CONSULTATION PAPER ISSUED BY THE INFO-COMMUNICATIONS MEDIA DEVELOPMENT AUTHORITY

SECOND CONSULTATION ON 5G MOBILE SERVICES AND NETWORKS

7 MAY 2019

Contents

Chapter 1: Introduction to 5G

Background

1. In 2015, the International Telecommunication Union – Radiocommunication sector ("**ITU-R**") officially adopted the term International Mobile Telecommunication beyond 2020 ("**IMT-2020**") as the vision for fifth generation ("**5G**") mobile networks and finalised the projected timeline towards IMT-2020. While the third generation ("**3G**") and fourth generation ("**4G**") mobile networks[1] are currently still in service (and are expected to continue in the immediate few years from now), there has been significant discussions around the arrival of the next generation mobile networks, 5G.

2. On 23 May 2017, the Infocomm Media Development Authority ("**IMDA**") issued a public consultation on the key 5G mobile technology developments and the associated spectrum requirements ("**2017 Public Consultation**"). Through that public consultation, IMDA sought 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 both licensed and unlicensed spectrum bands.

3. At the close of the 2017 Public Consultation, IMDA received comments from 26 respondents: (individually referred to as a "**Respondent**" and collectively, the "**Respondents**"):

    a. Arete M Pte Ltd;
    b. Asia-Pacific Satellite Communications Council ("**ASPCC**"), Cable and Satellite Broadcasting Association of Asia ("**CASBAA**"), Global VSAT Forum ("**GVF**"), and the EMEA Satellite Operators Association ("**ESOA**");
    c. Ericsson Telecommunications Pte Ltd;
    d. Eutelsat Asia;
    e. Global Mobile Suppliers Association;
    f. GSM Association;
    g. Global TD-LTE Initiative;
    h. Huawei International Pte Ltd;
    i. Inmarsat Singapore;
    j. Intel Corporation;
    k. Intelsat Corporation;
    l. M1 Limited;
    m. Microsoft Operations Pte Ltd;
    n. Motorola Solutions;
    o. Nokia Networks;

[1] Second generation ("**2G**") services were ceased in 2017.

p. Qualcomm Incorporated;
q. Ruckus Wireless Inc;
r. Samsung Electronics Co Ltd;
s. SES World Skies Singapore;
t. Singtel Mobile Singapore Pte Ltd;
u. Speedcast International Ltd;
v. StarHub Mobile Pte Ltd;
w. Thuraya Telecommunications Company;
x. ViaSat Inc;
y. Wi-Fi Alliance; and
z. Wireless Broadband Alliance.

4. IMDA thanks all Respondents for their submissions to the consultation.

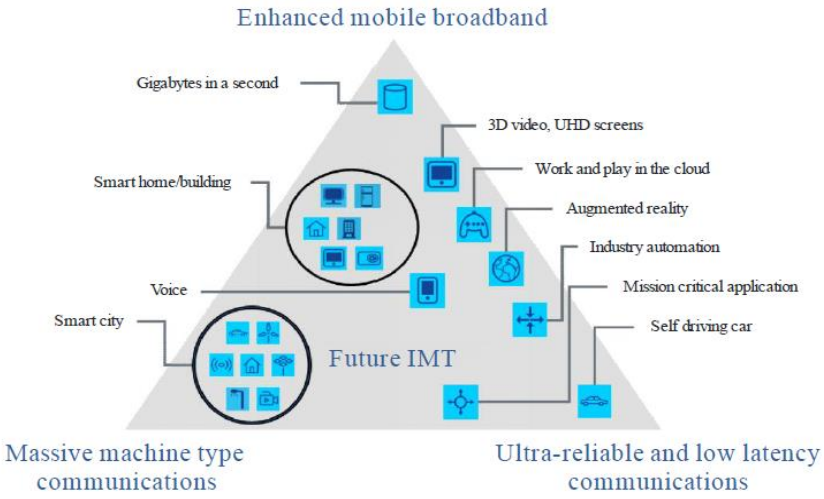
5. This document sets out the key issues raised in the 2017 Public Consultation, and IMDA's responses and decisions with regard to these issues. IMDA will separately address the comments on the use of licence-exempt spectrum. In addition, IMDA would like to consult the industry on IMDA's views regarding the issuance of spectrum for the provision of 5G services and the development of the overall 5G ecosystem for Singapore.

Potential Capabilities of 5G and its Impact on Businesses and Consumers

6. The arrival of the 2G mobile network has enabled high capacity voice networks and introduced very low bandwidth mobile data services to users for the first time. 3G and 4G enhanced the mobile broadband experience for users with higher speeds and capacity, enabling the use of mobile data for high-definition ("**HD**") videos and other over-the-top ("**OTT**") services. However, the evolutionary characteristics of 5G is expected to go beyond just delivering an enhanced mobile broadband experience.

7. Globally acknowledged to be the next big leap in mobile and wireless communications, the ITU has categorised 5G for three broad usage scenarios areas shown below in Figure 1: namely enhanced mobile broadband ("**eMBB**"), ultra-reliable and low latency communications ("**uRLLC**"), and massive machine type communications ("**mMTC**").

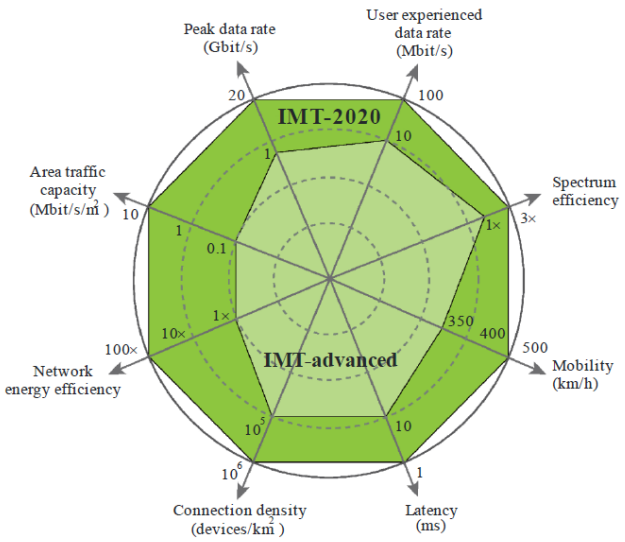
Figure 1: The Usage Scenarios Defined for 5G[2]



8. In order to support these usage scenarios, 5G will need to deliver superior, secure and resilient performance as compared to its predecessors. ITU has also defined eight key targets for 5G to meet and improve upon, as shown in Figure 2. The potential benefits include enhanced mobile broadband experience with theoretical peak speeds of up to 20 Gbps (20-fold increase over 4G's theoretical peak speed), ability to support large-scale machine type communications of up to 1 million devices per km^2 (1000-fold increase over 4G's capacity, ability to fulfil ultra-reliable and low latency needs of less than 1 millisecond over-the-air latency (25-fold improvement over 4G's latency), and a 100 times improvement in energy efficiency. These significant improvements in capabilities have led to a considerable amount of excitement around 5G. In a 5G era, a 4K ultra high-definition ("**UHD**") movie could be downloaded in merely a few seconds, games could be played in the cloud and battery-operated devices will last much longer.

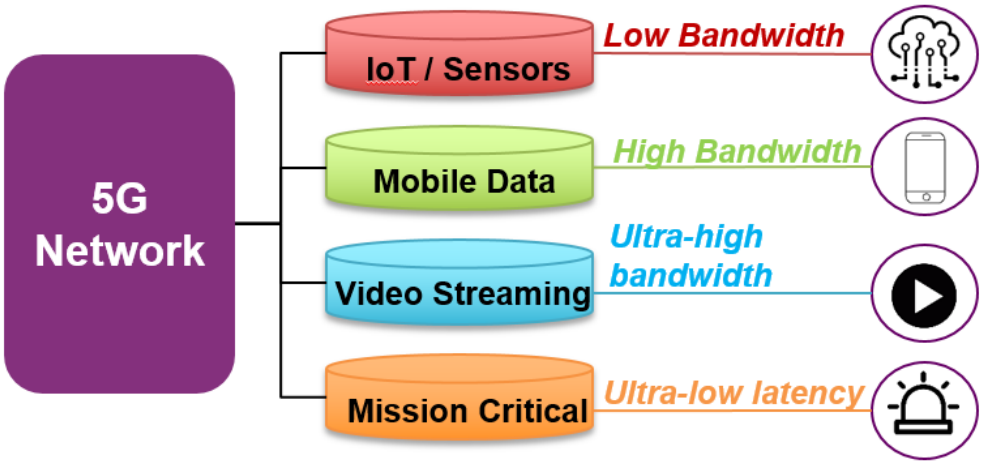
[2] Recommendation ITU-R M.2083-0 (09/2015), IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond.

Figure 2: Target Enhancement of Key Capabilities from 4G (IMT-Advanced) to 5G (IMT-2020)[3]



9. Another important capability in 5G is “network slicing”, which allows a single physical infrastructure to be segmented into multiple virtual networks. This gives operators the ability to customise and tailor services to meet the demands of their customers, enabling them to provision diverse use-cases with different performance requirements (see Figure 3). This approach is cost efficient, offers a shorter time-to-market, and enables businesses to innovate faster.

Figure 3: Example of Network Slicing That Can Take Place Concurrently in the Same Location



[3] Recommendation ITU-R M.2083-0 (09/2015), IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond.

10. As 5G continues to mature and proliferate, both businesses and consumers will benefit from the transformative impact that 5G catalyses. For businesses, 5G would enable more things to be connected, with better reliability, lower latencies and higher throughput, thereby accelerating certain digitalisation trends such as the Internet of Things ("**IoT**") and Industry 4.0. For instance, factories could increasingly be more automated and be able to scale their operations quicker, while raising safety standards with more precise operations on the ground. Autonomous systems (vehicles, drones, logistics load carriers, etc.) can operate with more effectiveness in concert, while closer remote monitoring and control improves operational efficiencies and security. Such benefits can positively impact a wide range of vertical industries, such as manufacturing, automotive, healthcare and media will be impacted.

11. For consumers, 5G would mean that they are now able to enjoy on-demand content with more interactive and immersive experiences. Anytime, anywhere streaming of 4K/8K videos, mixed reality, and cloud gaming are just some of the examples that 5G could bring. Real-time, anticipatory and autonomous services enabled by 5G such as driverless cars, seamless cloud-based translation, and remote medical services will also progressively enrich consumer's lives.

Difference between 5G and Legacy Networks

12. 4G, based on Long Term Evolution ("**LTE**") technology, was developed to enhance the mobile broadband experience that 3G delivered. Even though 4G today can support a wide variety of use-cases, including long battery life IoT devices, it was not natively designed to support the advanced usage scenarios as described in the above section.

13. On the other hand, 5G is designed to support the envisioned usage scenarios and performance targets, integrating the lessons and experiences derived from previous generations of mobile technologies. There will be a new radio air interface termed as the 5G new radio ("**NR"**), and a cloud-native, service-based architecture ("**SBA**") core network.

14. Most Respondents projected that 5G would be an ecosystem of multiple technologies working together, with a combination of licensed, shared-licensed and licence-exempt bands, to support different use-cases that may differ significantly in characteristics. Some of the technologies that are expected to play a part in 5G include software-defined networks ("**SDN**"), network functional virtualisation ("**NFV**"), network slicing, multiple-input multiple-output ("**MIMO**"), scalable transmission time interval ("**TTI**"), 3D beamforming and small cells.

5G Readiness

15. While the vision and capabilities of 5G are defined by ITU, the development of the 5G technical specifications are undertaken by the 3rd Generation Partnership Project ("**3GPP**"), the same organisation responsible for the development of the 3G and 4G standards we use today. 3GPP uses a system of parallel "Releases", with each Release ascribing a firm set of features and specifications agreed by the international mobile communications community. This provides developers with a stable platform for the implementation of features at a given point in time and allows the addition of new functionality in subsequent Releases.

16. To meet the defined targets of 5G by ITU, 3GPP has structured the development work for 5G into two phases. The first phase of the 5G specifications, Release 15, focuses on establishing the foundation for the 5G NR and core network, the implementation of the non-standalone ("**NSA**") and standalone ("**SA**")[4] deployment options, and the eMBB aspects. The second phase, Release 16, will address the rest of the more advanced capabilities, including the uRLLC and mMTC features.

