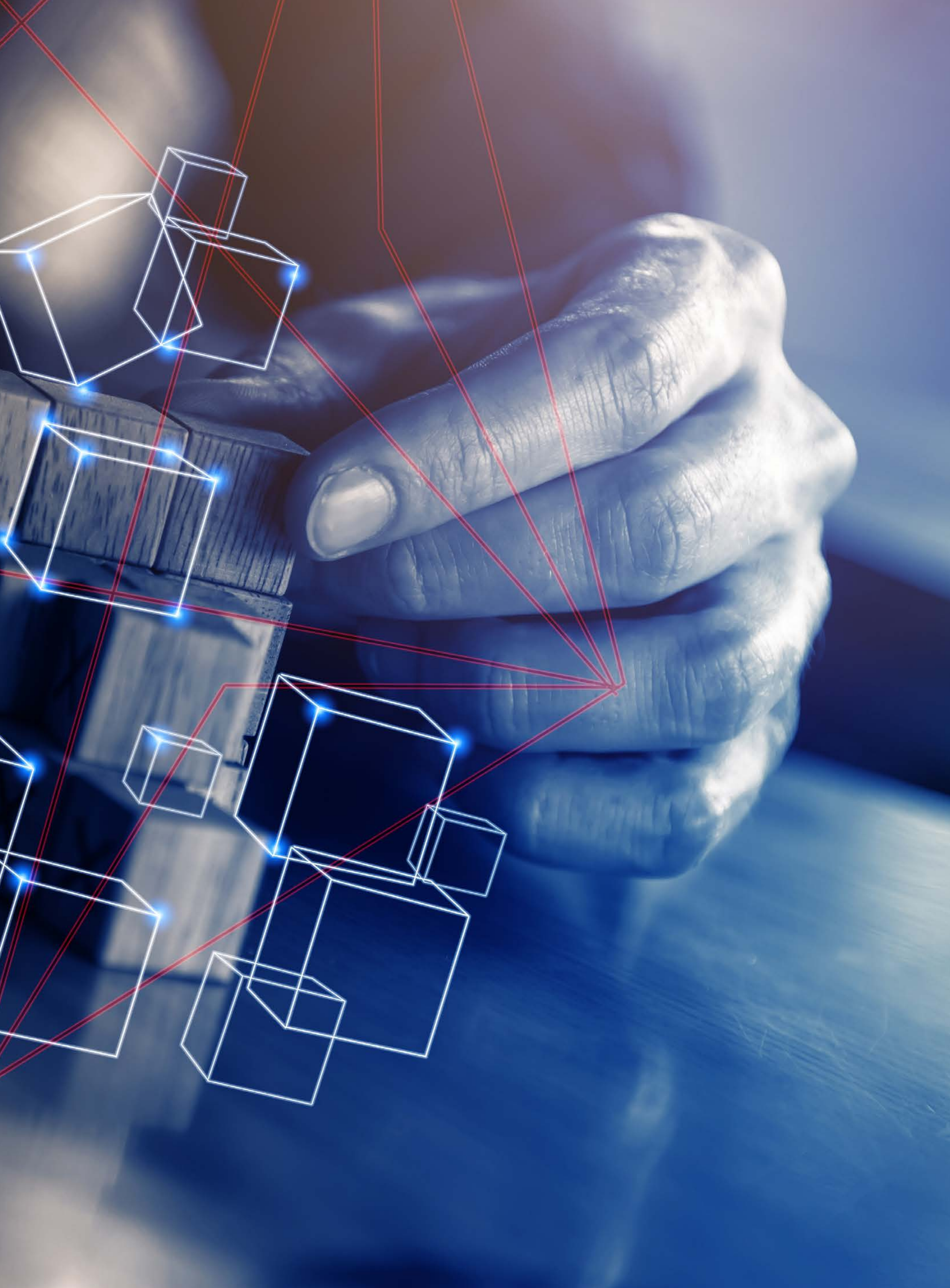
5G Spectrum

Public Policy Position

February 2020



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Executive summary

5G is the new generation of mobile technology, capable of ultra-fast speeds, low latency, and excellent reliability. The 5G New Radio (5G-NR) interface is positioned to address the enhanced requirements for highly heterogeneous usage scenarios of 2020 and beyond, including tremendous growth in connectivity and density/ volume of traffic. Appropriate 5G spectrum availability is required to address such a wide range of usage scenarios and requirements.

At least 80-100 MHz of contiguous spectrum per MNO at mid-bands for the first wave of 5G deployment: TDD bands at 3300-3800 MHz, 2600 MHz (n41), and 2300 MHz (n40) have become the industry requirement to achieve 10x user speed and 1/10 bit cost.

The mid frequency bands in the 2 to 8 GHz range, namely TDD bands at 3300-3800, 2600 and 2300 MHz, are emerging as the primary frequency bands for the introduction of 5G by 2020, providing an optimal balance between coverage and capacity for cost efficient implementation. The availability of at least 80-100 MHz of contiguous spectrum per 5G network operator, and with the adoption of massive MIMO, will boost peak, average and cell edge throughput with affordable complexity.

TDD bands at 4800-4990 MHz and 3800-4200 MHz to complement the 5G primary bands in specific countries.

In the countries where it is difficult to make the 5G primary bands (3300-3800, 2600 and 2300 MHz) available for 5G, 4800-4990 MHz and 3800-4200 MHz can serve as alternatives to the 5G primary bands, and can also provide a suitable compromise between coverage and capacity, as well as sufficient bandwidth.

It is recommended to release mid-bands as the first step. New FDD bands or existing FDD bands (via dynamic spectrum sharing) could also be used in 5G networks to complement mid-bands for fast rollout of 5G.

Mid-bands, providing a good compromise between coverage and capacity performance, can meet the enhanced mobile broadband (eMBB) service requirements for the initial stage of 5G deployments. Therefore, the release of these bands as the first step is essential for 5G development and business success.

FDD bands at lower frequencies can be used in combination with mid-bands to provide wider and deeper 5G coverage and to improve latency performance if needed. Such lower frequencies can also be considered for the early and rapid deployment of 5G, considering that in some markets sufficient mid-band spectrum may not be available, and these markets might not require large capacity during the first phase of 5G.

New FDD bands at lower frequencies (e.g. 600, 700 MHz) could be used as dedicated 5G spectrum, or existing 2G/3G/4G FDD bands (e.g. 800, 900 MHz) could be shared with 5G through dynamic spectrum sharing (DSS), providing wider and deeper coverage for 5G. Other FDD bands can also be considered for this purpose (e.g.1800 and 2100 MHz).

6 GHz is the potential future primary band for 5G development in the long term.

With the fast development of 5G, and the expected take-up of HD/UHD video and AR/VR services, the data that each user consumes on a monthly basis may exceed 150 GB by 2025. This trend will impose great pressures on the capacity of 5G networks. The 6 GHz band represents a great opportunity to address such challenges, considering the availability of as much as 1200

MHz of spectrum at 5925-7125 MHz, and noting that coexistence with incumbent services can be achieved through the use of advanced 5G technologies without undue restrictions on the usability of the band for 5G.

Synchronized operation is required for 5G TDD networks to ensure efficient use of spectrum.

In order to avoid interference between TDD networks operating in adjacent frequency carriers, radio transmissions of the TDD networks should be synchronized and their uplink and downlink frames should be time aligned. While the choice of the specific frame structure should be left to operators, administrations could facilitate timely agreements between operators on a common frame structure.

Synchronized operation should be achieved within each country, and as much as possible between countries, thereby avoiding the severe constraints of 5G deployment along the borders.

On the other hand, unsynchronized operation would lead to large inter-operator guard bands (e.g. 25 MHz) as well as additional operator-specific base stations filtering.

Global harmonisation, technology neutrality and national licensing are essential.

The global availability of harmonised regulatory frameworks for 5G spectrum will enable economies of scale, and facilitate cross-border coordination and roaming for end users. Consistent spectrum release timelines and harmonisation measures are key enablers for the success of 5G. The award of national spectrum licences is the preferred authorisation model for 5G, bringing certainty for investments, predictable network performance and quality for end-user connectivity.

Significantly lower pricing of 5G spectrum compared to 4G, with appropriate provisions to enhance end user experience are proposed.

To accelerate the delivery of affordable, high quality 5G services to end users, a reasonable 5G spectrum price is essential. The excessive spectrum pricing resulting from 3G assignment procedures imposed a heavy burden on the mobile operators, and eventually a highly negative impact on the 3G business development. Fortunately, the 4G spectrum prices were significantly lower, facilitating the business success of 4G. Learning lessons from the past, and facing potential challenges associated with the 5G business case (i.e., the need for further lowering of the cost per bit in the context of stagnating ARPUs), we strongly recommended that 5G spectrum pricing (including one-time fees and annual fees) should be significantly lower than for 4G in each country. Moreover, where regulators propose to set up provisions – such as targets for mobile network performance – we suggest that they account for appropriate requirements, such as data rate, in order to appropriately maximise the quality of the end user experience.

Uplink enhancement using existing MNOs' spectrum will help address the capacity requirement of vertical services, but more uplink bands will be needed over time to meet even higher uplink capacity requirements at specific locations.

Live uploading of HD video by end users and the needs of many vertical industry applications will require significantly greater (e.g. 10 fold) uplink capacity at some specific locations in the mid to long term. Accordingly, technology solutions are needed to enhance the uplink performance of TDD 5G-NR at cell edge. While the use of existing FDD bands is being considered in combination with mid-band spectrum as an initial “supplemental uplink” solution, the option of using new “uplink bands” which can accommodate large spectrum bandwidths for uplink should also be assessed for further uplink capacity enhancements.

