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5G MOBILE SERVICES AND NETWORKS

23 May 2017

PART I: INTRODUCTION

1. The telecommunications industry has been undergoing rapid and significant transformation since the arrival of smartphones almost a decade ago. The following key drivers are expected to shape the future of the mobile industry:

i) <u>Availability and wide-spread adoption of mobile devices.</u> Smart phone take-up is increasing and the GSM Association ("**GSMA**") estimates that by 2020 the number of connections will reach 5.8 billion[1]. A survey conducted by Deloitte in 2015 has also revealed that Singapore has one of the highest smartphone penetration rate, with nine out of ten respondents having smartphone access[2].

ii) <u>Service level innovation and competition.</u> There is an ever increasing range of applications and uses being developed for mobile and smartphone devices. As of 2015, almost 250 billion mobile applications have been downloaded globally[3]. This has put many over-the-top ("**OTT**") services in competition with the traditional voice and SMS services offered by Mobile Network Operators ("**MNOs**") and Mobile Virtual Network Operators ("**MVNOs**"), as well as audio-visual services by terrestrial broadcasters and other media outlets.

iii) <u>Technology evolution in the mobile networks.</u> The rollout of Long Term Evolution - Advanced ("**LTE-Advanced**") technology has enabled vastly improved speeds, better coverage and user experience, and has fuelled growth in mobile data consumption. To meet the increasing demand for mobile data services, new frequency bands have been made available to facilitate growth and innovation while MNOs upgrade their networks from 2G to 3G and 4G to take advantage of the significant improvements in spectral efficiency with technology advancement. Today, of the 8.4 million mobile subscribers, about 67% of them are on 4G networks[4]. In addition, technologies such as Network Function Virtualisation ("**NFV**") and Software Defined Networks ("**SDN**") have the potential to provide MNOs with simpler network architecture solution that is able to tailor to different industries and applications.

iv) <u>Data-centric revenue trends.</u> Emerging and disruptive technologies have shifted consumer demand from traditional voice and messaging services towards IP-based communication and content delivery. Mobile data has emerged as a major driver of telecom revenue growth. Global mobile data

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[1] GSMA, The Mobile Economy 2016, https://www.gsmaintelligence.com/research/?file=97928efe09cdba2864cdcf1ad1a2f58c&download

[2] Deloitte, Mobile Multiples: Global Mobile Consumer Survey 2015, https://www2.deloitte.com/content /dam/Deloitte/sg/ Documents/technology-media-telecommunications/sg-tmt-global-mobile-consumer-survey-noexp.pdf

[3] Plum Consulting, A policy toolkit for the app economy (April 2016), http://plumconsulting.co.uk/policy-toolkit-app-economy/

[4] https://www.imda.gov.sg/industry-development/facts-and-figures/telecommunications/statistics-on-telecom-services/statistic-on-telecom-service-for-2017-jan

revenue accounted for approximately half of the total mobile revenue in 2015 and it is projected to grow at an annual rate of 7% till 2020[5].

2. The rapid growth in mobile data traffic and consumer demand for enhanced mobile broadband experience have led to an increasing emphasis on the upcoming fifth generation of mobile technology ("**5G**"). Seen as a comprehensive wireless-access solution with the capacity to address the demands and requirements of mobile communication beyond 2020, it is projected that this technology will operate in a highly heterogeneous environment and provide ubiquitous connectivity for a wide range of devices, new applications and use cases.

3. Since 2013, commercial and regulatory activities have begun preparations for 5G technology. Commercial activities include collaborative field trials to validate the use of different mobile radio access techniques. On the regulatory front, administrations world-wide are making efforts to identify additional spectrum for 5G. Additionally, standards bodies are working to complete the 5G technical standards. In 2015, the International Telecommunication Union ("**ITU**") published a detailed timeline and process to deliver the specifications for IMT-2020 as part of its plans to realise its vision of a 5G mobile broadband connected society.

4. Hence, through this public consultation, the Infocomm Media Development Authority ("**IMDA**") hopes to seek views and comments on the various aspects of 5G technology development and spectrum requirements in a data centric environment, and the increasing heterogeneity of networks using unlicensed and licensed spectrum bands. Feedback received from this public consultation would assist IMDA in developing the necessary policies to facilitate the deployment of more innovative and advanced mobile technology, networks and services in Singapore.

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5 Pyramid Research 2016, http://www.pyramidresearch.com/about-us/media-center/press-releases/mobile-network-operators-set-to-earn-over-600-billion-per-year-from-mobile-data-by-2020-says-pyramid-research/

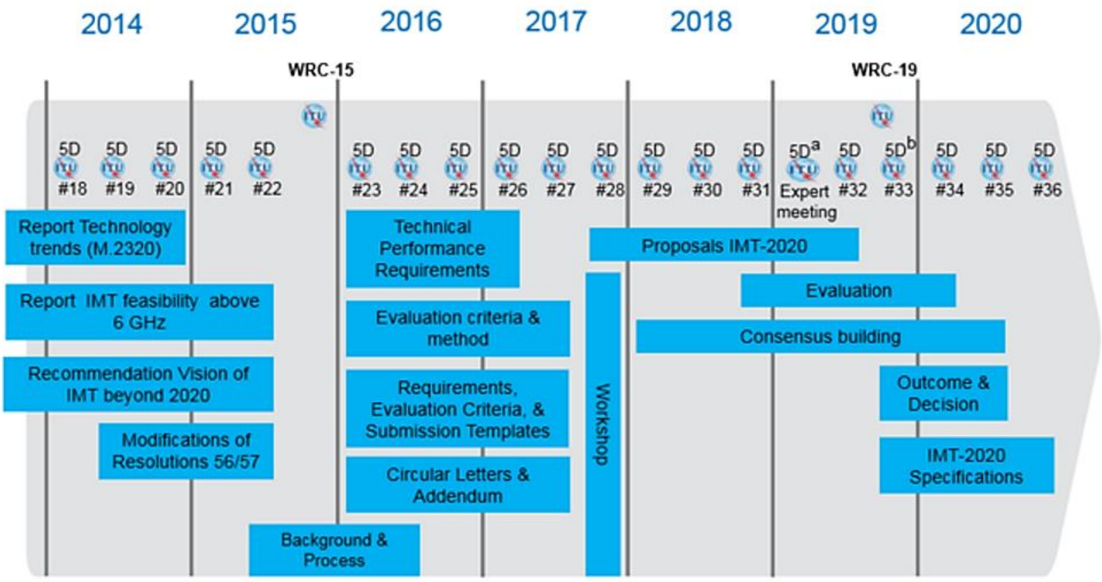
PART II: TECHNOLOGY AND USE CASES

Overview

5. The heterogeneous nature of the next generation of mobile broadband technology suggests that 5G technology is likely to consist of several different platforms or networks which will be made available to users on a seamless basis. There might also be a need for "densification" of mobile sites to support the increase in speed, capacity and user experience.

6. Since early 2012, the radio-communication sector of ITU ("**ITU-R**") has begun developing its vision for International Mobile Telecommunication beyond 2020 ("**IMT-2020**"). The "IMT Vision for 2020 and beyond" was finalised in September 2015 with the aim of building a mobile broadband connected society through enhanced mobile broadband, massive machine type communications and, ultra-reliable and low latency communications[6]. Through the leading role of Working Party 5D ("**WP5D**"), ITU-R has also established its projected timeline towards IMT-2020 (see Figure 1). Studies on the different elements of IMT-2020 are already in progress as ITU-R works together with the mobile broadband industry and various stakeholders in the 5G community.

Figure 1: Detailed Timeline & Process for "IMT-2020" in ITU-R



Source: ITU-R

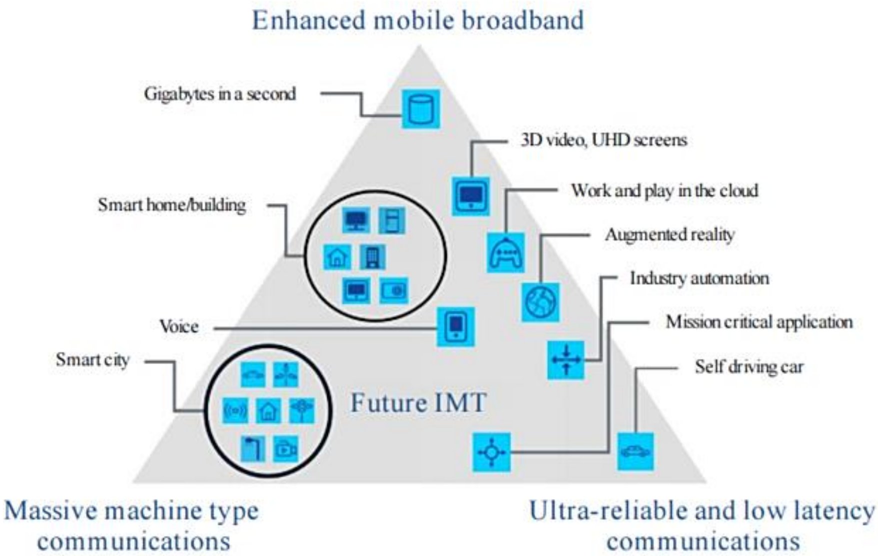
7. With the standardisation process at an early stage, it is anticipated that 5G will be commercialised around 2020 and in the few years after. It may possibly take until 2025 or later before 5G becomes the predominant communications solution. There are ongoing and upcoming trials on 5G technologies (e.g. Winter Olympics in 2018) to test out the possible technologies and techniques that are likely to be included in 5G.

6 ITU (2015), ITU Working Party 5D study areas and deliverables for 5G technology, http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx

Potential 5G Use Cases

8. The ITU-R, specifically WP5D, and industry associations such as the Next Generation Mobile Networks Ltd ("**NGMN**") have developed their visions of the potential applications that will be part of 5G[7]. Generally, 5G is envisaged to support a wide range of applications and services with heterogeneous performance requirements. ITU-R has identified three broad use cases for 5G and the possible applications and industries that could benefit from the network. Figure 2 illustrates the envisioned usage scenarios for IMT-2020 and beyond.

