrum. In countries which have little or no 3.5 GHz spectrum the need for 6 GHz spectrum for IMT is more pressing compared to countries which have 600 MHz or even 700 MHz of C-Band spectrum licenced to mobile operators.

In areas with a population density below 6,000 per km², using 6 GHz spectrum in addition to 3.5 GHz spectrum would still deliver benefits. The benefit would either be a lower site density or a higher experienced data rate. A lower site density translates into a lower cost per bit which will in turn translate into lower retail prices. The latter point is particularly relevant for developing countries.

Our analysis leads to the following conclusions:

- While the amount of 3.5 GHz spectrum available differs between countries, the charts show that all countries would benefit from an IMT identification of the 6 GHz band and that the availability of the 6 GHz band will be critical in some markets.
- The use of additional spectrum at 6 GHz would enable the 5G-NR experienced data rate of 100 Mbit/s to be delivered in an economically feasible manner in the cities we examined, any time, anywhere, citywide.

¹⁵ In analysing population density it is appropriate to look at a grid cell analysis of population density clusters rather than dividing a city’s population by the area within its administrative boundary.
4.4.2 Lagos, Nigeria

In Lagos, a contour of 17,500 people/km² has been used to identify the central region(s) of the city. This is illustrated in Exhibit 12. The urban extent of Lagos is also shown for reference (the urban extent and population data are sourced from SEDAC). For Lagos, the central regions represent an area of 192.7 km² with an average population density of 28,356 people/km², i.e. a population of 5.5 million in the identified central regions.

Exhibit 12: Lagos, Nigeria: Population density and central region(s)

Source: Coleago Consulting, based on SEDAC data

The area traffic capacity (the supply side) and area traffic demand are shown in Exhibit 13 below.

The area traffic capacity per km² available in the urban area is shown as the horizontal lines. In our modelling, around 1,391 macro sites and up to 2,472 upper mid-bands small cells are used to provide speed coverage in the identified central regions of Lagos. We assumed that by 2030, 600 MHz of legacy low-bands and lower mid-bands will be available and 400 MHz in the 3.5 GHz band.

There are three area traffic capacity supply lines, one for each of the three scenarios (no 6 GHz spectrum, 700 MHz of 6GHz spectrum, and 1200 MHz of 6 GHz spectrum). The lines are horizontal i.e. they do not vary with population density because the area traffic capacity supply is related to the type of sites and spectrum used at those sites.

As regards area traffic demand, the five coloured lines (derived from the assumptions in section 4.3.3) relate to the traffic demand per km² as a function of population density (the horizontal axis) using the 100 Mbit/s figure and a varying activity factor of between 5% and 25%. This shows that:

- The area traffic demand per km² increases proportionally to the population density. This is inherent in the demand model, as explained above; and
- The greater the activity factor, the greater the instantaneous or concurrent demand for area traffic capacity per km².

There is nothing new in this since it is broadly how networks are dimensioned. However, what is new is to examine the challenge of providing capacity in a city using the IMT-2020 requirement of a user experienced data rate of 100 Mbit/s as a starting point. To deliver true 5G, this requirement must be met.

The dashed purple vertical line in Exhibit 13 locates the central areas of Lagos in the Traffic Demand and Capacity Supply chart.
• In scenario 1, using <3GHz and 3.5 GHz spectrum, the traffic demand can almost be met for a 5% activity factor.

• With 700 MHz of 6 GHz spectrum being used, traffic demand assuming a ~10 activity factor can be met.

• In the ‘best case’ spectrum scenario, using 1.2 GHz at 600MHz, an activity factor of around 15% can be accommodated, i.e. still below the 25% we expect in 10 years’ time.

Earlier, we noted the expectation that 15% to 20% is likely to be representative, taking account both of human users and other uses such as connected vehicles, smart city, cameras, network slices, etc. In Lagos, with an activity factor of 15%, traffic demand could only be met if the entire 1.2 GHz of the 6 GHz band is used. For Lagos, an activity factor of 15% is conservative, since in Africa there is a lack of fixed network access and the mobile network must also carry traffic which in developed countries might be carried over fibre, cable or DSL. This illustrates the value of identifying the 6 GHz band for IMT for Nigeria and other African countries with large, high population density cities.

Exhibit 13: Lagos, Nigeria: Traffic demand and capacity supply

Source: Coleago Consulting
4.4.3 Moscow, Russian Federation

A contour of 17,500 people/km² has been used to identify the central region(s) of Moscow. This is illustrated in Exhibit 14, and delivers a large number of distinct distributed areas. The urban extent of Moscow is also shown for reference. For Moscow, these central regions aggregate to an area of 204.3 km² with an average population density of 20,975 people/km², i.e. a population of 4.3 million across all the identified areas.

Exhibit 14: Moscow, Russia: Population density and central region(s)

In the modelling that we have undertaken, the central regions of Moscow require around 1,474 macro sites and up to 2,621 upper mid-bands small cells for speed coverage. Exhibit 15 shows the 20,975 people/km² average population density across the identified central regions in Moscow against the three scenarios.

In Moscow, the C-Band is not available. However, we assume that 200 MHz of spectrum in 4.5 GHz will be available in Moscow. Due to the lack of 3.5 GHz spectrum, supply is constrained and the chart clearly shows that the 6 GHz spectrum is required even with a conservative 10% activity factor. Moscow is a good example where in cities where the C-Band is not available, the 6 GHz band is essential to deliver the 5G requirement of a experienced data rate of 100 Mbit/s.
In Paris, we have identified the central region contained by the Boulevard Périphérique – as illustrated in Exhibit 16. The urban extent of Paris is also shown for reference using data sourced from SEDAC. This central region represents an area of 85.3 km² with an average population density of 25,018 people/km², i.e. a population of 2.1 million within the Boulevard Périphérique).

Exhibit 15: Moscow, Russia: Traffic demand and capacity supply

Source: Coleago Consulting

Exhibit 16: Paris, France: Population density and central region

Source: Coleago Consulting
In our modelling, around 616 macro sites and up to 1,094 upper mid-bands small cells are used to provide speed coverage to the area inside the Boulevard Périphérique. Exhibit 17 shows the average population density across this central area of Paris mapped against our earlier results for our three spectrum scenarios.

Above, we noted our expectation that 15% to 25% is likely to be representative. At an activity factor of 15%, scenario 2 (700MHz at 6 GHz) would result in traffic demand being met. By comparison, scenario 3 (1.2GHz at 6 GHz) could meet demand with an activity factor of up to 20%.

**Exhibit 17: Paris, France: Traffic demand and capacity supply**

![Graph showing traffic demand and capacity supply](image)

Source: Coleago Consulting

### 4.4.5 Sao Paulo, Brazil

A contour of 17,500 people/km² has been used to identify the central region(s) of Sao Paulo. This is illustrated in Exhibit 18 and delivers a large number of distinct distributed areas. The urban extent of Sao Paulo is also shown for reference. For Sao Paulo, these central regions aggregate to an area of 266.4 km² with an average population density of 21,542 people/km², i.e. a population of 5.7 million across all the identified areas.
In the modelling that we have undertaken, the central regions of Sao Paulo require around 1,923 macro sites and up to 3,418 upper mid-bands small cells for speed coverage. Exhibit 19 shows the 21,542 people/km² average population density across the identified central regions in Sao Paulo against the three scenarios discussed earlier.