17. 5G NSA will enable the provision of eMBB services through the use of large bandwidths and hardware improvements at the edge networks (e.g., using massive MIMO and advanced antenna techniques), but also leverages existing 4G network for connectivity. On the other hand, standards for SA networks, which are independent 5G networks will address the more advanced capabilities such as ultra-low latency and higher density of connections. 5G SA will bring about a brand new end-to-end network architecture including a virtualised core network ("**5GC**") to fully realise the capability of 5G NR.

18. Network slicing will also be enabled by 5G SA. With 5G SA, Mobile Network Operators ("**MNOs**") will be able to deploy decentralised data centres and servers within close proximity to the end-users. By storing and processing data closer to where it is generated, it will result in faster transmission and lower latency that could be critical to some applications such as vehicle-to-vehicle communications, real-time analytics of video surveillance and public safety functions. Edge computing may also be required for certain scenarios set out for uRLLC.

19. Both Release 15 and 16 were initially targeted for completion by 2020. However, in December 2018, 3GPP delayed both Releases till March 2019 and March 2020 respectively to ensure better stability and compatibility for future

[4] NSA refers to 5G networks that will be assisted by existing 4G networks, whereas SA refers to an independent 5G network.

Releases. Development of 5G is expected to continue beyond Release 16, with enhancements to be incorporated in subsequent Releases. This is the case with 4G as well, which was initially completed in Release 8 and is still being enhanced today in Release 15.

20. Even though the full 5G standards have yet to be finalised, there are a number of 5G trials and early network deployments taking place globally. Some of these are not standardised and are proprietary solutions. 5G commercial products have also been introduced, such as the recently announced 5G smartphones from manufacturers like Samsung, Huawei and Xiaomi.

21. Apart from the standardisation of 5G and the availability of commercial 5G products, there are other challenges and considerations that impact the deployment of 5G networks in Singapore. These are elaborated in Chapters 2 and 3 of this document.

Chapter 2: 5G for Singapore

Interest in 5G Deployment Globally and in Singapore

22. The hyper-connectivity potential of 5G technology has piqued the interest of industry players to maximise the market potential of the technology as their next trench of growth.

23. Countries, particularly those that are home to established network equipment vendors, chipset manufacturers and device vendors, are driven to stay ahead of 5G deployment. This is in part, driven by the patent sharing or IP licensing model of the mobile equipment industry[5]. Several countries such as South Korea, United States ("**U.S.**") and Japan have rolled out pre-standard 5G networks or have announced plans to deploy large-scale 5G networks in the next two years.

24. Countries seeking to deliver ultra-high speed broadband services to homes and business premises are looking to leverage 5G to deliver last-mile fixed wireless access[6] ("**FWA**") to homes, e.g., U.S. and Australia.

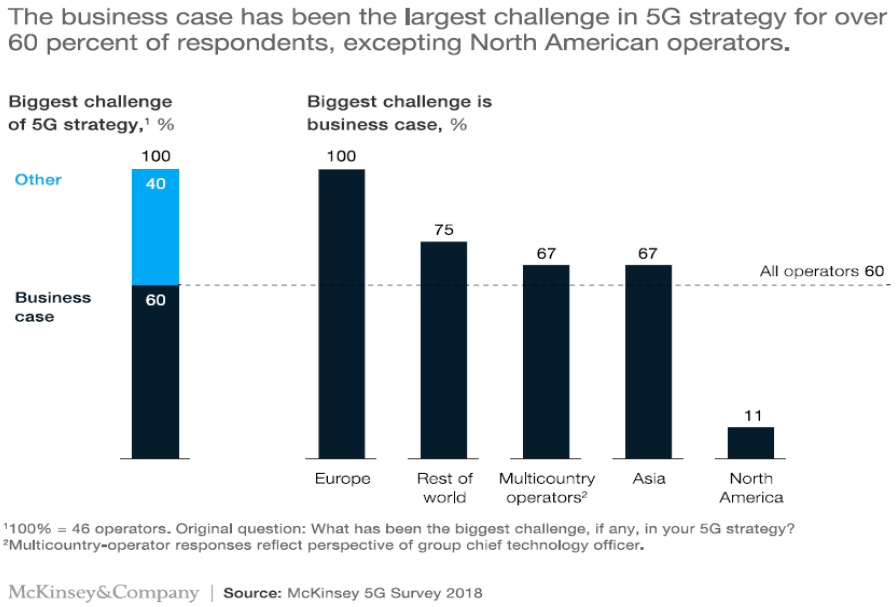
25. Singapore has a different economic composition, and does not have domestic network equipment vendors, chipset manufacturers and device vendors. Also, the availability of a nationwide fibre broadband network with residential wired broadband household penetration rate of more than 90%, capable of delivering 1 Gbps for as low as $34 per month, reduces the need for an alternative fixed-wireless last-mile access service in Singapore.

26. Beyond FWA, the business case and economics of 5G remain unclear amongst most operators globally (Figure 4).

[5] Source: 1 December 2018, "5G IP leadership – it's too early to determine", Forbes

[6] Fixed Wireless Access refers to an established technology means to provide internet connectivity to customer premises (typically homes) using wireless mobile network technology instead of wired lines (fibre or copper). Source: Catapult Digital

Figure 4: Challenge of 5G Strategy for Operators[7]



27. From the 2017 Public Consultation, most of the Respondents agreed that 5G would likely be commercially introduced from 2020 onwards while there would be early network deployments in some countries such as U.S., Japan and South Korea. Some Respondents were supportive of IMDA's estimated deployment timeline[8] and proposed for IMDA to only consider deploying 5G after 2020 to benefit from the globally and regionally harmonised spectrum outcomes at the 2019 World Radiocommunication Conference ("**WRC-19**"). Deployment after 2020 would also allow Singapore to reap the economies of scale from commercially available 5G equipment, learn from the experiences of overseas markets and take advantage of the increasingly mature 5G mobile ecosystem. However, several Respondents were of the view that IMDA should accelerate the timeline and consider 5G commercialisation by no later than 2020. This would be in line with the deployments in leading markets.

28. The allocation of radio frequency spectrum for 5G is the first step towards enabling the deployment of 5G networks and the provision of 5G services in Singapore. Besides commercial readiness of 5G technology, IMDA will have to take other factors into consideration when allocating spectrum for 5G services. These include the harmonisation of 5G spectrum bands amongst neighbouring countries in the region, refarming of spectrum frequencies assigned for existing use and re-assigning them for 5G use, and addressing coexistence issues with the neighbouring countries, amongst others. Regional and international

[7] Source: February 2019, "Cutting through the 5G hype: Survey shows telcos' nuanced views", McKinsey
[8] In the 2017 Public Consultation, IMDA estimated that 5G will be introduced on or after 2020.

spectrum harmonisation is particularly important for a small market like Singapore to reap the benefits of global roaming and the availability of mass market devices.

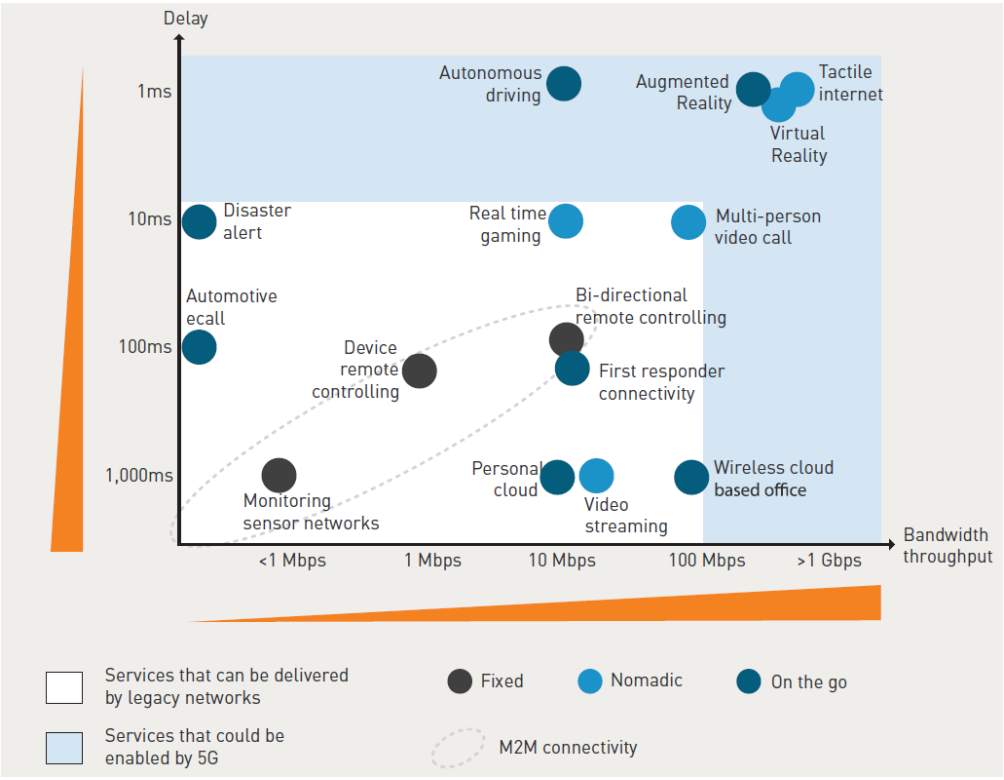
29. Taking these international developments into consideration, IMDA maintains its projection that 5G will be commercialised around 2020 with wider scale deployment from 2023/2024 onwards.

30. At this nascent stage of market and technology development, IMDA is also of the view that Singapore could undertake a proactive approach to create a secure and robust 5G ecosystem that enables innovation in new business models, and development of innovative products, services, applications and experiences.

5G as an Innovation Play for Singapore

31. 5G goes beyond a communication network and paves the way for new innovative applications that LTE technology cannot support. It takes on an expanded role as an innovation platform that offers enterprises and operators the ability to develop new business models, applications (Figure 5), services, products and capabilities.

Figure 5: New Applications Enabled by 5G[9]



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

32. To unlock the full potential of 5G, Singapore could look beyond the pursuit of a pervasive 5G deployment and exploit market opportunities emerging at the innovation stratum instead. Given the limited scope of services offered by overseas operators as well as a lack of successfully deployed and impactful use-cases, Singapore could seize the opportunity to spearhead innovation in 5G technologies and develop a multiplicity of differentiated services in 5G applications.

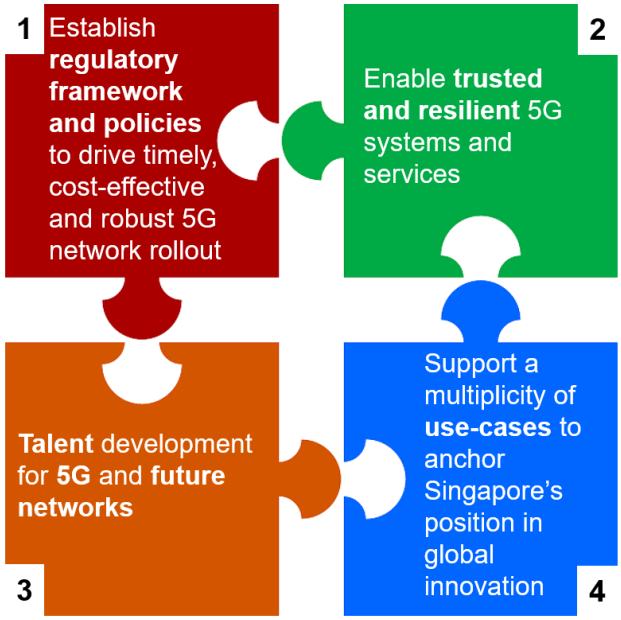
Our Vision and Recommended Playbook

33. IMDA's vision is for Singapore to have a thriving Digital Economy, where every business is a digital business, every worker is empowered by tech, and every citizen a connected citizen. World-class connectivity infrastructure will be essential to achieving these objectives.

34. 5G, globally acknowledged to be the next big leap in mobile and wireless communications, will be a critical part of this infrastructure. More than higher speeds, 5G will enable more things to be connected, with better reliability and lower latencies. The 5G network architecture will allow operators the ability to customise and tailor services to meet the demands of different end-users, to support the innovative services and applications driving Singapore's Digital Economy.

