DECISION ISSUED BY THE INFO-COMMUNICATIONS MEDIA DEVELOPMENT AUTHORITY

POLICY FOR FIFTH-GENERATION (5G) MOBILE NETWORKS AND SERVICES IN SINGAPORE

17 October 2019

Chapter 1: Background

1. On 7 May 2019, the Info-communications Media Development Authority ("**IMDA**") issued a second public consultation, setting out Singapore's overall 5G vision and strategy, as well as the proposed policy design and regulatory framework for 5G network deployment ("**2nd Public Consultation**").

2. 5G has been acknowledged as the next big leap in mobile and wireless communications. The potential capabilities of 5G are expected to go beyond just delivering an enhanced mobile broadband ("**eMBB**") experience, to ultra-reliable and low latency communications ("**uRLLC**"), and massive machine type communications ("**mMTC**")[1]. Another important 5G capability is "network slicing", which allows a single physical infrastructure to be segmented into multiple virtual networks and provide diverse use-cases with different performance requirements.

3. 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 consumers, 5G would mean that they are now able to enjoy on-demand content with more interactive and immersive experiences such as VR cloud gaming, augmented events, and virtual tactile shopping.

4. In the 2nd Public Consultation, IMDA noted that the global standards for full-fledged 5G will only be finalised next year. Although there are a number of 5G trials and early network deployments taking place globally, these non-standalone ("**NSA**") deployments are built over existing 4G networks for connectivity and mostly provide eMBB capabilities. On the other hand, some of the more advanced capabilities such as network slicing, uRLLC and mMTC features will only be enabled and achieved by 5G standalone ("**SA**") deployments.

5. In Singapore's context, IMDA noted that NSA deployments might be less meaningful given the availability of competitive and pervasive high-speed mobile and fibre broadband services nationwide. It is thus important to balance the speed-to-market 5G deployments to reap early-mover advantage as we facilitate the deployment of future-ready 5G networks to reap the full benefits of the new technology.

6. Against the above backdrop, IMDA sought views and comments on the policy objectives and strategies it should take to develop the 5G ecosystem, in

[1] Based on the 5G or IMT-2020 minimum technical performance requirement set by ITU, 5G is expected to deliver a peak data rate of 20Gbps downlink speeds, a latency as low as 1ms for uRLLC use-cases and a connection density of 1,000,000 devices/km^2.

particular, with regard to the issuance of the spectrum for 5G networks and facilitating their deployment.

7. At the close of the 2nd Public Consultation on 9 July 2019, IMDA received comments from 63 respondents (individually referred to as a "**Respondent**" and collectively, the "**Respondents**", refer to **Annex A**).

8. IMDA thanks all Respondents for their responses to the consultation.

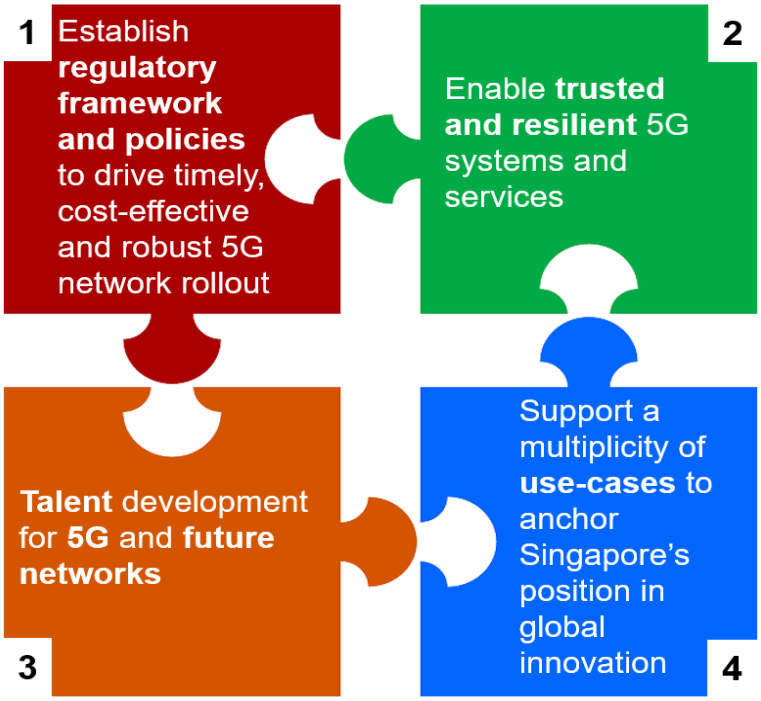
9. This document sets out the key issues raised in the 2nd Public Consultation, and IMDA's responses and decisions on these issues.