Introduction and context

5G networks are emerging not only as the foundation for advanced communication services, but also as the infrastructure supporting socio-economic development and driving the digital transformation for industries and society as a whole. Spectrum and its regulation play fundamental roles in making 5G a success: the timely availability of the spectrum under appropriate conditions allows 5G wireless technology development to respond to consumer and industrial demands for advanced connectivity. This position paper presents Huawei's insights and recommendations on 5G spectrum and regulations, aiming at effective spectrum assignments to mobile operators.

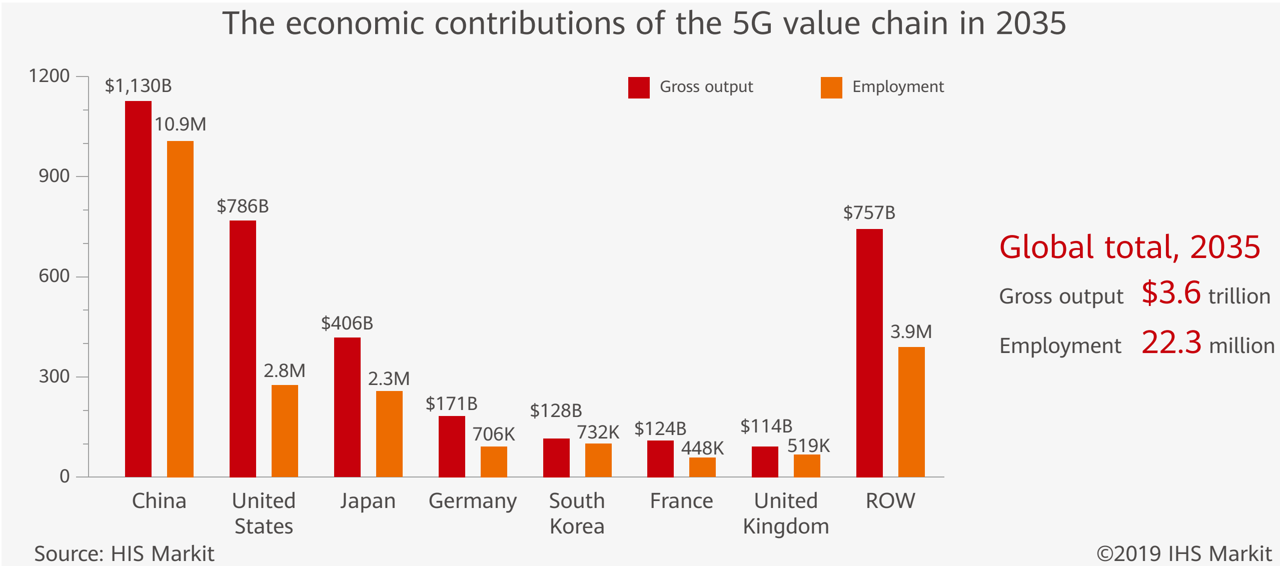
1 5G is the key enabler for national ICT transformation

5G is the fifth generation wireless technology for digital cellular networks. Compared with 4G, 5G offers a new network architecture to help significantly boost overall performance. 5G will deliver over 10 Gbps data rate, millisecond-level latency, and ultra-high-dense connections. With these remarkable features, 5G is set to welcome a world filled with unlimited possibilities and an exciting new era that promises the connectivity of everything.

5G will elevate the mobile network to not only interconnect people, but also interconnect and control machines, objects, and devices. It will deliver new levels of performance and efficiency that will empower new user experiences, enable smart families and connect new industries. In the future, 5G will be deeply integrated with cloud computing, big data, artificial intelligence (AI), virtual reality (VR), and augmented reality (AR). It will promote the connectivity of people with everything and arise as essential infrastructure for the digital transformation of all industries. The wide range of 5G applications will serve as a solid base for entrepreneurship development and innovation.

It is forecasted that 5G will enable $13.2 trillion of global economic output in 2035. That is nearly equivalent in current dollars to US consumer spending ($13.9 trillion) and the combined spending by consumers in China, Japan, Germany, UK, and France ($13.4 trillion) in 2018. The global 5G value chain will generate $3.6 trillion in economic output and support 22.3 million jobs in 2035 (Figure 1). This is approximately the combined revenue of the top-10 companies on the 2019 Fortune Global 1000: a list that includes Walmart, Sinopec Group, Royal Dutch Shell, China National Petroleum, State Grid, Saudi Aramco, BP, ExxonMobil, Volkswagen, and Toyota. Fortune estimates these companies employ almost 6.5 million workers. Thus, for the same level of output, the 5G value chain will support 3.4 times as many jobs. For the 2020–35 period, the global real GDP will grow at an average annual rate of 2.5%, of which 5G will contribute almost 0.2% of that growth. In other words, global actual GDP would expand at a slower pace of 2.3%, absent the deployment of 5G, i.e., 5G will add 8% to the overall GDP growth rate.

Figure 1: 5G contributions to global economy

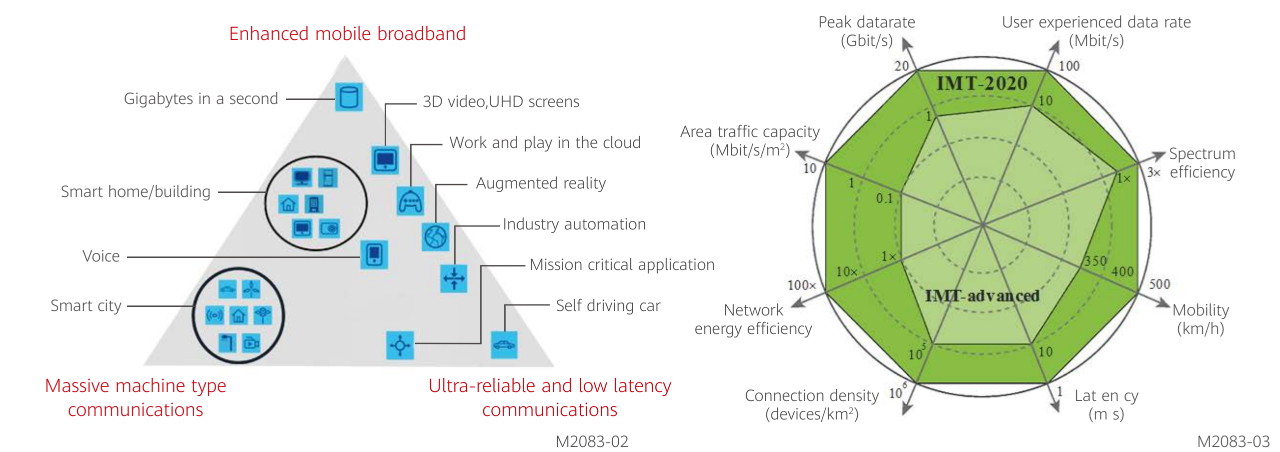


Source: IHS, "The 5G Economy, how 5G will contribute to the global economy", November 2019

2 5G spectrum requirements across multiple layers

The ITU-R IMT-2020 (5G) Vision[1] includes three usage scenarios: eMBB, mMTC and uRLLC. It also specifies the key capabilities of IMT-2020 (Figure 2), which represent great improvements in comparison with the previous generation of IMT systems.

Figure 2: IMT-2020 usage scenarios and key capabilities



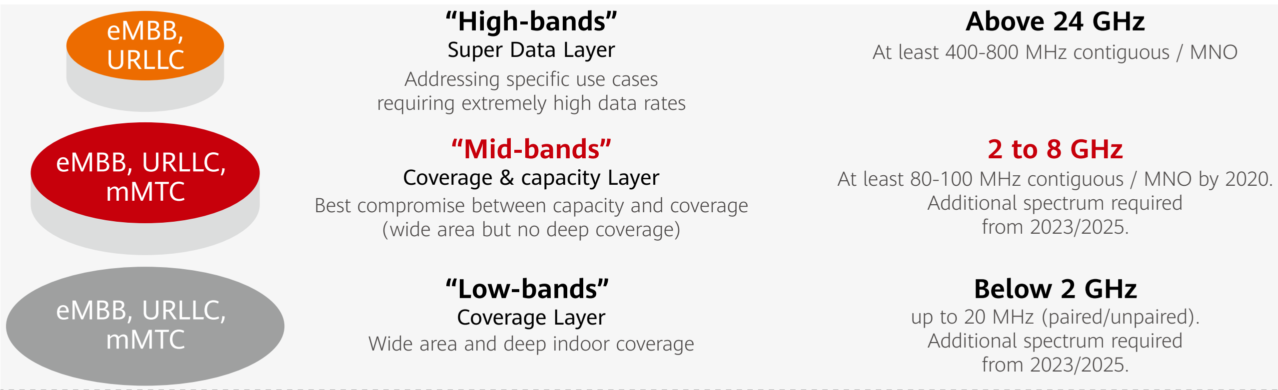
Source: ITU-R

To address diversified requirements from the envisioned usage scenarios in different phases of 5G, 5G needs access to "high", "mid" and "low" frequency bands (Figure 3), exploiting specific characteristics of different portions of the spectrum: frequencies between 2 and 8 GHz (e.g., 3300-4200, 4400-5000, 2500-2690, 2300-2400, and 5925-7125 MHz) in combination with frequencies below 2 GHz (e.g. 700 MHz) and above 8 GHz (e.g. 24.25-29.5 and 37-43.5 GHz). A sufficient amount of harmonised spectrum in each layer should be made available by national regulators in a timely manner to enable mobile operators

[1] Recommendation ITU-R M.2083, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond"

to deliver 5G services. The assignment of contiguous wide spectrum bandwidth in each layer reduces system complexity associated with carrier aggregation, which will improve energy efficiency and reduce network cost.