35. Overall, we envisage Singapore to be a **global front-runner for innovation in secure and resilient 5G applications and services**. In order to capitalise 5G potential and fulfil our ambition in the global arena, IMDA seeks to nurture the 5G ecosystem by focusing our development efforts in four key focus areas (Figure 6).

Figure 6: Key Focus Areas ("**KFA**") to Create a Thriving 5G Ecosystem in Singapore



36. **KFA One: Establish regulatory frameworks and policies to maximise value for the economy and welfare for consumers** – IMDA seeks to facilitate the commencement of 5G rollout from 2020 after the SA network standards have been finalised. This will place Singapore amongst the early wave of countries deploying 5G networks capable of supporting full-fledged 5G functionalities and services nationwide. IMDA will also seek to ensure market competitiveness to incentivise investments in new technologies and innovation, and ensure network diversity for resilience. This KFA will be discussed in detail in Chapter 3.

37. **KFA Two: Enable trusted and resilient 5G systems and services** – 5G will introduce new technology concepts such as SDN, network slicing, NFV, edge computing and distributed networks. It will also escalate the provision of IoT where it is expected to support greater user and device mobility, and a massive number of simultaneously connected devices. With these enhanced capabilities, IMDA is cognisant that 5G presents new security and service resilience dimensions. The ability to use technologies in future mobile networks that are trusted and reliable will become important to avoid service disruptions and network breaches.

38. IMDA seeks to collaborate with industry experts, vendors and operators to study the cyber security and network resilience aspects of 5G. This KFA will also be discussed in detail in Chapter 3 of this document.

39. **KFA Three: Enhance the expertise (and quality) of the workforce in 5G and future of networks** – The major shifts in deploying networks of the future,

including 5G, will require a transformation in skills. New skillsets will be necessary to handle new technologies and spectrum characteristics, as well as cyber security and network resilience issues. For example, knowledge and skills in the application of SDN and NFV technologies will be required for the design and operation of new telecommunication networks. The evolutionary nature of 5G will also trigger a shift in workforce demand across the 5G ecosystem, from a declining proportion of network-centric engineers to an increasing demand for hybrid engineers with skills in planning and architecture, software and application development/integration, etc.

Question 1: IMDA would like to seek the industry's views on skills requirements and the potential job demands in the future of networks and next generation of application/use-cases with 5G technology.

40. **KFA Four: Support a multiplicity of use-cases to anchor Singapore's position in global innovation** – As 5G is still in its nascent phase, use-cases with demonstrated benefits of 5G is a key success factor underlying the timely development of secure 5G applications and services. The benefits brought about by ultra-reliable low latency communications and network slicing capabilities are expected to be the linchpin of 5G innovation. Industry-driven use-cases, enabled by localised 5G deployment, will be key in substantiating the value of 5G-enabled capabilities.

41. Since May 2017, IMDA has made available radio frequencies and waived frequency fees for 5G technology trials until December 2019 (refer to ***ANNEX A: Technology Trials*** for more details). The MNOs have since implemented a number of 5G trials, demonstrating the possibilities of 5G applications such as drone deliveries for emergency medical supplies, cloud analytics to enhance efficiency and minimise production errors in manufacturing, and the use of Virtual Reality for sports fans to enjoy "live" events virtually.

42. IMDA is now embarking on the next phase of 5G trials, for operators and vendors to work with enterprises on actual industry use-cases. One example is the maritime sector, where 5G could be the enabling communication infrastructure for enhanced Smart Port operations[10].

43. Moving forward, IMDA envisages a more concerted effort in accelerating and scaling innovation efforts in 5G. For a start, IMDA will be identifying use-cases

[10] On 8 March 2019, IMDA announced that it will be launching a series of Technology Calls ("**Tech Calls**") to invite interested industry players to submit proposals to deploy 5G trials. These Tech Calls will assess and validate the performance and capabilities of 5G in various clusters. For the first phase of the Tech Calls, it will be a joint-collaboration effort between IMDA and PSA to test and assess the capabilities of 5G for ports. Application started on 22 March 2019 and will close on 15 May 2019.

in areas where 5G is expected to trigger new growth opportunities or bring significant value to existing strategic pillars of Singapore. Some examples of potential areas include Education, Smart City, Ports and Aviation, Industry 4.0 and Immersive Media.

44. IMDA plans to work with industry owners to facilitate a multiplicity of use-cases to explore research and innovation opportunities in 5G-enabled technologies[11] and demonstrate the technology and commercial potential of 5G. IMDA aims to deepen partnerships with global technology players and vendors in the 5G value chain to develop 5G applications and scale differentiated offerings for each vertical. By facilitating collaboration between operators and other ecosystem players, IMDA seeks to entrench long-term commitment from these players, land expertise in 5G development from major global players and sustain continuous innovation in 5G within Singapore.

45. IMDA will also extend the frequency fee waiver period for 5G trials under the Technical Trial and Market Trial frameworks until the commencement of the spectrum rights in relevant spectrum bands. This will continue to lower the regulatory and cost barriers with the intent of encouraging the industry to trial 5G capabilities in Singapore.

Question 2: IMDA would like to seek views on:

i) The types of innovative use-cases that could capitalise and further enhance Singapore's competitive advantages, trigger new growth potential and/or strengthen Singapore's existing strategic pillars; and

ii) Areas of government support that the industry require in order to enable innovation and development in 5G.

46. In summary, we aim to foster a healthy and robust ecosystem to facilitate continuous innovation in the development of secure 5G applications and differentiated offerings to achieve favourable economic outcomes. As Singapore continues to grow its expertise and experience in 5G innovation, we aim to deepen collaboration with international partners and position Singapore as a front-runner in this space.

[11] For example, in the use of the higher frequencies in the mmWave band, massive MIMO antennas, SDN and NFV.

Chapter 3: Proposed Regulatory Policy and Framework for 5G Deployment in Singapore

Mobile Market Environment Today

47. Mobile connectivity is an important foundation in meeting the wireless communication needs of both businesses and consumers in Singapore. Our mobile connectivity is provisioned by four MNOs namely: M1 Limited ("**M1**"), Singtel Mobile Singapore Pte Ltd ("**Singtel**"), StarHub Mobile Pte Ltd ("**StarHub**") and TPG Telecom Pte Ltd ("**TPG**"). Incumbent operators have deployed 4G mobile networks nationwide since 2012, while the new entrant, TPG, has launched service trials since January 2019 while continuing to deploy its 4G network nationwide.

48. In recent years, there have been a number of new mobile virtual network operators ("**MVNOs**") entering the market, such as Liberty Wireless Pte Ltd operating under the commercial brand of **Circles.Life**, MyRepublic Limited ("**MyRepublic**"), Zero1 Pte Ltd ("**Zero1**") and Zero Mobile Pte Ltd ("**Zero**"). Unlike MNOs who build their own wireless network infrastructure, these MVNOs enter into commercial agreements with the MNOs to ride on their deployed infrastructure to resell mobile connectivity and provide services under the MVNOs' own branding.

49. As a result, Singapore's mobile market has become more vibrant, with greater price and service innovation such as the introduction of SIM-only plans, data add-ons and unlimited data plans. For example, there are 1 GB mobile plans from as low as $0, and unlimited data plans from $29.99 per month (4G speeds capped at first 15 GB).

50. Our vibrant, multi-operator environment has served us well, providing network and service diversity, as well as competitive and innovative service offerings. This has allowed Singapore to lead in Southeast Asia and positions us amongst the world's bests in delivering high mobile download speeds and fast network response times nationwide[12]. Together with our nationwide fibre infrastructure rolled out to all homes and building premises, Singapore is in a strong starting position to deploy 5G.

[12] Source: https://www.opensignal.com/reports/2018/11/singapore/mobile-networks-update

Key Policy Objectives

51. IMDA seeks to achieve the following key policy objectives for the deployment of 5G networks in Singapore:

    a. Maximise value of 5G for the economy and welfare for the consumers;

    b. Facilitate efficient allocation of scarce resources such as spectrum;

    c. Ensure that Singapore's 5G networks are designed to be trusted and resilient; and

    d. Support the growth of a vibrant telecommunication sector.

52. IMDA proposes to adopt the following strategies to achieve the above policy objectives:

    a. **Facilitate early deployment of 5G starting from 2020 based on SA network specifications:** This takes into consideration assessment by the industry and the technology community that the new SA network standards will deliver the full capabilities and performance of 5G such as network virtualisation, intelligence at network edges, and dynamic provisioning of differentiated services for different use-cases. IMDA seeks to facilitate the commencement of network rollout from 2020, soon after the SA standards in Release 16 are finalised in March 2020. This will place Singapore amongst the early wave of countries deploying full-fledged 5G networks nationwide.

    b. **Facilitate sustainable competition with at least two nationwide networks in initial years:** IMDA believes that facilities-based competition in the mobile market will continue to be key to ensure that players in the market have the incentive to invest in new technology, innovate and compete. However, this will need to be complemented by services-based competition to bring about greater choice and service innovation. This is especially so where there are market constraints, such as spectrum resources, thus limiting the number of operators and networks that the market can accommodate. In recognition of the need to optimise the limited spectrum resources in the initial waive of spectrum globally identified for 5G, and to deliver maximum performance and service experience to end-users in Singapore, IMDA will facilitate the deployment of at least two nationwide networks in the initial years. IMDA will also encourage network sharing amongst MNOs and facilitate services-based competition.

c. **Impose regulatory requirements to ensure 5G networks remain resilient and trusted.** IMDA will propose certain baseline regulatory requirements for compliance to ensure that 5G networks are trusted and resilient.

d. **Provide flexibility in the regulatory frameworks to allow market to grow and adjust:** In view of the fast pace of technological advancements and market developments, IMDA's regulatory framework will allow migration paths for future network builds and technology upgrades, taking into account new spectrum bands coming on board that may alter market dynamics.

53. The sections below elaborate the regulatory frameworks and measures IMDA will adopt in support of the above strategies. They include the approach to assigning spectrum to MNOs interested to deploy 5G networks, the key regulatory obligations and requirements to be imposed on MNOs awarded 5G spectrum, and regulatory measures to facilitate 5G network rollout.

Spectrum Allocation for 5G

54. Unlike today's cellular networks, 5G is projected to operate in a mix of frequency bands with different characteristics. This spectrum mix includes radio frequencies below 1 GHz to support massive IoT applications, frequencies from 1 to 6 GHz for enhanced mobile broadband and mission control, and high frequencies above 6 GHz for dense networks (commonly known as the millimetre Wave or **mmWave** band). The low frequencies have better propagation properties, and are ideal for wide geographical coverage and good in-building penetration with fewer cells. The above-1 GHz spectrum is typically used for capacity enhancements.

55. Based on the global spectrum roadmap, the front-runner 5G bands today are the 3.5 GHz, 26 GHz and 28 GHz bands. These bands have the most commercially developed device ecosystem. Other radio frequencies such as those in the 2.5 GHz and 4.5 GHz band have been identified to be commercially ready in the next wave (see Table 1).

Table 1: Overview of Spectrum Bands Identified for 5G Services

	Spectrum band	Current allocation	Amount of spectrum available	Available from
Initial wave of 5G spectrum	3.5 GHz	Fixed Satellite Services ("**FSS**") (downlink)	200 MHz	Estimated 2021/2022[13]
	26/28 GHz	FSS (uplink) for specific frequencies in 28 GHz band	>4000 MHz	2020
Next wave of 5G spectrum	700 MHz	4G	90 MHz	After Analogue Switch Off ("**ASO**") for neighbouring jurisdictions at the border areas
	1.4 GHz (L-band)	Digital audio broadcasting	Approximately 91 MHz	Currently 1452 – 1492 MHz is available for trials
	2.1 GHz	3G (4G allowed)	135 MHz, including Time Division Duplex bands	To be renewed in January 2022
	2.5 GHz TDD	4G	45 MHz	Spectrum Rights commenced in 2017 and will expire in 2032
	4.5 GHz	Fixed Service ("**FS**")	Approximately 200 MHz	Post 2025[14]

3.5 GHz (Initial Wave)

56. Several leading 5G markets such as the European Union[15] ("**EU**"), China, Japan and South Korea have considered all or portion(s) of the C-band from 3.3 – 4.2 GHz as a primary 5G band. However, for Asian countries in the equatorial region, this band is heavily utilised for FSS offering a wide range of communication services such as distribution of TV channels, enabling rural communications and disaster recovery management. Countries in the equatorial region who have satellite service providers in this band will not be

[13] Subject to the migration of FSS users.
[14] Subject to the migration of existing FS users.
[15] There are plans for EU to establish 3.4 – 4.2 GHz for 5G. In the United Kingdom ("**UK**"), 150 MHz of spectrum in the 3.4 – 3.6 GHz band has been auctioned for 5G in April 2018 and won by four operators, namely O2 (40 MHz), EE (40 MHz), Vodafone (50 MHz) and Three (20 MHz). Another 200 MHz within 3.6 – 3.8 GHz will be made available for auction in 2020. In Germany, 5G auction with 3.4 – 3.7 GHz has recently commenced on 19 March 2019.

able to deploy 5G as quickly as operators elsewhere. It is also noted that any disruption to the services in this band may impact countries relying on satellite services for their communication needs.