Chapter 2: Overall Policy Aims and Strategies for 5G

10. 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 is a connected citizen. World-class connectivity infrastructure, both wired and wireless, will be needed to realise this vision. 5G, touted to be the next quantum leap in mobile technology, will be key in supporting Singapore's effort in attaining this vision.

11. In this regard, IMDA envisages Singapore to be a global front-runner for innovation in secure and resilient 5G applications and services. IMDA's 5G strategy will go beyond the pervasive deployment of 5G infrastructure and will focus on growing the 5G innovation ecosystem. This entails driving industry adoption of 5G applications across various sectors and building local capabilities. Such a strategy will give Singapore companies and workers a competitive advantage as the 5G ecosystem matures and avails more economic opportunities.

Figure 1: Key Focus Areas ("**KFA**") to Create a Thriving 5G Ecosystem in Singapore



Building the 5G Ecosystem in Singapore

Consultation Proposal

12. In the 2nd Public Consultation, IMDA expressed its interest to work with the industry to facilitate a multiplicity of use-cases to explore research and innovation opportunities in 5G-enabled technologies and demonstrate the technology and commercial potential of 5G.

13. Additionally, IMDA was of the view that the major shifts in deploying networks of the future will require a transformation in skills. IMDA anticipated rising demand for new skillsets to handle new technologies and spectrum characteristics, as well as to address cybersecurity and network resilience issues.

Industry and Public Response

14. The enterprise Respondents were largely of the view that 5G use-cases would be built around automation, remote operations, and safety and security.

15. Regarding 5G skills requirements, the Respondents were largely of the view that 5G would be integrated with other technologies, applications and processes. The more commonly mentioned areas are Software-Defined Networks, Network Virtualisation, Network Slicing, Data Analytics, Software Applications, Cloud Computing, Cybersecurity, IoT and Artificial Intelligence.

IMDA's Assessment and Decision

16. The Respondents' comments are in line with IMDA's view that Singapore could explore a few strategic clusters as a start to focus on where 5G bears the most potential, namely Maritime Operations, Urban Mobility, Smart Estates, Industry 4.0, Government applications and Consumer applications.

17. IMDA has launched the 5G Grant on 27 June 2019 to support efforts in conducting industry technical trials that would demonstrate the transformative impact of 5G for enterprises and catalyse the development of 5G. As a start, $40 million has been designated to build an open, inclusive 5G ecosystem. The objective of the 5G Grant is to work with key industry partners in the above strategic clusters to catalyse the development of 5G through:

    i) Nurturing the growth of 5G use-cases (innovative applications and solutions);

ii) Understanding the technical capabilities and performance of the emerging 5G technology in a test and/or live environment; and

iii) Deriving critical learning for future 5G development.

18. IMDA is also working with other government agencies, enterprise users and technology companies to explore more impactful and strategic use-cases in other clusters and to develop a series of open testbeds for both government and industry use. The grant will also be used to support R&D efforts in communications, e.g., in enhancing cybersecurity.

19. In terms of readying the Singapore workforce for the 5G era, the industry responses are in line with IMDA's consideration that there will be increasing demand for engineers with hybrid skillsets in domains that are relevant to 5G. IMDA will take in the inputs to refresh the Skills Framework for Infocomm Technology, as part of efforts under TechSkills Accelerator ("**TeSA**").

20. The following chapters will discuss the key policy design and regulatory frameworks needed to facilitate the deployment of resilient and secure 5G systems, in order to support the development of Singapore's 5G innovation ecosystem.