Figure 3: Multi-layer frequency band approach for 5G usage scenarios



Source: Huawei

Mid-bands between 2 to 8 GHz are crucial to support most 5G usage scenarios in wide-areas. The unpaired (TDD) bands at 3300-4200, 4400-5000, 2500-2690 and 2300-2400 MHz deliver the best compromise between wide-area coverage and high capacity. Taking into consideration that eMBB services are dominant in the initial phase of 5G, it is highly recommended to release the mid-bands at first. In this respect, at least 80-100 MHz of contiguous spectrum bandwidth from such mid-bands should be secured as the first step for each 5G network operator in the 5G multi-layer spectrum assignment process.

Low frequency bands (below 2 GHz) will extend the 5G mobile broadband experience to wider areas and deeper indoor environments. Moreover, uRLLC and mMTC type services will also greatly benefit from superior coverage at the low frequency bands. The available low frequency bands (e.g. 700, 800, 900, 1800 and 2100 MHz) may be exploited for LTE/NR uplink spectrum sharing in combination with NR in the 3300-3800 MHz band to allow operators to ensure faster and cost-effective deployment.

High frequency bands (above 24 GHz) will prove indispensable for providing additional capacity and delivering the extremely high data rates required by some 5G eMBB applications at specific locations ("hotspots"). At least 400-800 MHz of contiguous spectrum per network operator is recommended from higher frequencies to achieve good return on investment and meet service requirements.

The low and high frequency bands layers can be released as the second step to meet different usage requirement in the later phases of 5G development, e.g. the requirements for better coverage, lower latency or higher capacity.

3 The need for globally harmonised 5G spectrum

Spectrum harmonisation continues to be important for the mobile industry in the 5G era. Globally harmonised spectrum enables economies of scale and facilitates cross-border coordination and roaming for end users: a critical factor for the initial deployment of 5G. Therefore, regulators and the industry should take immediate action to achieve the following objectives:

1. Spectrum should be allocated to the Mobile Service on a primary/co-primary basis globally or regionally.

2.Consistent frequency arrangements (including harmonised band plans and duplexing mode) should be adopted across all markets.

3.Consistent regulatory frameworks should be strived for: the same technical conditions should govern the use of a particular frequency band in different countries (including harmonised emission masks to ensure sharing and coexistence with other services in the band or in adjacent bands).

4.Harmonised standards: the same technology standard should be adopted. ITU-R Working Party 5D is leading the development of IMT-2020 standards and the mobile industry is working on the 3GPP specifications for the next 5G-NR releases as the harmonised standard for 5G.

3.1 Mid-bands

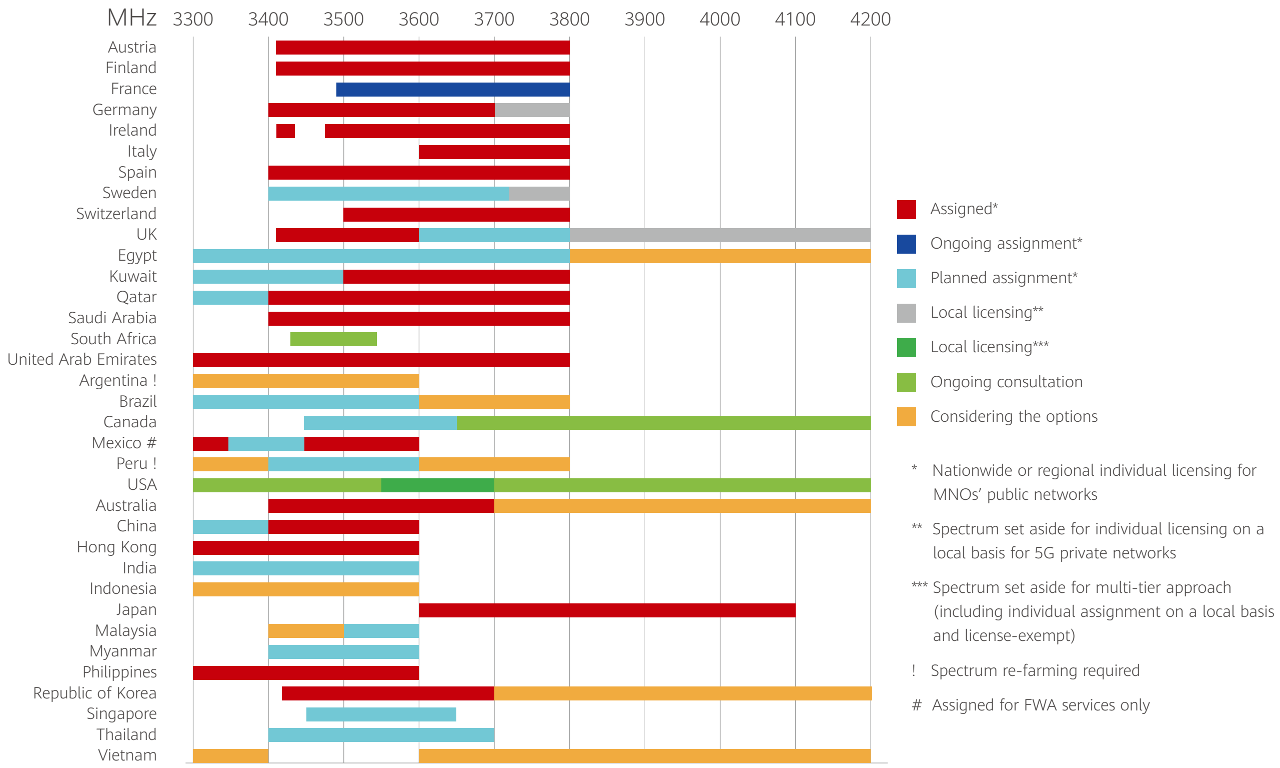
3300-4200 and 4400-5000 MHz

Spectrum availability for IMT in the 3300-4200 and 4400-5000 MHz ranges is increasing globally. The 3300-3600 MHz frequency band is allocated to the Mobile Service on a co-primary basis in almost all countries throughout the world. Administrations will make different portions of the 3300-4200 and 4400-5000 MHz ranges available at different times, incrementally building large contiguous blocks.

3300-3800 MHz

The 3GPP 5G-NR specifications support 3300-3800 MHz from the start, using a TDD duplex scheme. In line with the release plans in many countries, the 3300-3800 MHz band has become the primary 5G band with the greatest potential for global harmonisation over time: it is recommended that at least 80-100 MHz of contiguous bandwidth from this band be allocated to each 5G network operator by 2020.

Figure 4: Global availability and planning of the 3300-4200 MHz and 4400-5000 MHz frequency ranges



Source: GSA, "3300-4200 MHz: A key frequency band for 5G", February 2020

In order to take full advantage of the 3GPP 5G NR specifications for the 3300-3800 MHz band, regulators, especially in countries within the same region, are recommended to adopt a harmonised frequency arrangement with an aligned lower block edge of the usable spectrum, and harmonised technical licence conditions.

In 2018-2019, several countries, such as UK, South Korea, Spain, Finland, Italy, Australia, KSA, Austria, Switzerland, Japan, Germany, and China have assigned portions of 3300-3800 MHz for 5G with consistent regulatory frameworks (i.e. frequency arrangements and emission masks). The updated European regulatory framework for the 3300-3800 MHz band, optimised for the introduction of 5G NR networks including base stations equipped with Active Antenna Systems, was published in October 2018, representing an important reference also for countries from other regions.

4800-5000 MHz

At WRC-19 held in Egypt this autumn, a number of countries were added to the Footnote 5.441B of the 4800-4990 MHz frequency band for IMT. Currently, the existing PFD limit to protect incumbent services is very stringent. It was agreed to further study this protection criterion at WRC-23. In addition, some countries, including Russia, China, Brazil, South Africa, and others, were agreed to be exempted from this PFD limit, effective immediately after WRC-19. Moreover, the Chinese government has allocated the 4900 MHz band to 5G in 2019.

3800-4200 MHz

The current use of the 3800-4200 MHz band varies across the world. The main use is for the Fixed Satellite Service (FSS) (space to earth), although parts of the band are also used for Radiolocation and the Fixed Service (FS) (mainly point to multipoint or wireless broadband services), which reduces the potential for the use of these frequencies for 5G in most countries. In spite of this unfavourable situation, and considering that the number of FSS earth stations is relatively low (Figure 5), some countries have released or plan to release 3800-4200 MHz for 5G. Japan has already made 3600-4100 MHz available for 5G. The US and UK are using different mechanisms to make the bands 3700-4200 MHz and 3800-4200 MHz, respectively, available for 5G. South Korea, Belgium, Sweden and Canada have also launched public consultations in relation to release of portions of these bands for 5G.