We assume that only 200MHz of 3.5 GHz spectrum will be available in Brazil and 200 MHz in 4.5 GHz. Because only 400 MHz 3.5 GHz / 4.5 GHz spectrum is available, supply is constrained and the chart clearly shows that the 6 GHz spectrum is required even with a conservative 15% activity factor.
4.4.6 Tokyo, Japan

In Tokyo, a contour of 17,500 people/km² has been used to identify the central region(s) of the city. This is illustrated in Exhibit 20. The urban extent of Tokyo is also shown for reference which extends beyond the map area along the south of the island. For Tokyo, the central regions represent an area of 173.6 km² with an average population density of 19,440 people/km², i.e. a population of 3.3 million in the identified areas.

Exhibit 20: Tokyo, Japan: Population density and central region(s)

Source: Coleago Consulting

Around 1,253 macro sites are used to provide speed coverage to these central areas in our modelling – and around 2,227 mid-bands small cells. Exhibit 21 shows the average population density of 19,440 people per km² across these central regions of Tokyo mapped against our earlier results for our three spectrum scenarios.

Tokyo benefits from 700 MHz of spectrum in the 3400-4100 MHz range and 100 MHz in the 4500-4600 MHz range which reduces, but does not eliminate, the need for 6 GHz spectrum at lower activity factors. Above, we noted our expectation that an activity factor of 10% is representative for the near term and 25% appropriate by 2025-2030. At an activity factor of 15%, scenario 1 (no 6 GHz spectrum) would result in traffic demand being met. Scenario 2 sees all traffic demand at 20% activity factor being met; Scenario 3 (1.2 GHz at 6 GHz) shows traffic demand being met in the long term with an 25% activity factor.
Exhibit 21: Tokyo, Japan: Traffic demand and capacity supply

Source: Coleago Consulting

4.5 The role of high bands in cities

4.5.1 High bands are no substitute for mid-bands

High bands (e.g., 26, 28, 40, 66 GHz) offer several GHz of bandwidth, several bands already have a 3GPP 5G specification, while specification for additional high bands will be added over time. The spectrum will be used for mobile use in traffic hotspots outdoors and indoors. However, due to the more challenging propagation characteristics of high bands, it is not economically feasible to build consistent speed coverage across a city to satisfy the 5G requirement of a 100 Mbit/s user experienced data rate, any time, anywhere.

Comparing upper mid-bands with high bands, the following differences are crucial:

- Upper mid-bands can be used on an existing city cell grid with a typical cell range of 200 - 300 meters in cities and may deliver acceptable throughputs up to a range of 6 km in rural areas. In contrast, high bands have a useful cell range of ca. 70 meters before throughput drops off rapidly.

- While not being able to penetrate deep into buildings, the ability to penetrate foliage, windows and thin walls with upper mid-bands is twice as good compared to high bands. This matters because obstructions such as trees, bus shelters and even people rather than a theoretical range are likely to be the limiting factor in an urban area.

- Looking at vertical coverage, upper mid-bands can be beamed at higher floors. Hence outdoor mid-bands cell sites can provide some indoor coverage. Outdoor high bands sites provide coverage at street level. To provide indoor coverage in multi-storey buildings, high-bands sites would have to be deployed on all floors.

Taken together, this means that building consistent speed coverage with high bands in urban areas would require an extremely high number of sites.
It is possible to estimate the number of high bands sites that would replicate mid-bands coverage. As a starting point we use the area of the city to be covered. Using Paris as an example, which is covered by a macro site grid of around 616 sites, to cover the area with high bands assuming a 100 metre inter-site distance would require 9,850 sites. This is based on a flat area without buildings or any other obstruction. Coleago estimates that to achieve consistent speed coverage comparable with 6 GHz spectrum, 3 times that number of sites is required, i.e. in the order of 30,000 just for Paris, a city with an area of only 85.3 km². The number of sites needed depends very much on the characteristics of a particular city, such as whether streets are mainly straight or not, presence of trees, building heights, etc. Taking the 30,000 estimate, this means that trying to provide speed coverage with high bands is not economically feasible.

This finding is corroborated by Google who performed a preliminary study for the Defence Innovation Board to ascertain the approximate capital expenditure (capex) and base station counts needed for high bands deployments: "Most operators are looking at deploying mmWave 5G sites on utility poles, given the poles’ ease of accessibility and abundance. Using a database of utility poles in the United States, the study indicated that it would require approximately 13 million pole-mounted 28-GHz base stations and $400B dollars in capex to deliver 100 Mbps edge rate at 28 GHz to 72% of the U.S. population, and up to 1 Gbps to approximately 55% of the U.S. population." The magnitude of the investment demonstrates that this is not a feasible option.

4.5.2 High bands are required to achieve 10 Mbit/s/m²

The sections above examined how the 5G user experienced data rate of 100 Mbit/s could be delivered using 3.5 GHz and 6 GHz spectrum. However, high bands are still required to deliver the required 5G area traffic capacity of 10 Mbit/s/m² in traffic hotspots. Exhibit 22 shows the area traffic capacity that can be delivered incrementally by low and mid-bands on a dense site network (100m site radius) and high bands on a pico-site network (20m cell radius). This demonstrates that high bands are essential to deliver the 5G area traffic capacity requirement of 10 Mbit/s/m².

Exhibit 22: Spectrum and area traffic capacity

Source: Coleago Consulting

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16 The 5g Ecosystem: Risks & Opportunities for DoD Defense Innovation Board, April 2019, page 9
4.6  Key findings

We have detailed our analysis examining how 5G requirements for citywide speed coverage and high traffic densities can be met using different spectrum scenarios. Several consistent conclusions all arise from this analysis:

- Using 6 GHz spectrum in addition to 3.5 GHz (and/or 4.5 GHz in some cases) spectrum would deliver the required citywide “speed coverage” with a 100 Mbit/s user experienced data rate in the 2025 – 2030 timeframe.

- Given the propagation characteristics of high bands, it is not economically feasible to cover an urban area with high bands. In contrast, it is economically feasible to cover an urban area with 6 GHz spectrum.

- To build an area traffic capacity of 10 Mbit/s/m$^2$ for indoor and outdoor traffic hotspots, high bands are required.

5  The role of the 6 GHz band outside cities

5.1  6 GHz spectrum for 5G FWA

5.1.1  Wireless is the fastest growing fixed broadband access technology

Fixed Wireless Access (FWA) is one of the 5G use cases. As a result of the performance improvement of LTE-A and now 5G-NR, FWA is experiencing rapid growth world-wide. GSA identified 401 operators in 164 countries selling FWA services based on LTE. In addition, of the 75 operators that have announced 5G launches worldwide, GSA counted 38 operators that have announced the launch of either home or business 5G broadband using routers. Of these 38, GSA identified 31 operators selling 5G-based FWA services.$^{17}$

The figures from the GSA are corroborated by research from Point Topic. "Wireless (mostly FWA) and FTTH connections were the fastest growing categories, having increased by 22.7 per cent and 14.1 per cent respectively between Q4 2018 and Q4 2019."$^{18}$, see Exhibit 24.

While some countries, such as South Korea and UAE, have near universal fibre access, most countries do not. In many countries, notably in Africa, emerging Asia, Eastern Europe and Latin America copper or fibre network access is almost an irrelevance. 5G FWA is relevant in developed markets with a high fibre availability as well as in countries where fibre and older copper broadband connect only a small percentage of homes and businesses.