Chapter 3: Policy Design and Regulatory Frameworks for 5G Deployment in Singapore

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

    i) Maximise value of 5G for the economy and welfare for the consumers;

    ii) Facilitate efficient allocation of scarce spectrum resources;

    iii) Bring about 5G networks that are secure and resilient; and

    iv) Support the growth of Singapore's telecommunications sector.

Consultation Proposal

22. In the 2nd Public Consultation, IMDA proposed to adopt the following strategies to achieve the above policy objectives:

    i) **Facilitate early deployment of 5G starting from 2020 based on SA network specifications, where possible:** This takes into consideration the 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. This will place Singapore amongst the early wave of countries deploying 5G networks.

    ii) **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 wave 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 Mobile Network Operators ("**MNOs**") and facilitate services-based competition.

iii) **Impose regulatory requirements to ensure 5G networks remain resilient and trusted:** With many other enabling technologies that will be employed for the rollout of 5G, such as software-defined networks ("**SDN**"), network functional virtualisation ("**NFV**") and Cloud Computing, they may give rise to security and resilience issues given the extensive use of virtualisation technologies and more interfaces between software layers. Hence, IMDA will propose key regulatory requirements for compliance to ensure that 5G networks are trusted and resilient.

iv) **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.

Industry/Public Response and IMDA's Assessment

23. The industry generally agreed with IMDA's policy objectives and strategies, and provided comments and suggestions to refine the strategies. IMDA will set out the specific regulatory frameworks and measures to support the above strategies in the following sections.

First Tranche of Frequency Spectrum Bands for 5G

24. Based on the global spectrum roadmap and the availability of spectrum in Singapore, the front-runner 5G bands today are the 3.5 GHz, 26 GHz and 28 GHz bands. Currently, both the 3.5 GHz and 28 GHz bands have the most commercially developed device ecosystem. Other radio frequencies such as those in the 2.1 GHz, 2.5 GHz and 4.5 GHz bands have been identified to be commercially ready in the subsequent wave, and will require harmonisation and coordination with existing users and/or neighbouring countries (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	3.5 GHz (3450 – 3650 MHz)	Fixed Satellite Service ("**FSS**") (downlink)	200 MHz	2021[2]
	26/28 GHz	FSS (uplink) for specific frequencies in 28 GHz	3200 MHz	2020
Next wave of 5G spectrum	700 MHz	4G	90 MHz	After Analogue Switch Off ("**ASO**") for neighbouring countries at border areas
	1.4 GHz (L-band)	Digital audio broadcasting	About 91 MHz	Currently available for trials
	2.1 GHz	3G (4G allowed, subject to IMDA's approval)	135 MHz, including TDD bands	To be renewed in January 2022
	2.5 GHz TDD	4G	45 MHz	Spectrum Right commenced in 2017 and will expire in 2033
	3.5 GHz (3400 – 3450 MHz)	FSS	50 MHz	Post 2023
	4.5 GHz	Fixed Service ("**FS**")	About 200 MHz	Post 2025[3]

3.5 GHz / C-Band

Consultation Proposal

25. In the 2nd Public Consultation, IMDA noted that several leading 5G markets had considered all or portion(s) of the C-band from 3.3 – 4.2 GHz as a primary 5G band. At the same time, IMDA was cognisant of FSS operations within Asian countries, including Singapore. After considering the interest of all stakeholders to enable 5G mobile services in Singapore while continuing satellite operations in the C-band, IMDA proposed to refarm the 3.4 – 3.7 GHz band for mobile service and retaining 3.7 – 4.2 GHz band for FSS (space-to-Earth).

26. Within the 3.4 – 3.7 GHz band that would be allocated for mobile services, IMDA sought views on its proposal to designate the 3.4 – 3.5 GHz band for restricted use and 3.5 – 3.6 GHz for unrestricted use for 5G telecommunication systems and services, as well as the lot sizes and number of lots to be allocated.

[2] Subject to the migration of FSS users.
[3] Subject to the migration of existing FS users.

27. IMDA also sought views on the suitable technical parameters, including the reasonable amount of guard band within 3.6 – 3.7 GHz to reduce potential interference between international mobile telecommunications ("**IMT**") and FSS use in the 3.5 GHz band.