57. In Singapore, most of the key FSS operations today operate in the 3.7 – 4.2 GHz range of the C-band, while the extended C-band in the 3.4 – 3.6 GHz range is generally used for the purpose of satellite signals reception for TV Receive-Only ("**TVRO**") stations to individual sites (e.g., hotels, hospitals). IMDA had earlier proposed two approaches for the migration of existing services: (a) Full migration; and (b) Partial migration, in order to implement IMT services in the extended C-band. This is considering that co-channel operations of both IMT and FSS (downlink) services is not possible, given Singapore's geographical conditions. In either approach, satellite users within the extended C-band will have the option to migrate upwards to the 3.7 – 4.2 GHz frequency band.

58. Some Respondents were supportive of the migration of satellite services out of the extended C-band and highlighted the potential of the extended C-band to support a wide range of 5G services with its wide bandwidth available. In view of the growing interest in the full C-band for 5G services due to its large contiguous bandwidth, some Respondents also proposed for the existing satellite services to be migrated out of the C-band in order to avoid a second migration. However, a few Respondents had pointed out that it might not be practical for existing satellite operations to be migrated out of the extended C-band, citing that significant costs and effort would be required. One Respondent suggested opening up the 3.4 – 3.5 GHz band for mobile services while retaining the 3.5 – 3.7 GHz band for existing satellite operations. This would provide 100 MHz of bandwidth (i.e., 3.4 – 3.5 GHz) for IMT services while minimising any disruptions and challenges that might be posed to the satellite operations.

59. To address co-channel and adjacent band deployment of FSS and IMT services in the extended C-band, some Respondents submitted that coexistence parameters established in earlier studies conducted by ITU and other bodies could be used as references. A few Respondents pointed out that in determining the appropriate coexistence parameters, realistic assumptions on the operational parameters and modelling of both FSS and IMT systems should be made to reflect the actual performance and deployments of both systems. Some of the other suggestions to manage coexistence between IMT and FSS operations include the implementation of guard bands, power flux density limitations, close coordination between IMT and satellite operators, and adopting IMT techniques such as multi-antenna beamforming, antenna tilt adjustment and antenna backplane screening.

60. Some Respondents noted that any decision by Singapore in the extended C-band should take into consideration possible interference to co-frequency and/or adjacent band satellite operations above 3.6 GHz in neighbouring countries. With regard to this, a few Respondents had encouraged IMDA to conduct bilateral agreements and cross-border coordination with neighbouring countries to minimise interference issues.

61. Besides taking guidance from the coexistence parameters from various studies, IMDA is aware that the implementation of regionally or globally harmonised frequency arrangements will greatly facilitate cross-border coordination and minimise any coexistence issues that might arise at the borders. Such harmonisation across the region helps to reduce the need for countries to address potential cross-border interference on a case-by-case basis. IMDA is already in discussions with our neighbouring countries through bilateral and regional-level meetings to harmonise the use of IMT in the extended C-band.

62. IMDA has carefully considered the interests of all stakeholders, along with ongoing efforts in enabling 5G mobile services in Singapore while continuing the use of satellite operations in the C-band, and has decided that:

a. The primary allocation of the 3.4 – 3.7 GHz band will be changed from FSS (space-to-Earth) to mobile service; and

b. The primary allocation of the 3.7 – 4.2 GHz band will be retained as FSS (space-to-Earth).

63. The table below shows the change in frequency allocations:

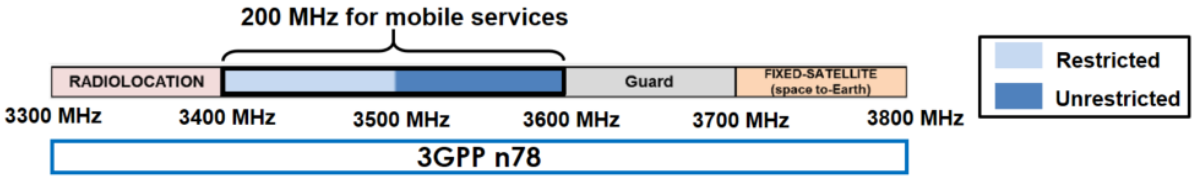
Table 1: Frequency Allocation for the C-band

Frequency band (GHz)	**Singapore**	
	Current	**New**
3.4 – 3.7	FIXED-SATELLITE (space-to-Earth)	MOBILE
3.7 – 4.2	FIXED-SATELLITE (space-to-Earth)	FIXED-SATELLITE (space-to-Earth)

64. Taking all technical constraints into consideration, IMDA plans to make available 100 MHz of spectrum for outdoor, indoor and underground ("**unrestricted**") use within the 3.5 – 3.6 GHz band for 5G telecommunication systems and services (see Figure 7) in the immediate term. Additionally, while IMDA notes that more restrictions will be required for mobile service usage within the 3.4 – 3.5 GHz band, IMDA intends to make available up to 100 MHz

spectrum within this band on a "**restricted**" use basis, where deployments may have to be limited to indoors and underground.

Figure 7: Available Spectrum in the 3.5 GHz Band



65. IMDA has commissioned technical studies to assess the feasibility of 5G deployment within these bands which will determine the final amount of guard band, within 3.6 – 3.7 GHz, necessary between FSS and mobile service, and the recommended technical and operational parameters of 5G usage in the bands. In the interim, to protect the FSS (downlink) services above 3.7 GHz, IMDA is looking to implement approximately 100 MHz of guard band between the two services. Technical trials will be conducted to determine the technical feasibility of the recommended parameters (e.g., guard band, emission power limits, etc.).

66. IMDA has sought feedback from affected C-band licensees on the migration of satellite services occupying the 3.4 – 3.7 GHz band (the "**Migration Exercise**").

67. To avoid potential radio interference in the future 5G rollout, IMDA will assist and work closely with affected FSS users in the 3.4 – 3.7 GHz band to migrate their services to other suitable spectrum bands such as the 3.7 – 4.2 GHz range of the C-band. IMDA is looking at approximately 18 months until end 2020 to complete this Migration Exercise. Concurrently, existing users operating in the remaining parts of the C-band for FSS (downlink) purposes are advised to take the necessary preparatory steps such as retrofitting an appropriate band pass filter to protect the signal reception of their telecommunication equipment or system to mitigate potential interference against 5G transmissions from the extended C-band. IMDA will review and assess concerns from licensees who may face migration-related issues arising from the Migration Exercise.

68. IMDA notes that there are geographical clusters in Singapore with dense deployment of FSS services such as the Seletar Earth Station, which houses the telemetry, tracking and control ("**TT&C**") operations of an operational satellite, including manoeuvring the satellite in orbit and monitoring the operational status of the satellite. IMDA is exploring the setting up of exclusion zone(s) in Singapore to protect such critical FSS operations from desensitisation or interference caused by strong radio emissions of 5G mobile base stations in the 3.5 GHz band. IMDA encourages proposals from the

industry to conduct technical trials to determine the feasibility and requirements of the exclusion zone(s).

69. Due to Singapore's close proximity with our neighbouring countries, IMDA will continue to engage the regulators from Indonesia and Malaysia to achieve cross-border coordination and harmonisation on the use of spectrum within 3.4 – 3.7 GHz for 5G use. Therefore, the spectrum availability and timing include, amongst other things, results of the cross-border coordination and migration of existing users. Nevertheless, IMDA endeavours to make available the 3.5 GHz band for 5G deployment in 2021 at the earliest.

Question 3: IMDA would like to seek views and comments on the suitable technical parameters, including the reasonable amount of guard band needed to reduce potential interference between IMT and FSS use in the 3.5 GHz band.

26 GHz and 28 GHz (Initial Wave)

70. A number of mmWave bands such as the 26 GHz and 28 GHz (i.e., 24.25 – 27.5 GHz and 27.5 – 29.5 GHz) have been identified for 5G deployment. Most Respondents agreed that mmWave bands are important in providing extremely high data rate and capacity, complementing the sub-6 GHz bands that deliver coverage and service continuity. However, given the nature and propagation characteristics of mmWave bands, 5G mobile systems operating in mmWave spectrum will mainly be deployed in hotspots and indoor scenarios, with each individual cell providing limited coverage.

71. Generally, most Respondents recommended for IMDA to make available 800 MHz of contiguous spectrum per MNO for initial deployment of mmWave 5G systems. Some Respondents had also cited that the 3GPP had adopted a component carrier bandwidth of 400 MHz in the mmWave bands for 5G NR which can be aggregated to provide even larger contiguous bandwidths.

72. IMDA observed that developments in the 28 GHz band had been driven by major mobile markets such as the U.S., South Korea and Japan, and early 5G deployments are taking place in this band. The ecosystem, use-cases and business models developed in the 28 GHz are also estimated to accelerate the development of the other mmWave bands, particularly the 26 GHz band. Focus in this band will allow Singapore to benefit from the wide tuning range spanning across 26 GHz and 28 GHz bands in future commercial equipment. However, some Respondents had highlighted that the 28 GHz band is heavily used worldwide for various satellite services and extensive satellite investments have been incurred in the 28 GHz band. The 28 GHz band is also seen as a critical

band for the continued innovation and deployment of the high throughput satellites ("**HTS**") and very high throughput satellites ("**VHTS**"). A few Respondents noted that co-channel coexistence between satellite services and 5G networks is generally difficult, and that FS and FSS in neighbouring countries would cause interference to the IMT services deployed in the 28 GHz band in Singapore.

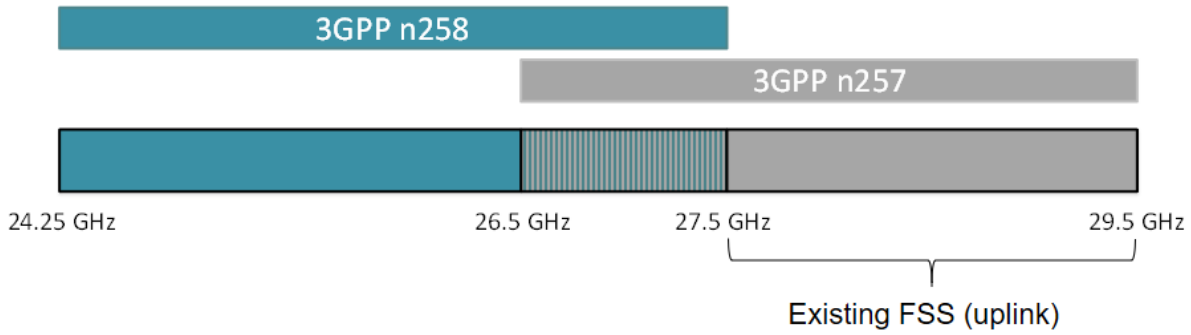
73. In Singapore, the 28 GHz band is currently used for FSS (uplink), and specifically transmission from maritime vessels to the satellites, to provide on-board broadband connectivity. IMDA recognises that coexistence between IMT and FSS services could be made possible through coordination of the technical parameters and usage in this band.

74. Moving forward, it is also expected that there will be additional satellite deployments in the 28 GHz band for aircraft platforms[16]. However, since satellite operations are confined to air and space platforms, IMDA is of the view that coexistence between these satellite service and 5G is possible. If necessary, IMDA will put in place operational guidelines within the licensing condition for satellite services to mitigate interference issues. For example, the minimum distance away from shore and stage of flight for these platform to transit from terrestrial to satellite services. With the exception of satellite services, there are no indications from the industry of any future planned local deployments in this band.