With 5G FWA, fixed wireless growth is likely to accelerate further to become the dominant form of fixed broadband connectivity in developing countries: "We estimate there were 51 million FWA connections by the end of 2019. This number is forecast to grow threefold through 2025, reaching close to 160 million. FWA data traffic is estimated to have represented around 15 percent of global mobile network data traffic by the end of 2019. This is projected to grow by a factor of around 8 to reach 53EB in 2025, accounting for 25 % of total mobile network data traffic globally."$^{19}$

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17 Fixed Wireless Access, General Report, Global mobile Suppliers Association, 19 May 2020
18 Point Topic, World Fixed Broadband Statistics – Q4 2019
19 Ericsson Mobility Report, June 2020
It could also be argued that 5G eMBB and FWA are becoming indistinguishable from each other. After all, one of the key pillars in the vision for 5G is for ubiquitous fibre-like connectivity. However, 5G FWA has one key advantage over 5G eMBB, namely that outdoor Customer Premises Equipment (CPE) can be used. This results in a better spectral efficiency compared to eMBB and translates into a wider cell range and throughput thus improving the economics of bringing broadband connectivity to homes and business premises.

Exhibit 23: Growth of fixed broadband subscribers by technology in 2019

Exhibit 24: FWA connections

5.1.2 5G FWA is used to close the digital divide in developed markets

In many advanced economies bringing 100 Mbit/s broadband to rural users is a problem and copper based access is nearing the end of its useful life. Copper networks, even with the latest upgrades, cannot provide modern broadband speeds of 100 Mbit/s or more. For example, upgrading the copper network to deliver up to 50 Mbit/s has been abandoned in Germany and subsidies now focus on FTTH. Several fixed network operators are in the process of retiring their copper network, such as BT in the UK which expects to retire the copper network by 2027.
The investment required to connect all premises to fibre would be extremely high. While the cost of connecting buildings in relatively densely populated areas may be manageable, deploying FTTH to rural premises is likely to require substantial subsidies. Depending on the local situation, connecting a building with 5G FWA in rural areas is in the order of 50%-80% lower in cost compared to fibre. Hence rural broadband connectivity subsidy schemes leave it up to the provider to build rural broadband access with either fibre or FWA, as evidenced by the following examples:

- In Canada, operators can obtain subsidies to build broadband connectivity to rural premises using either fibre or FWA depending on the local situation. The aim is to minimise the subsidy per premises connected. For example, on the 7th of February 2020, Xplornet a rural telecoms specialist announced that it will deploy fibre and FWA. “To deliver this service, Xplornet will deploy fibre optic cable and 5G-ready wireless broadband infrastructure to its existing network, enabling the delivery of fibre-to-the-home and fixed wireless services. The project will cover 16,000 homes through the Nova Scotia Internet Funding Trust (NSIFT), along with an additional 8,000 homes outside of the scope of the program. … The result will be access to competitively priced Internet packages, unlimited data, and speeds up to 100 Megabits per second (Mbps), exceeding targets established by the CRTC. Better still, the network is designed to support future customer needs, with speed capabilities that exceed 1 Gbps.”

- In the European Union, FWA is part of the solution to achieve the EU’s target of offering Internet connectivity of at least 100 Mbit/s to all European households by 2025. The time frame to reach the 2025 goal is short. From a logistical and funding perspective it is not possible to reach the goal without FWA. While currently available upper mid-bands spectrum can be sufficient to address today’s FWA requirements, more mid-bands spectrum is required to secure a long term FWA solution.

- The directives of the European Parliament and Council 2014/61/EU, 15.05.2014 refer to fixed wired and wireless to lower the costs for deploying broadband. Several national broadband development plans explicitly acknowledge the role of FWA, for example Sweden: “Given the geographical aspects of Sweden, and the repartition of its population, a completely connected Sweden requires a combination of different technologies – fixed and wireless.”

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21 According to the EC Digital Economy and Society Index Report (2019), ca. 30% of European households were reached by Fibre to the Premises (FTTP) coverage in 2018 (ca. 15% in rural areas)
Exhibit 25: European broadband policy

The Commission’s strategy on Connectivity for a European Gigabit Society, adopted in September 2016, sets a vision of Europe where availability and take-up of very high capacity networks enables the widespread use of products, services, and applications in the Digital Single Market.

This vision relies on three main strategic objectives for 2025:

- Gigabit connectivity for all of the main socio-economic drivers,
- uninterrupted 5G coverage for all urban areas and major terrestrial transport paths, and
- access to connectivity offering at least 100 Mbit/s for all European households.

It confirms and builds upon the previous broadband objectives for 2020, to supply every European with access to at least 30 Mbit/s connectivity, and to provide half of European households with connectivity rates of 100 Mbit/s.


- On the 9th of June, the Federal Communications Commission of the US “adopted procedures for Phase I of the Rural Digital Opportunity Fund auction (Auction 904), which will award up to $16 billion in support over 10 years for the deployment of fixed broadband networks to millions of unserved homes and businesses across rural America. The $20.4 billion Rural Digital Opportunity Fund is the FCC’s most ambitious step ever toward bridging the digital divide.”

The programme is technology neutral provided minimum requirements are met. “We’ve focused on maintaining technological neutrality and maximizing competition in our USF programs. And here, we do that by opening the door to new types of technologies to apply for different tiers in the auction. For example, we allow fixed wireless and DSL providers for the first time to apply to bid in the gigabit tier.”

This announcement also demonstrates that even in a highly developed country such as the US, substantial amounts of public funds are required to bridge the digital divide.

5.1.3 Improving the economics of FWA with 6 GHz spectrum

The lack of rural broadband access is due to the poor economics of connecting homes and business premises in areas with a low population density. This is relevant in developed and developing countries.

What constitutes rural in the context of population density varies depending on the country and, in the context of broadband access, the availability of fibre. For example:

- In Canada rural is defined as the population outside settlements with fewer than 1,000 inhabitants and a population density below 400 people per km²; and
- Eurostat, the EU statistical agency, uses a definition based on clusters of urban grid cells with a minimum population density of 300 inhabitants per km² and a minimum population of 5,000. All the cells outside these urban clusters are considered as rural.

23 FCC, press release, 9th of June 2020
24 FCC, Statement of Chairman Ajit Pai, 9th of June 2020
25 Because of national differences in the characteristics that distinguish urban from rural areas, the distinction between the urban and the rural population is not yet amenable to a single definition that would be applicable to all countries or, for the most part, even to the countries within a region. Where there are no regional recommendations on the matter, countries must establish their own definitions in accordance with their own needs. (Source: UN Statistic Division, B. Urban and rural, paras. 2.81.– 2.88.)
The FWA business case is highly dependent on the number of connections that can be supported per cell tower. In turn, this is a function of the data rate that must be delivered and, crucially, the amount of spectrum used at a cell tower.

We compared three scenarios examining 5G FWA delivering a household experienced data rate of 100 Mbit/s:

- in scenario 1, 600 MHz at 3.5 GHz is available;
- in scenario 2, 600 MHz at 3.5 GHz plus an additional 700 MHz at 6 GHz; and
- in scenario 3, 1.2 GHz is available at 6 GHz.