28. In the 2nd Public Consultation, it was indicated that IMDA had commissioned technical studies to assess the feasibility of 5G deployment in the 3.5 GHz band, which would determine the final amount of guard band, and the recommended technical and operational parameters of 5G usage in these bands. IMDA also conducted interview sessions with industry stakeholders to gather relevant inputs for the technical studies.

29. IMDA has since completed these technical studies and has engaged industry stakeholders, i.e., the mobile and the satellite operators/service providers (**"Community"**), in August 2019 to share the findings, the recommended mitigation measures and the proposed 5G deployment guidelines. The Community was also given the opportunity to provide further feedback after the engagement sessions and IMDA will refer such feedback to be from the "**Representative**" or "**Representatives**" to reflect the views and comments from the Community.

Industry and Public Response

30. From all the responses received, IMDA noted that the industry had largely welcomed the decision to make part of the 3.5 GHz band available for 5G deployment. A few Respondents were supportive of the full 100 MHz guard band within the 3.6 – 3.7 GHz band. Several other Respondents suggested that it would be possible for a smaller guard band by introducing appropriate measures, including installation of filters on equipment or apparatus used by FSS and IMT services. One Respondent suggested having better clarity on the guard band allocation, as it might not be appropriate to label the frequency for guard band as being allocated for mobile service.

31. Respondents also shared the need for technical studies and field trials to determine relevant protection measures for coexistence between 5G and FSS (downlink) services. To facilitate coexistence, there were also suggestions for IMDA to adopt dynamic spectrum sharing such as the Spectrum Access System, which was implemented in the United States. Some Respondents also indicated the need to consider the protection of FSS usage in neighbouring countries.

32. The Community also welcomed the technical studies conducted by IMDA. Overall, the feedback focused on the conditions required for protection of

satellite use. Several Representatives, mostly from the satellite community also commented on the need for appropriate technical coexistence parameters to address deployment of FSS and IMT services in adjacent frequency bands. Majority of the Representatives concurred with IMDA's study analysis where the outcome of the studies recommended the installation of filters to protect FSS (downlink) from adjacent 5G transmissions. One Representative highlighted that the technical specification of the filters used for modelling might not reflect the actual performance of the FSS operations. A few Representatives had also shared that significant cost and effort would be required for the migration and protection of existing satellite operations.

33. A set of preliminary 5G deployment guidelines to minimise interference issues for deployment of FSS and IMT services in adjacent bands was shared during the engagement with the Community. Several Representatives had suggested that IMDA review the demarcation of the proposed zone sites to take into consideration the density of FSS receivers at the location, including the type of services they maintain. There were also suggestions to impose power limit(s) as an interference criterion to protect FSS receivers from 5G transmissions. On the other hand, one Representative also highlighted that such limit(s) might be technically challenging for practical measurements and enforcement. A few Representatives also highlighted the need for responsive, remedial actions in case of interference to FSS operations during the 5G deployment.

IMDA's Assessment and Decision

34. IMDA has assessed that where the C-band is used for 5G, FSS (downlink) users operating in the remaining parts of the C-band must take necessary preparatory steps such as retrofitting an appropriate band pass filter ("**BPF**"). This is to protect the signal reception of the telecommunication equipment or system receiving in the frequency range of 3.7 to 4.2 GHz band (the "**FSS System**") against 5G transmissions[4].

35. Additionally, the findings from the studies also showed that it is possible to use frequencies above 3.6 GHz for 5G services without causing harmful interference to FSS (downlink) service above 3.7 GHz. This would be when all FSS Systems[5] are fitted with BPFs, which would achieve at least 45 dB rejection at a frequency of 3.65 GHz. In this regard, all FSS Systems operating above 3.7 GHz shall have BPFs installed with similar or better specifications to provide a reasonable amount of protection to the FSS System.

[4] IMDA's technical studies showed that adjacent 5G transmission channel is likely to overdrive the low-noise amplifier/block-converter ("**LNA/LNB**"), resulting in non-linear operation of the FSS System.
[5] With the exception of the satellite receiver for Telemetry, Tracking & Control ("**TT&C**") operations that is modelled based on consultation with the TT&C operator.