75. Given global developments related to the use of the 26 GHz and 28 GHz bands for 5G services, IMDA has decided to allocate these bands on a primary basis to mobile service, in addition to existing allocations, if any. Under this arrangement, mobile service and fixed satellite service operating in the frequency band 28.5 – 29.5 GHz will be on a co-primary basis. Stations in the FSS are expected to take measures to ensure protection of, and not impose undue constraints on, 5G services operating in the band, such as coordinating with MNOs holding spectrum rights in the same frequency band.

[16] Taking into consideration that Agenda Item 1.5 of WRC-19 considers the use of frequency bands 17.7 – 19.7 GHz (space-to-Earth) and 27.5 – 29.5 GHz (Earth-to-space) by earth stations in motion ("**ESIMs**") communication with geostationary space stations in the fixed-satellite service, there is a possibility for more satellite deployments in the 28 GHz after 2019, depending on the outcomes of WRC-19. IMDA also understands that there are plans to install ESIMs in the 29.0 – 29.5 GHz range to provide additional capacity to the ESIMs deployed in the 29.5 – 30 GHz on future aircrafts. However, further studies will be required to mitigate coexistence issues and this will be addressed in WRC-19 Agenda Item 1.5.

Figure 8: Available mmWave Spectrum



76. The table below shows the change in frequency allocations:

Table 3: Frequency Allocation for the 26 and 28 GHz Bands

Frequency band (GHz)	Singapore	
	Current	**New**
24.25 – 27.5	No allocation	MOBILE
27.5 – 28.5	FIXED	MOBILE FIXED
28.5 – 29.5	FIXED FIXED-SATELLITE (Earth-to-space)	MOBILE FIXED FIXED-SATELLITE (Earth-to-space)

Other Spectrum Bands for 5G (Next wave)

Below 1 GHz Frequency Bands

77. Most Respondents supported the re-farming of the 800 MHz band by adopting 3GPP Band 26, or a combination of 3GPP Bands 27 and 5. Some Respondents also indicated the growing global interest of the sub-700 MHz band and suggested for IMDA to consider the 600 MHz band (614 – 698 MHz) in its long-term planning for mobile services. This is in view of the recent U.S. incentive auction and interests from several administrations in the Asia Pacific region. Some Respondents also noted the importance of harmonising low-frequency bands, such as the recently allocated 700 MHz, in the Asia Pacific region to avoid cross-border interference and ensure economies of scale for the region.

78. IMDA is proposing to allocate 810 – 823 MHz paired with 855 – 868 MHz to IMT services. The available spectrum is currently overlapping 3GPP Bands 26 and 27 where the device/network ecosystems are less developed, and there

are no known 5G developments. IMDA has assessed that there is a low opportunity cost to not using this spectrum for 5G and therefore will be proposing to make the spectrum available for dedicated LTE-based enterprise use. IMDA will separately consult on the proposed band plan and assignment approach.

79. For the sub-700 MHz band, it is heavily utilised by terrestrial broadcasting services in Singapore and the region. As such, the noise floor level in the sub-700 MHz band is relatively high and it may not be suitable for mobile service deployment. In view of the above, IMDA will not be releasing the sub-700 MHz spectrum for mobile services in the near term, but will continue to monitor international trends and developments in the sub-700 MHz band and consider further re-farming when the environment is more ready.

80. On the other hand, the 700 MHz has been identified by the European Commission for 5G and has mandated the EU countries to make spectrum available in this band for 5G use by 2020[17]. Over the last few years, there have been a number of auctions in the 700 MHz band carried out in Europe. With the superior propagation characteristics of this band, including the potential 5G usage in Europe, 700 MHz is seen as a potential 5G band with development of the 5G device ecosystem supporting this band expected around 2020. In Singapore, the 700 MHz band was auctioned in 2017, with a 15-year spectrum right duration. Currently, its commencement date is dependent on neighbouring countries' completion of ASO at the border areas.

81. Spectrum availability in the sub-1 GHz range is recognised to be essential to enable large-scale IoT deployments due to its good propagation characteristics.

82. At present, the demand for IoT services is relatively low with most IoT services being limited to small scale deployments. Hence, some Respondents indicated that the current generations of mobile networks and existing 3GPP-based cellular IoT technologies (i.e., enhanced machine-type communications, Narrowband-IoT ("**NB-IoT**")) and vendor proprietary technologies (i.e., Sigfox, LoRa) would be sufficient to support the current demands of IoT applications. IMDA notes that, currently, NB-IoT and/or LTE CAT-M1 have already been deployed by the MNOs in some of the 3GPP bands such as 900 MHz and 1800 MHz that are assigned to them.

83. Moving forward, MNOs can leverage the 700 MHz to deploy IoT services, in addition to 4G services, once available. IMDA may consider permitting this band for deployment of 5G services when the spectrum becomes available.

[17] See https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32017D0899

L-Band

84. At WRC-15, the L-band was harmonised for IMT, providing up to a total of 91 MHz[18] of spectrum within the Asia Pacific and the Americas regions. Following the global momentum to deploy IMT in this band, IMDA is also looking at the possibility of making this band available for IMT services. IMDA notes the interest from a majority of the Respondents on their preference to allocate the full 91 MHz bandwidth.

85. Currently, there are ongoing studies in regional and international fora to address both the frequency arrangements and adjacent channel coexistence issues for this band. Studies are being conducted to address the issue of adjacent band sharing with Mobile Satellite Service ("**MSS**") around the 1518 MHz band edge. Some of the possible mitigation techniques include the implementation of a guard band between IMT and MSS, and an out-of-band emission mask where a 3 MHz guard band is recommended at the upper and lower band edge.

86. Three potential IMT deployment techniques currently considered for the L-band include the frequency division duplex ("**FDD**"), time division duplex ("**TDD**") and the supplemental downlink ("**SDL**") technologies. A majority of Respondents had recommended the SDL frequency arrangement adopted by Europe as it provides additional downlink capacity and would lead to more efficient spectrum use as compared to the FDD frequency arrangement. There was also some support for the FDD frequency arrangement which had been adopted by Japan[19].

87. IMDA has studied the various pairing arrangements of the L-band, using LTE Carrier Aggregation and LTE-NR Dual Connectivity combinations based on 3GPP Release 15[20], with other bands in the MNOs' spectrum holdings. IMDA has determined that these existing combinations either do not maximise the use of the full band (i.e. 91MHz) for mobile services or are paired with frequency bands that are not yet readily available in Singapore. However, IMDA is cognisant that there may be a possibility for the adoption of additional L-band pairing arrangement in subsequent 3GPP releases that would be suited for Singapore. As for the device ecosystem, most Respondents were generally of the view that L-band equipment would be commercially available around 2020 or after. Hence, IMDA will continue to monitor the regional and international harmonisation of the L-band channelling arrangements, and the ecosystem

[18] 1427 – 1518 MHz
[19] In Japan, the L-band is being deployed based on 3GPP Band 11 and 21.
[20] Based on March 2019 updates.

development within this band before allocating this band for mobile use. In the interim, IMDA will continue to keep the L-band open for trial[21].

2.1 GHz Band

88. Today, the 2.1 GHz band is primarily used for 3G mobile services, and is increasingly being deployed for 4G services with more countries and operators planning to re-farm the band for 4G use. It is noted that the 2.1 GHz band, i.e., 3GPP Band 1 has already been adopted as a 5G NR band. IMDA recognises that the 2.1 GHz is a candidate band for 5G deployment in Singapore but is also cognisant that the 5G device/network ecosystem in this band will only be developed after 2020/2021. Moreover, IMDA is of the view that the band is still required for the continued provision of 3G services in Singapore within the short to medium term, possibly until at least 2025, if not later. IMDA will separately consult on the use of the 2.1 GHz band.

2.5 GHz Band

89. The 2.5 GHz band comprises spectrum in 2500 – 2560 / 2620 – 2680 MHz ("**2.5 GHz FDD**") and 2570 – 2615- MHz ("**2.5 GHz TDD**"), that were auctioned in 2013 and 2017 respectively, and the spectrum rights expire on 30 June 2030 and 30 June 2033 respectively. They are currently deployed for 4G services based on 3GPP Band 7 (for FDD) and Band 38 (for TDD), and both bands have been adopted as 5G NR bands. The 2.5 GHz band also falls within 3GPP Band 41 (2496 – 2690 MHz, and also adopted as a 5G NR band) and IMDA understands that both Band 38 and Band 41 are amongst the popular bands deployed for LTE TDD worldwide, with Band 41 gaining traction internationally for 5G. It is expected that the 2.5 GHz band will be the next key sub-6 GHz band for 5G and brings along with it a fast growing ecosystem, which is expected to become commercially more ready in 2020/2021.

90. However, given the current extensive use of 2.5 GHz FDD for 4G and the need for border coordination with neighbouring countries, it will be technically challenging to adopt Band 41 in Singapore at this juncture. IMDA will review the opportunity to refarm the 2.5 GHz band for 5G services in the future when the ecosystem is more ready.

[21] IMDA will continue to 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 or Market Trial frameworks.

4.5 GHz

91. Spectrum availability for IMT in the 4.4 – 5.0 GHz range ("**4.5 GHz**") is increasing globally and some Respondents had indicated that frequencies in this band had potential for long term 5G development. IMDA notes that 3GPP Release 15 specification for 5G NR included the NR operating band "**n79**" (i.e., 4.4 – 5.0 GHz) which will be used in TDD mode. Currently, three administrations are looking at 4.5 GHz as a possible 5G band: Japan with a primary interest in 4.5 – 4.6 GHz, China who is considering 4.8 – 5.0 GHz, and Hong Kong who has decided to assign spectrum in the 4.83 – 4.93 GHz range. In Europe and the U.S., this band is mainly used by the military and there is currently little traction to assign it for 5G services. Therefore, global harmonisation of the 4.5 GHz band for 5G use would likely be achieved at a later stage, with device/network ecosystem estimated to be available from or after 2021.

92. Currently, frequencies within this band are being utilised in Singapore for FS. Subject to cross border-coordination and migration of existing users, the availability of spectrum in the 4.5 GHz band for 5G deployment (approximately 200 MHz) will take at least 3 – 5 years to be repurposed.

In Summary

93. IMDA will allocate the 3.5 GHz, and the 26 GHz and 28 GHz mmWave bands to 5G in the initial wave of spectrum allocation to existing MNOs who are interested to deploy 5G technology. IMDA will open up other spectrum bands a few years later, e.g., around 2025, when the global ecosystem is more ready for cost efficient deployment.

Question 4: IMDA would like to seek views and comments on the following:

i) Whether the industry agrees with the timelines on the expected availability of the next wave of 5G spectrum; and

ii) Whether current deployments in the 2.5 GHz FDD spectrum band (based on 3GPP Band 7) and in the 2.5 GHz TDD spectrum band (based on 3GPP Band 38), should be refarmed to 3GPP Band 41 for future 5G services in Singapore, and the views on the associated cost and challenges.

Initial 5G Market Structure and 3.5 GHz and mmWave Band Plan Options

Initial 5G Market Structure

94. Today, Singapore's 4G networks offer nationwide coverage and have average download speeds of at least 40 Mbps[22], and are capable of achieving theoretical download speeds of 1 Gbps. As 5G NSA networks will be dependent on existing 4G networks, they will only result in incremental benefits in enhanced mobile broadband services. To realise the full potential of 5G, such as virtualisation and network slicing capabilities, operators will need to deploy SA networks.

95. The 3.5 GHz band is the current frontrunner 5G band that is needed to efficiently achieve both capacity and pervasive coverage. In terms of capacity, IMDA notes that spectrum holding of less than 40 MHz would not give throughput speeds that are noticeably different from 4G today. At the same time, the maximum single carrier size for the 3.5 GHz band is 100 MHz, which will allow a peak downlink throughput of 1750 Mbps[23] per user per cell. However, as discussed earlier, there is limited spectrum in the 3.5 GHz band, in particular for unrestricted spectrum to allow for pervasive outdoor coverage.