Figure 2: Usage Scenarios of IMT for 2020 and Beyond



Source: ITU-R

i) Enhanced mobile broadband ("**eMBB**")
Experience with LTE networks has demonstrated that the improved throughput provided by new mobile networks will in turn bring about an increase in demand and consumption of bandwidth-hungry applications, such as video services. eMBB is a natural evolution to the data rates consumers enjoy today with LTE, and will enjoy tomorrow with LTE-A Pro (or 4.5G). Within the global mobile community, the ultimate 5G target is to deliver up to 10Gbps peak throughput and up to 1000 times increase in bandwidth per unit area[8].

ii) Massive Machine-Type Communications ("**mMTC**")
Machine-type communication is identified as an emerging paradigm of interconnected systems, machines and things that communicate with each other automatically without human intervention. Current wireless networks are mainly designed for human type communications. mMTC, also commonly referred to as Machine-to-Machine ("**M2M**") communications, with its various

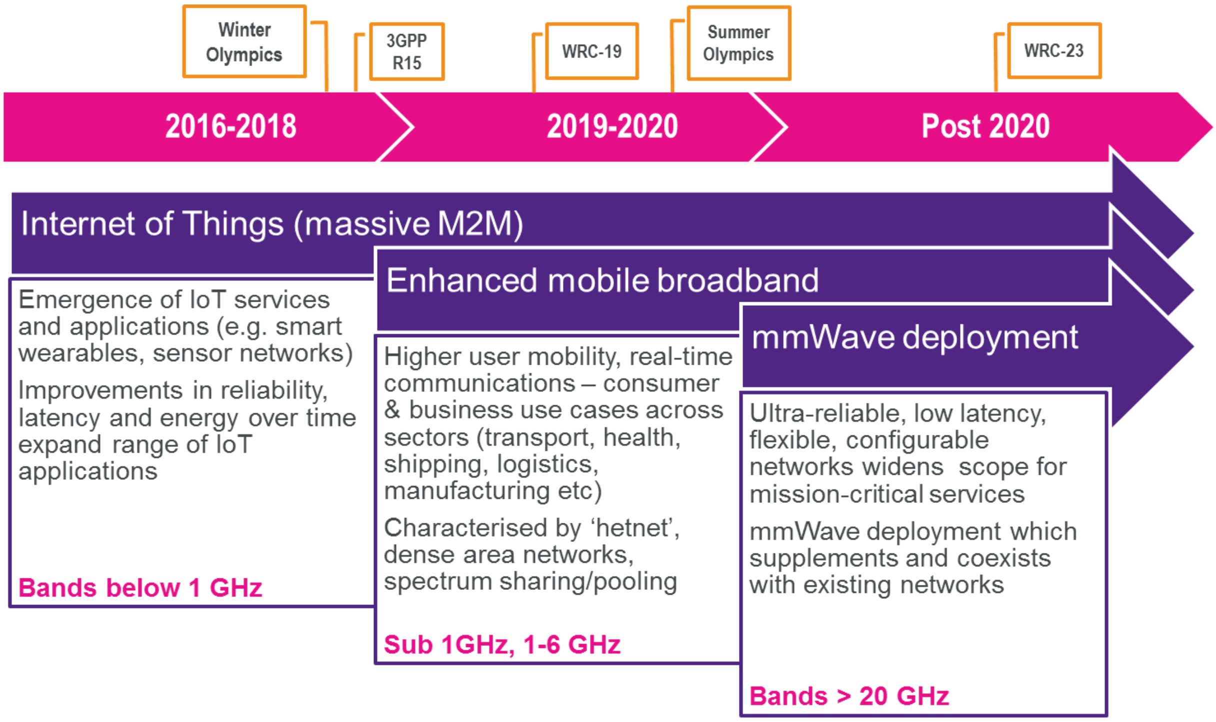
[7] Further information can be found in the "IMT Vision for 2020 and beyond" developed by ITU WP-5D and the 5G White paper developed by NGMN Alliance, 17 February 2015.
[8] GSMA Intelligence Report, "Understanding 5G: Perspectives on future technological advancements in mobile"

device types, low data volume, and performance requirements will have to be supported by very different network structures. With 5G, there is an opportunity to redefine the mobile networks to enable not only faster data access and to support greater capacity, but also incorporate mMTC to support a wealth of new and diverse connected devices and services that comprise the Internet of Things ("**IoT**").

iii) <u>Ultra-Reliable and Low-Latency Communications ("**uRLLC**")</u>
Some use cases and applications might have much more stringent requirements on latency, reliability, availability and possibly throughput. These future applications will demand an end-to-end latency of a few milliseconds and extremely high reliability. 5G is projected to have the capability to fulfil these key performance requirements and therefore to support these unprecedented real-time or mission-critical applications and services.

9. With 5G anticipated to be introduced on or after 2020, MNOs are looking at enhancing their existing networks in order to meet the 5G requirements. The figure below shows the likely deployment phases for some of the major elements that will influence the development of 5G in Singapore.

<u>Figure 3: Estimated Deployment Phases</u>



Question 1: IMDA would like to seek views and comments on the estimated timeline for the deployment of 5G. Besides ensuring that spectrum is made available in a timely manner, what other regulatory measures could assist in facilitating the deployment of 5G technology and applications? What other use cases should IMDA take note of when developing the regulatory framework?

10. IoT and M2M services are recognised as one of the key drivers contributing to the development of digital economy. According to the Ericsson Mobility Report, the M2M market is expected to grow at an annual growth rate of 25 percent to reach approximately 28 billion connected devices by 2021. Similar forecast from Gartner has also shown that there will be approximately 21 billion connected devices by 2020. These projections illustrate a strong growth potential for IoT in the next few years.

11. In this space, there is a need for interconnection and autonomous exchange of data among electronic devices or machines, which often involve sensors and actuators. Current developments within the cellular community indicate that future IoT deployments are likely to be based on the new NarrowBand IoT ("**NB-IoT**") standard which was recently finalised by the 3rd Generation Partnership Project[9] ("**3GPP**") and included as part of 3GPP Release 13[10]. The new NB-IoT standard will help reduce IoT device complexity and cost, enable multi-year (up to 10 years) battery life and provide deeper coverage.

12. Such new cellular-based IoT technologies are popular amongst industry players as IoT services and newer applications could be deployed on existing wireless networks with incremental investments, allowing M2M communications to take advantage of existing cellular network coverage and reduced power consumption. NB-IoT is also widely supported by the industry as it meets the operational requirements of various applications such as those in the industrial sector (e.g. smart manufacturing), public services sector (e.g. intelligent transportation) and home spaces (e.g. smart homes). MNOs in Singapore are currently looking at deploying nationwide IoT networks and have already partnered different technology organisations to roll out IoT services[11].

13. The timing of IoT deployment is expected to precede the ITU's 5G standardisation timetable. The industry anticipates that large-scale IoT deployments will emerge in the coming five years, before any commercial deployment of 5G technology. 5G is expected to enable better integration of IoT within cellular networks when deployed.

Question 2: To facilitate and understand potential spectrum requirements for IoT deployments in Singapore, IMDA would like to seek views on the following:

i) Based on the current spectrum allocated for mobile services in the sub-1 GHz frequency bands, are there further suitable spectrum resources that could be released to support both IoT and LTE services?

9 3GPP Standardisation of NB-IoT Completed, 22 June 2016, http://www.3gpp.org/news-events/3gpp-news/1785-nb_iot_complete

10 Besides cellular-based IoT technologies, there are also other technologies and standards operating in unlicensed bands such as Sigfox, LoRa and Weightless. These technologies, together with NB-IoT are considered as Low-Power Wide Area Network ("**LPWAN**") solutions that could potentially address the gaps in the current M2M solutions.

11 M1 has partnered Nokia and aims to roll out the first nationwide commercial NB-IoT network in Singapore by 2017. Singtel has partnered Ericsson to trial NB-IoT technology in the second half of 2016. Singtel has recently unveiled an integrated IoT solution, Assured+, which connects devices across existing 3G/4G networks, NB-IoT and LTE Cat-M capable of supporting eldercare, connected cars, and other emerging IoT applications. In 2016, StarHub has rolled out its HubLife beta trial which promises a user-centric smart living experience with the use of IoT technology.

ii) How will future generations of mobile networks (e.g. high capacity, low latency) support the growth of IoT and what would be the spectrum requirements?

Capabilities of 5G Technology

14. This section highlights the 5G standardisation efforts and key technology developments that will bring about the vision of a unified mobile network that brings together, seamlessly, various existing and developing technologies and heterogeneous platforms.

Standardisation

15. The key standardisation activities for 5G are being undertaken within ITU-R and 3GPP[12]. ITU-R aims to complete the IMT-2020 radio interface development process in October 2020 (see **Annex A** for the schedule). In 3GPP, the deliverables that relate directly to 5G technology are 3GPP Release 15, Phase 1, which is targeted for completion in June 2018 to meet the needs of the Tokyo Olympic Games in 2020, and 3GPP Release 16, Phase 2, also referred to as 5G+, is aimed for completion in December 2019.

16. The current proposals and views tend to support the thinking that the 5G radio interface may evolve through 4G and 4.5G (i.e. LTE-A and LTE-A Pro) rather than being a new solution. Operators are likely to continue to work on their investments in 4G technologies, and LTE-A Pro will provide capabilities close to those of 5G. For instance, the current LTE-A Pro standards include a number of key 5G technologies such as increased Multiple-Input and Multiple-Output ("**MIMO**") antennas, NFV and Network Slicing.

Multiple-Input Multiple-Output

17. MIMO technology[13] is considered by the industry to be an important element of 5G as it provides the potential for incremental performance improvement over single input single output ("**SISO**") communications systems. It is an established technology and has been included in current LTE standards – for example LTE-A (Release 10) provides for 8 x 8 MIMO for down-link and 4 x 8 MIMO in the up-link.

18. The principal benefit of MIMO is that there are multiple radio paths and each of these carry data. In theory, doubling the number of antennas at both the transmitter and receiver doubles the transmission data rate. However, this requires the radio paths to have perfect spatial separation, which in practice will be challenging to achieve. Furthermore, there are practical constraints on the number of antenna elements that may be deployed especially in user devices, which are constrained by considerations

[12] 3GPP will submit their candidate technology to the IMT 2020 process in the form of final specifications that are based on the key requirements specified by WP5D with a view of it becoming an accepted IMT 2020 technology.
[13] MIMO is an antenna technology in which multiple antennas are used at both the transmitter and receiver.

such as size of device and battery life to accommodate the additional processing requirements. There is also increased complexity of the hardware (number of RF amplifiers at the front end that may be required). Research is currently ongoing into MU-MIMO (multi-user) and also Massive MIMO[14]. On balance, higher order MIMO arrays may be more challenging for most user devices, it will be an important consideration for base station arrays because of the potential performance improvement.

Software-Defined Networking / Network Functional Virtualisation and Network Slicing

19. SDN originated in the early 2000s in the enterprise IT domain and defines elements of network processing in software rather than hardware. In 2012, SDN concepts were developed further in the telecommunication industry, with developments in the European Telecommunications Standards Institute ("**ETSI**"), leading to the definition of NFV technology. Currently, SDN and NFV technologies are attracting significant commercial interest and attention across both core and access networks with significant product development still ongoing.

20. NFV technology deployed across both Radio Access Network ("**RAN**") and core network is commercially attractive as network systems can be cumbersome when new services are to be implemented. Due to complexity and inflexibility in configuring systems to deliver new services, the concept-to-market cycles for making enhancements across the telecommunication networks and IT systems can run into months in some cases. With NFV, networks and systems can be more easily reconfigured via software updates and this is potentially quicker and more cost effective than custom developments across multiple network elements. This will enable faster configuration for service innovation by allowing closer integration of commercial service design and network configuration functions. Through SDN and NFV, it is possible to configure the network architectures dynamically depending on the service / use case (e.g. low latency, high capacity, low bandwidth machine-machine communication). Such "network slicing" is also considered to be an important feature of 5G.

Handover

21. Another consideration for 5G is how handover will be achieved considering the use of heterogeneous networks[15] ("**Hetnet**") and shared access networks[16]. Traditional mobility services such as voice have been built with an inherent cell-to-cell handover solution and users are used to receiving stable quality of voice calls even in mobile situations (e.g. when driving at high speed along a highway). The need for handover in data services is arguably less, where service elements such as video clips and media files are downloaded in bursts. From a user perspective, there is little difference between high speed cellular data and Wi-Fi like services. How seamless handovers

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14 Massive MIMO uses a very large number of service antennas that are operated fully coherently and adaptively. The benefit of utilising such a large number of antennas is that they can be used to focus the transmission and reception of signal energy into smaller geographic areas (spaces) and when combined with simultaneous scheduling of a large number of user terminals, it can lead to significant improvements in throughput, energy efficiency, latency, and robustness to interference.