**Exhibit 26: Key variables in the FWA business case**

- Required data rate per FWA connection
- Concurrent use (activity factor)
- Amount of spectrum deployed on cell tower
- Supported number of connections per cell tower
- Required number of connections per cell tower to positive FWA business case

Source: Coleago Consulting

The assumptions used for FWA are slightly different from those used for mobile 5G. We assume outdoor customer premises equipment (CPE) is used and this uplifts otherwise lower values of spectral efficiency (caused by the distances being covered). Secondly, we assume a higher activity factor than mobile because fixed broadband monthly data usage is far higher than mobile broadband usage. We have used an activity factor of 50%.

- In Q3 2019, average monthly broadband usage per household was 264.4 Gbytes / month\(^2\). For subscribers with a 100 Mbit/s+ connection usage was 333 Gbytes/month in Europe and 398 Gbytes in the US.
- A further reference point is the service definition in the Connect America Fund Phase II Auction (Auction 903) rural broadband funding programme. The 100 Mbit/s broadband service must include a 2 Terabyte monthly usage allowance.

The values for the key assumptions used in our FWA modelling are shown below.

**Exhibit 27: 5G FWA modelling assumptions for future rural environment**

<table>
<thead>
<tr>
<th>Band</th>
<th>Typical Cell Radius (m)</th>
<th>Number of sectors</th>
<th>Average DL spectral efficiency (bit/s/Hz)</th>
<th>Amount of spectrum (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3GHz</td>
<td>6,000</td>
<td>3</td>
<td>3</td>
<td>190</td>
</tr>
<tr>
<td>3.5 GHz</td>
<td>6,000</td>
<td>3</td>
<td>5</td>
<td>600</td>
</tr>
<tr>
<td>6 GHz</td>
<td>6,000</td>
<td>3</td>
<td>5</td>
<td>Zero or 700 or 1200</td>
</tr>
</tbody>
</table>

Source: Coleago Consulting

Note: The spectral efficiency takes account of the use of outdoor CPE.

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\(^2\) Broadband Industry Report (OVBI) 3Q 2019, OpenVault
Scenario 3 can support around 496 homes per site in rural areas compared to 381 in scenario 2 and 220 in scenario 1. This means that having access to using 6 GHz for rural FWA would significantly improve the business case for operators offering broadband access and may eliminate the need for subsidies.

**Exhibit 28: Number of premises supported per 5G FWA site**

![Number of premises supported per 5G FWA site](image)

**Source:** Coleago Consulting

**Within 5 years the 3.5 GHz band will be insufficient to serve a large number of premises with 100 Mbit/s FWA.**

In the short term the 3.5 GHz spectrum will be sufficient for a viable FWA business case that delivers 100 Mbit/s to rural premises. However, within 5 years the 3.5 GHz band will be insufficient to serve an economically viable number of premises with 100 Mbit/s FWA. The definition of broadband keeps increasing. 100 Mbit/s may be considered sufficient now, but we are moving to what is now defined as ultra-fast broadband: Ofcom, the telecoms regulator of the United Kingdom, defines ultrafast broadband as broadband with download speeds of greater than 300 Mbit/s\(^{28}\).

The European Commission has already increased its broadband target speed and this provides an illustration of the trend in broadband speed requirements as shown in Exhibit 25. In their assessment of the sustainability of using FWA to deliver policy objectives, the European Commission notes that FWA may be an "interim solution: investment in fibre infrastructure will be necessary within 10-15 years" and goes on to state "Sustainability: To access future NGA-services, bandwidth needs requires additional frequencies; however the available spectrum is limited"\(^{29}\).

We examined the sustainability of FWA against a background of an increase in speed requirements for broadband. To model this we kept the number of households per site constant at 220. This delivers a user experienced data rate of 100 Mbit/s, where only spectrum at 3.5 GHz is available, as explained above. We then examined two spectrum scenarios (see Exhibit 29 below):

- With an additional 700 MHz of 6 GHz spectrum a data rate of 173 Mbit/s can be provided for these 220 households
- When adding 1,200 MHz of 6 GHz spectrum, the household experienced data rate increases to 225 Mbit/s.

\(^{28}\) UK Home Broadband Performance, Technical Report, paragraph 5.10, page 20, Ofcom, 13 May 2020

This demonstrates that using 6 GHz spectrum in addition to 3.5 GHz spectrum (and/or 4.5 GHz in some cases) for 5G FWA future ensures that FWA is a long-term solution for subsidy-free rural broadband connectivity.

Exhibit 29: FWA data rate depending on 6 GHz spectrum availability

In developing countries internet access is synonymous with wireless access and the case for an IMT identification for 6 GHz is not simply a technical issue but also an economic one.

5.1.4 5G FWA in developing countries

In theory, fibre can be built to all locations and thus provide “unlimited” access network capacity. However, this is not economically feasible even in advanced economies let alone in developing countries where affordability is a key issue. In most countries broadband will be wireless, including in mega cities such as Lagos, Cairo, and Dhaka. 6 GHz spectrum has a key role to play and is required to provide fibre like access at a cost that makes it affordable even for lower income groups.

In the case of developing countries an IMT identification for 6 GHz is not simply a technical issue but also an economic one. There are around 2 to 2.4 billion households worldwide. At the end of Q4 2019, the number of global fixed broadband connections stood at 1.11 billion\(^{30}\) to 1.2 billion\(^{31}\) (excluding mobile). Based on these figures approximately 0.9 to 1.2 billion households have a broadband connection in the form of DSL, fibre, cable, or FWA. This leaves 1.1 to 1.2 billion households without broadband access and the vast majority of these are in developing countries.

In developing countries internet access is synonymous with wireless access. In many developing countries fixed network connections account for less than 10% of all connections and this proportion is declining further. The predominant role of wireless for broadband in countries with lower ARPU is recognised in the United Nations Sustainable Development Goals (SDG). The indicator for SDG 9.c is to “Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020” is the “Proportion of population covered by a mobile network, by technology”.

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30 Point Topic, World Fixed Broadband Statistics – Q4 2019
31 Ericsson Mobility Reporting, citing Omnia, June 2020
Broadband connectivity in developing countries goes hand in hand with affordability. The Broadband Commission\(^\text{32}\) for Sustainable Development 2025 Targets make this explicit: “By 2025, entry-level broadband services should be made affordable in developing countries, at less than 2% of monthly gross national income per capita.”\(^33\) IMT spectrum is an essential element to attain the SDGs and the Broadband Commission 2025 targets in the context of affordability are:

- using more spectrum means fewer cell towers need to be built, thus lowering costs;
- the ability to deploy radios with 100 MHz wide bands or more per operator reduces the cost of capacity, i.e. lower the cost per bit; and
- identifying the 6 GHz band for IMT would make a significant contribution to delivering affordable broadband.

As regards the unlicensed use of the 6 GHz band in developing countries, given the lack of fibre or other wired fixed network broadband access, building connectivity using Wi-Fi to connect to non-existent lines is not an option. In other words, using 6 GHz for Wi-Fi does not solve the connectivity problem. Therefore, especially in developing countries the IMT identification for the 6 GHz would produce socio-economic benefits which would not be the case if the 6 GHz band is used for unlicensed (Wi-Fi or other) access.