96. A 50 MHz carrier size in the 3.5 GHz band will allow an MNO to achieve a theoretical peak downlink throughput of 850 Mbps[24] per user per cell. In a similar radio environment, an individual end-user throughput will always be higher with more spectrum. However, higher order antennas (e.g., 64 receive, 64 transmit antenna which is also known as 64T64R) can be deployed to increase the cell throughput by simultaneously serving many user terminals in the cell. The cell throughput that can be theoretically achieved with the different order antennas is illustrated[25] in the table below.

Table 4: Theoretical Throughput for 50 MHz and 100 MHz based on 16T16R, 32T32R and 64T64R Antennas

	3.5 GHz throughput per cell (Mbps)		
	16T16R	**32T32R**	**64T64R**
50 MHz	850	1700 (850 per user)	3400 (850 per user)
100 MHz	1750	3500 (1750 per user)	7000 (1750 per user)

[22] Based on Opensignal report, November 2018.
[23] Based on 3GPP TS 38.306 V15.5.0 using a subcarrier spacing of 30 kHz, 256 quadrature amplitude modulation, 4 layers, uplink/downlink ratio of 1:3 and overhead of 0.14.
[24] Based on a similar set of calculations used for the 100 MHz carrier but with a 50 MHz carrier size.
[25] Based on a particular vendor's portfolio of active antenna systems.

97. For the mmWave band, given its limited propagation characteristics, deploying the mmWave spectrum alone will be challenging to achieve pervasive deployment, and grafting this band onto existing 4G networks, i.e., 5G NSA, would not reap the full benefits of 5G. Therefore, assigning the mmWave on a standalone basis will not meet IMDA's policy objectives.

98. Bearing in mind the various spectrum constraints as well as IMDA's policy outcomes of having 5G networks that are capable of delivering full-fledged 5G functionalities and capabilities, IMDA proposes to assign the 3.5 GHz and mmWave bands as a package. Such an approach will also allow optimal outdoor and indoor performance.

99. In particular, IMDA will facilitate the deployment of at least two nationwide, trusted and resilient networks in the initial years. Facilities-based competition in the mobile market will continue to be key to ensure that players in the market have the incentive to invest in new technology, innovate and compete for business. IMDA also encourages network sharing amongst MNOs and facilitate services-based competition. IMDA will only assign spectrum to existing MNOs[26], given the spectrum constraints and the uncertainty in early use-cases. Assignment to non-MNOs may fragment the market further.

3.5 GHz and mmWave Band Plan Options

100. As explained in the sections above, IMDA proposes to assign unrestricted spectrum in the 3.5 GHz band to two MNOs and/or joint ventures involving MNOs, i.e., each will be assigned a block of unrestricted 50 MHz that will enable pervasive coverage at higher speeds.

101. Additionally, IMDA sees value to pair the left most 50 MHz of unrestricted spectrum with additional contiguous restricted spectrum that can be deployed indoors and underground. Based on a recent UK consultation[27], operators in UK have generally indicated that a minimum of 80 MHz bandwidth in the 3.5 GHz band is sufficient for 5G deployment. However, to optimise performance for at least one network, IMDA proposes to pair the left-most 50 MHz of unrestricted spectrum with 50 MHz of restricted spectrum (i.e. 100 MHz of 3.5 GHz in total). This will enable at least one network to reach a peak throughput of 1750 Mbps for indoor and underground deployment as a start.

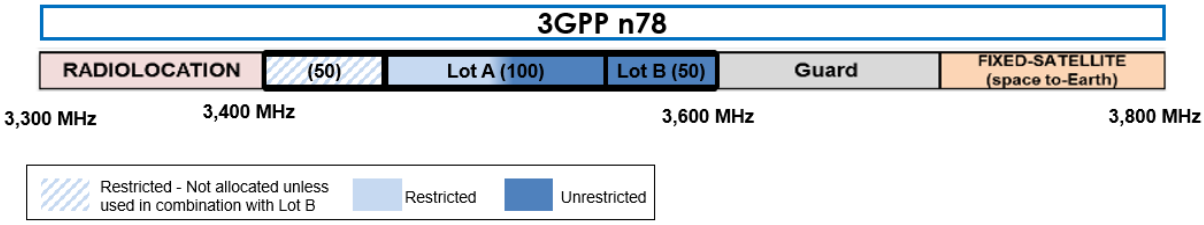
[26] This may include any joint ventures and/or consortiums involving at least one existing MNO, or between two or more existing MNOs.

[27] https://www.ofcom.org.uk/__data/assets/pdf_file/0019/130726/Award-of-the-700-MHz-and-3.6-3.8-GHz-spectrum-bands.pdf

102. IMDA notes that there are currently no standards for intra-band carrier aggregation between non-contiguous spectrum in the 3GPP Release 15. Even if there are standards in the future, IMDA notes that aggregating non-contiguous spectrum would be less efficient[28]. As there may be little benefits in having spectrum with only restricted use, and in view of the nascent technology and market environment at this juncture, IMDA proposes to assign the remaining restricted spectrum in the next phase. IMDA is, however, open to hearing if there are compelling reasons to pair this with the right-most unrestricted 50MHz spectrum.

103. IMDA is thus considering to assign two spectrum packages of (a) a 50 MHz unrestricted lot, and (b) a 100 MHz lot comprising a 50 MHz unrestricted lot paired with a 50 MHz restricted lot (refer to Figure 9). IMDA is also prepared to consider adjustments to these lot sizes in assigning the two packages of 3.5 GHz spectrum, if these will better meet the policy outcomes for Singapore.

Figure 9: Proposed Band Plan Option for the 3.5 GHz Band

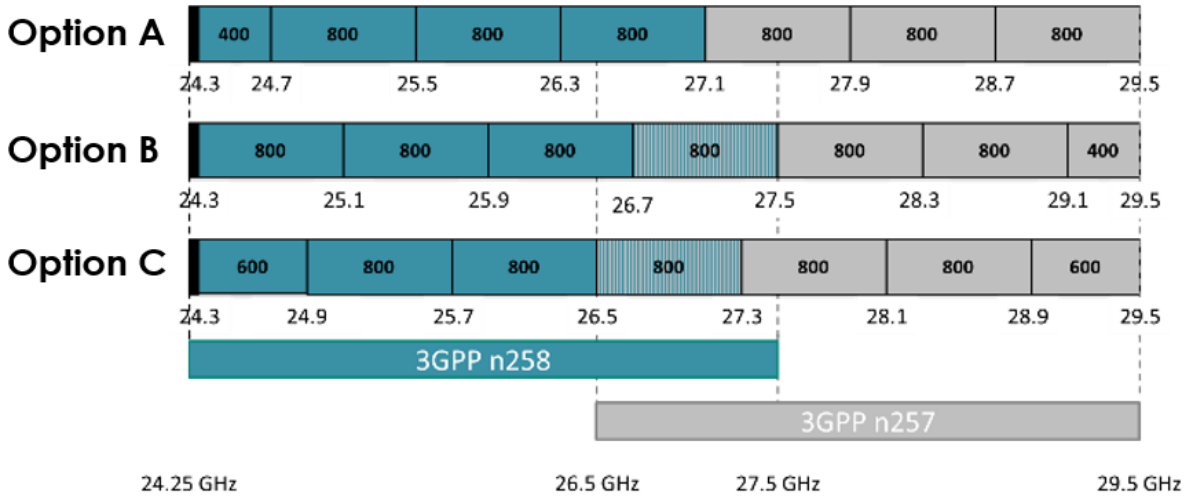


104. For the mmWave band, IMDA notes that the maximum single carrier size is 400 MHz, with the ability to carrier aggregate up to 800 MHz of contiguous spectrum. With this and taking into consideration that there are no spectrum constraints in this band, IMDA is prepared to assign mmWave in blocks of 800 MHz. As noted earlier, grafting mmWave onto 4G networks will not give full 5G capabilities. IMDA proposes to assign the 3.5 GHz and the mmWave bands in a package. The remaining mmWave spectrum can be opened up and paired with low/mid-bands when the latter are made available.

105. IMDA is considering three possible band plan options for the mmWave (refer to Figure 10). Of the three possible options, IMDA's preference is for either Option B or C as the channelling arrangements are more aligned with the 3GPP bands n257 and n258. The operators who have been successfully assigned the 3.5 GHz spectrum will get to select their preferred assignment in the mmWave based on the finalised band plan option.

[28] Based on an April 2019 GSA report, it is noted that the channel utilisation of non-contiguous 50 + 50 MHz is 95.8%, while a contiguous 100 MHz is 98.3%.

Figure 10: Proposed Band Plan Options for the mmWave Spectrum



Question 5: IMDA would like to seek views, comments and suggestions on:

i) Whether Singapore should have two nationwide networks as a start given the considerations and trade-offs;

ii) The proposed 3.5 GHz lot sizes and spectrum packages;

iii) Whether 5G equipment would be able to support 3.5 GHz bandwidths in multiples of 50 MHz;

iv) The value, if any, in assigning the remaining 50 MHz restricted 3.5 GHz spectrum in the same assignment exercise as the unrestricted lots;

v) The proposed mmWave lot sizes and preferred band plan option; and

vi) The rank order preference of the 3.5 GHz spectrum package and mmWave lot combinations.

Key Obligations and Requirements

106. To bring about at least two nationwide, trusted and resilient 5G networks, IMDA proposes to impose the following obligations and requirements on MNOs who are awarded the 3.5 GHz and mmWave spectrum. Broadly, these will be in the areas of network rollout and performance, network design and resilience, and wholesale arrangements.

Network Rollout and Performance

107. Spectrum right holders shall deploy 5G SA networks with >50% coverage within 24 months from the commencement of the 3.5 GHz spectrum right, and put the mmWave band to use within 12 months from the commencement of the spectrum right. For the avoidance of doubt, the spectrum right holders may use a combination of spectrum to meet the >50% coverage requirement.

108. Unlike previous spectrum assignments, IMDA recognises that it could potentially be more challenging to deploy 5G SA networks from the onset. For example, the limited propagation characteristics of the mmWave spectrum means that it can only be deployed on a localised basis and is not suitable for nationwide deployment. Furthermore, MNOs will have to deploy denser networks that are closer to the end-users (e.g., on street side furniture). This phased approach will also allow operators to reap cost efficiencies as the technology matures and allow plans for expansion when new spectrum bands come on board. The rollout obligations have thus been calibrated to ensure that IMDA's policy outcomes can be realised and met practically.

109. As a start, IMDA will not impose Quality of Service ("**QoS**") requirements on the nationwide networks, but reserve the right to do so subsequently when there is greater certainty on 5G demand.

110. Nevertheless, given that IMDA is allocating at least 50 MHz of unrestricted spectrum in the 3.5GHz band and 800 MHz in the mmWave bands, an improvement in the overall network performance is expected when compared to existing 3G/4G networks.

Network Design and Resilience

111. As mentioned in Chapter 1, there are also many other enabling technologies that will be employed for the rollout of 5G, such as SDN, NFV and Cloud Computing. While these enabling technologies have the potential to support innovative features and functionalities, they may also give rise to security and resilience issues given the extensive use of virtualisation technologies and more interfaces between software layers (i.e., more potential points of compromise and failure). In addition, 5G will adopt a more distributed architecture, where computing functions would be performed at the edge to enable ultra-low latency performance, e.g., Multi-access Edge Computing, which in turn poses greater cybersecurity risks.

112. Given the above, it is necessary for 5G networks to be designed to be secure (both from physical and cyber aspects) and resilient at the outset, minimally based on best practices and technical specifications from relevant standards

bodies and forums, such as 3GPP, IETF, ETSI, and IEEE, and the regulatory requirements imposed by IMDA.

113. Singapore encourages vendor diversity in our telecommunication systems to mitigate risks from dependency on any one vendor. In addition, operators should ensure that the performance and reliability of equipment purchased from vendors meets their commercial operational needs and regulatory requirements, including those pertaining to quality of service, resilience and security.

Wholesale Arrangement

114. Spectrum right holders shall provide 5G wholesale services to other mobile service providers, specifically to any MNOs and MVNOs, upon request. The negotiation principles for wholesale access published by IMDA under the decision on the Framework for the Allocation of Spectrum for IMT and IMT-Advanced Services and for the Enhancement of Competition in the Mobile Market dated 18 February 2016 continue to remain relevant and will apply. IMDA will update the negotiation principles guiding wholesale access provision and will issue a separate consultation in due course.