15 HetNet is a network with complex interoperation between macrocell, small cell and in some cases Wi-Fi network elements.

16 Shared access is where cellular networks can access additional spectrum otherwise apportioned for use by other services.

could be achieved in the Hetnet environment is an area still being studied and developed.

22. One of the key new features promised in 5G is the separation of control and data plane. The idea is that control signalling will be sent over a macro or umbrella cell while data and voice will be handled via a small cell. That makes handover easier because there is a constant channel to the device although it does require the device to be dual-connected. Some manufacturers have acknowledged that this is still work-in-progress and that handover for fast-moving mobile devices in a small-cell environment will be challenging.

23. In view of these forthcoming technologies, IMDA will continue to review existing policies and regulations to ensure that they continue to foster technology advancement and service innovation.

Question 3: IMDA would like to seek views and comments from industry on what they consider will be the key technologies for 5G and whether current regulatory frameworks sufficiently facilitate the deployment of such technologies.

PART III: SPECTRUM REQUIREMENTS

Overview

24. With increased demand for connectivity services and data-intensive applications, adequate and timely availability of spectrum is essential to support the future growth of mobile broadband systems. More importantly, harmonised worldwide spectrum bands are important in order to facilitate global roaming and allow the industry and consumers to benefit from competitive telecommunication equipment arising from economies of scale.

25. Currently, there is a substantial focus on identifying the higher frequency bands for 5G technology. IMDA noted that recent tests conducted by universities and equipment vendors have demonstrated the possibility of using spectrum bands above 6 GHz, also referred to as millimetre wave ("**mmWave**") bands, to support data-intensive applications. However, based on the services and associated key parameters for 5G, it is expected that a mix of low frequency as well as high frequency spectrum is required to more effectively support this technology. Some industry players had indicated that frequencies within the following ranges would be necessary to fulfil the different aspects of 5G[17]:

i) < 1 GHz ("**sub-1 GHz**") will substantially be used for massive IoT;

ii) 1 – 6 GHz for wider bandwidths for enhanced mobile broadband and mission control; and

iii) > 6 GHz (for example mmWave) for dense networks requiring large bandwidths and where the shorter range access is not a problem.

Below 1 GHz frequency bands

26. In February 2016, the then-IDA issued its decision to award spectrum in the 700 MHz and 900 MHz bands through an auction mechanism[18]. Typically, spectrum in the sub-1 GHz bands is used as a coverage layer while the above-1 GHz spectrum is employed as a capacity layer.

27. Considering spectrum is a scarce resource and that Singapore is densely populated with strong mobile data demand, it is important to ensure that spectrum is efficiently utilised to meet the needs of the consumers and the economy. Given the wider telecommunication community's focus on the above-1 GHz bands to support the development of 5G, this paper will focus on identifying additional spectrum in the above-1 GHz bands for future allocation.

[17] Qualcomm, presentation at FCC Spectrum Frontiers Workshop, https://www.fcc.gov/news-events/events/2016/03/spectrum-frontiers-workshop

[18] The spectrum in the two spectrum bands have been successfully auctioned at two auctions held by IMDA in December 2016 and April 2017.

28. However, the foregoing should not be construed as there will be no sub-1 GHz spectrum allocation that will be released going forward. For example, IMDA had earlier identified the 800 MHz band for mobile services and sought the industry's views on the possible band plans and approaches to re-farm this band in the public consultation document titled "Second consultation on proposed framework for the allocation of spectrum for international mobile telecommunications ("IMT") and IMT-Advanced services and for the enhancement of competition in the mobile market"[19]. Based on the responses, the then-IDA projected that approximately 3 to 5 years is required before this band can be released for mobile services. This timeline takes into consideration existing users in the 800 MHz band and the complexity of the re-farming process. Since then, IMDA has begun engaging affected users in this band and proceeded with the migration with the target to complete the process by 2021. IMDA will also conduct a separate consultation on its plans to re-allocate the 800 MHz band for mobile services when ready.

Question 4: IMDA would like to seek views and comments on whether going forward, there is a need for further spectrum below 1 GHz to be identified and release for mobile services?

1 – 6 GHz Frequency Bands

29. IMDA has earlier identified several spectrum bands in the 1 – 6 GHz range for mobile services. These frequency bands include the 1.4 GHz, 1.9 GHz, 2.1 GHz, 2.3 GHz, 2.5 GHz and 3.5 GHz band. Based on feedback gathered from the earlier consultations with the industry, IMDA has decided to allocate the 2.3 and 2.5 GHz bands (namely 2300 – 2340 MHz and 2570 – 2615 MHz) via an auction mechanism[20]. There have been recent developments in the 1427 – 1518 MHz band ("**L-band**") and the 3400 – 3600 MHz band ("**extended C-band**") at the regional and international forums. IMDA is further exploring the possibility of allocating these two bands for IMT services.

<u>L-Band</u>

30. At WRC-15, the L-band was harmonised for IMT, providing up to a total of 91 MHz of spectrum within the Asia Pacific and Americas regions. However, in the European region, only part of the L-band (i.e. 1427 – 1452 MHz and 1492 – 1518 MHz) was harmonised for IMT through regional footnotes and this limits the allocation of this band for IMT to countries specified in the footnote. With this band largely harmonised for IMT at WRC-15, the industry would now have a stronger impetus to develop IMT devices that function in the L-band. The three potential IMT deployment techniques in the L-band include the frequency division duplex ("**FDD**"), time division duplex ("**TDD**") and the supplemental downlink ("**SDL**") technologies.

31. In Europe, the sub-band 1452 – 1492 MHz has already been allocated by the European Communication Committee ("**ECC**") for mobile or fixed communication

[19] https://www.imda.gov.sg/~/media/imda/files/inner/pcdg/consultations/20150707_secondpublicconsultation/consultation.pdf?la=en
[20] The identified spectrum in the two spectrum bands have been successfully auctioned at two auctions held by IMDA in December 2016 and April 2017.

networks based on 3GPP Band 32 which specifies an SDL frequency arrangement[21]. However, with the increasing growth in downlink traffic, there are currently proposals to support additional spectrum above and below this band to also be used for downlink[22]. In view of the above developments, it is anticipated that SDL deployment in the 1452 – 1492 MHz band may potentially be effected within the next 5 years. For deployment in the upper and lower parts of the L-band and the use of it outside of Europe, it may take more than 5 years.

32. Based on submissions to ITU Working Party 5D and the APT Working Group ("**AWG**") meetings, IMDA understands that there are some countries within the Asia Pacific region that supports the FDD deployment and this aligns closely to the 3GPP band 11 and 21. The FDD arrangement requires a centre gap and there are still ongoing discussions on the spectrum bandwidth required for this gap but it ranges between 5 to 20 MHz.

33. In Singapore, most of the existing mobile networks are based on FDD technology and as such the FDD eco-system is better established in terms of infrastructure and equipment availability. To complement the existing infrastructure, it would seem that either the FDD or the SDL arrangement is preferred. However, IMDA also recognises the limitations of both approaches. The FDD arrangement may not offer optimal spectrum utilisation due to the need for a centre gap, while the SDL arrangement would only increase capacity in the downlink direction (i.e. communication link from the base station to the mobile phone). In addition, both the FDD and SDL approaches do not allow flexible uplink to downlink ratios to cater to the varying traffic demands.

34. Besides the FDD and SDL arrangements, IMDA notes that 3GPP band 45 (1447 – 1467 MHz) is based on the TDD arrangement. However, it is not known if there has been any support or interest in deploying the L-band using the TDD technology, because while it has its advantages (e.g. higher spectrum efficiency and variable downlink ratio), TDD has a shorter operating range and higher latency.

35. There are further studies required post WRC-15 to address both the frequency arrangement and adjacent channel coexistence. Currently, there are discussions ongoing within the ITU-R and the European Conference of Postal and Telecommunications Administrations on the issue of adjacent band sharing with Mobile Satellite Service ("**MSS**") around the 1518 MHz band. The satellite industry has highlighted that the technical restrictions would most likely consist of a guard band between IMT and MSS and an out-of-band emission mask. WP4A and WP5D have produced a few co-existence solutions and a number of possible band plans but none has been adopted so far.

36. Singapore supported the identification of the L-band for IMT at WRC-15 and plans to release a portion of this spectrum when the co-existence studies are finalised at the ITU-R. Based on feedback gathered from this public consultation, IMDA plans to submit proposals on the L-band frequency arrangements to WP5D and AWG meetings

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[21] ECC Decision 13(03) and a subsequent EC Decision 2015/750(EU)

[22] In addition to 3GPP Band 32, there are other 3GPP band plans within the range of 1427 – 1518 MHz. For example, 3GPP Band 11 with FDD arrangement in 1427.9 – 1447.9 MHz and 1475.9 – 1495.9 MHz, and 3GPP Band 21 with FDD arrangement in 1447.9 – 1462.9 MHz and 1495.9 – 1510.9 MHz.

for regional and global harmonisation. This is part of IMDA's continuing work from WRC-15 on the harmonisation of the L-band for the Asia Pacific region.

37. In the meantime, IMDA has made available the L-band in Singapore for trial. In the decision paper issued by the then-IDA on "Framework for the Allocation of Spectrum for International Mobile Telecommunications ("IMT") and IMT-Advanced services and for the enhancement of competition in the mobile market" on 18 February 2016, IMDA stated that it will make available spectrum in the 1452 – 1492 MHz band for interested parties to conduct trials, for temporary use, and/or offer commercial services. Trials may be conducted under IMDA's Technical Trial ("**TT**") or Market Trial ("**MT**") frameworks and commercial services may be offered using spectrum assigned on a non-interference and non-protection basis. As refarming of the identified L-band spectrum for mobile services will take approximately 3 to 5 years, it is anticipated that suitable L-band frequency spectrum will be released for IMT thereafter.

Question 5: IMDA would like to seek views and comments on the following:

i) The frequency arrangement that is better suited for adoption in Singapore for the L band (i.e. SDL, TDD or FDD) and the supporting reasons; and

ii) The timeline for access to the L band and the availability of the equipment (specifically whether it will be available earlier or later than 2020).

Question 6: Considering the spectrum bands within the range of 1-6 GHz to support the deployment of enhanced mobile broadband services, IMDA would like to seek views on whether all of the 91 MHz of spectrum in the L-band should be allocated for IMT to address Singapore's data demand and growth.

Extended C-Band

38. There is increasing interest and support for accessing the C-band[23] for mobile, either for LTE or possibly 5G depending on availability, especially in those countries with little or no use of the C-band for satellite services. For example, it has been proposed that the EU should establish 3400 - 4200 MHz for 5G, focusing on urban deployment with satellite use to continue in non-urban areas[24] and it is understood that China is considering the use of C-band as the foundation for the 5G coverage layer[25] while in the US, the 3.5 GHz band (3550 – 3650 MHz) has been opened up through a three-tiered spectrum sharing scheme[26] which enables incumbents' continued access to the 3.5 GHz band while allowing new services to be deployed in the band.