5.1.5 Simultaneous FWA and mobile use of 6 GHz spectrum

As explained above, using the 6 GHz band for FWA in rural areas produces significant socio-economic benefits. In cities, the use of 6 GHz spectrum is essential to produce the 100 Mbit/s user experienced data rate. In reality the 6 GHz spectrum would be used for both use cases. For example, in sub-urban areas the capacity provided by 6 GHz sites would be used simultaneously for eMBB and FWA for premises which do not have a wired broadband connection. Furthermore, even in rural areas there are mobile traffic hotspots, such as a train station, an airport, or some other place where people congregate. In such rural traffic hotspots the 6 GHz spectrum would be used to provide the 100 Mbit/s user experienced data rate to mobile users. Therefore, nation-wide service neutral licencing of 6 GHz spectrum would produce the most efficient outcome.

5.1.6 High bands are not a good substitute for 6 GHz spectrum

The economics of rural FWA are driven by how many premises can be served by one cell-site. Typically, with upper mid-bands the cell radius can be up to 3 km and still deliver the required minimum speed at the cell edge.

In contrast, with high bands throughput drops off rapidly after 100 meters. The short distance from a cell tower means there would be too few users per tower to turn this into an economically feasible solution for rural broadband unless fibre is deployed close to the premises to be connected. In sub-urban areas fibre may run close to homes but in most rural areas this is not the case. Hence high bands are not a good substitute to 6 GHz spectrum for rural FWA.

Of course there are other issues associated with the propagation characteristics of high bands. Foliage and even rainfall constitute an obstruction, and obstruction by foliage is particularly an issue in rural areas where buildings tend to be below the tree line. While both the 6 GHz spectrum and high bands suffer from path loss due to foliage, the loss with high bands is twice as high as it is with 6 GHz spectrum.

\(^{32}\) ITU and UNESCO set up the Broadband Commission for Digital Development in response to UN call to step-up UN efforts to meet the Millennium Development Goals (MDGs). The Commission was established in May 2010 with the aim of boosting the importance of broadband on the international policy agenda and expanding broadband access in every country as key to accelerating progress towards national and international development targets.

\(^{33}\) Broadband Commission for Sustainable Development 2025 Targets: "Connecting the Other Half", 2018
5.2  6 GHz to deliver 100 Mbit/s along highways and transport paths

The vision of a user experienced data rate of 100 Mbit/s everywhere means that this also has to be assured on road and rail links.

On roads, use of autonomous vehicles means people do not have to do the driving freeing them up for other tasks, such as consuming digital media or video calling. This means that eMBB type traffic from cars will be much higher than today.

In addition, substantial capacity is required on roads to serve the connected car and smart road use cases. In January 2019, the 5G Automotive Association (5GAA) reported that “At present, more than 100 million vehicles connected to cellular networks (V2N) are on the roads. This V2N connection is used for a wide variety of services including telematics, connected infotainment, real time navigation and traffic optimization, as well as for safety services including automatic crash notification (ACN) such as eCall, the recognition of slow or stationary vehicle(s) and informational alerts for events including traffic jams, road works and other traffic infrastructure related information, inclement weather conditions and other hazardous conditions. Several OEMs share safety related warnings between their vehicles and have started to exchange this information across OEMs”.

Moving beyond such services into the future of autonomous cars implies a significant step change in the data generated and transmitted per car. 5GAA notes that the 5G NR standards “offer the features which are paramount to highly and fully automated and cooperative driving such as the exchange of:

- sensor data sharing for collective perception (e.g., video data);
- control information for platoons from very close driving vehicles (only a few meters gap); and
- vehicle trajectories to prevent collisions (cooperative decision making).”

As such, autonomous cars generate several Terabytes of data a day from the hundreds of on-vehicle sensors and large quantities of on-board processing which are essential to the functioning of the car.

- According to industry estimates, cameras deployed in such cars alone will generate 20 to 40 Mbit/s of traffic. “Each autonomous car driving on the road will generate about as much data as about 3,000 people. And just a million autonomous cars will generate 3 billion people’s worth of data” (Brian Krzanich, CEO, Intel, 2019).
- Google stated that in their self-driving car trials, a car generates around 1 Tbyte of data in an 8 hour driving period (equivalent to a constant 35 Mbit/s, if transmitted in real-time).

By no means all data generated by autonomous vehicles will be transmitted while mobile, but autonomous vehicles will add to area traffic density and traffic demand on a scale which dwarfs today’s smartphone traffic.

In addition, smart road traffic management will add to area traffic capacity needs. The extensive deployment of smart devices and sensors along 5G-enabled roads will allow cars and physical road infrastructure to interact in real-time – as well as the real-time management of road networks.

Of course what matters for all these use cases is reliability and low latency. Having the required area traffic capacity, consistently available, is a prerequisite. This can be delivered in a cost effective manner by using 6 GHz in addition to the C-Band and legacy IMT bands. While it might be possible to “cover” a road or rail link with High Band, it is unlikely to be economically feasible.

Many examples of densely occupied roads exist around the world. Here the ~100 km length of the E11 linking Abu Dhabi to Dubai is used as an example, although similar
cases could be cited from many other countries. This highway has 4 lanes, in each direction, along much of its length. At 120 km/h (slightly slower than the maximum permitted speed – to account for density of traffic in peak hours), safe following distances of typically 40 meters to 60 meters are recommended.

If macro sites dedicated to road coverage are spaced every 6 km using 3.5 GHz (i.e. a 3 km site radius) then, in peak hours, one dedicated road site could be serving 800 to 1,200 cars – or 400 to 600 cars per sector (assuming two linear sectors pointing up and down the road). To provision 100 Mbit/s ‘speed coverage’ to each car and its passengers (an under-estimate of the 5G requirements which, arguably, could require 100 Mbit/s provision for each passenger as well as for the car) assuming 15% concurrent use would require a site sector downlink throughput of up to 6 to 9 Gbit/s.

If a 5G spectral efficiency at 3.5 GHz and 6 GHz of 8 bit/s/Hz is assumed (as used earlier, in our city analysis) then between 750 MHz and 1.1 GHz of spectrum will be needed to deliver this throughput. Whilst a smaller portion of the traffic could be carried in below 3GHz spectrum, it will not have a significant impact on this overall requirement.

With only 400 to 600 MHz available at 3.3-4.2GHz, it is clear that additional spectrum at 6 GHz – or an alternative solution – is required.

Such an alternative solution could be the use of high bands (in conjunction with 3.5 GHz spectrum). However, with cars being relatively evenly distributed along the road and with high band cell radii typically being comparatively small, colocation at just 3.5 GHz sites would not be practical. Many high band cell sites would need to be deployed across the distance covered by one 3.5 GHz site. This is not likely to be economically feasible along the ~100 km length of the E11 as it would require hundreds of high band sites in aggregate – and this scenario would repeat for similar roads and highways across the UAE.
6 IMT identification vs unlicensed use of 6 GHz spectrum

6.1 Unlicensed spectrum

Some radio frequencies are designated for specific types of use without the need for users to obtain a spectrum or apparatus licence. This is referred to as licence exempt spectrum (also referred to as general authorisation regime). The term “unlicensed spectrum” is also used. There is no need for a user to obtain an individual licence from the regulator as long as the devices used meet certain technical standards which are designed to minimise interference. The most notable example is Radio Local Area Networks (RLAN) which include Wi-Fi. The technologies operating in license exempt bands are required to operate at low-power levels to avoid excessive interference, meaning they can only cover short distances. However, since every user has an equal right to use these bands, it is not possible to guarantee a predictable quality of service.