36. Therefore, without further restrictions to the 5G deployments and ensuring minimum impact to the adjacent FSS (downlink) service, IMDA will make available and allocate the 3.6 – 3.65 GHz band for restricted use only (i.e., deployments may have to be limited to indoors and underground). Correspondingly, the bandwidth of the guard band will be 50 MHz (i.e., 3.65 – 3.7 GHz). With that, IMDA maintains that the primary allocation of the C-band will be as follows:

Table 2: 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)

37. The mobile base stations shall at least comply with the unwanted emission limits specified for Wide Area Base Station (Category B) prescribed in the 3rd Generation Partnership Project ("**3GPP**") Technical Specification ("**TS**") 38.104v15.6.0, including the latest version, regardless of the 3.5 GHz band assigned. This is to address the unwanted emissions (i.e., out-of-band and spurious emissions) that could cause interference to the FSS Systems (operating in the 3.7 – 4.2 GHz band).

38. Due to our small geographical area and dense deployment of FSS clusters in various parts of Singapore, IMDA had proposed to set up two different deployment zones as part of the 5G deployment guidelines. They are as follow:

i) Exclusion zones – for areas that house critical FSS operations and no 5G base station is allowed in this zone(s); and

ii) Precautionary zones – for areas with relatively high density of FSS (downlink) service and 5G mobile operators are required to observe certain 5G deployment guidelines.

39. Details on the technical conditions to be observed for 5G deployment in the 3.5 GHz band are in **Annex B**.

40. With regard to the deployment of dynamic spectrum sharing, IMDA is of the view that this method may not be feasible in this band given the small geographic area of Singapore. Technical studies including the one carried out by IMDA have also shown that a large separation distance will be required for

both 5G and FSS to coexist in the same frequency range. In view of Singapore's close proximity with our neighbouring countries, IMDA will need to continue to engage the regulators from Indonesia and Malaysia to achieve cross-border coordination and harmonisation, and minimise any coexistence issues that might arise at the borders.

41. To ensure the coexistence of both IMT and FSS in the C-band, the deployment of 5G within the 3.4 – 3.7 GHz band will need to observe the 5G deployment guidelines (which will be effective from the commencement of the 3.5 GHz spectrum rights). Based on further engagement with the industry, IMDA understands there could be plans for Bukit Timah Earth Station to house critical FSS operations in the near future. Considering the possible need to protect these critical services, IMDA will designate the Bukit Timah Earth Station as an exclusion zone. This status will be reviewed after 31 December 2022, where it is expected that such plans would have been firmed up. This will be in addition to the exclusion zone for the Seletar Satellite Earth Station as originally proposed.

42. In summary, IMDA has assessed and identified a total of two (2) exclusion zones and six (6) precautionary zones. Aligned with the findings from IMDA's technical studies, any deployment of 5G base stations will be prohibited in the exclusion zones. Deployment of 5G base stations within the precautionary zones will need to abide by the deployment guidelines in Annex B, which will ensure that MNOs take necessary actions to mitigate interference.

43. IMDA noted that several other technical studies have recommended imposing a power density limit on 5G signals received by the FSS receivers. However, specifying such a limit can be challenging for practical measurements and may require extensive resources from all parties. IMDA is of the view that the technical and operational conditions listed in the deployment guidelines are able to ensure the coexistence of 5G and FSS. IMDA will closely monitor the initial 5G deployment and if necessary, make appropriate adjustments to the guidelines accordingly.

44. In order to minimise the interference from 5G deployment to existing FSS (downlink) users, IMDA will provide the list of existing FSS locations to the successful spectrum rights holders to facilitate their 5G deployment and site planning. Where necessary, MNOs may be required to coordinate with the FSS users to mitigate the risk of interference. For new FSS installations, to minimise interference from 5G base stations, they should be installed within the precautionary zones identified by IMDA. However, new FSS users will still be required to take their own protection measures against 5G transmissions.

45. Currently, IMDA has a unit in-charge of handling interference matters where affected users can provide IMDA with details of the interference for its investigation. During the initial 5G deployment phases, IMDA plans to establish Points-of-Contact between MNOs and FSS users to facilitate more immediate interference notification. IMDA will continue to monitor progress and make further adjustments to the interference reporting process where necessary.