[23] This in theory could be anywhere between 3300 and 4200 MHz.
[24] This view was expressed at the Radio Spectrum Policy Group Stakeholder Workshop in March 2016 held in London. The Radio Spectrum Policy Group is a high level advisory group that assists the European Commission in the development of radio spectrum policy.
[25] See http://www.mobileworldlive.com/asia/asia-news/china-preps-ground-for-5g/
[26] The three-tiered approach is based on incumbents being provided with the highest level of protection based on their current licences / usage, followed by new geographical licences that would occupy part of the spectrum and cover a specified localised area, and then general access users who will be afforded the least protection on an opportunistic basis (possibly licence-exempt use). https://www.fcc.gov/rulemaking/12-354

39. IMDA previously, in the public consultation on the "Proposed Framework for the Allocation of Spectrum for International Mobile Telecommunications and IMT-Advanced Services and for the Enhancement of Competition in the Mobile Market"[27], sought views from industry players on interest in the extended C-band for IMT systems and proposed that the use of the band could be for deployment of in-building mobile systems which would limit any impact on existing users of the Fixed Satellite Services ("**FSS**") and TV Receive-Only ("**TVRO**") services. In February 2016, IMDA indicated that it would take in the industry's comments and the outcome of the WRC-15 discussions, and conduct further technical assessment on the co-existence between mobile services and existing users before deciding on the long-term plan for this band[28].

40. This paper thus further examines the options and technical solutions possible to overcome the co-existence challenges with satellite uses in the region, particularly in the extended C-band.

41. IMDA recognises that there is an extensive number of C-band satellites in the geostationary orbit in the Asia Pacific region that is providing a wide range of communication services (e.g. distribution of TV channels, enabling rural communications and disaster management). Satellite operations in the C-band is also preferred in the Asia Pacific region due to its resistance to rain attenuation. Across Asia, distribution of TV channels through C-band satellite capacity has also been fast growing; reported usage includes transmission of TV channels to the head-end of terrestrial networks, and broadcast of TV channels direct-to-home. Any disruption to the C-band services may thus have a severe impact for countries relying on satellite services for their communication needs.

42. In Singapore, while there is extensive use of the C-band, most of these operations are in the 3.7 – 4.2 GHz range. Some of the uses within this band are for satellite teleport for terrestrial networks. However, for the extended C-band, which is from 3.4 – 3.6 GHz, it is generally under-utilised with a small number of users utilising this band. The majority of users in the extended C-band are for the purpose of satellite signals reception for TVRO stations to individual sites (e.g. hotels, hospitals, etc).

43. Based on the current users and assignments, although the extended C-band spectrum is generally under-utilised, there is still a lack of contiguous spectrum to support the deployment of new services. Considering the geographical size of Singapore, co-channel operations of both IMT and FSS (downlink) services may not be possible. In the event that IMDA makes available the extended C-band for IMT services, IMDA will have to consider either:

i) A full migration, which involves moving all satellite users out of the extended C-band and making available approximately 200 MHz of spectrum for IMT; or

[27] https://www.imda.gov.sg/~/media/imda/files/inner/pcdg/consultations/20140422_proposedallocationspectrumimt/consultationpaper.pdf?la=en

ii) A partial migration, which involves moving part of the users to the upper ranges of the extended C-band and making available part of the 200 MHz spectrum for IMT.

44. In either approach, satellite users within the extended C-band will have the option to migrate upwards to the C-band in the 3.7 – 4.2 GHz, and from a technical perspective the operations should not be impacted since the propagation characteristic of the C-band is similar to the extended C-band. A guard band will also have to be put in place to address any adjacent channel coexistence issues.

45. Regardless of which approach is adopted, IMDA will still have to put in place criteria to manage cross-border coexistence in the extended C-band. Such criteria are already defined within the ITU Radio Regulations ("**ITU RR**") and this is through limiting the power flux density of the mobile base station at the border of the territory of another country. IMDA will have to adhere to the guidelines stipulated within the ITU RR.

46. Studies undertaken prior to WRC-15 in the ITU-R Joint Task Group ("**JTG**") 4-5-6-7[29] considered a range of different deployments, from macro suburban to small cell indoor, and the related IMT-Advanced system parameters for base stations and user equipment. The calculated separation distances[30] required to protect FSS earth stations when operating co-channel are such that macro-cell deployment is not feasible. However, the distances, when considering small-cell outdoor and indoor deployments are significantly less to avoid co-channel interference[31]. These distances range from 5 km to 26 km.

47. Bilateral agreements between Singapore and its neighbouring countries may have to be established to ensure that any IMT deployment in Singapore will not cause interference to satellite services across the borders. As part of this agreement, coexistence parameters will have to be defined so as to mitigate cross-border interference, this could either be coordinated at the regulatory or operator level. In the long term, should the extended C-band be fully harmonised internationally for IMT services, it is possible that such cross-border interference mitigation techniques will no longer be required.

Question 7: If it is only the extended C-band that is considered for IMT, would the migration of existing satellite users to the other parts of the C-band (i.e. 3.7-4.2 GHz) impact their service provisioning?

Question 8: Considering the challenges of co-channel deployment of FSS and IMT services in the extended C-band, IMDA would like to seek views and

[29] See Annex 17 to the JTG 4-5-6-7 Chairman's Report.
[30] For example, separation distances in excess of 30 km have been indicated.
[31] A study by Transfinite for the UK regulator, Ofcom that looked at sharing in C-band examined in detail, a scenario where there were 50 small cell outdoor base stations deployed in an area of a circle of radius 1.69 km around a VSAT in Central London. The analysis suggested that an exclusion zone of between 0.56 – 3.3 km² around the VSAT would be sufficient. This was considered feasible due to the mobile network base stations operating in a dense urban environment. It was concluded that the exclusion zone could be as small as 0.02 km² if various mitigation methods such as site shielding or limiting the number of base stations in the vicinity to limit aggregate interference were implemented.

comments on the coexistence measures for adjacent bands and cross border operations.

Question 9: IMDA would like to seek views and comments on whether there are other frequency bands in the 1-6 GHz frequency band that IMDA should consider for IMT / 5G.

Above 6 GHz Frequency Bands

48. One of the key concepts for delivering 5G services involves the use of mmWave bands to deliver high-speed mobile services and other high-bandwidth uses. Frequency bands above 20 GHz have been specifically identified as being used for 5G. However, there is currently no consensus on the amount of spectrum that might be required in these bands. Estimated calculations based on the requirement to support 1000 times increase in mobile data traffic and assuming a spectrum efficiency increase of 5 times still suggest the need for 20 times more spectrum. Studies have estimated that between 500 MHz and 2 GHz of spectrum[32] in the 6 – 100 GHz frequency bands are required to provide the required capacity and support the data rates that consumers expect.

49. Currently, frequency spectrum above 20 GHz can be broadly divided into three groups, low (24 – 40 GHz), medium (40 – 53 GHz) and high (66 – 86 GHz), and the table below compares the characteristics of the three groups.

Table 1: Comparison of Frequency Bands above 20 GHz

Broad grouping	**Key characteristics**
Low: 24 – 40 GHz	At the lower end of this frequency range, the relatively large wavelengths constrain the gain and directivity that can be implemented in small antennas. As such, the circuits and devices developed for this frequency bands take a traditional form, this would assist in minimising development costs as existing components can be used in new designs. The majority of industry trials in the mmWave band for 5G have taken place at the 28 GHz.
Medium: 40 – 53 GHz	Allows for implementation of devices with relatively low-cost chipsets.

32 Ten Key Rules of 5G Deployment, Nokia, http://resources.alcatel-lucent.com/asset/200006

Broad grouping	Key characteristics
High: 66 – 86 GHz	At the lower end of this range, propagation is constrained by the upper edge of the oxygen absorption peak which is centred at 60 GHz. Although the technology constraints in this band are potentially challenging, these may be ameliorated by the investments being made in two mass-market applications; IEEE 802.11ad (aka 'WiGig') at 57-66 GHz and automotive radar at 77-81 GHz.

50. At WRC-15, a number of mmWave bands have been identified for consideration at WRC-19 for 5G deployment. These mmWave bands are highlighted below and studies still need to be undertaken to assess the viability and feasibility of IMT deployment in these bands.

Table 2: mmWave bands identified for consideration for 5G deployment

Broad grouping	Candidate Bands (Allocated for Mobile Services in the ITU RR on a Primary Basis)	Candidate Bands (Not allocated to Mobile Services in the ITU RR)
Low: 24 – 40 GHz	24.25 - 27.5 GHz 37 - 40.5 GHz	31.8 - 33.4 GHz
Medium: 40 – 53 GHz	42.5 - 43.5 GHz 45.5 - 47 GHz 47.2 - 50.2 GHz 50.4 - 52.6 GHz	40.5 - 42.5 GHz 47 - 47.2 GHz
High: 66 – 86 GHz	66 - 76 GHz 81 - 86 GHz	

51. The 32 GHz and 66 GHz bands received support from all Regions at WRC-15[33] which is a possible indication that these two bands are most like to be globally harmonised.

52. There may well be inputs for other bands to be considered such as the 28 GHz band (i.e. 27.5 – 29.5 GHz), which a majority of vendors see as an important band and is supported by Japan, Korea and the US. IMDA understands that the 28 GHz band is used for feeder uplink and part of this band is used for uplink from user terminals. The user terminals are mobile, deployed on ships, aircraft and land vehicles, which may operate from almost any location in the world. The 28 GHz band in Singapore is currently under-utilised, and uplink transmission will mostly be confined to air platforms

[33] This was under agenda item 10, which was the proposed new agenda item for WRC-19.

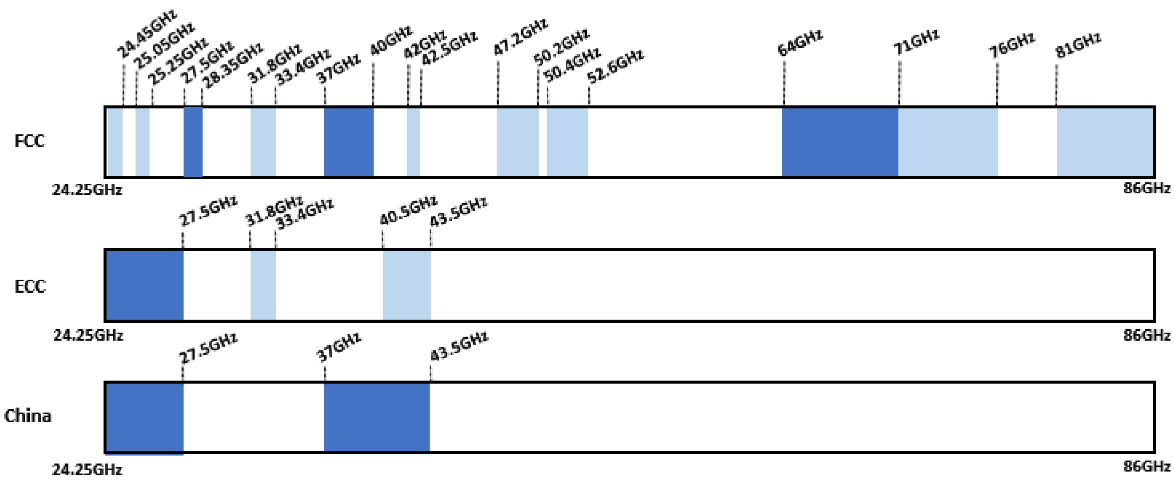
or vessels, restricted to certain technical parameters such as emission power and minimum operating elevation angle[34].