Figure 5: Registered FSS earth stations across Europe

MEMBER STATE		3.4-3.8 GHz band		3.8-4.2 GHz band	
		Nr of sites	Nr of Earth stations	Nr of sites	Nr of Earth stations
AT	Austria	1	6	1	6
BE	Belgium	2	3	7	10
BG	Bulgaria	3	3	2	3
CY	Cyprus	2	2	9	14
CZ	Czech Republic	0	0	0	0
DK	Denmark	3	3	3	3
EE	Estonia	0	0	1	1
ES	Spain	0	0	0	0
FI	Finland	0	0	2	2
FR	France	11	18	11	18
GE	Germany	15	31	27	49
GR	Greece	3	3	5	13
HU	Hungary	0	0	0	0
IE	Ireland	0	0	2	2
IT	Italy	5	10	2	25
LT	Lithuania	0	0	3	3
LU	Luxembourg	1	1	1	1
LV	Latvia	0	0	2	2
MT	Malta	0	0	1	1
NL	Nederland	5	15	5	18
PL	Poland	1	5	0	0
PT	Portugal	1	1	4	9
RO	Romania	2	2	1	1
SE	Sweden	0	0	0	0
SI	Slovenia	0	0	1	1
SK	Slovakia	0	0	0	0
UK	United Kingdom	19	50	31	102
NO	Norway	4	17	5	19
TOTAL		78	170	126	303

Source: RSCOM Survey 2010

TDD 2600 MHz and 2300 MHz mid-bands can complement the 3300-3800 MHz 5G primary band

Although the 3300-3800 MHz has already been the global first priority for the first wave of 5G deployment, there are still some countries facing great challenges in making at least 80-100 MHz of contiguous spectrum available to each 5G network operator. Such countries can rely on additional mid-bands to enable sufficient contiguous spectrum for all MNOs; the TDD 2500-2690 MHz and 2300-2400 MHz bands may represent viable options with this respect.

2500-2690 MHz

ITU-R has identified the 2500-2690 MHz mid-band as a global band for IMT and this was formally included in the Radio Regulations in accordance with Resolution 223 (Rev.WRC-15). There are three important 3GPP-defined LTE spectrum bands in this frequency range. Band 7 is an FDD band with separate DL and UL spectrum blocks at 2500–2570 MHz and 2620–2690 MHz. Band 38 is a TDD band extending from 2570 to 2620 MHz. 3GPP Band 41 identifies the entire 2500-2690 MHz based on the TDD duplex scheme. Driven by China, Japan, India, KSA and the USA, assignments of the 2600 MHz band as TDD were harmonised globally, and there are 17 launched networks covering 40% of global population with 4,229 supporting LTE devices[2,3].

The use of the LTE Band 41 with its unpaired (TDD) configuration brings significant benefits over employing the hybrid LTE Bands 7/38 configuration:

- Advantages in dealing with traffic asymmetry
- Provides more capacity and increased spectrum efficiency
- Comparable network coverage
- Avoids inter-band interference
- Simplified network operation
- Key global roaming band
- Typically lower spectrum cost for TDD spectrum
- Easier to transition LTE Band 41 to 5G NR

2300-2400 MHz

The band 2300-2400 MHz was identified for IMT at WRC-07, see footnote 5.384A of the Radio Regulations, and is known as 3GPP Band 40. It is the eighth most popular band used by public mobile operators for LTE network deployments, with reportedly over 52 commercial networks[4] covering 50% of the global population and 4,449 supporting LTE devices[2]. All major base station / chipset / smartphone / device manufacturers will support the 2300 MHz band in 2020.

TDD technology offers a viable evolutionary path from 4G towards 5G networks and services. It should be noted that the TDD bands at 2600 MHz and 2300 MHz are also included in 3GPP 5G NR Release 15, renamed as n40/n41, respectively. Therefore, the two bands can provide up to 290 MHz of mid-band 5G primary spectrum for those countries with insufficient 3300-3800 MHz spectrum.

[2] GSA, "Status of the LTE Ecosystem", November 2018. https://gsacom.com/

[3] GSA, "2496–2690 MHz Ecosystem Evolution", DATE. https://gsacom.com/

[4] https://gsacom.com/gambod-nts-search/

When working for the availability of spectrum from mid-bands which is required to support the initial launch of 5G (at least 80-100 MHz, contiguous, per operator), countries can also exploit the solid ecosystem which is becoming available for 5G NR in the TDD 2600 MHz and 2300 MHz bands. This option will be of great importance in those countries were the current use of the 3300-3800 MHz band cannot meet the operators' requirements in the short and medium term.

Unfortunately, there are still some countries that have difficulties to even release either the 3300-3800 MHz or 2600 / 2300 MHz TDD bands for 5G, because of use by 4G or by incumbent services. For these countries, 4800-4990 MHz and 3800-4200 MHz could be alternatives to 5G primary bands, and can also provide a compromise between coverage and capacity as well as sufficient bandwidth. Furthermore, these bands are respectively the upper parts of the 5G 3GPP bands N77 and N79, which are supported by most of the available 5G devices. With more countries having released or planning to release these bands for 5G (e.g. China, Russia, UK, Sweden and South Korea), the E2E ecosystems of 4800-4990 MHz and 3800-4200 MHz would have maturity that is comparable to the current 5G primary bands, and are ready for large scale commercial 5G deployments.

3.2 Low bands

Mid-bands can meet the eMBB service requirements for the initial stage of 5G, therefore the release of these bands as the first step is essential for 5G development and business success.

Low FDD bands can be used in combination with mid-bands to provide wider and deeper (indoor) 5G coverage, and to improve latency performance if needed. Such low frequencies can also be considered for early 5G deployments considering that there are some markets that might not need to address large capacities for the first phase of 5G.

New low FDD bands (e.g. 600, 700 MHz) could be used as dedicated 5G spectrum. Alternatively existing 2G / 3G / 4G FDD bands (e.g. 800, 900 MHz) could be shared by 5G through dynamic spectrum sharing (DSS), providing wider and deeper coverage, and allowing fast rollout of 5G. Other bands can also be considered for this purpose (e.g.1800 and 2100 MHz).

The better coverage at lower bands will provide an important contribution in meeting the coverage obligations that are often associated with regulatory spectrum usage rights.

3.3 High bands ("mmWave")

At WRC-19, after intensive discussions, breakthroughs were made on Agenda Item 1.13 relating to millimetre wave frequency bands for IMT. The following was agreed:

- 24.25-27.5 GHz identification for IMT globally
- 37-43.5 GHz identification for IMT globally
- 66-71 GHz identification for IMT globally
- 45.5-47 GHz identification for IMT in multiple countries
- 47.2-48.2 GHz identification for IMT in multiple countries
- 31.8-33.4, 47-47.2, 48.2-50.2, 50.4-52.6, 71-76 and 81-86 GHz: No Change (not for IMT)

The established conditions to protect incumbent services are favourable or acceptable to IMT network deployment. A two-stage approach was agreed as a compromise to protect the EESS (passive) below 24

GHz: an out-of-band emission limit of -33 dB(W/200 MHz) is applied to IMT base stations immediately after the WRC-19, with this limit tightened to -39 dB(W/200 MHz) for deployments after 1 September 2027.

Comparing with mid-bands, mmWave bands suffer from poor radio propagation and significant outdoor – indoor penetration loss, which make continuous citywide coverage not economically viable. According to the report by the U.S. Defense Innovation Board, 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[5]. The base station number might exceed the total number of all the existing base stations worldwide[6], while the capex would be comparable to the global mobile industry total expenditure in 2018-2020[7], which makes it impossible to use mmWave bands to deploy national 5G networks with continuous geographic coverage.

Thus the mmWave usage scenarios are limited to fixed wireless access (FWA) and hotspot coverage, which do not require continuous national coverage.

3.4 Other frequency bands for 5G

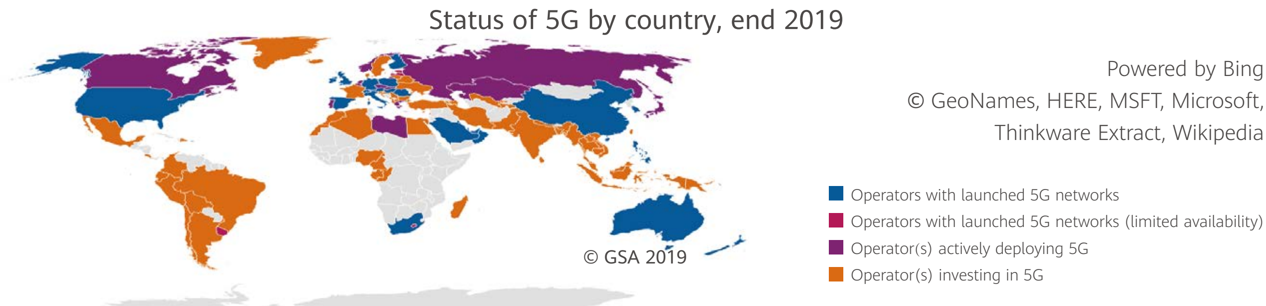
The L-band (1427-1518 MHz) is another candidate 5G band that has the potential to be allocated to mobile communications in most countries in the world. The CEPT and CITEL regions have adopted the supplemental downlink (SDL) scheme for this band. The requirement for standalone operation in the band (both UL and DL transmissions) has emerged in some other regions. In the case of standalone 5G systems, a TDD access scheme is a potentially appropriate option, which can accommodate traffic asymmetry in the UL/DL directions with good potential for economies of scale. The same 5G-NR equipment can serve both the TDD and SDL markets.

4 5G industry progress

4.1 5G industry progress around the world

By the end of 2019, 348 operators in 119 countries had announced that they were investing in 5G. 77 operators had announced that they had deployed 3GPP compliant 5G technology in their networks. A total of 61 operators in 34 countries had launched one or more 3GPP-compliant 5G services[8].