Question 6: IMDA would like to seek views, comments and suggestions on:

i) The proposed network rollout and performance obligations to be imposed on the spectrum right holders;

ii) The methodology and measurement criteria for the coverage obligation;

iii) The network design and resilience challenges of 5G (in particular, enabling technologies, such as SDN, NFV and Cloud Computing that may fundamentally change how the network would be designed and deployed) and possible measures to address them, and whether there are other aspects that should be considered to enable trusted and resilient 5G network; and

iv) The framework for the provision of 5G wholesale services.

Spectrum Assignment Mode

Proposed Spectrum Assignment Approach

115. In view of the policy objectives of facilitating early rollout of 5G SA networks that deliver strong performance and capabilities, trusted and resilient networks, while working with the spectrum constraints and nascent business case, IMDA recognises that the auction mechanism will not be able to bring about the desired policy outcomes in this first wave of spectrum assignment. As such, IMDA intends to assign the spectrum via a call for proposal ("**CFP**") approach instead. MNOs will compete based on the merits of their proposals that can best deliver future-ready 5G networks to meet IMDA's policy objectives.

116. Specifically, IMDA is considering to assign the 3.5 GHz and mmWave bands together via a one-envelope CFP approach.

117. Under this approach, applicants shall submit detailed proposal(s) for the proposed 5G deployment, indicate the rank order preference for the 3.5 GHz package and mmWave lot combination that they wish to apply for[29], and submit the offer price(s) they are willing to pay for the 3.5 GHz package, which shall be above the base price(s) to be determined by IMDA. IMDA will assess whether the proposals are able to meet IMDA's baseline requirements (as covered under the section on Key Obligations and Requirements), and will immediately cease assessing these proposals any further if they are unable to minimally meet IMDA's baseline requirements.

118. IMDA will score and rank the proposals based on the proposed evaluation criteria as detailed in the section below. IMDA will award the two 3.5 GHz packages to the two applicants with the highest scores. The two successful applicants of the 3.5 GHz package will be assigned the mmWave lots based on their desired sitting. In the event of competing demand for the same mmWave lot, the two successful applicants will be allowed to discuss and propose a mutually agreeable assignment for IMDA's consideration. If no consensus can be reached, IMDA will conduct a one-time sealed bid auction for the mmWave assignment.

119. IMDA reserves the right not to award the 3.5 GHz packages and mmWave lots to any of the applicants if the proposals are assessed to be unable to bring about IMDA's policy outcomes and/or fully meet IMDA's baseline regulatory obligations and base prices for the spectrum.

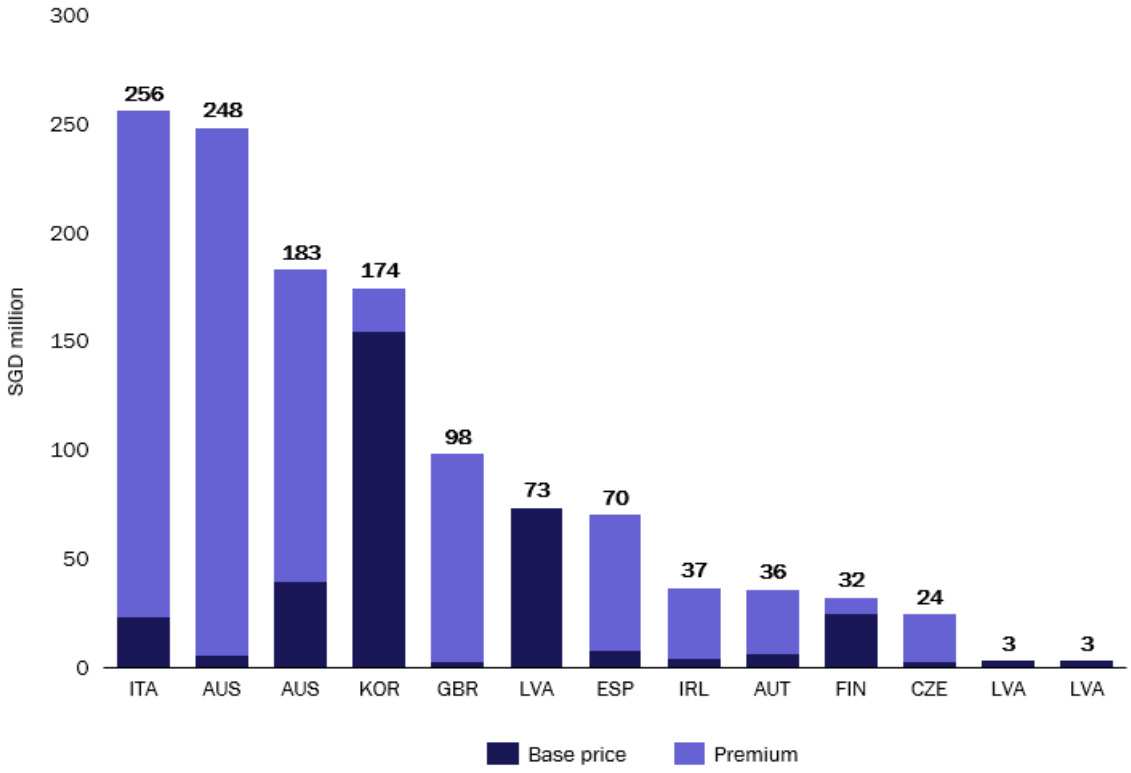
[29] IMDA does not expect the 5G deployments on either 3.5 GHz packages to vary significantly. Applicants shall clearly indicate the delta to the 5G deployment, if any, in their proposals.

Spectrum Right Duration and Base Prices

120. IMDA is proposing around 12 - 15 years for the duration of the spectrum rights to provide sufficient investment certainty for the MNOs, especially considering the denser deployment needed, while catering for technological changes and new 5G spectrum bands that will become available in the coming years. Additionally, IMDA proposes for the 3.5 GHz and mmWave spectrum rights to expire at the same time. Given that the 3.5 GHz spectrum rights will only commence after the migration of existing users has completed, while the mmWave spectrum rights will commence after the completion of the spectrum allocation process, the mmWave spectrum rights will have a longer duration.

121. To arrive at the base prices for the allocation of the 3.5 GHz spectrum packages, IMDA is considering taking reference from international benchmarks of base and final bid prices for similar bands auctioned globally between 2017 and 2019[30] (refer to Figure 11).

Figure 11: International Base and Clearing Prices for 100 MHz of Spectrum in the 3.4 – 3.8 GHz Band (Normalised to Singapore's Population and 13-year Spectrum Duration)



Source: Analysys Mason and regulators' websites

[30] 2017 was the year when the 3 – 4 GHz band was confirmed as a 5G band with the development of the first 5G standards (i.e., 3GPP Release-15).

122. Based on the international benchmarks for a 100 MHz unrestricted 3.5 GHz spectrum (normalised), the clearing price at the 25th percentile, median, and 75th percentile are approximately S$32 mil, S$70 mil, and S$174 mil respectively.

123. As for the mmWave, given that there is excess supply, there will be no spectrum premium payable. However, spectrum right holders will need to pay the applicable annual charge for both bands, as specified in the Telecommunications (Radio-communication) Regulations.

124. For the avoidance of doubt, the successful applicants will be required to pay the one-time application and processing ("**A&P**") fees for both the 3.5 GHz and the mmWave bands.

Table 5: One-time A&P Fees and Annual Charges

Spectrum	One-time A&P fee	Annual charge
3.5 GHz: 50 MHz unrestricted	S$3,000	S$77,000
3.5 GHz: 50 MHz unrestricted paired with 50 MHz restricted	S$6,000	S$154,000
mmWave: 800 MHz	S$48,000	S$1,232,000

Evaluation Criteria

125. As mentioned earlier, IMDA's baseline regulatory requirements are:

a. Provide 5G standalone networks with >50% coverage within 24 months from the commencement of the 3.5 GHz spectrum right and put the mmWave spectrum to use within 12 months from the commencement of the spectrum right;

b. Design and build 5G networks based on best practices and technical specifications from relevant standards bodies and forums, such as 3GPP, IETF, ETSI, and IEEE and comply with IMDA's regulatory requirements; and

c. Provide 5G wholesale services based on IMDA's regulatory requirements and principles to other MNOs/MVNOs upon request.

126. Beyond the baseline regulatory requirements that IMDA will require, IMDA proposes the following evaluation criteria with the respective weights:

Table 6: Evaluation Criteria

Evaluation Criteria	Elaboration
Network Rollout and Performance (30%)	This criterion will look at applicants' proposed network rollout and performance potential. For example, IMDA will consider the extent of 5G coverage, speed of network rollout, capabilities of the proposed SA network and performance standards beyond the baseline requirements set by IMDA.
Network Design & Resilience (40%)	This criterion will look at whether the proposed 5G network is designed with trust and resilience in mind.
Financial Capability (15%)	This criterion will assess whether the applicants have the financial ability to fund their proposed 5G network rollout and have the means to meet their projected costs.
Offer Price (15%)	This criterion will look at the offer price submitted beyond the base price(s).
Wholesale Arrangements	This criterion will require applicants to commit to providing wholesale arrangements to any MNO or MVNO would may request for this.

Question 7: IMDA would like to seek views, comments and suggestions on the spectrum assignment framework, including:

i) The proposed assignment approach;

ii) The spectrum right duration of the 3.5 GHz package and mmWave lots;

iii) The evaluation criteria, sub-criteria and weights to assess the proposals;

iv) The assessment methodology, including evidence (documentary or otherwise) to evaluate the proposals; and

v) The enforcement and/or audit mechanisms to ensure that applicants are able to deliver on their proposals.

Facilitation for Rollout of 5G Networks

Infrastructure Access

127. As 5G is likely to utilise the high frequency bands which have limited propagation range, small cells are poised to be an important part in the future telecommunication landscape. There will be an increasing need for investments in network densification and small cell deployments within building premises and on outdoor facilities (i.e., lamp posts and bus stops).

128. In view of this, a coordinated Whole-of-Government approach is required to facilitate access to commercial and non-commercial locations for the deployment of small cells and other new telecommunication infrastructure. Currently the Code of Practice for Info-communications Facilities in Buildings ("**COPIF**") already provides for the use of space and facilities in buildings and tunnels, and may need to be further amended to include space and facilities needed for 5G infrastructure. To this end, IMDA has set up a working group with the MNOs to better scope the space and facilities requirements for 5G infrastructure, and will be engaging the relevant agencies (e.g., LTA and HDB) to facilitate 5G deployment.

Network Sharing Possibilities

129. In view of the spectrum constraints in the initial years, IMDA will encourage infrastructure sharing amongst MNOs as a means of achieving more cost effective network deployment.

130. Within a mobile network, the key elements that could be shared are the passive facilities, radio access network ("**RAN**"), backhaul, spectrum and core network elements. The various sharing models are highlighted in the following table.

Table 7: Possible Network Sharing Models

	Infrastructure elements shared					
Model	**Site**	**Passive Antennas**	**Active RAN**	**Backhaul**	**Spectrum**	**Core network**
Colocation	X					
Backhaul				X		
Passive sharing	X	X				
Multi Operator RAN ("**MORAN**")	X	X	X	X		
Multi Operator Core Network ("**MOCN**")	X	X	X	X	X	
Hosted (Wholesale)	X	X	X	X	X	X

131. The colocation and backhaul models are the most basic form of network sharing, where operators share either their sites or transmission, while deploying other passive and active elements on their own. In Singapore today, infrastructure sharing has been employed by the MNOs for certain deployment scenarios, and these are largely limited to in-building and in-tunnel antenna systems. Sharing arrangements are adopted for these scenarios due to space constraints at these premises, rendering deployment of multiple networks difficult. The hosted model is at the other end of the spectrum, where the end-to-end elements of the network are owned by one party who then offers wholesale services to other parties, e.g., the typical MNO-MVNO arrangement.

132. With 5G, IMDA is assessing the benefits of extending the infrastructure sharing arrangements beyond in-building and in-tunnel antenna systems to cover the active edge components of the network (e.g., RAN or core network). However, IMDA recognises that the benefits of infrastructure sharing will have to be weighed against the potential impact on network resilience with reduced network diversity, service differentiation and technology innovation (such as beamforming and edge computing) due to technical complexities, and competitiveness of the telecommunication markets.