53. At WRC-15, Singapore, along with the other proponents of the 28 GHz band had highlighted that the purpose of including this band into the WRC-19 agenda item was to invite ITU to conduct technical studies to explore the possibility of coexistence. However, due to concerns of potential interference from several countries that had assigned this band for FSS uplink and fixed services, the 28 GHz band was not included in the WRC-19 studies.

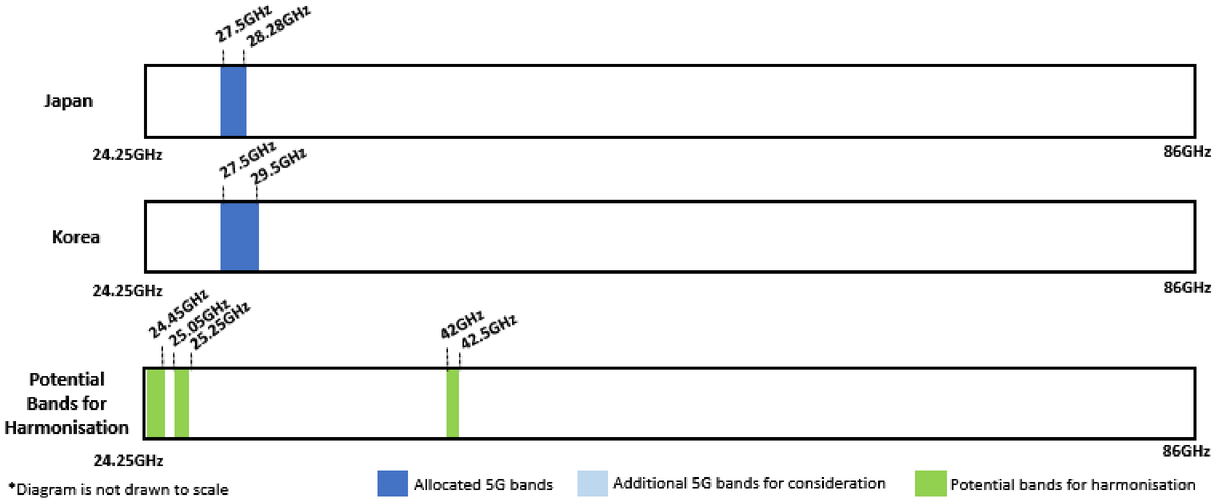
54. Notwithstanding this development, US has opened up this band for mobile services[35] and it is likely that Korea and Japan will follow suit. IMDA will closely track global technology and market developments in this band and assess if there will be commercially available devices that will be developed to support IMT services in the 28 GHz band[36].

55. In addition to the 28 GHz band, the Federal Communications Commission ("**FCC**") has made available the 37 GHz (37 – 38.6 GHz), 39 GHz (38.6 – 40 GHz) and the 64 – 71 GHz bands for 5G services in the US, with further consideration given to eight other spectrum bands. While in the European region, the ECC has indicated that their key interest will be in the 26 GHz (24.25 – 27.5 GHz), and further consideration will be given to the 32 GHz (31.8 - 33.4 GHz) and 42 GHz (40.5 – 43.5 GHz) bands. China is also targeting to deploy commercial 5G networks in the 26 GHz (24.25 – 27.5 GHz) and 42 GHz (37 – 43.5 GHz) bands. A summary of these bands and their potential for harmonisation is highlighted in the chart below.

Figure 4: Summary of FCC and ECC identified bands for 5G



34 In Singapore, such usage is restricted to only 28.6 – 29.1 GHz (for uplink).
35 On 14 July 2016 the Federal Communications Commission adopted rules that opened up nearly 11 GHz of spectrum (3.85 GHz of licensed and 7 GHz of unlicensed spectrum) allowing flexible mobile use. Unlicensed use is in the 64 – 71 GHz band and when combined with existing high band unlicensed spectrum at 57 – 64 GHz, it provides 14 GHz of contiguous spectrum. A Further Notice of Proposed Rulemaking proposes to make additional bands available under the same flexible framework.
36 If IMDA were to open up this band for IMT, IMDA will have to coordinate the use of this band bilaterally and, if necessary, put in place coexistence measures to minimise cross-border interference.



56. In Singapore, there is currently no incumbent users in any of the frequency bands that have been identified for 5G studies at the WRC-19 so these bands could be made available for 5G trials and IMT at any time. IMDA has waived the frequency fees associated with 5G trials conducted during these 2 – 3 years up to 31 December 2019 to encourage the industry to test the capabilities of a 5G network in Singapore. Trials may be conducted under IMDA's Technical Trial ("**TT**") or Market Trial ("**MT**") frameworks[37] and these trials will provide valuable insights and prepare the industry in the lead-up to the discussions at WRC-19 and for actual 5G commercialisation. Globally, a considerable number of 5G trials are ongoing and more trials are expected in the next 2-3 years leading up to WRC-19. These trials include experimenting with beamforming and tracking, massive MIMO and super-wide bandwidth transmission. Many of these trials are being carried out in the mmWave bands so as to understand the propagation characteristics in these higher bands. The outcome of these trials have been encouraging as they indicate that there is potential to meet the data rates, coverage and latency associated with 5G[38].

57. Separately, IMDA has also received industry interest in the use of the E-band, 71 – 76 GHz paired with 81 – 86 GHz, for commercial applications in Singapore which include fixed-wireless backhaul, inter-building fixed-wireless network and mobile

[37] Broadly, TT may be conducted for the purpose of equipment testing and R&D for any telecommunication service, while MTs may be conducted to assess the commercial potential of a new technology, service or product that is not commercially deployed or offered in Singapore. As such, TTs must be on a non-commercial basis, i.e., trial participants shall not be charged for any service or equipment made available to them during the trial. On the other hand, under the MT framework, operators may commercially charge participants for trial services and each MT licence shall be valid for a period of 6 months from the date of issue. TTs are also limited to localised testing, subject to IMDA's approval.

[38] For example, in May 2016 NTT DoCoMo and Nokia announced that they had "achieved the world's first wireless real-time transmission of ultra-high-resolution 8K video deploying radio access technology for 5G mobile communications systems". The video was compressed by the encoder into signals between 145 Mbps and 85 Mbps and was transmitted using the 70 GHz band using beam-tracking techniques. (http://www.digitaltvnews.net/?p=27503)

fronthaul/backhaul. IMDA notes that jurisdictions such as the US[39], UK[40] and Australia[41] have allowed for such use. Given the ongoing discussions and works on the mmWave bands, IMDA will make available the spectrum in the E-band for short-term commercial use of up to 12 months in conjunction with the frequency bands made available for 5G trials for the same period until 31 December 2019 as mentioned in para 56 above. Interested applicants may apply for short-term commercial use of this band where the applicable frequency fee is gazetted in the First Schedule of the Telecommunications (Radio-communication) Regulations under the shared use of radio frequency[42]. Any request for renewal shall be subject to IMDA's approval. IMDA will monitor market and technology developments of the E-band, and take into consideration the WRC-19 recommendations before allocating the spectrum in this band beyond 2020.

Question 10: IMDA would like to seek your views and comments on the following:

i) The role mmWave bands will play in delivering the vision of 5G, in particular, what services could not be delivered by alternative frequency bands and / or technologies;

ii) The amount of spectrum required in the mmWave spectrum bands to meet 5G applications that will require higher bandwidths; and

iii) The specific mmWave bands that you consider should be a priority in Singapore for IMT services and why?

Question 11: Considering that there are 11 candidate bands under consideration at WRC-19, how would making available the 28 GHz band help in the deployment of 5G services in Singapore? Would this band play a significant role in achieving the targets set out for 5G (i.e. higher throughput, ultra-low latency)?

Question 12: If the 28 GHz band is opened for IMT services in Singapore, would there be any future competing services that may be deployed in this band which may cause interference issues?

[39] See FCC's Millimetre Wave 70/80/90 GHz Service: https://www.fcc.gov/wireless/bureau-divisions/broadband-division/millimeter-wave-708090-ghz-service#block-menu-block-4

[40] See Ofcom's Spectrum Management Approach in the 71-76 GHz and 81-86 GHz bands: https://www.ofcom.org.uk/__data/assets/pdf_file/0011/50240/statement.pdf

[41] See ACMA's Millimetre Wave Point to Point (Self-Coordinated Stations): http://www.acma.gov.au/~/media/Spectrum%20Engineering/Information/pdf/RALI%20FX20%20Millimetre%20Wave%20Point%20to%20Point%20Self%20Coordinated%20Stations.pdf

[42] https://www.imda.gov.sg/~/media/imda/files/industry development/acts and regulations/telecomregulation2016.pdf?la=en

Estimating Spectrum Demand

58. As part of IMDA's effort in making available spectrum in a timely manner, regular spectrum modelling exercise has been undertaken to estimate the amount of spectrum that would be needed to deliver the anticipated data demand growth and the optimal timing for spectrum availability. While IMDA recognises that such modelling techniques would shed light on the required spectrum, the actual frequency bands that could be made available for IMT services would need to be harmonised internationally and regionally.

59. In 2014, the then-IDA estimated that between 1 GHz and 2 GHz of spectrum will be required to deliver mobile broadband services by around 2025, depending on the demand scenarios. This estimation was based on Recommendation ITU-R M.1768-1 which follows a technology-neutral approach and takes into account market, technology and deployment-related information. With the move towards 5G, IMDA will have to take into consideration the new technologies that will be deployed and the improvements to overall spectrum efficiency. As such, it is timely for IMDA to undertake another spectrum modelling exercise to update these figures and estimations.

60. There are a range of predictions for the growth in mobile data demand which will require the MNOs to increase their network capacity. In general, there are four ways to increase the capacity of mobile communications networks:

i) Use more radio spectrum, with capacity increasing linearly with spectrum (twice the spectrum equals twice the capacity);

ii) Use more efficient technology to achieve similar linear increases;

iii) Enable more efficient reuse of spectrum channels (e.g. complement a large cell covering with multiple smaller cells); and

iv) Off-load traffic onto other connectivity platforms, e.g. onto fibre through other wireless solutions such as Wi-Fi.

61. Several models have been developed to estimate the total spectrum requirement to meet the demand for mobile data traffic. The "Report ITU-R M.2290-0" that was released in 2013 estimated that the spectrum required for mobile services in 2020 would be between 1340 MHz and 1960 MHz in low and high demand situations respectively. The GSMA's submission to the ITU indicated that 1600 – 1800 MHz of spectrum would be needed for IMT. Several ITU member states also gave the ITU various benchmarks (see **Annex B**).

62. IMDA understands that the above models had adopted a traffic forecast-based approach that utilises user demand forecasts to predict the future usage of IMT and the necessary spectrum requirements. However, at the ITU WP5D (26th meeting), two other modelling approaches were considered to estimate the amount of spectrum required in the mmWave bands (i.e. from 24.25 – 86 GHz) to support IMT-2020 network deployments. These two approaches were defined as the application-based approach and the technical performance-based approach. The former approach computes the spectrum requirements based on the type of advanced applications that may be

deployed with IMT-2020 while the latter approach computes based on the technical parameters that are associated with an IMT-2020 system. The spectrum requirements from all the approaches, together with the spectrum estimates provided by various countries, are summarised in the table below.