46. IMDA also notes that there are other operational and cost-related concerns raised due to the migration of FSS users in the 3.4 – 3.7 GHz band. While IMDA is not obliged (statutorily or otherwise) to reimburse or compensate affected FSS users for any changes to the frequencies which the users are permitted to use in conjunction with their licences, IMDA will continue to work with the affected users to ensure that the migration is completed by 31 December 2020. In addition, Singapore has a dense fibre deployment with varied means to deliver and receive media contents. IMDA therefore plans to review the use of FSS within the 3.7 – 4.2 GHz band together with the industry with the intention to manage and optimise the number of precautionary zones in Singapore in the longer term.

26 GHz and 28 GHz Band Plan (Millimetre Wave or mmWave)

Consultation Proposal

47. In the 2nd Public Consultation, IMDA noted that mmWave band is another forerunner 5G band, which can help to deliver ultra-high-speed broadband. IMDA also noted the global developments related to the use of the 26 GHz and 28 GHz bands for 5G services. IMDA proposed to allocate these bands on a primary basis to mobile services, in addition to existing allocations, if any. Under this arrangement, mobile services and FSS operating in the 28.5 – 29.5 GHz band would be on a co-primary basis. Stations in the FSS are expected to have measures in place to ensure the 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.

Industry and Public Response

48. Respondents who are supportive of allocating the mmWave band for 5G opined that the mmWave band would be important in providing extremely high data rate and capacity, complementing the sub-6 GHz bands.

49. On the other hand, the satellite industry had requested IMDA to consider the activities by all regional satellite operators and their long-term investments prior to making available the mmWave band for 5G.

Concerns with 5G Deployment in 26 GHz Band

50. Pertaining to the 26 GHz band, IMDA notes that the World Meteorological Organisation ("**WMO**") information systems have extensive use of radio-communication systems and radio-frequency spectrum using the satellites with weather sensors that are operating adjacent to the 26 GHz band. IMDA is cognisant that weather sensors are used by the meteorological services, and have an essential role in determining and predicting the weather on a global scale. Timely warnings and accurate climate predictions are considered to be critical for the global community.

51. In recent months, the WMO and the scientific community have expressed concerns with the possible 5G deployment in the 26 GHz band. They have informed the International Telecommunication Union ("**ITU**") that there are existing weather satellites with passive sensors operating in the 24 GHz band to sense water vapour[6]. WMO has concerns that if 5G base stations are allowed to operate without any constraints in the 26 GHz band, this can potentially interfere with those passive sensors on-board the weather satellites. This will result in unreliable data, which will be rendered unusable in forecasting or in climate monitoring models thereby affecting meteorological agencies across the globe. Regarding the interference concerns, WMO is proposing stringent Out-Of-Band ("**OOB**") emission limits (-55dBW/200 MHz) on 5G base stations. This is to facilitate coexistence between 5G services in the 26 GHz band, with passive sensors on the weather satellites operating in the adjacent band of the 24 GHz band.

52. The mobile industry has also been studying the feasibility of meeting more stringent limits, which may constrain operations in the 26 GHz band, possibly resulting in a substantial impact on performance, throughput and costs of 5G networks and services. As such, the regulators and industry players are still in discussion on a suitable OOB limit that can offer a good compromise between protecting meteorological services and the deployment of the 5G services.

28 GHz Band Specific Issues

53. Most Respondents from the satellite industry disagreed with the use of the 28 GHz band for 5G deployment, citing that it would be unlikely for the 28 GHz band to be internationally harmonised. They highlighted that the 28 GHz band is currently being used extensively for satellite services globally, such as for the operations of earth stations in motions ("**ESIMs**") which is commonly used by the aeronautical and maritime sectors to provide end-to-end data connectivity

[6] The passive sensor is operating in the 24 GHz band, and is determined by fixed physical properties (molecular resonance) that cannot be changed nor are these physical properties able to be duplicated in other bands.

to users on the move. While there might be potential interference between satellite uplink and the 5G services operating in the same frequencies, restrictions on the 28 GHz band for satellite use may limit Singapore's opportunity to offer gate-to-gate and port-to-port broadband communications.