Figure 6: Countries with operators investing in 5G networks



Source: GSA, "Global 5G status – Snapshot", January 2019

[5] Defense Innovation Board, "THE 5G ECOSYSTEM: RISKS & OPPORTUNITIES FOR DoD", 2019, https://media.defense.gov/2019/Apr/03/2002109302/-1/-1/0/DIB_5G_STUDY_04.03.19.PDF

[6] https://www.mobileworldlive.com/blog/blog-global-base-station-count-7m-or-4-times-higher/

[7] http://www.c114.com.cn/news/16/a1071615.html

[8] GSA, "GLOBAL 5G STATUS – SNAPSHOT JANUARY 2020 ", https://gsacom.com/

4.2 5G band specification

3GPP specifications for the 5G initial bands and associated band-combinations were finalised by June 2018 for 5G deployment. The following tables[9] show the new 5G-NR frequency bands specified by 3GPP.

New bands for 5G NR

NR band	UL	DL	mode
n1	1920 – 1980 MHz	2110 – 2170 MHz	FDD
n2	1850 – 1910 MHz	1930 – 1990 MHz	FDD
n3	1710 – 1785 MHz	1805 – 1880 MHz	FDD
n5	824 – 849 MHz	869 – 894 MHz	FDD
n7	2500 – 2570 MHz	2620 – 2690 MHz	FDD
n8	880 – 915 MHz	925 – 960 MHz	FDD
n12	699 – 716 MHz	729 – 746 MHz	FDD
n20	832 – 862 MHz	791 – 821 MHz	FDD
n25	1850 – 1915 MHz	1930 – 1995 MHz	FDD
n28	703 – 748 MHz	758 – 803 MHz	FDD
n34	2010 – 2025 MHz	2010 – 2025 MHz	TDD
n38	2570 – 2620 MHz	2570 – 2620 MHz	TDD
n39	1880 – 1920 MHz	1880 – 1920 MHz	TDD
n40	2300 – 2400 MHz	2300 – 2400 MHz	TDD
n41	2496 – 2690 MHz	2496 – 2690 MHz	TDD
n50	1432 – 1517 MHz	1432 – 1517 MHz	TDD
n51	1427 – 1432 MHz	1427 – 1432 MHz	TDD
n66	1710 – 1780 MHz	2110 – 2200 MHz	FDD
n70	1695 – 1710 MHz	1995 – 2020 MHz	FDD
n71	663 – 698 MHz	617 – 652 MHz	FDD
n74	1427 – 1470 MHz	1475 – 1518 MHz	FDD
n75	N/A	1432 – 1517 MHz	SDL
n76	N/A	1427 – 1432 MHz	SDL
n77	3300 – 4200 MHz	3300 – 4200 MHz	TDD
n78	3300 – 3800 MHz	3300 – 3800 MHz	TDD
n79	4400 – 5000 MHz	4400 – 5000 MHz	TDD
n80	1710 – 1785 MHz	N/A	SUL
n81	880 – 915 MHz	N/A	SUL
n82	832 – 862 MHz	N/A	SUL
n83	703 – 748 MHz	N/A	SUL
n84	1920 – 1980 MHz	N/A	SUL
n86	1710 – 1780 MHz	N/A	SUL
n257	26500 – 29500 MHz	26500 – 29500 MHz	TDD
n258	24250 – 27500 MHz	24250 – 27500 MHz	TDD
n260	37000 – 40000 MHz	37000 – 40000 MHz	TDD
n261	27500 – 28350 MHz	27500 – 28350 MHz	TDD

[9] 3GPP TS 38.104 V15.7.0 (Oct '19)

Band combinations for LTE/NR supplemental uplink (SUL)

3GPP has also agreed upon a number of LTE-NR sharing combinations where the UL direction of some low frequency bands (e.g. 700, 800, 900, 1800 and 2100 MHz) is paired with the 3300-3800 MHz band. Below are some example of NR band combinations for SUL.[10]

Examples of operating band combination for SUL in FR1

NR Band combination for SUL	NR Band
SUL_n41-n80	n41, n80
SUL_n41-n81	n41, n81
SUL_n77-n80	n77, n80
SUL_n77-n84	n77, n84
SUL_n78-n80	n78, n80
SUL_n78-n81	n78, n81
SUL_n78-n82	n78, n82
SUL_n78-n83	n78, n83
SUL_n78-n84	n78, n84
SUL_n78-n86	n78, n86
SUL_n79-n80	n79, n80
SUL_n79-n81	n79, n81
SUL_n79-n84	n79, n84

Band combinations for LTE/NR dual connectivity

3GPP has identified several hundred band combinations for LTE/NR (Dual Connectivity). Several categories have been defined, based on the number of LTE and/or 5G-NR component carriers (CC) to be combined[11]. In addition, 3GPP has also agreed to reuse existing LTE band numbers for future long term migration from LTE to NR in the respective bands.

5 Regulations to support 5G business development

5.1 5G Spectrum licensing and pricing

Spectrum management, regulations and pricing have a direct impact on 5G commercialisation and service provision.

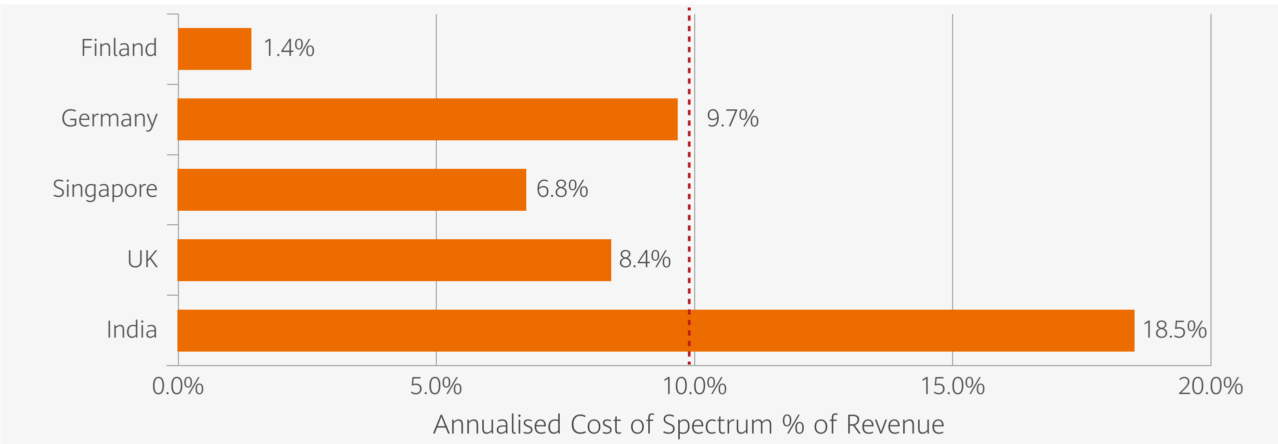
Pricing: lower auction fees, annual payments and regulatory obligations

[10] 3GPP TS 38.101-1 (Jan ’20)

[11] 3GPP TS 37.340 (Jan ’20)

High spectrum prices have been linked to lower investment in networks, worse quality and coverage, and lower consumer welfare[12]. Because the spectrum cost is amortised over the annual costs of the mobile operator, as the number of bands required for the provision of mobile services increases, the total annual amortisation of spectrum cost to operators also increases. For some major operators, the annual spectrum cost has exceeded the investment in equipment. Effective spectrum pricing policies are vital to ensure that operators have the resources to invest in the network. The price of 5G spectrum should be affordable and predictable. According to a report from a third-party research institute, Coleago[13], so long as the average annual amortisation of the operator's spectrum costs is within 5% of the operator's revenues, it would not represent a significant burden for the operator to build a mobile network.

Figure 7: Examples of spectrum cost as a proportion of operator revenue



Source: Coleago

Proportionate spectrum fees will allow operators to remain more focused on network investment, and it will drive down end user prices, bringing long-term socio-economic benefits through 5G digital connectivity. To achieve the above goals, Huawei proposes the following recommendations with reference to 5G spectrum pricing policy:

- The total cost of 5G spectrum should be significantly lower than that of 4G, which is essential to keep the annual amortised spectrum costs below the 5% threshold, considering that the operators have to bear the spectrum cost for 2G/3G/4G in addition to 5G.
- Sufficient spectrum supply is essential to ensure that each of the typically 3-4 existing operators in a country has at least 80-100 MHz of contiguous spectrum in mid-bands, as scarcity can lead to excessive prices. Otherwise, some operators may need to deploy 5G based on existing spectrum holdings, and this may only partially achieve the expected requirements of 5G.

[12] GSMA, "Effective spectrum pricing", DATE. https://www.gsma.com/spectrum/effective-spectrum-pricing/

[13] Coleago, "Sustainable spectrum pricing", June 2019.

- It is important not to assign spectrum before actual availability or market demand. Otherwise, the licence fees for such unused spectrum will have negative effects on the investment in 5G network deployments. It is recommended that mid-bands are released first, with other bands released as a second step based on market demand and actual availability.
- Moderate reserve auction prices, and affordable annual fees (if there are any), are important factors in removing barriers to network investment.
- When a cap on spectrum holding is used to mitigate the risk of unbalanced competition in the mobile market, it is important that this does not result in a spectrum holding of less than 80 MHz in the mid-bands.