Table 3: Spectrum Estimates based on various approaches

Frequency Range	**24.25 – 33.4 GHz**	**37 – 52.6 GHz**	**66 – 86 GHz**	**Total**
Traffic Forecast-Based Approach	-	-	-	1.34 – 1.96 GHz
Application-Based Approach	2 – 3.3 GHz	3.7 – 6.1 GHz	5.7 – 9.3 GHz	11.4 – 18.7 GHz
Frequency Range		**24-25 - 43.5 GHz**	**45.5 – 86 GHz**	**Total**
Technical Performance-Based Approach		5.8 – 7.87 GHz	9 – 12 GHz	14.8 – 19.7 GHz
Estimates from some countries		2 – 6 GHz	5 – 10 GHz	7 – 16 GHz

63. IMDA has reviewed the various approaches taken to compute the spectrum requirements and has undertaken a spectrum modelling exercise to update its 2014 estimates. Several assumptions were made in the process of computing the spectrum requirements and these assumptions may differ from the ITU model, as highlighted below:

i) Data Growth: The ITU model is based on data forecasts from 2011 to 2020. The low usage case scenario assumes 44x growth over this period and its high usage case scenario assumes an 80x growth. However, in Singapore's context, the actual growth over a 6-year period (i.e. 2010-2016) was from 2.33 to 10.96 petabytes[43] which translates to approximately 5x growth. As such, to take into consideration further demand for data, the modelling took an assumption that data growth in Singapore is likely to be 10x from 2017 to 2025.

ii) Wi-Fi Offload: While it is unclear the assumptions taken for the ITU model on the percentage of traffic offloaded to Wi-Fi, locally-gathered statistics have shown that the percentage of Wi-Fi offload in Singapore is about 50%[44]. This is close to the international estimation which has shown that Wi-Fi networks is expected to carry about 60% of mobile data in 2019[45]. We have projected the percentage of Wi-Fi offload to continue to remain at about 50% over the next few years and a relatively constant Wi-Fi offload percentage will have little impact on the cellular data demand growth.

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43 Mobile Data Usage, https://data.gov.sg/group/technology
44 Based on MyConnectionSG Results: July 2016 – December 2016
45 http://www.juniperresearch.com/press/press-releases/wifi-to-carry-60pc-of-mobile-data-traffic-by-2019

iii) Number of Sites: Considering the GSMA submission, the spectrum requirement is based on the number of macro sites per operator. In Singapore's densely built-up environment, the numbers of sites are higher than these estimates for the countries considered.

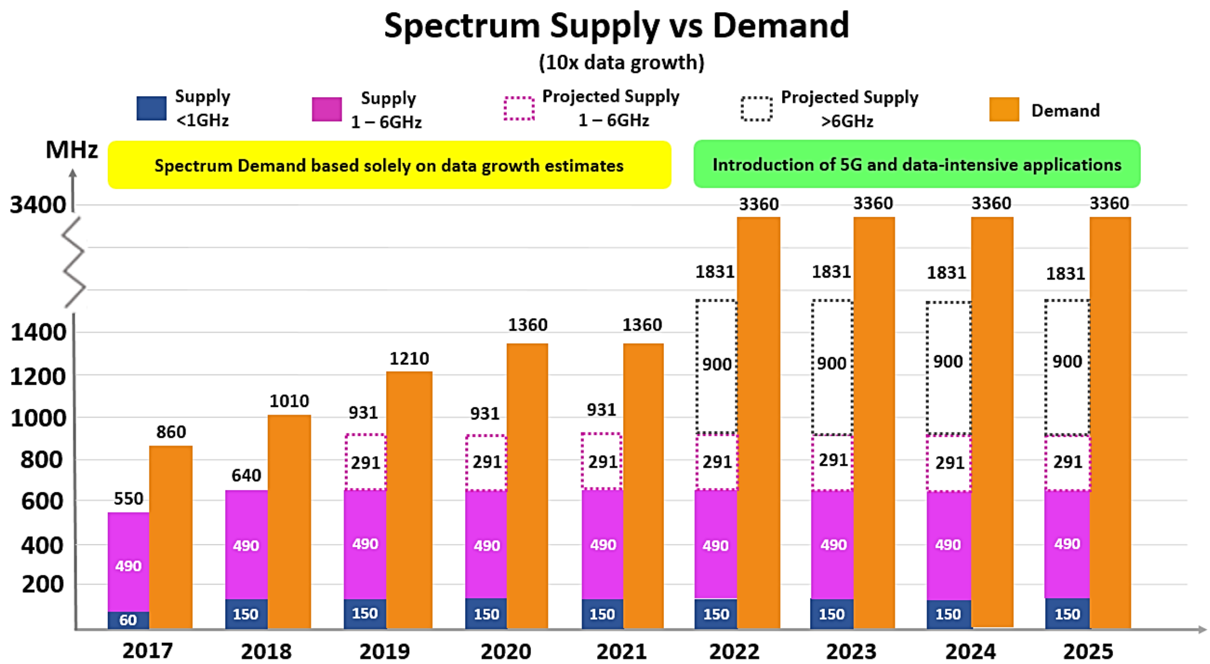
iv) Introduction of New Services and Applications: With the improvement of mobile networks and the move towards 5G, there will be developments of new bandwidth-heavy applications (e.g. augmented reality, virtual reality, ultra-high definition video streaming, etc) that may lead to an increase in data consumption. As such, it is estimated that a minimum of 2 GHz bandwidth is required in the higher frequency ranges (i.e. above 6 GHz) to support the slew of new services and applications that may be developed with 5G[46].

64. The results from the modelling indicated that spectrum demand is projected to increase to at least about 3360 MHz by 2022 once there is commercial deployment of 5G services and applications. This increase in spectrum demand will be met by the release of more spectrum in the above identified frequency bands in the 1 – 6 GHz range and mmWave bands if harmonisation is achieved globally and/or for the Asia Pacific region at WRC-19, bringing the projected spectrum supply to 1831 MHz (see Figure 5)[47]. If additional spectrum in the 28 GHz band is also made available for mobile services, it will provide an additional 2000 MHz of spectrum that will allow us to meet the anticipated demand for spectrum up to 2025.

[46] The estimated amount of 2 GHz bandwidth was the minimum amount derived from various countries' spectrum estimation which were submitted to WP5D (refer to Table 3 of this public consultation document)

[47] The projected spectrum supply includes the L-band, extended C-band and the potential mmwave bands that may be harmonised globally which are as highlighted in Figure 4 of this public consultation document.

Figure 5: Spectrum Modelling for 10X Data Demand Growth



*Projected supply in the 1-6GHz range includes the potential release of 91MHz of L-Band (1427-1518MHz) and 200MHz of extended C-Band (3.4-3.6GHz). However, it does not include any potential release of the 800MHz (806-894GHz) band. Projected supply >6GHz includes the 24.25 – 24.45GHz, 25.05 – 25.25GHz and 42 – 42.5GHz which are most likely to be globally harmonised.
**Spectrum demand from 2022 onwards includes 2GHz of frequency from the above 6GHz frequency bands.

Question 13: IMDA seeks views and comments on the estimated spectrum demand of 3360 MHz by 2025 and whether this estimate is realistic?

Question 14: Noting that several regulators have made available mmWave bands for IMT services, IMDA would like your views and comments on whether access to the mmWave spectrum should be provided earlier than 2022 for commercial network deployment?

PART IV: USE OF LICENCE-EXEMPT SPECTRUM FOR IMT SERVICES

Overview

65. With burgeoning demand for mobile connectivity, MNOs and consumers have been offloading data using the unlicensed band through the use of Wi-Fi. Over the years, the increasing number of Wi-Fi enabled devices and widespread adoption of Wi-Fi networks have led to the growing importance of Wi-Fi in unlicensed spectrum.

66. Today, Wi-Fi and cellular are seen as complementary technologies, with both being integrated on the same devices and operating seamlessly. Wi-Fi standards have been continuously evolving and new standards such as 802.11ax are intended to increase the total throughput and hence improve the per user performance[48]. It is common for MNOs to off-load mobile data traffic to Wi-Fi networks, operating in the licence-exempt 2.4 GHz and 5 GHz bands, as a means of meeting the increasing data demand from mobile devices. The nationwide rollout of fibre infrastructure to homes and business premises providing high-speed broadband connectivity has also fuelled Wi-Fi offloading.

67. By 2020, Wi-Fi is expected to carry 67 percent of total wireless traffic[49], up from the 60 percent today. In Singapore, over 50 percent of smartphone traffic is carried over Wi-Fi, helped by the widely available public Wi-Fi. The public Wi-Fi network in Singapore, Wireless@SG, has around 10,000 hotspots currently and this will double to 20,000 by 2018.[50] The increase in Wi-Fi hotspots signifies the growing reliance on Wi-Fi technology and licence-exempt spectrum for wireless communication.

68. To date, LTE networks have been deployed using licensed spectrum across bands spanning 450 to 3600 MHz. With increasing amount of mobile data traffic, there has been movements in the mobile industry to promote carrier aggregation of licensed and licence-exempt spectrum, which is a feature of current LTE-A networks and future LTE-A Pro. 5G may use licence-exempt spectrum through the following technical approaches:

i) Licensed Assisted Access[51] (“**LAA**”) and LTE-Unlicensed (“**LTE-U**”): LTE is primarily deployed in the licensed spectrum, while leveraging on the licence-exempt bands to provide a boost in data rates;

ii) MuLTEfire: LTE is deployed primarily in the licence-exempt spectrum; and

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48 Draft standards are already available with final publication due in 2019 and implementation is expected after 2019.

49 Bell Labs, Who will satisfy the desire to consume? (April 2016), https://pages.nokia.com/1503.bell-labs-mobility-report.html

50 https://www.imda.gov.sg/about/newsroom/media-releases/2017/wirelesssg-enhances-login-experience-and-expands-operator-pool

51 LAA: Use of licence-exempt bands (such as bands used for Wi-Fi) for short distance cellular data traffic transmission on a shared basis.

iii) LTE-Wi-Fi aggregation[52] ("**LWA**"): Integrating Wi-Fi in licence-exempt bands more closely to the cellular network.

69. Although future generation of networks will most likely continue with the usage of licence-exempt spectrum as part of the mobile networks, implementing such carrier aggregation requires careful consideration as many businesses and users rely on Wi-Fi for wireless connectivity. Hence, overcrowding the licence-exempt band may lead to a loss in Wi-Fi capacity, leading to detrimental effects on Wi-Fi users. Before the aforementioned carrier aggregation techniques are introduced, studies should be performed to confirm that these technology deployment does not lead to a reduction of spectrum capacity for Wi-Fi services and adversely impact Wi-Fi users. The following sections examine the above said approaches further.