6.2 IMT identification and licenced spectrum

While spectrum licencing is not within the remit of the WRC, there is a link between the identification of spectrum for IMT and licencing spectrum to mobile network operators. ITU-R allocates frequencies to radio services regionally and globally and further identifies specific frequency ranges for IMT, as captured in the ITU-R Radio Regulations (RR). Identification for IMT is key to the international harmonisation of spectrum and technology. National agencies responsible for spectrum management publish a National Frequency Plan which must be consistent with the Radio Regulations (RR) of the ITU-R. National agencies then may licence spectrum with an IMT identification to operators in the form of individual spectrum usage rights. An individual usage right guarantees the licence holder protected use of the spectrum within a geographically defined licence area.

Individual spectrum usage rights are an essential tool of spectrum management and are relevant where substantial investment is required to make use of spectrum. Individual usage rights have been the key element in the wide-spread deployment of mobile networks and as a result mobile services are the main means of communications for the majority of the population and businesses. Individual usage rights are a critical element to trigger economies of scale, attracting the large investment required to build 5G mobile networks and to enhance network coverage. 5G cannot be delivered with unlicensed spectrum because a near guaranteed 100 Mbit/s data rate, anytime and anywhere is central to the vision of 5G. To deliver this an operator must have control over the resources which enable this of which spectrum is an essential part. In contrast unlicensed spectrum does not guarantee that a 5G operator will have access to the spectrum resources as and when needed. It is not possible to ensure delivery of ultra reliable and low latency using unlicensed spectrum. Nor would it be possible to deliver network slicing where capacity reservation is the essence of the service. In other words, 5G operators require individually assigned spectrum usage rights (i.e. “licensed spectrum”).

Once equipment using unlicensed spectrum is allowed on the market, it is difficult to control their use: despite specified usage conditions, the actual use and position of transmitters is not known. Administrations and operators would need to expend significant efforts to react to cases of harmful interference and disturbances to other services.

In case of licensed spectrum, coordination on a case-by-case basis with incumbent systems (e.g. the Fixed Service) is easier. License conditions can include provisions to ensure incumbents’ protection with oversight from regulators.
6.3 IMT vs. Wi-Fi use of the 6 GHz band

It is important to assess whether the 5925-7125 MHz band should be licensed to operators (for 5G networks) or if it should be made available on a license exempt basis (for RLAN equipment such as Wi-Fi or 3GPP NR-U).

With billions of Wi-Fi enabled devices, Wi-Fi is a critical element providing device connectivity in homes, business premises, venues, and other indoor uses. There is also limited outdoor use of Wi-Fi. Wi-Fi uses unlicensed spectrum to provide the radio channel between Wi-Fi enabled devices and a Wi-Fi access point over a range of around 30 metres and perhaps up to 100 metres outdoors with Wi-Fi 6. All smartphones and many other devices such as tablets, laptops, TVs, appliances, controllers and sensors are Wi-Fi enabled.

Wi-Fi only provides the last hop between devices and the broadband access network. In developed countries which have a well developed broadband access network using copper, fibre, or cable, Wi-Fi is present in virtually every home, commercial and public premises. In other words, the usefulness of Wi-Fi depends on the availability of a broadband access network.

As mentioned above, in developing countries the access network is essentially provided by mobile operators using 4G and now 5G, so the notion of using 6 GHz Wi-Fi to distribute traffic around buildings is pointless because the connectivity bottleneck is the connection to the network. Therefore the 6 GHz spectrum should be used to overcome this bottleneck, i.e. have an IMT identification.

6.4 Wi-Fi offload vs. Wi-Fi onload

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.

However, 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:

- 5G mobile offers a fibre-like user experienced data rate while most Wi-Fi connections are not connected to FTTH and hence offer a lower speed. This is borne out by real world measurements: “5G offers faster average download speeds than Wi-Fi in seven out of eight leading 5G countries”35 as shown in Exhibit 30.
- 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.

35 OpenSignal, May 2020
Wi-Fi offload can only work where there is fibre, cable, or good DSL access to which Wi-Fi access points can be connected. This is not the case in most places in the world. Therefore in reality we are seeing a phenomenon which we refer to as “Wi-Fi onload”. Driven by lower mobile broadband prices and higher data speeds, shipments of 4G and now 5G enabled Wi-Fi access points are fast increasing. Wi-Fi enabled devices are connected to the router and the traffic is loaded onto the mobile network. The rapid growth of 5G FWA is evidenced by the growth in the availability of 5G FWA routers. “After phones, the most prevalent category of 5G device is the FWA CPE form factor. The number of announced devices has grown to reach 84 devices. Eighteen of these have been identified as commercially available.”

The Wi-Fi onload phenomenon is of course present in places with poor or non-existent wired access networks, but it is also present in developed markets. Indeed, much of the high mobile usage in Finland is explained by households going mobile only.

6.5 Regional differences

The Federal Communications Commission of the US decided to permit unlicensed devices to operate in the 6 GHz band rather than licencing the spectrum to mobile operators. One of the key drivers is Wi-Fi 6 (802.11ax), which offers performance improvements over Wi-Fi 5, notably speed improvement of around 30% and the ability to connect more devices with different streams. Of course the FCC is concerned with demand for spectrum in the USA, a country with a highly developed wired broadband infrastructure.

Decisions that produce good outcomes for the US are not necessarily the best solution for other countries, notably developing countries in Africa, Asia, and Latin America. The reality for most of the world is that Wi-Fi 6 will do nothing to improve broadband connectivity because fibre or other wired broadband access is virtually non-existent. The bottleneck is the broadband access network. Hence in developing countries Wi-Fi 6 is not helpful in reaching the goal of affordable broadband for all.

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36 Fixed Wireless Access - June Snapshot, GSA, June 2020
Wi-Fi at 6 GHz would be useful to only a minority of the world’s population, namely those living in well connected developed countries. Hence allocating the 6 GHz spectrum to Wi-Fi (unlicensed use) would be inconsistent with the United Nations Sustainable Development Goals (SDGs).

### 6.6 Technical differences between 5G-NR and Wi-Fi 6

5G has been rightly described as the enabling platform of the “4th industrial revolution”. This is because 5G is much more than a new radio interface. Ultra reliable low latency communications (uRLLC) are not only delivered by means of the radio interface but also by core network developments and edge computing. Specifically:

- Edge computing and other capabilities are an integral part of 5G but not the RLAN world;
- The ability for 5G to deliver predictable guaranteed QoS (e.g. throughput, latency, jitter) is inherent in 5G but not Wi-Fi 6. For example, uRLLC is a feature of 5G but not of Wi-Fi 6;
- The ability for 5G to deliver a network slice which cannot be done with Wi-Fi; and
- The ability to serve mobile users.

In contrast to 5G, Wi-Fi 6 is only an access technology, albeit a very useful one, but which cannot deliver the benefits of 5G. Wi-Fi cannot serve mobile use nor deliver a guaranteed QoS. By contrast 5G is designed to deliver both.

### 6.7 Key takeaways

For most of the world’s countries and most of the world’s population, an IMT identification of the 6 GHz band will deliver better socio-economic benefits compared to the unlicensed (Wi-Fi) use of the 6 GHz band.