54. One Respondent suggested that satellite use and 5G be made available in different bands. There was a request to consider 5G deployment in the upper part of the 28 GHz band (i.e., 28.5 – 29.5 GHz) and FSS be allowed in the lower 28 GHz (i.e., 27.5 – 28.5 GHz).

IMDA's Assessment and Decision

55. With regard to the use of the 26 GHz band, IMDA has considered the recent development and concerns raised by the WMO. IMDA will need to balance the competing demands for 5G deployment, protection of the weather satellites and satellite services.

56. IMDA has assessed that with the right technical solutions in place and the appropriate technical parameters, it will be possible for the 5G deployment to exist adjacent to the weather satellite band. However, IMDA notes that with weather satellites' interference concerns, the quantity of mmWave band available for mobile use in the 26 GHz band may have to be reduced.

57. Bearing in mind all considerations and IMDA's policy objectives, IMDA will allocate a total of 3.2 GHz of mmWave band within the 26 GHz and 28 GHz bands for 5G services in Singapore (see Table 3).

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)

58. In view that discussions are still ongoing for the OOB limits and the necessary guard bands for weather satellites operating in the 24 GHz band, and these will only be determined after the World Radiocommunication Conference 2019 ("**WRC-19**"), IMDA will specify the exact frequency ranges in both the 26 GHz and 28 GHz bands after WRC-19. IMDA will continue to engage the mobile industry and other regulators to discuss the appropriate OOB limits and

necessary regulatory measures to protect weather satellites while ensuring sufficient flexibility for 5G deployment in the 26 GHz band.

59. In the case of the 28 GHz band, IMDA notes that in Singapore, there is limited use of the 28 GHz band for FSS. Currently, part of the spectrum in the band is only used by maritime ESIMs. While aeronautical ESIMs are also allowed in this band, there is currently no assignment. Land ESIMs on the other hand, are not allowed. IMDA also notes that global efforts are underway to protect terrestrial services while enabling use of FSS in the 28 GHz with operational conditions and regulatory frameworks being specified for ESIM operation at the upcoming WRC-19[7].

60. IMDA is closely monitoring the discussions under WRC-19 agenda item 1.5 for ESIM, including the appropriate technical and operational requirements. Pending the outcomes of WRC-19, IMDA will determine the spectrum ranges for the mmWave band by end 2019 and various technical and operational parameters. IMDA will work with the affected users to put in place measures, such as minimum distance away from shore, for the use of FSS in the same frequencies as mobile services to allow coexistence.

Other Spectrum Bands for 5G ("Subsequent Tranches")

Consultation Proposal

61. Apart from the 3.5 GHz and mmWave bands, IMDA shared the possibility of making available other spectrum bands for 5G in the Subsequent Tranches and sought views on whether the overall timeline of 2025 is reasonable. IMDA also sought industry views on re-farming the 2.5 GHz FDD spectrum band (based on 3GPP Band 7[8]) and the 2.5 GHz TDD spectrum band (based on 3GPP Band 38[9]) to 3GPP Band 41[10] for future 5G services.

Industry and Public Response

62. IMDA notes that most Respondents agreed that more spectrum should be made available for 5G in the Subsequent Tranches and were generally supportive of IMDA's proposed timeline of around 2025. However, a few Respondents requested to accelerate the timeline.

[7] WRC-19 agenda item 1.5 considers the use of the 17.7-19.7 GHz (space-to-Earth) and 27.5-29.5 GHz (Earth-to-space) frequency bands by ESIM communicating with geostationary space stations in the FSS.
[8] 2500 – 2560 MHz / 2620 – 2680 MHz
[9] 2570 – 2620 MHz
[10] 2496 – 2690 MHz

63. For frequency bands below 1 GHz, some Respondents suggested IMDA to make available 600 MHz for mobile use. Other respondents also requested IMDA to make available 700 MHz for 5G in Singapore.