LAA and LTE-U

70. LAA was introduced in 3GPP Release 13 to standardise LTE operations in the 5 GHz Wi-Fi spectrum. The LAA approach combines the use of licensed and licence-exempt spectrum using carrier aggregation technology. Licensed bands can provide reliable connectivity, mobility, signalling and guaranteed data rate services, while the licence-exempt bands can provide additional spectrum capacity and provide a boost in data rates. LAA features were finalised and published in 3GPP's Release 13 specification and it is expected that further enhancements may be made in subsequent releases[53]. IMDA understands that for 3GPP Release 14, the industry has put forward the Enhanced LAA ("**eLAA**") proposals. These include uplink carrier aggregation across licensed and licence-exempt bands and the use of more efficient channel coding and modulation schemes.

71. LTE-U was developed outside of established standards bodies and it is compatible with Rel. 10/11 3GPP LTE standards. While LTE-U aims to achieve the same objective as LAA, the key difference between both technologies is the measures that can be taken to ensure coexistence with other users in the licence-exempt spectrum (e.g. Wi-Fi users). LAA utilises the listen-before-talk ("**LBT**") protocol, whereby the LAA radio transmitters will be required to first sense its radio environment before it starts a transmission. This means that Wi-Fi users will not suffer more impact from LAA when compared to a situation where the users are in the presence of another Wi-Fi network. While for LTE-U, it utilises a proprietary Carrier Sensing Adaptive Transmission ("**CSAT**") technique that allows for dynamic channel selection to avoid channels occupied by Wi-Fi users and adaptive duty cycling where LTE transmission duty cycle is adjusted dynamically to accommodate Wi-Fi devices.

72. The LBT protocol is a well-established approach in ensuring fair access to the licence-exempt spectrum. There are concerns from some industry players that the LTE-U proprietary method may not allow for fair coexistence with Wi-Fi users. These industry players are of the view that the LTE-U proprietary approach allows for a wide implementation and configuration choices (i.e. setting of the detection threshold,

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[52] LWA technology remains under development in 3GPP and is based on co-existence (not spectrum sharing) across Wi-Fi and cellular data plane traffic flows.
[53] LAA downlink is specified in Release 13. Work on LAA uplink still in progress for R14.

sharing ratio, duty cycle, etc). As such, the extent to which LTE-U shares spectrum with other technologies can vary widely from one vendor to another.

73. In Europe and Japan, a specific waveform requirement on supporting LBT at milliseconds scale is required for operations in the licence-exempt band and this includes the 5 GHz spectrum band. This will ensure that all devices will have equal and fair chance of accessing the spectrum. As such, any LTE operation in this spectrum band would have to be based on LAA which was incorporated into 3GPP Release 13. However, LAA would likely only be commercialised in 1 to 2 years since there are no available market products currently.

74. Notwithstanding the above, the adoption of LBT protocol is not currently a requirement in other countries (e.g. US, Korea and China) and operators are free to begin LTE-U deployment earlier using Release 10, 11 or 12 protocols. However, there were concerns from the Wi-Fi community that since LTE-U utilises the CSAT technique, there may be a risk of severe interference to Wi-Fi users and as such deployment of LTE-U networks had been limited to temporary or trial basis. In September 2016, the Wi-Fi Alliance developed a coexistence plan ("**Coexistence Plan**") in collaboration with the LTE-U community which will help to ensure that LTE-U devices can fairly share the unlicensed spectrum with Wi-Fi users and other unlicensed devices operating in the 5 GHz band. The Coexistence Plan includes a comprehensive set of co-existence guidelines and evaluation test plans which will help to determine fair sharing.

75. In February 2017, FCC authorised the first set of LTE-U devices in the 5 GHz band for sale in the US. The FCC-approved devices consist of LTE-U base stations from Ericsson and Nokia and these devices are certified to be in compliance with FCC's rules and have passed the industry-developed Coexistence Plan[54]. With FCC's recent certification and the commercialisation of LTE-U devices, it is expected that the mobile operators will explore the deployment of LTE-U in their networks.

76. While companies have expressed interest in deploying LTE-U in Singapore, it is unclear what are the impacts and benefits of such carrier aggregation techniques (i.e. LTE-U and LAA) in a densely built-up and urbanised environment. In Singapore, Wi-Fi is not only used in most households, but there is also an established and extensive public Wi-Fi network. Currently, the MNOs are operators of the public Wireless@SG networks which are deployed in more than 10,000 hotspots in Singapore[55] . Apart from the public Wireless@SG networks, some of the MNOs are also offering enterprise Wi-Fi solutions to its customers[56].

77. Notwithstanding the above, IMDA recognises that the licence-exempt spectrum, with its light-touch regulations, could create opportunities for innovation and for companies to explore new business cases. As such, IMDA would encourage MNO/MVNOs[57] to conduct trials on LTE-U/LAA services and share its findings with IMDA. Insights from these trials would assist IMDA in understanding if there are any

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54 https://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-delivers-lte-u-coexistence-test-plan

55 https://www.imda.gov.sg/~/media/imda/files/community/consumer%20education/wirelless%20sg/hotspot%20list1.pdf?la=en

56 https://www.singtel.com/business/products-and-services/internet/singtel-bizwifi

57 Noting that LAA and LTE-U deployments will have to be paired with a primary mobile network, operators looking to deploy such technologies will likely be limited to MNOs or MVNOs.

coexistence issues with other technologies and develop an appropriate regulatory framework to facilitate the deployment of these technologies if shared use is feasible.

78. MNO/MVNOs interested in conducting technical trials will need to apply for a technical trial licence from IMDA under the TT framework[58]. Those interested in conducting commercial trials may apply for a market trial licence under the MT framework[59].

79. With regard to the operating requirements, any LAA/LTE-U deployment in Singapore has to comply with the key technical requirements for licence-exempt use in the 5 GHz band. Based on IMDA's Short Range Device framework, licence-exempt operations are limited to the 5150 – 5350 MHz and 5470 MHz – 5850 MHz band, and the power transmission should not exceed 200mW EIRP and 1000mW EIRP respectively[60]. Operations in these band should also be on a localised basis. Any exception will require a separate approval from IMDA and may be subject to licensing requirements.

80. Specifically, for LTE-U trial deployments, considering the proprietary technique that is being used to access the licence-exempt 5 GHz spectrum and potential issues of interference, IMDA is proposing for interested MNO/MVNOs to submit the following additional information for IMDA's assessment:

i) Site survey results: IMDA recognises that there may be areas within a building that do not have public Wi-Fi coverage and LTE-U may be a suitable candidate to provide mobile broadband services. Companies will have to provide findings from its site survey to identify a suitable location for LTE-U deployment, which shall include a spectrum scan to verify that there are limited Wi-Fi users around the vicinity.

ii) Proposed parameters for LTE-U deployment: IMDA understands that there are various parameters that can be configured for LTE-U deployment, such as the duty cycle, spectrum sharing ratio and threshold for detection. Defining the values of these parameters are dependent on the spectrum environment of the selected deployment location. For example, if there is only a handful of Wi-Fi users in the vicinity, the spectrum sharing ratio may be set to a higher value.

81. IMDA understands that if a company does decide to deploy LTE-U, the technology can be upgradeable to the LAA standard when that technology is available. Such an upgrade does not require extensive effort, instead it will be in the form of a software or firmware update. IMDA may consider requiring upgrading to LAA for all

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58 Terms and conditions for telecommunication technical trials. Available from: https://www.imda.gov.sg/~/media/imda/files/regulation%20licensing%20and%20consultations/licensing/licenses/techtriallic.pdf?la=en

59 Guidelines for submission of application for market trial licence. Available from: https://www.imda.gov.sg/~/media/imda/files/regulation%20licensing%20and%20consultations/licensing/licenses/guidemtriallic.pdf?la=en

60 https://www.imda.gov.sg/~/media/imda/files/regulation%20licensing%20and%20consultations/ict%20standards/telecommunication%20standards/radio-comms/imdatssrd.pdf?la=en

companies that are deploying LTE-U to ensure that there is fair access to the licence-exempt spectrum.

Question 15: Considering the current regulations/policies for licence-exempt use and the possibility of LTE-U interfering with Wi-Fi users, IMDA would like to seek views and comments on the following:

i) The adoption of LBT to facilitate sharing of licence-exempt spectrum and whether there would be any implication arising from such a requirement;

ii) The need for further technical requirements and regulatory measures to facilitate the sharing of licence-exempt spectrum in an efficient and fair manner; and

iii) The need for companies with commercial LTE-U networks to upgrade to LAA once the software/hardware products are commercially available.

Question 16: During the interim period before regulations are finalised, IMDA plans to facilitate industry trials for LAA/LTE-U technologies. As such IMDA would like to seek views and comments on the following:

i) Besides the information listed in Para 80, should MNOs/MVNOs interested in conducting LTE-U trials submit any further information for IMDA's assessment; and

ii) To minimise impact to Wi-Fi users, should IMDA limit LAA/LTE-U trials to parts of the 5 GHz licence-exempt spectrum?

MuLTEfire

82. MuLTEfire differs slightly from the LAA, in that it does not require an anchor carrier in the licensed spectrum and fully operates in the licence-exempt spectrum, particularly in the 5 GHz band. The advantage of MuLTEfire is that it can potentially be deployed by other companies (e.g. fixed-line service providers, Internet Service Providers, venue owners, etc) as well as the MNOs. Specific benefits of MuLTEfire are the (i) low price point; (ii) opportunities for other companies to operate stand-alone LTE networks in licence-exempt spectrum; and (iii) opportunities to offer wireless services and provide additional capacity to users. IMDA understands that trials conducted using MuLTEfire technology show that coexistence with Wi-Fi is possible and this technology is able to offer the benefits of LTE (e.g. performance, speeds and security, etc) in densely populated environments.

83. Although MuLTEfire opens up various opportunities for the industry, congestion in the licence-exempt spectrum is likely to be exacerbated since its operation is primarily reliant on licence-exempt spectrum. Currently, there has yet to be any formal application from the industry to use such a technology in Singapore.

84. Since MuLTEfire is also operating on a LBT protocol to enable spectrum sharing with Wi-Fi users, it should provide similar LTE performance, when compared to LAA.

As such, IMDA's preliminary view is that any regulations adopted for LAA should also be applied to MuLTEfire operations. This includes but are not limited to (i) technical conditions prescribed in the Short Range Device Framework; and (ii) LBT protocol. Similarly, during the interim period where coexistence criteria are yet to be finalised, IMDA would welcome the industry to trial the MuLTEfire technology.

Question 17: IMDA would like to seek views and comments on the following: ***i) The possibility of deploying LAA and / or MuLTEfire in other frequency bands besides the licence-exempt 5 GHz band; and*** ***ii) The regulatory and coexistence measures that should be adopted for MuLTEfire.***

LTE-Wi-Fi Aggregation ("LWA")

85. LWA is part of 3GPP LTE Release-13 and enables aggregation of LTE and Wi-Fi spectrum to improve the capacity of cellular networks. Aggregation occurs at the RAN and allows the total system capacity to be improved by managing radio resources amongst users using the intelligence mostly gathered at the edge of the network (in handsets and servers) to intelligently and dynamically aggregate streams.

86. The primary connection remains with an LTE channel in licensed spectrum and the additional Wi-Fi data path is only used to increase bandwidth when required, such as when watching video or using other higher bandwidth services. Optimising traffic over the two data streams would lead to more capacity being made available over the licence-exempt spectrum which would benefit other licence-exempt users as well. This approach takes advantage of the continuing evolution of Wi-Fi standards and existing sharing protocols of LBT.