In addition, the spectrum in most countries in the world is currently assigned by auction, and auction fees are expected to be paid by the operators within a specific time, or even as a lump sum. This greatly affects the financial status of operators (free cash flow or net debt) in the initial stages of network deployment and hinders the progress of network rollout.

To alleviate the negative effect brought about by lump-sum payments of spectrum auction fees, it would be preferable for the operators to be allowed to pay the auction fees in annual instalments during the spectrum authorisation period.

Moreover, in order to enable the retained funds to be effectively used in network construction, the regulator may stipulate appropriate network provisions. For example, to ensure that 5G users receive a high quality service experience, it is necessary to set provisions that are related to both population/geographic coverage and network data rates (e.g. 100 Mbps in certain areas to meet the 5G average user-experienced data rate)[14]. Some countries, such as Germany, France, Italy, KSA, and others have set appropriate network data rate provisions when 5G spectrum is assigned, which will lay a solid foundation for the development of 5G services and the migration of users to 5G. Furthermore, policies could be put into place for the relevant annual spectrum fees to be reduced if the operator is able to surpass the requirements of these provisions.

Exclusive national assignments

Given the large-scale investments in new nationwide networks that are required for 5G, there is still a need for operators to have exclusive[15] access to spectrum for 5G, as has been the case for previous generations of mobile technologies. Exclusive national licences give mobile operators certainty that they can deploy their networks when and where there is demand from their customers, and at the required level of quality, free from concerns in relation to co-channel interference. Mobile networks evolve as operators extend coverage to unserved areas, or increase capacity at locations with high traffic demands. This flexibility is key for an MNO's business and should be preserved through exclusive national licences in 5G bands.

It is important to note that regional licences have significant disadvantages compared to national licences:

[14] ITU, "Setting the Scene for 5G: Opportunities & Challenges", 2018

[15] In those cases where the incumbent services may not be cleared or migrated to other frequency bands, least restrictive provisions should be considered to ensure sharing and coexistence between the nationwide mobile networks and the incumbents.

- Regional licences require buffer zones at their boundaries to mitigate co-channel interference between licensees. This can result in inefficient use of spectrum.
- There is an additional burden for the spectrum regulator to define, issue and manage regional licences, and for the operators to plan their networks.
- Seamless coverage along transport paths (railways, roads) becomes challenging with regional licences.
- Regional licences do not have a good track record: past initiatives to allocate spectrum licences on a regional or local basis (e.g. 3300-3800 MHz bands around 10 years ago in some countries) have not been very successful. Many small players acquired these regional licences but did not deploy extensively.

In summary, mobile network operators have had over thirty years of experience in deploying national communication infrastructures. They are well placed to invest in 5G and establish a firm foundation for an ecosystem of next generation radio communications for both mobile broadband and vertical use cases. It is of critical importance to avoid undermining investment certainty, and hence the regulatory frameworks in place should not diverge from the exclusive national licences that have been a key underpinning of the phenomenal success of mobile services. A different approach in 5G bands could disrupt a well-established regulatory framework and ruin take-up of 5G.

Technology neutrality and other licence conditions

Spectrum assignments for specific mobile technologies (e.g. 2G, 3G and 4G), and in some countries for specific services (e.g. voice, data, broadband access), can no longer keep up with the speed of market demand for new network capabilities and for new services with enhanced performance. The principle of technology neutrality is a best practice that has been followed by many countries, including the most advanced markets. Such an approach has allowed operators to swiftly respond to the changes in market demands with tangible benefits for end users.

Moreover, longer licence durations protect the long term investment plans of the operators. It is recommended that licences are awarded for longer periods than is common practice today. If an indefinite licence duration cannot be achieved, a duration of 20 years is recommended as a minimum.

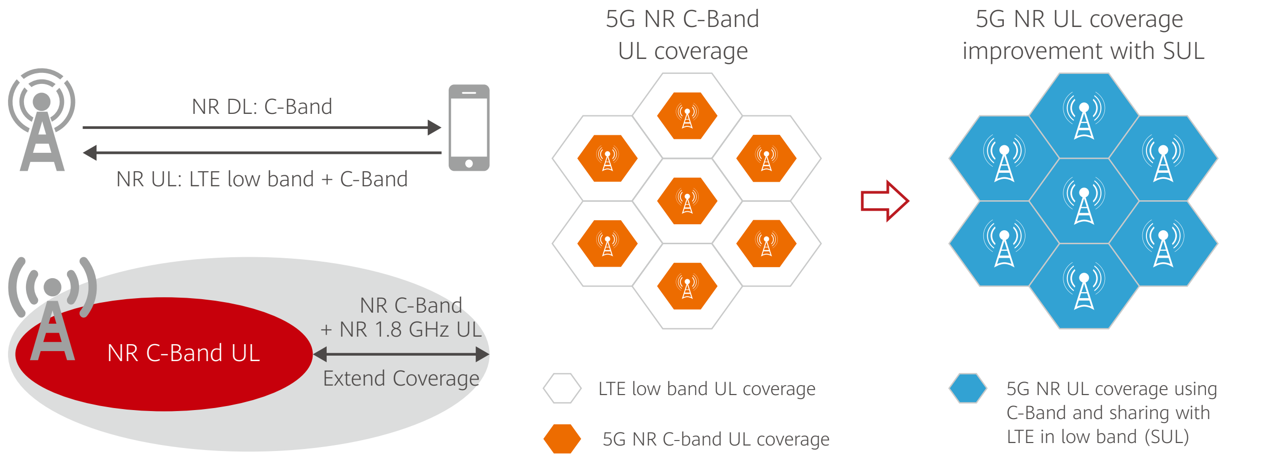
5.2 Technical enablers for 5G regulations

5G networks and devices will embrace many new features, exploiting the latest technical innovations. Some innovations provide an opportunity for regulators to adjust regulations for more efficient and flexible spectrum utilisation.

LTE/NR uplink spectrum sharing for SUL

An important feature of the 3GPP Release 15 standard resides in the ability for LTE and 5G-NR to co-exist and share the same low frequency bands without having to fully free those bands from LTE use. In the initial stages of 5G deployment, the new bands likely to be made available for 5G are higher in frequency (e.g. 3300-3800 MHz band), support fewer sub-frames for uplink, and are subject to more challenging link budgets on the uplink than existing 2G/3G/4G bands. Such new bands will therefore have more uplink coverage limitations compared to existing bands.

Figure 8: LTE/NR uplink spectrum sharing to extend 5G coverage at higher frequencies (e.g. 3300-3800 MHz C-band), to accelerate deployment and reduce cost



Source: Huawei

Figure 9: SUL bands in 3GPP 38.104

NR operating band	Uplink (UL) operating bandBS receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	Downlink (DL) operating bandBS transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL
n86	1710 MHz – 1780 MHz	N/A	SUL
n89	824 MHz – 849 MHz	N/A	SUL
...	...	...	...

Source: 3GPP 38.104

With uplink spectrum sharing between LTE and 5G-NR, the 5G-NR uplink and downlink transmissions can occur at the higher frequency 5G bands (e.g. 3300-3800 MHz), while the 5G-NR uplink can also exploit spectrum resources in lower frequency bands that the operator has been using for LTE (e.g. 700, 800, 900, 1800 and 2100 MHz). This scheme allows improved uplink coverage by using lower frequencies in combination with higher frequencies, leading to a considerably faster and more cost-efficient 5G-NR deployment by reusing the existing sites and enabling more efficient and flexible use of all spectrum assets.

Network synchronisation

In order to avoid interference between TDD networks operating in adjacent frequency carriers, radio transmissions of adjacent TDD networks should be synchronised and with the uplink and downlink frames aligned in time. Such synchronisation of 5G networks is very important because it is the best way to avoid interference between networks and ensure efficient use of spectrum resources by avoiding inter-operator guard bands and additional base stations filtering.

Network synchronisation has been successfully implemented in 4G TDD networks ensuring efficient use of the spectrum resource by avoiding the need for guard bands between operators' assignments.

Similarly, inter-operator synchronisation and time alignment of uplink/downlink transmissions (slot and frame synchronisation) are also necessary for efficient deployment of 5G-NR networks in unpaired band assignments. Therefore, regulations should facilitate synchronised operation among 5G networks operating in adjacent frequency blocks to make the best use of the valuable spectrum resource. We recommend two transmission frame structures for 5G macro-cell networks operating in unpaired 5G-NR bands, taking into account technology advances and system design requirements:

- Scenario 1: 5G only, no legacy LTE TDD networks: 2.5ms periodicity frame structure (DDDSU) for high system capacity and efficiency (Figure 10), and 2.5ms dual periodicity frame structure (DDDSU+DDSUU) for prioritisation of UL transmission (Figure 11).
- Scenario 2: 5G co-existence with LTE TDD network: 5ms periodicity frame structure compatible with LTE TDD network (DDDDDDDSUU) (Figure 12). But this is accompanied with twice the latency of Scenario 1.