133. With the increased complexity from infrastructure sharing, massive IoT connectivity and vast deployment of virtualisation technologies, IMDA welcomes proposals from the industry on possible infrastructure sharing models for 5G in Singapore, and technical trials are encouraged to determine the feasibility and versatility of these arrangements.

Synchronisation of TDD Networks

134. In transiting to 5G, synchronisation of TDD networks is expected to become more stringent to support 5G features such as massive MIMO and beamforming, together with the adoption of Active Antenna System ("**AAS**")[31] for 5G NR and IMT systems.

135. Synchronised operation helps to minimise performance degradation due to interference without requiring additional base station filtering or inter-operator guard bands. Less coordination may also be required between operators on the geographical placement of their base stations. Overall, IMDA notes that operators operating TDD networks will be required to agree on alignment of the start of the frame and compatible frame structure.

136. Currently, 4G TDD networks are in operation in many countries, including Singapore, with networks operating in 3GPP Band 40 (i.e. 2300 – 2340 MHz) and the 2.5 GHz TDD band. On a national level, operators coordinate the synchronisation amongst themselves, including coordinating with cross-border TDD operators at the national borders. Synchronisation can be achieved when operators use the same technology (e.g., 4G) and plan to deliver similar services (e.g., faster speeds).

137. Moving forward, in a multi-operator environment, operators may use the 5G network to support different specific use-cases. These translate to different service requirements, e.g., uplink/downlink transmission ratio, spectral efficiency and latency. The adoption of unsynchronised operations will increase the likelihood of interference between TDD networks operating within the same geographic area.

138. Without inter-operator synchronisation, interference mitigation techniques such as the implementation of operator-specific filters for both the transmitters and receivers of the base stations and mobile stations, appropriate inter-operator guard bands and geographical separation between base stations may need to be employed. All these factors may have an impact on the implementation cost.

139. Interference between non-AAS base stations can be mitigated through the specification of Block Edge Mask ("**BEM[32]**") to restrict the unwanted emissions through the installation of external customised filters deployed base on the

[31] AAS refers to a system where the antenna systems and radio transmitters are designed together. Non-AAS ("**non-AAS**"), on the other hand, refers to radio transmitters which are manufactured or supplied separately to antenna systems.

[32] A Block Edge Mask is a spectrum mask that is defined, as a function of frequency, relative to the edge of a block of spectrum that is licensed to an operator. On one side of this frequency boundary is the in-block power limit and on the other side is the out-of-block spectrum mask.

spectrum usage. However, it becomes challenging to implement the same for AAS base stations due to its architectural difference from non-AAS base station. Thus, for AAS base stations to meet the BEM requirement, it must be done during the product design.

140. For the 3.5 GHz band, IMDA expects that network deployments in this band will be pervasive to provide 5G services, both indoors and outdoors, with multiple operators having deployments at the same site or building. IMDA is of the view that this band should be fully synchronised, so that there is no need for any of the available spectrum to be used for guard bands to avoid interference, leading to more efficient use of spectrum.

141. In the mmWave band, mobile network deployments could be deployed indoors and outdoors, and will support mainly hotspot areas using cells with a small coverage range. Due to the propagation characteristics of this frequency band, deployments in this frequency band are unlikely to result in mutual interference with sufficient geographic separation. IMDA is of the view that there is no need to specify full synchronisation of network deployments in the mmWave band in order to afford greater flexibility for operators to customise the network parameters to ensure efficient delivery of services for specific traffic profiles or network requirements. In the event of interference between networks operating in the same location, operators are expected to coordinate the synchronisation amongst themselves.

Question 8: IMDA would like to seek views and comments on the trade-offs (particularly on resilience, 5G capabilities) and technical feasibility of the various levels of infrastructure sharing.

Question 9: IMDA would like to seek views and comments on the following:

- ***i) The synchronisation approach for 5G TDD networks in a multi-operator environment for the 3.5 GHz and mmWave bands, specifically for the following:***
  - ***a. Synchronised networks: the required frame alignment, compatible frame structures and BEM specifications for AAS and non-AAS base stations; and***
  - ***b. Unsynchronised networks: the amount of guard band, geographical separation and BEM specifications for AAS and non-AAS base stations;***

ii) The adoption of other suitable mitigation measures to mitigate interference between unsynchronised networks; and

iii) The need for IMDA to mandate a regulatory requirement for synchronisation across the 5G TDD networks or leave it to operators to co-ordinate their network deployment and parameters in order to reduce interference between networks.

Other Facilitations/Reviews Required

142. Besides allowing for various levels of infrastructure sharing, IMDA is also proposing, or have done, the following to facilitate 5G deployments in Singapore:

Numbering and Standards

143. IMDA reviews the National Numbering Plan ("**NNP**") from time to time to ensure its continued relevance to technological advances and emergence of new services. For example, IMDA has expanded the service allocation for '3' series number level to include user-centric data-only services, providing the licensees a 'light-touch' alternative to the use of '8' and '9' series number levels. IMDA engages the Information and Communications Technology ("**ICT**") industry regularly through various channels to ensure that interest in ICT standardisation is broadly represented. The ICT industry plays a critical role in enabling the implementation of new technologies through the formulation of conformity assessment requirements and validation of technical standards for publication, by participating in the work of the Telecommunications Standards Advisory Committee ("**TSAC**"). Concerted effort of industry players, garnered through the TSAC, will continue to make available technical standards, which form the basis for the Supplier's Declaration of Conformity ("**SDoC**") and facilitate ease of market entry. IMDA's equipment registration (approval) framework has also been streamlined, which primarily requires equipment suppliers to make a declaration of conformity for each of their ICT product intended for sale and use in Singapore, supported by test results or evidence of equipment certification given by the manufacturer or an accredited body.

144. IMDA views that the above existing frameworks remain relevant today to support 5G rollout, addressing the numbering resources required, and ascertaining the performance and interoperability of 5G devices entering the Singapore market. IMDA will continue to work with the industry to review these frameworks where necessary, in supporting future technical advancement and new services.

5G Electromagnetic Radiation Limits

145. There are on-going studies looking at 5G electromagnetic radiation issues. In particular, Study Group 5 under the ITU-Telecommunication Standardisation Sector ("**ITU-T**") is reviewing the impact of electromagnetic fields ("**EMF**") relating to 5G. Current studies have shown that 5G deployment, with new advanced radio and core architecture, will lead to lower EMF levels as compared to existing networks.[33] The exposure levels will also be a small fraction of the international exposure limits set by the International Commission on Non-Ionising Radiation Protection ("**ICNIRP**") and IEEE. IMDA will continue to monitor the regional and international studies on this issue and take these findings into consideration to specify the application standards for adoption when facilitating 5G deployment in Singapore.

Fixed Wireless Services

146. While the availability of a nationwide fibre infrastructure generally eliminates the need for an alternative last-mile access in Singapore, IMDA also recognises that mobile spectrum bands in general (such as 3G and 4G bands) can be used for fixed-wireless services, and there may be interest from industry for a flexible use policy that allows the industry to commercially decide the use of their mobile spectrum rights for fixed or wireless technologies that support mobile services.

147. As such, IMDA proposes to allow MNOs to use existing and upcoming 5G spectrum rights for fixed-wireless services, as long as the spectrum is still primarily used for the intended mobile service.

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

i) The interest from industry players to leverage 5G spectrum or other mobile spectrum bands for fixed-wireless services that support mobile connectivity; and

ii) The policies (e.g., spectrum allocation, numbering) that should be considered to facilitate such use-cases.

[33] Refer to the "ITU-T Series K Supplement 9 (11/2017): Protection Against Interference, 5G Technology and Human Exposure to RF EMF"

Chapter 4: Conclusion

148. IMDA is of the view that 5G will usher in innovative services and applications, beyond an incremental development in wireless connectivity. With 5G's disruptive capabilities and features (such as network slicing), the technology will bring about new business models, products, services, innovative applications and experiences. As such, in addition to exercising regulatory levers to facilitate the deployment of 5G network in Singapore, IMDA seeks to support and nurture the 5G ecosystem for innovation and development across a span of 5G applications and services. In conclusion, IMDA seeks to spearhead Singapore's efforts to be a global front-runner for innovation in secure and resilient 5G applications and services.

149. IMDA foresees facilitating two nationwide networks in the initial years for sustainable competition and resilience. To this end, IMDA is proposing to allocate two spectrum packages in the 3.5 GHz and mmWave bands for 5G in the initial phase, via a CFP process, and encourage network sharing and services-based competition amongst operators. With more spectrum to be availed in the longer term and technology changes that may alter market dynamics, IMDA is of the view that such an approach affords flexibility for the market to evolve by allowing a migration path for future network build and technology upgrade.

150. To participate in the CFP, applicants will have to submit detailed proposal(s) that will be evaluated based on criteria such as: (a) network rollout and performance; (b) network design and resilience; (c) financial capability; (d) offer price; and (e) wholesale arrangement.

151. The successful applicants shall commit to its proposal. This is in addition to meeting IMDA's baseline regulatory requirements.

152. As part of the consultation process, IMDA will have various streams of engagement with the MNOs and vendors to allow for deeper discussions on the various questions and concerns. IMDA also welcomes proposals from the industry to conduct technical trials on interference mitigation measures, and infrastructure sharing models to determine the feasibility and versatility of these arrangement.

Chapter 5: Invitation to Comment

153. IMDA would like to seek views and comments from the industry and members of the public on the proposed 5G framework set out in this document.

154. Respondents who submit their views or comments regarding the issues identified in this consultation document should organise their submission as follows: (a) cover page (including their personal/company particulars and contact information); (b) table of contents; (c) summary of major points; (d) statement of interest; (e) comments; and (f) conclusion. Supporting materials may be placed as an annex to the comments raised.

155. All views and comments should be submitted in soft copies (Microsoft Word or PDF Format), and should reach IMDA by **12 noon, 19 June 2019**. All views and comments should be addressed to:

Ms Aileen Chia
Director-General (Telecoms and Post)
Deputy CE (Policy, Regulation & Competition Development)
Infocomm Media Development Authority
10 Pasir Panjang Road
#03-01 Mapletree Business City
Singapore 117438

AND

Please submit your soft copies, with the email header "Second Consultation on 5G Mobile Services and Networks", via email to Consultation@imda.gov.sg.

156. IMDA reserves the right to make public all or parts of any written submission and to disclose the identity of the source. Respondents may request confidential treatment for any part of the submission that the respondent 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 will 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 of information submitted. IMDA will not accept any submission that requests confidential treatment for all, or a substantial part, of the submission.

ANNEX A: Technology Trials

A1. With the development of 5G gaining momentum in Singapore, more 5G trials are expected to take place in the coming months prior to the 5G spectrum allocation. Since the 2017 Public Consultation, IMDA has made available a list of frequencies, including the 3.5 GHz (i.e., 3400 – 3600 MHz) and 28 GHz (i.e., 27500 – 29500 MHz) bands for 5G trials under the appropriate trial frameworks. The frequency fees associated with 5G trials was also waived to encourage the industry to test the capabilities of a 5G network in Singapore.

A2. In addition, IMDA ensures fair access to the spectrum available for trial by all industry players. In our assessment, IMDA will review the requested frequencies, test sites, trial parameters and existing usage by incumbent users, amongst others. Additional efforts are required to ensure minimal impact to existing users (e.g., FSS (downlink) users of the 3.5 GHz band who will be susceptible to the relatively higher power 5G transmission).

A3. To date, IMDA has facilitated a number of 5G trials, primarily in the 3.5 GHz and 28 GHz bands. We see continuing interest from local MNOs to conduct trials on potential 5G use-cases and its capabilities in these bands, including the inter-workings with their existing 4G networks. Meanwhile, MNOs have leveraged 5G trials to forge collaborations with industries on potential 5G use-cases (e.g., enhanced mobile broadband, massive machine-type communications, and ultra-reliable and low latency communications) and applications (e.g., drones, autonomous vehicles and virtual reality).

A4. With a good understanding on the performance of 5G, IMDA expects MNOs to begin gearing up for 5G trials with different industry verticals, for example manufacturing, healthcare and logistics, which will create the wireless technology needs across the different user sectors.