87. IMDA notes some service providers[61] adopted the LWA architecture to automatically connect users to the best network at their location, which may be an open Wi-Fi hotspot or an LTE network, and provide seamless traffic transfer across the networks.

88. The LWA approach does not require the operation of LTE-based devices in the licence-exempt spectrum, instead Wi-Fi devices will continue to operate in the licence-exempt spectrum and throughput is increased through aggregating the capacity of both the existing Wi-Fi networks and LTE networks. As such, there will not be any concerns of coexistence between the LTE and Wi-Fi users.

Question 18: Considering that the LWA approach would not create coexistence issue with Wi-Fi users, would this approach be better suited for countries with extensive Wi-Fi usage?

[61] For instance, Google for its Project Fi (see https://fi.google.com/about/network/).

Question 19: IMDA would like to seek views on how the above approaches (i.e. LAA, MuLTEfire and LWA) would enhance the capacity of the mobile network in ways that Wi-Fi offloading is not able to achieve.

PART V: SUMMARY

89. In summary, this consultation seeks industry views on the possible 5G technologies, spectrum bands and spectrum sharing mechanisms. Specifically, the questions raised in this consultation are summarised as follows:

<u>5G Technology and Use Cases</u>

1) IMDA would like to seek views and comments on the estimated timeline for the deployment of 5G. Besides ensuring that spectrum is made available in a timely manner, what other regulatory measures could assist in facilitating the deployment of 5G technology and applications? What other use cases should IMDA take note of when developing the regulatory framework?

2) To facilitate and understand potential spectrum requirements for IoT deployments in Singapore, IMDA would like to seek views on the following:
   - i) Based on the current spectrum allocated for mobile services in the sub-1 GHz frequency bands, are there further suitable spectrum resources that could be released to support both IoT and LTE services?
   - ii) How will future generations of mobile networks (e.g. high capacity, low latency) support the growth of IoT and what would be the spectrum requirements?

3) IMDA would like to seek views and comments from industry on what they consider will be the key technologies for 5G and whether current regulatory frameworks sufficiently facilitate the deployment of such technologies.

<u>Below 1 GHz Frequency Bands</u>

4) IMDA would like to seek views and comments on whether going forward, there is a need for further spectrum below 1 GHz to be identified and release for mobile services?

<u>1 – 6 GHz Frequency Bands</u>

5) IMDA would like to seek views and comments on following:
   - i) The frequency arrangement that is better suited for adoption in Singapore for the L band (i.e. SDL, TDD or FDD) and the supporting reasons; and
   - ii) The timeline for access to the L band and the availability of the equipment (specifically whether it will be available earlier or later than 2020).

6) Considering the spectrum bands within the range of 1-6 GHz to support the deployment of enhanced mobile broadband services, IMDA would like to seek views on whether all of the 91 MHz of spectrum in the L-band should be allocated for IMT to address Singapore's data demand and growth.

7) If it is only the extended C-band that is considered for IMT, would the migration of existing satellite users to the other parts of the C-band (i.e. 3.7-4.2 GHz) impact their service provisioning?

8) Considering the challenges of co-channel deployment of FSS and IMT services in the extended C-band, IMDA would like to seek views and comments on the coexistence measures for adjacent bands and cross border operations.

9) IMDA would like to seek views and comments on whether there are other frequency bands in the 1-6 GHz frequency band that IMDA should consider for IMT / 5G.

Above 6 GHz Frequency Bands

10) IMDA would like to seek your views and comments on the following:
   i) The role mmWave bands will play in delivering the vision of 5G, in particular, what services could not be delivered by alternative frequency bands and / or technologies;
   ii) The amount of spectrum required in the mmWave spectrum bands to meet 5G applications that will require higher bandwidths; and
   iii) The specific mmWave bands that you consider should be a priority in Singapore for IMT services and why?

11) Considering that there are 11 candidate bands under consideration at WRC-19, how would making available the 28 GHz band help in the deployment of 5G services in Singapore? Would this band play a significant role in achieving the targets set out for 5G (i.e. higher throughput, ultra-low latency)?

12) If the 28 GHz band is opened for IMT services in Singapore, would there be any future competing services that may be deployed in this band which may cause interference issues?

Future Spectrum Estimation

13) IMDA seeks views and comments on the estimated spectrum demand of 3360 MHz by 2025 and whether this estimate is realistic?

14) Noting that several regulators have made available mmWave bands for IMT services, IMDA would like your views and comments on whether access to the mmWave spectrum should be provided earlier than 2022 for commercial network deployment?

Use of Licence-Exempt Spectrum

15) Considering the current regulations/policies for licence-exempt use and the possibility of LTE-U interfering with Wi-Fi users, IMDA would like to seek views and comments on the following:
   i) The adoption of LBT to facilitate sharing of licence-exempt spectrum and whether there would be any implication arising from such a requirement;
   ii) The need for further technical requirements and regulatory measures to facilitate the sharing of licence-exempt spectrum in an efficient and fair manner; and

iii) The need for companies with commercial LTE-U networks to upgrade to LAA once the software/hardware products are commercially available.

16) During the interim period before regulations are finalised, IMDA plans to facilitate industry trials for LAA/LTE-U technologies. As such IMDA would like to seek views and comments on the following:

i) Besides the information listed in Para 80, should MNOs/MVNOs interested in conducting LTE-U trials submit any further information for IMDA's assessment; and

ii) To minimise impact to Wi-Fi users, should IMDA limit LAA/LTE-U trials to parts of the 5 GHz licence-exempt spectrum?

17) IMDA would like to seek views and comments on the following:

i) The possibility of deploying LAA and / or MuLTEfire in other frequency bands besides the licence-exempt 5 GHz band; and

ii) The regulatory and coexistence measures that should be adopted for MuLTEfire.

18) Considering that the LWA approach would not create coexistence issue with Wi-Fi users, would this approach be better suited for countries with extensive Wi-Fi usage?

19) IMDA would like to seek views on how the above approaches (i.e. LAA, MuLTEfire and LWA) would enhance the capacity of the mobile network in ways that Wi-Fi offloading is not able to achieve.

PART VI: INVITATION TO COMMENT

90. IMDA would like to seek views and comments from the industry and members of the public on the proposed approaches to introduce the next generation of mobile services in Singapore.

91. All views and comments should be submitted in writing and in both hard and soft copies (Microsoft Word Format), and should reach IMDA by **7 July 2017**. Respondents are required to include their personal or company particulars, correspondence address, contact number and email address in their submissions. IMDA reserves the right to make public all or parts of any written submission and to disclose the identity of the source. Commenting parties may request confidential treatment for any part of the submission that the commenting party believes to be proprietary, confidential or commercially sensitive. Any such information should be clearly marked and placed in a separate annex. If IMDA grants confidential treatment it will consider, but not publicly disclose, the information. If IMDA rejects the request for confidential treatment, it will return the information to the party that submitted it and will not consider this information as part of its review. As far as possible, parties should limit any request for confidential treatment for information submitted. IMDA will not accept any submission that requests confidential treatment of all, or a substantial part, of the submission. All comments should be addressed to:

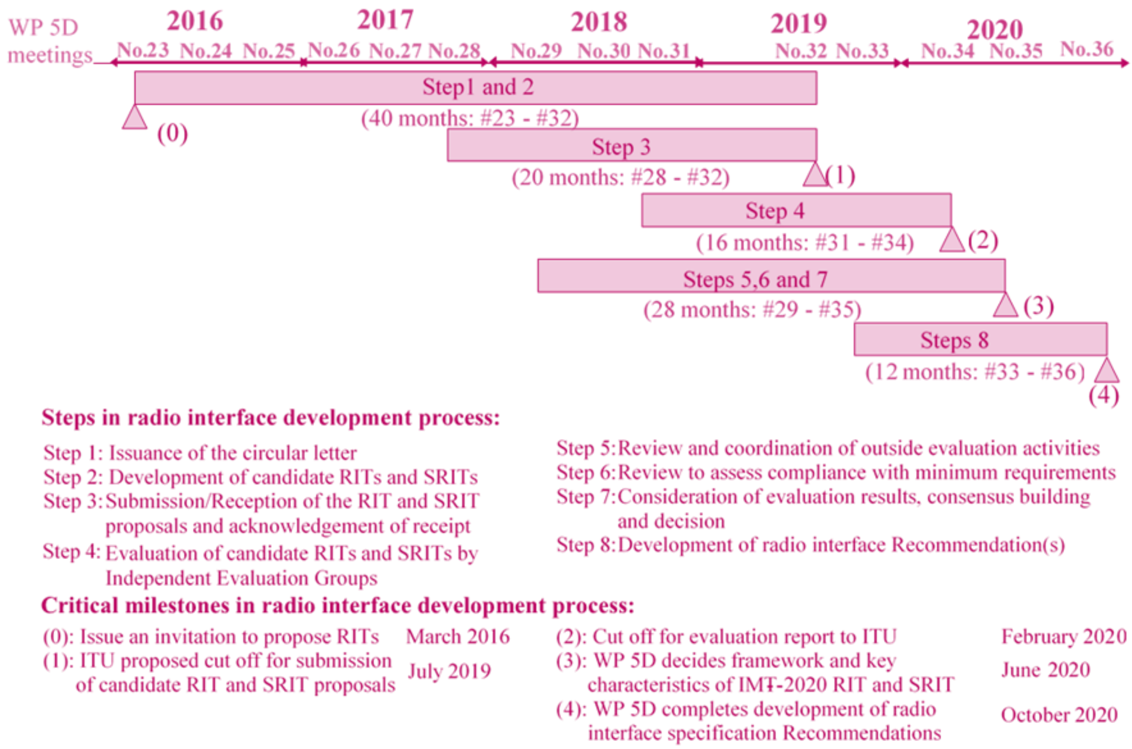
Ms Aileen Chia
Director General (Telecoms and Post)
Infocomm Media Development Authority of Singapore
10 Pasir Panjang Road
#10-01 Mapletree Business City
Singapore 117438
Fax: (65) 6211 2116

AND

Please submit your soft copies, with the email header "Consultation on the Proposed Approaches to Introduce the Next Generation of Mobile Services" via email to consultation@imda.gov.sg.

Annex A

Time Schedule for 5G Radio Interface Development Process



Source: ITU

Annex B

ITU Member States' Estimation of Spectrum Requirements

Source	US	Australia	Russia	China	GSMA6	India	UK
Estimation year	Until 2014	Until 2020	2020	2015, 2020	2020	2017, 2020	2020
Spectrum requirements	Additional requirement of 275 MHz by 2014	Total requirement of 1 081 MHz (Additional requirement of 300 MHz by 2020)	Total requirement of 1 065 MHz (Additional requirement of 385 MHz by 2020)	Total requirement of 570-690 MHz (by 2015) Total requirement of 1 490-1 810 MHz (by 2020)	Total requirement of 1 600-1 800 MHz for some countries	Additional requirement of 300 MHz by 2017 Additional requirement of another 200 MHz by 2020	Total requirement of 775-1 080 MHz for the low demand setting Total requirement of 2 230-2 770 MHz for the high demand setting
Methodology	Using an original methodology	Using an original methodology	Using an original methodology	Using the methodology in Rec. ITU-R M.1768-1	Using a new methodology to complement the methodology in Rec. ITU-R M.1768-1	Using an original methodology	Using the methodology in Rec. ITU-R M.1768-1