For consumers, this would mean:

- Spectrum is not the bottleneck of user experience now and in the future for home broadband access; and
- Wi-Fi 6E only meets the high speed demand from FTTH users, which only consists of a small proportion of the total home broadband users. For the other users, the 5 GHz band is more than enough; (what they need is faster fixed home broadband access) so they will not benefit from Wi-Fi 6E, but 5G can provide the ultra fast speed experience to whoever needs it.

For enterprise, the advantages are:

- Reliability: Wi-Fi can not guarantee high level reliability while 5G-NR can provide 99.999% reliability;
- Capacity: Wi-Fi can only meet the capacity needs from fewer users, not competent for large scale wide-area deployment scenarios;
- Latency: Wi-Fi can not guarantee certain latency i.e. it is unsuitable for the increasing number of applications that require ultra-low latency; and
- Mobility: Compared to 5G mobile, even Wi-Fi 6 has high latency in handover with a high risk of packet loss

IMT high radiation power macro site deployment will be a more effective way of providing broadband access to people than that of low-power Wi-Fi. In other words, if a band coexistence condition is allowed, IMT deployment is the first priority.
7 Sharing with incumbents

7.1 Introduction and summary
This report has examined the need for additional spectrum at 6 GHz to provision the ITU-R 5G requirements. An important consideration around the future use of this band by 5G is the current uses of the band and how coexistence could be managed to facilitate 5G use.

Both the Fixed Satellite and Fixed (fixed links) services currently use the 6 GHz band. Studies on coexistence, and the conditions that might be required, are in their early stages. They are expected to provide some initial outcomes in the coming months and some final conclusions within the next couple of years.

Work in ITU-R is currently focused on defining the technical and operational parameters of both the incumbent users and 5G at 6 GHz. The relevant ITU-R technical groups are expected to provide a stable set of incumbents’ parameters for sharing studies by June 2021. Similarly, 3GPP will develop the characteristics of 5G covering the 6 GHz range, and communicate these to the ITU-R in the same timeframe. It is considered very important that future sharing studies are based on the same set of agreed typical parameters, so as to make the results directly comparable.

At the same time some initial sharing studies between 5G and incumbents at 6 GHz, based on typical parameter values, which are currently being carried out by the IMT industry indicate that coexistence is likely to be achieved – particularly in the 10 year timeframe for 5G at 6 GHz considered in this paper. It is in particular believed that certain technology developments and suitable regulatory frameworks could facilitate the co-existence. Among those elements are the following:

- **Active Antenna Systems (AAS) using beamforming**: This advanced technique allows the amount of energy transmitted in the direction of satellites to be controlled;
- **Propagation model enhancements**: More accurate models, in particular accounting for actual clutter loss for both terrestrial (Earth-to-Earth) and satellite (Earth-to-space) propagation paths are expected to give more realistic levels of interfering signals from 5G at the inputs to incumbents’ receivers operating in the same and adjacent frequency bands;
- **Lower spectral power density of 5G signals**: Lower (compared with 3G and 4G) relative levels of interference, in Watt/Hertz, are expected from 5G transmitters due to wider channel bandwidths used by 5G technology; and
- **Individual licensing of 5G**: Known positions and characteristics of 5G base stations will allow for efficient coordination with fixed links, providing the necessary protection. Such a coordination would be impossible in the case of general authorisation (used for Wi-Fi systems, for example) where no specific information would be available on the number and locations of the interfering stations.

7.2 Existing use of the 6 GHz band
Exhibit 31 shows that the 6 GHz band considered here, 5925 – 7125 MHz, has primary allocations in all regions to the Fixed and Mobile Services and to the Fixed Satellite Service in 5925 – 7075MHz.

Various footnotes to these allocations cover specific protection needs (of radio astronomy, for example) or specific uses of the bands in specific countries (for HAPS, frequency and time signals, earth stations onboard sea vessels, passive microwave sensors over oceans, and the space operations service, for example).
Exhibit 31: Radio Regulation allocations in the 6 GHz band

<table>
<thead>
<tr>
<th>Frequency range (MHz)</th>
<th>Region 1</th>
<th>Region 2</th>
<th>Region 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5925 – 6700</td>
<td>FIXED</td>
<td>FIXED SATELLITE (Earth-to-Space)</td>
<td>MOBILE</td>
</tr>
<tr>
<td>6700 – 7075</td>
<td>FIXED</td>
<td>FIXED SATELLITE (Earth-to-Space) (Space-to-Earth)</td>
<td>MOBILE</td>
</tr>
<tr>
<td>7075 – 7145</td>
<td>FIXED</td>
<td>MOBILE</td>
<td></td>
</tr>
</tbody>
</table>

Source: ITU Radio Regulations 2019

7.3 5G sharing with existing services

The examination of the sharing potential between 5G and existing services in the 6 GHz band is at an early stage regionally and internationally. The parameters that will underpin the coexistence studies are being discussed prior to

- initial views on potential outcomes being developed in the coming months; and
- final views being developed and agreed in the next couple of years.

The following subsections summarise the status of the Fixed and Fixed Satellite services in the band.

7.3.1 Fixed service

It is currently understood that fixed links in 6 GHz are typically used to cover longer hop distances, predominantly in rural and suburban areas, with only a very few operating in urban areas in some countries. It is also currently understood that the density of links in the 6 GHz band is also generally lower than in other (major) fixed service bands. These point towards low density use in urban areas – which are the primary focus for the 100 Mbit/s 5Gr experienced data rate and the 10 Mbit/s/m² 5G area traffic capacity requirements.

Given the above, coupled with the fact that each fixed link is authorised for a specific set of characteristics at a specific location, it is currently anticipated that coordination can be used to enable coexistence between fixed links and 5G. As a result of such a coordination, 5G licensees would be allowed to operate in most urban and a large portion of suburban areas, while some exclusions zones will still be needed to protect the existing fixed links at 6 GHz, noting that some of these are operated by users other than mobile operators. Initial studies indicate that coordination between 5G and fixed links is an efficient, though demanding resources from administrations, method of introducing 5G in cities while protecting the existing fixed links.

In the longer term, recognising the 10+ year timeframe anticipated for 5G at 6 GHz, there is also the potential for the migration of fixed links to other bands or technologies (for example, fibre). This would limit the coordination requirements and simplify the deployment of 5G at 6 GHz.
7.3.2 Fixed satellite service

The FSS uses this band for communications as well as tracking, telemetry and control (TT&C). FSS uplinks (Earth to Space) are operational in the band:

- The 5925 – 6725MHz uplink band is paired with 3400 – 4200MHz for downlink (typically, 5925 – 6425MHz paired with 3700 – 4200MHz and 6425 – 6725MHz paired with 3400 – 3700MHz)

- Appendix 30B of the Radio Regulations outlines the plan for the 6725 – 7025MHz portion of the band, where the frequencies are used to provide uplink in conjunction with downlink at 4500 – 4800MHz.

6700 – 7075MHz also allows for downlink (space-to-Earth) feeder links of non-geostationary Mobile Satellite Service systems.

Public information on the specific systems that make use of these allocations is not widely available. However the data that is available appears to indicate relatively limited use of the bands by operational satellites – when compared to the number of operational satellites across all bands estimated to be in excess of 2,000\(^\text{37}\), with over 500 being geostationary.