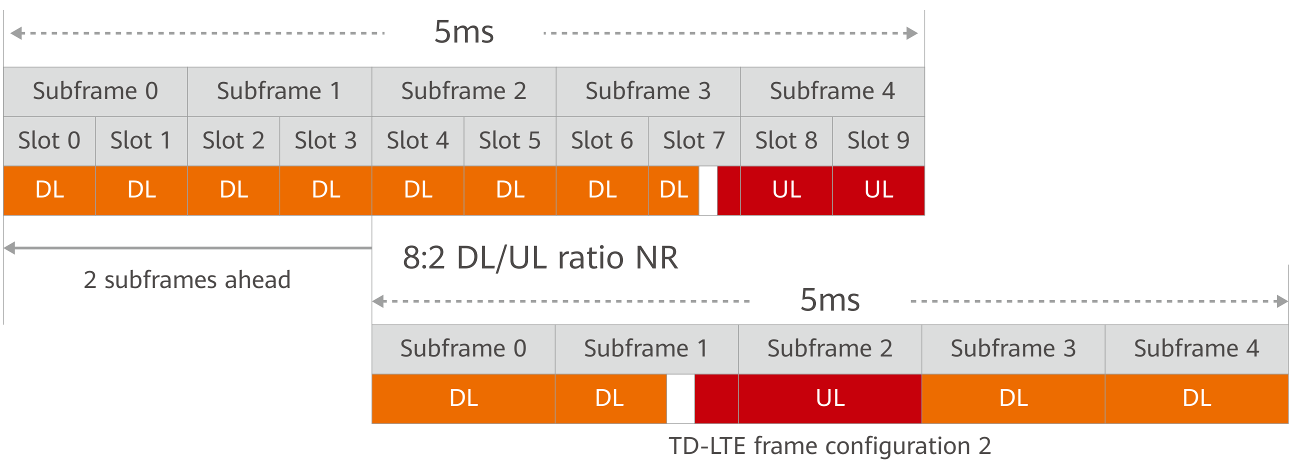
Figure 10: 2.5ms periodicity frame structure

2.5ms									
Slot 0	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8	Slot 9
DL	DL	DL	DL	UL	DL	DL	DL	DL	UL

Figure 11: 2.5ms dual periodicity frame structure

2.5ms									
Slot 0	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8	Slot 9
DL	DL	DL	DL	UL	DL	DL	DL	UL	UL

Figure 12: 5ms periodicity frame structure



6 Long-term Trends

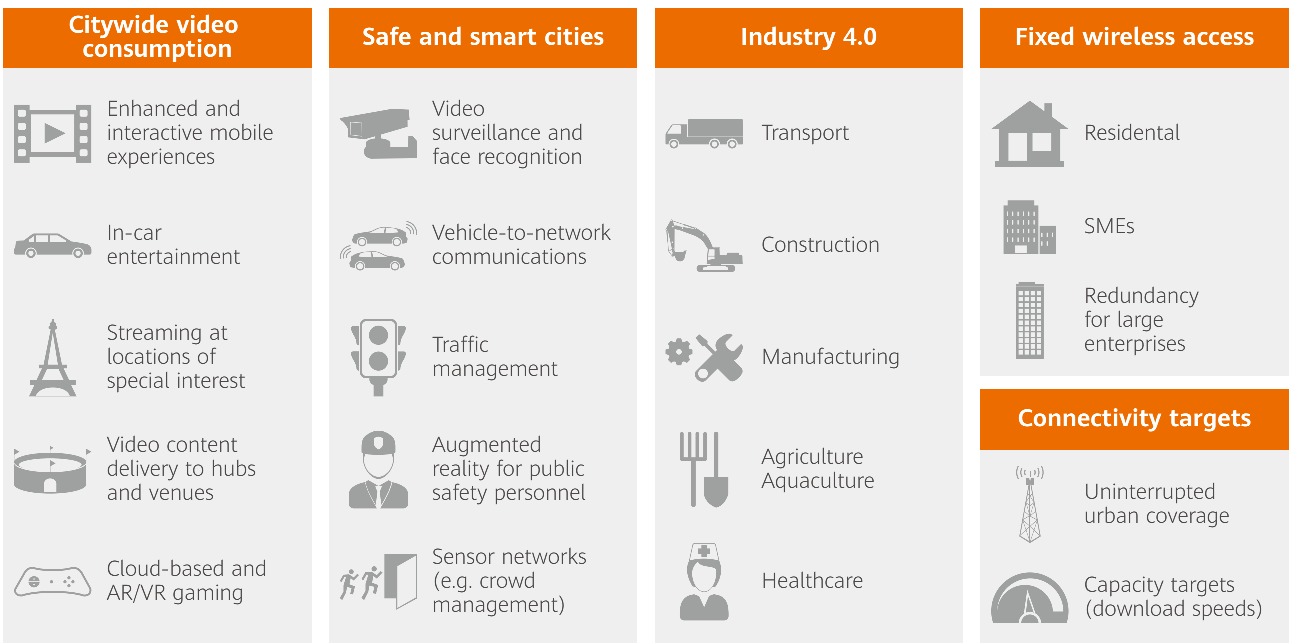
6 GHz band is essential for sustainable development of 5G in the next 10 years

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

- Mobile broadband and citywide video consumption
- Mobile networks for safe and smart cities
- Mobile networks for Industry 4.0
- Fixed wireless access (FWA)
- National connectivity objectives

The figure below depicts the many applications that could become available, and which could exploit mid-band spectrum availability, through 5G citywide high capacity coverage in urban and suburban areas.

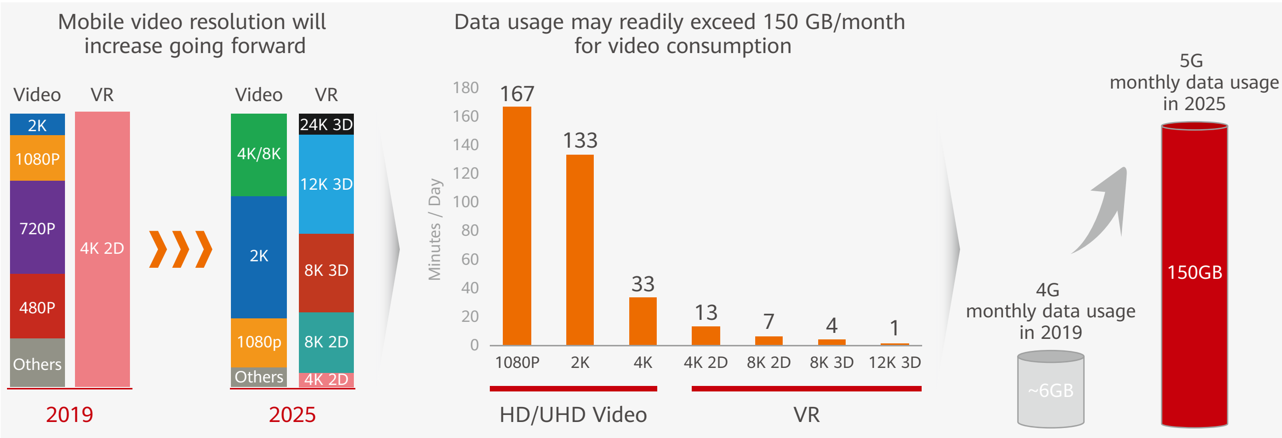
Figure 13: 5G applications for use of mid-band spectrum for citywide high capacity coverage



Source: Analysys Mason,"Discussion on the 6 GHz opportunity for IMT", November 2019

In the coming years, it is expected that data usage per user will continue to grow substantially and might exceed 150 GB per user per month in some advanced markets. This will be driven by HD/UHD video and AR/VR consumption (see examples in Figure 13), and by the increasing availability of unlimited data price plans or the deployment of fixed wireless access networks, although variability between countries and regions will remain.

Figure 14: Driven by HD/ UHD video and VR, 5G monthly data usage per user may exceed 150 GB by 2025



Source: Huawei

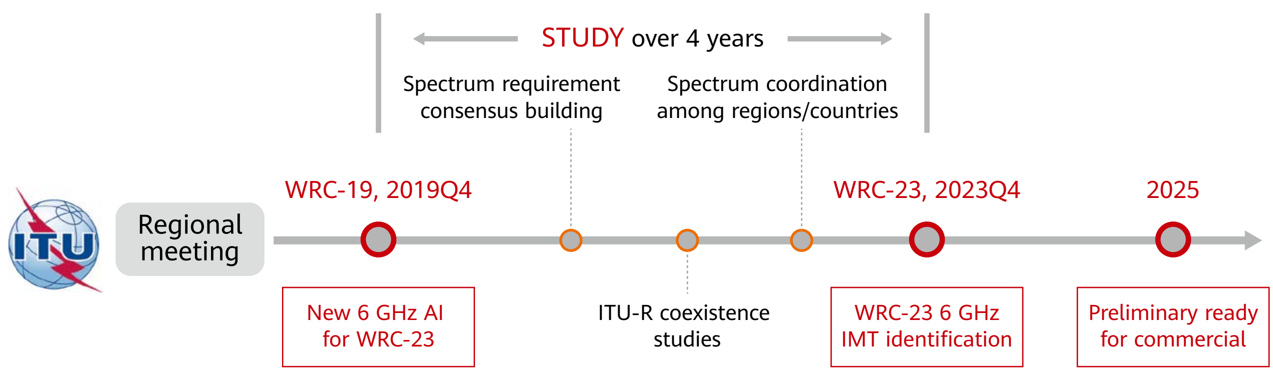
We consider the band 5925-7125 MHz to be a strong mid-band candidate to address the future connectivity needs that have been outlined above. The band presents several promising characteristics:

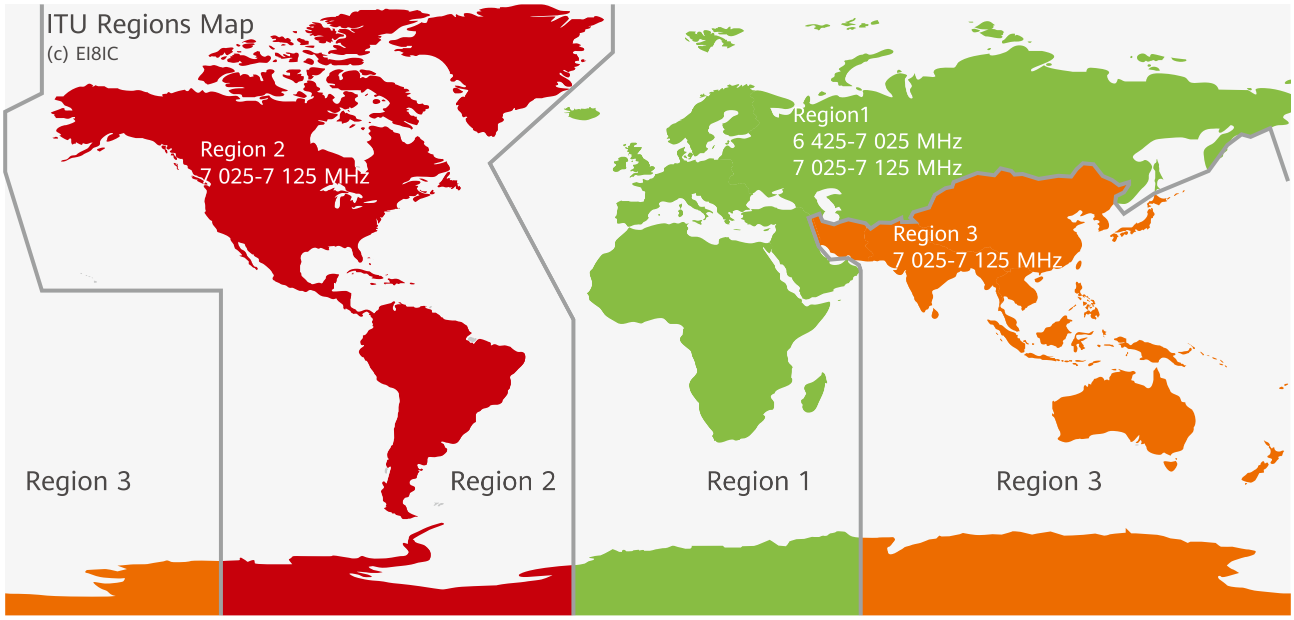
- There is a good balance between coverage and capacity in the band, comparable to the 3-5 GHz range;
- The outdoor to indoor coverage is comparable to the 3-5 GHz range;
- The band can support large contiguous blocks (within the potentially available 1.2 GHz);
- The frequency band 5925-7125 MHz has a primary allocation to the Mobile Service in all Regions in the Radio Regulations.

Other services with primary allocation in the band, namely the Fixed Service (FS) and Fixed Satellite Service (FSS), need to be considered and accounted for in the context of coexistence with IMT.

Indeed, the 6 GHz range has drawn the most common interest as a mid-band for future phases of IMT deployments globally. At WRC-19, a new WRC-23 agenda item for the study of 6 GHz for IMT identification was approved, with consideration of 7025-7125 MHz globally and 6425-7025 MHz in Region-1.

Figure 15: New agenda item for study of 6 GHz towards IMT identification at WRC-23





Source: Huawei

The agreed agenda item requires studies during the period 2019-2023, to understand the possibilities to deploy IMT while protecting existing services in the band. Based on the results of such studies, national administrations will be able to take informed decisions on the future availability of the band for IMT.

The concept of tuning range

While decisions on the future identification of the 6425-7125 MHz band will be taken at WRC-23, there is an ongoing debate across the globe in relation to the usage of the broader 5925-7125 MHz range. Therefore, the agreed WRC-23 agenda item and associated studies for 6425-7125 MHz should not prevent countries from proceeding with their respective regulatory actions on the 5925-7125 MHz frequency range, according to their national requirements. Given the current usage in this band, and:

– the fact that spectrum usage is different in different parts of the world, and

– the fact that some parts of the world may wish to use different mobile applications within the band,

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

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

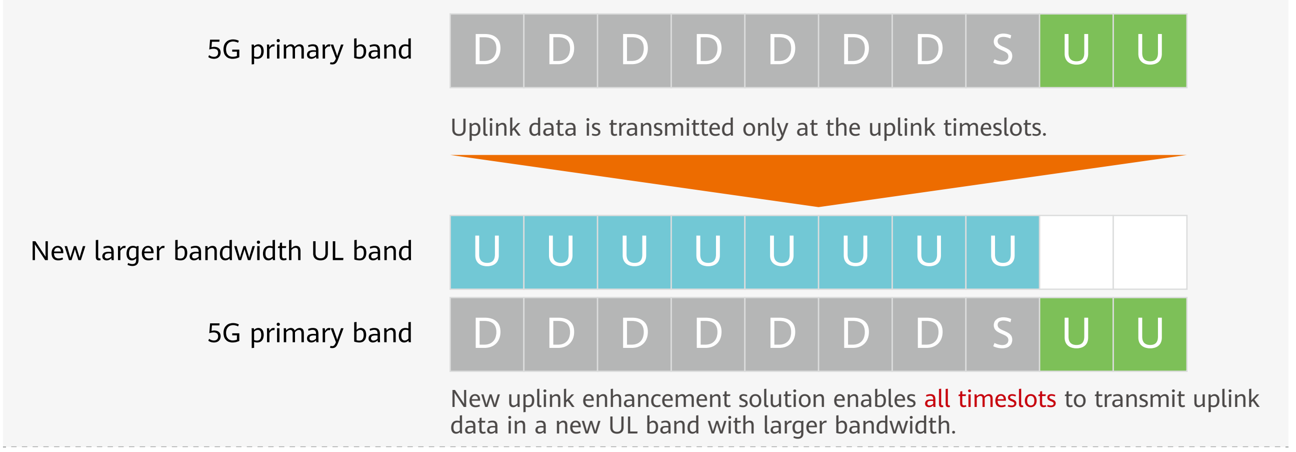
The benefit of this approach would be to provide international harmonisation even when different countries use different segments of 5925-7125 MHz for IMT. Harmonised spectrum and tuning ranges lead to a larger ecosystem for technologies, resulting in economies of scale and lower costs for deployment. Devices will be able to operate anywhere within the tuning range. However, they will only operate within the portions of the tuning range assigned within an individual country.

Uplink enhancement based on MNOs' public networks will meet the capacity requirements of vertical services, and more bands are needed for future uplink usage

There are a number of vertical industries whose productivity and business opportunities could greatly benefit from 5G. Currently, mobile operators are working with vertical industries to jointly explore applications and network architectures for 5G services in a wide range of vertical use cases, some of which are already being investigated in pilot projects. Among these use cases, tele-operated/autonomous driving, smart factories, and robotics are some of the most challenging, with requirements for high data rates on the uplink. For example, in a typical smart factory with an area of 10,000 m^2, the data rate requirement for the uplink may exceed 1 Gbps.

Moreover, as applications such as the uploading of HD live video by end users become increasingly popular, this will also drive a requirement for significantly increased uplink capacity in mobile networks at locations of special interest such as transport hubs, malls, tourist attractions, sports stadiums and others. However, today the vast majority of 5G deployments are in the unpaired 3300-3800 MHz band. Due to the propagation characteristic and downlink centric frame structures used in this band, uplink coverage and data rates face greater challenges here than at lower frequencies. Furthermore, restrictions in uplink coverage and throughput will have a negative impact on the overall user experience. To improve the uplink performance, especially capacity, of TDD 5G-NR at the cell edge, solutions for enhanced uplink can be introduced as outlined in Figure 16.

Figure 16: Example of new UL enhancement solution for 10x uplink capacity enhancement (5G NR co-existence with LTE TDD)



Source: Huawei

Although using traditional supplemental uplink in LTE bands as described in Section 5.2 could solve the uplink coverage issue, it may not bring sufficient improvement in uplink capacity due to the limited available bandwidth in these bands. This indicates the need for a mix of new bands at frequencies both above and below 3300-3800 MHz to support larger bandwidths in the uplink (e.g. at 2300-2400 MHz and 3300-3400 MHz).

7 Recommendations

Policy makers and regulators are recommended to account for the following factors in their spectrum management programs.

Spectrum for the deployment of 5G

- Unpaired mid-bands at 3300-3800 MHz, 2600 MHz and 2300 MHz are primary bands for 5G deployment. The availability of at least 80-100 MHz of contiguous spectrum per operator at mid-bands is important for the initial introduction of 5G.
- Mid-bands at 4900 MHz and 3800-4200 MHz are supplementary to the 5G primary bands in specific countries.
- Allocation of new FDD bands for 5G, or using dynamic spectrum sharing (DSS) between LTE and 5G-RN in existing FDD bands, would facilitate the fast rollout of 5G.
- The 6 GHz band is essential for the sustainable development of 5G in the next 10 years.
- While uplink enhancement techniques based on MNOs' public networks will help better meet the capacity requirements of vertical services, bands with larger bandwidths are needed to support future increased uplink usage.

Policy and regulations for 5G

- Exclusive national licensing is the preferred authorisation model for 5G.
- New spectrum assignments should be technology neutral.
- Inter-operator synchronisation and time alignment of uplink and downlink transmission frames is a necessity for efficient deployment of 5G-NR.
- Significant lower pricing of 5G spectrum compared to 4G, with auction fee payments spread over time, and regulations for appropriate network provisions to enhance end user experience are proposed.

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