In conjunction with this is the increasing assignment and use of 3.5 GHz spectrum for 5G mobile around the world. These frequencies lie within the downlink part of the FSS bands noted above. As they are increasingly assigned and used for 5G over time, their use for FSS is being reduced (potentially to zero in some countries). The corresponding uplink bands at 6 GHz will therefore also see decreased use over time.

Coupled with this is the anticipation that satellites, relying on a continuously improving satellite technology, continue their move into higher frequency bands to take advantage of the greater bandwidths available and further reducing the use of 6 GHz spectrum.

Studies have commenced which will establish the conditions under which 5G can share the band with FSS. However, in the 10 year timeframe anticipated by this report for use of 6 GHz by 5G, it can be expected that the conditions will become increasingly less onerous on 5G as FSS use declines.

Appendices

Appendix A: ITU definition of the user experienced data rate

From Report ITU-R M.2410-0 – page 5

4.3 User experienced data rate

User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e. the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time.

In case of one frequency band and one layer of transmission reception points (TRxP), the user experienced data rate could be derived from the 5th percentile user spectral efficiency through equation (3). Let \( W \) denote the channel bandwidth and \( \text{SE}_{\text{user}} \) denote the 5th percentile user spectral efficiency. Then the user experienced data rate, \( R_{\text{user}} \) is given by:

\[
R_{\text{user}} = W \times \text{SE}_{\text{user}} \quad (3)
\]

In case bandwidth is aggregated across multiple bands (one or more TRxP layers), the user experienced data rate will be summed over the bands. This requirement is defined for the purpose of evaluation in the related eMBB test environment.

The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment:

– Downlink user experienced data rate is 100 Mbit/s.
– Uplink user experienced data rate is 50 Mbit/s.

These values are defined assuming supportable bandwidth as described in Report ITU-R M.2412-0 for each test environment. However, the bandwidth assumption does not form part of the requirement. The conditions for evaluation are described in Report ITU-R M.2412-0.

Appendix B: ITU definition of area traffic capacity

From Report ITU-R M.2410-0 – page 7

4.6 Area traffic capacity

Area traffic capacity is the total traffic throughput served per geographic area (in Mbit/s/m²). The throughput is the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time. This can be derived for a particular use case (or deployment scenario) of one frequency band and one TRxP layer, based on the achievable average spectral efficiency, network deployment (e.g. TRxP (site) density) and bandwidth.

Let \( W \) denote the channel bandwidth and \( \rho \) the TRxP density (TRxP/m²). The area traffic capacity \( C_{\text{area}} \) is related to average spectral efficiency \( \text{SE}_{\text{avg}} \) through equation (6).

\[
C_{\text{area}} = \rho \times W \times \text{SE}_{\text{avg}} \quad (6)
\]

In case bandwidth is aggregated across multiple bands, the area traffic capacity will be summed over the bands. This requirement is defined for the purpose of evaluation in the related eMBB test environment. The target value for Area traffic capacity in downlink is 10 Mbit/s/m² in the Indoor Hotspot – eMBB test environment. The conditions for evaluation including supportable bandwidth are described in Report ITU-R M.2412-0 for the test environment.
Appendix C: Selected use cases requiring citywide speed coverage

We are considering the future evolution of 5G over the next ten years. Today not all applications or use cases that will be developed to make use of the capabilities of 5G are known. However, in the following section we provide illustrations of some of the use cases that drive the need for citywide speed coverage.

Video everywhere and “on the move”

Much of the increase in demand for area traffic capacity is driven by increased use of video and advanced forms of video. Exhibit 32 shows the speed requirement for different types of video which increase as video capabilities advance. Advanced video includes augmented reality (AR) and virtual reality (VR) with higher resolutions and frame rates. Large screen devices, where higher resolution video is more relevant, will also use 5G streaming.

Immersive gaming not only requires high resolution video but also low latency. The low latency of 5G networks allows offload of the heavy computational work from devices to data centres which allows simplification of end user devices and wearables. Gaming content can be streamed just like video streaming services for example Netflix or Amazon Prime. The new gaming platforms such as Microsoft (with Project xCloud) and Google (with Stadia) are developed with 5G in mind.

Advanced video over 5G is already a reality. For example, in December 2019 Korea Telecom launched Real 360 app, a platform for 360-degree live-streaming, video sharing and video chat. Real 360 app users can initiate a 4K 360-degree video chat from a smartphone. Because of the vast quantity of data involved in transmitting high-resolution 360-degree video in real time, 5G technology is essential for this new communication tool.

Exhibit 32: Speed requirement for video

<table>
<thead>
<tr>
<th>VR level</th>
<th>Nominal data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1080p</td>
<td>4 Mbit/s</td>
</tr>
<tr>
<td>2K</td>
<td>5 Mbit/s</td>
</tr>
<tr>
<td>4K</td>
<td>20 Mbit/s</td>
</tr>
<tr>
<td>8K</td>
<td>80 Mbit/s</td>
</tr>
<tr>
<td>VR 4K 2D</td>
<td>50 Mbit/s</td>
</tr>
<tr>
<td>VR 8K 2D</td>
<td>100 Mbit/s</td>
</tr>
<tr>
<td>VR 8K 3D</td>
<td>150 Mbit/s</td>
</tr>
<tr>
<td>VR 12K 3D</td>
<td>500 Mbit/s</td>
</tr>
</tbody>
</table>

Source: Coleago Consulting

FWA in cities in developing countries

In addition to 5G mobile connectivity, Fixed Wireless Access (FWA) is an important 5G use case. Traffic volumes on FWA are five times higher compared to mobile use and a video streaming to large screens creates a demand for high data rates of 300 Mbit/s.

While FWA provided with 4G is already experiencing some growth, the use of 5G means that particularly in developing countries with less developed wired (FTTH, xDSL, cable) broadband networks, 5G FWA is a major driver for an increase in mid-bands spectrum demand. Therefore in such countries, while demand for advanced 5G application such as connected cars may take time to develop, demand from FWA is much higher compared to developed countries with good wired broadband infrastructure.

More information on the 5G FWA market and trends available in section 5.1.
Connected cars in cities

In the long-term, substantial capacity is required on roads to serve the connected car and smart road use cases. Exhibit 33 shows the data rates for connected cars which in a ten year time-frame will require substantial capacity. A study by the 5G Automotive Association published in June 2020\textsuperscript{38} found that “At least 500 MHz of additional service-agnostic mid-band (1 to 7 GHz) spectrum would be required for mobile operators to provide high capacity city wide advanced automotive V2N services.”

Exhibit 33: Data rates for car automation sensors

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Quantity per vehicle</th>
<th>Data rate per sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar</td>
<td>4 – 6</td>
<td>0.1 – 15 Mbit/s</td>
</tr>
<tr>
<td>LIDAR</td>
<td>1 – 5</td>
<td>20 – 100 Mbit/s</td>
</tr>
<tr>
<td>Camera</td>
<td>6 – 12</td>
<td>500 – 3500 Mbit/s</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>8 – 16</td>
<td>&lt;0.01 Mbit/s</td>
</tr>
<tr>
<td>Vehicle motion, GNSS, IMU</td>
<td>-</td>
<td>&lt;0.1 Mbit/s</td>
</tr>
</tbody>
</table>

Source: Flash Memory in the emerging age of autonomy Stephan Heinrich, Lucid Motors

\textsuperscript{38}5GAA TRS-200127 Working Group Standards and Spectrum Study of spectrum needs for safety related intelligent transport systems, page 5.