64. Regarding the L-band, Respondents generally agreed with IMDA's approach of monitoring on-going studies in the regional and international fora to address both the frequency arrangements and adjacent coexistence issues. IMDA also notes the suggestions to protect Mobile Satellite Service in the adjacent band, including putting in place protective measures such as frequency separation. There were also suggestions for 5G use in the 2.1 GHz, 4.5 GHz and 39 GHz bands.

65. IMDA notes that majority of the Respondents commented that there were extensive deployment especially in 3GPP Band 7 by existing spectrum right holders for 4G services and it would be challenging to re-farm it to 3GPP Band 41 in the short to medium term. Some Respondents highlighted that close coordination and harmonisation with neighbouring countries would have to be carried out before such band plan changes could be adopted and implemented in Singapore. Some Respondents also commented that there would be potential future use of the band for 5G.

IMDA's Assessment and Decision

66. IMDA notes the industry's agreement that around 2025 would be a reasonable timeframe to start opening up new spectrum for 5G considering the ecosystem readiness in the identified bands. Notwithstanding this timeline, IMDA remains open to making available more 5G spectrum in the Subsequent Tranches in the near term, which includes re-farming and coordinating with neighbours should demand for 5G use picks up.

67. Due to the heavy usage of terrestrial broadcasting services in the 600 MHz band in this region, IMDA will maintain its decision of not releasing the spectrum until there are firmer plans for broadcasting services to migrate out of the band.

68. The 700 MHz frequency band has been re-farmed from analogue broadcasting to 4G services, and Singapore has completed its ASO on 1 January 2019. While the use of the band is now pending regional harmonisation with our neighbouring countries (i.e., Indonesia and Malaysia), IMDA will consider re-farming it for 5G services in the Subsequent Tranches when the spectrum is available for use. IMDA further notes the better propagation characteristics of low frequency bands, making them ideal for supporting 5G applications that require wider coverage and ultra-low latency requirements (e.g., vehicle-to-vehicle communications). Hence, the 700 MHz band is one of such potential 5G bands to support ultra-low latency applications.

69. IMDA also understands that the 2.1 GHz and 4.5 GHz bands can help to complement the 5G coverage in the 3.5 GHz band. There is an on-going consultation on the 2.1 GHz band where IMDA is evaluating the responses received for this and other related bands. As for the 4.5 GHz band, it is subject to the re-farming and migration of existing FS users and would take approximately 3 – 5 years to be made available for use. With the device/network ecosystem in these bands estimated to be available around 2020 or later, IMDA will consider both bands for 5G use in the Subsequent Tranches.

70. IMDA notes that the 2.5 GHz TDD spectrum rights were issued later in 2017. IMDA also recognises the heavy usage of the 2.5 GHz FDD spectrum band for existing 4G services in Singapore. As such, IMDA does not foresee the immediate likelihood of re-farming the band for 5G services. However, for the 2.5 GHz TDD spectrum, IMDA is open to the possibility to re-farm 3GPP Band 38 for 5G services, subject to several considerations such as coexistence with existing services and cross-border coordination.

71. The 39 GHz band is available for 5G trials in Singapore. IMDA notes that there are different on-going activities and discussions at international fora[11]. IMDA will thus continue to monitor developments in the use of the band before deciding whether to make available for 5G services in the Subsequent Tranches.

72. In summary, while IMDA notes the industry comments for the above-mentioned bands, IMDA will need to conduct further reviews, taking into account domestic and regional considerations, before re-farming these bands for the provision of 5G mobile services in the Subsequent Tranches. IMDA will conduct separate consultation(s) when opening up more spectrum bands for 5G.

Initial Tranche of 5G Spectrum and Market Structure

Nationwide Networks Complemented by Localised Deployments

3.5 GHz Band Plan

Consultation Proposal

73. In the 2nd Public Consultation, IMDA noted that a spectrum holding of less than 40 MHz in the 3.5 GHz band would not give throughput speeds that are

[11] The 39 GHz band is already included in 3GPP Release specification for 5G New Radio ("**NR**") as NR operating band "**n260**" (i.e., 37 – 40 GHz) which will be used in TDD mode. Additionally, IMDA notes that the Federal Communications Commission will be auctioning the 39 GHz, along with the 37 GHz and 47 GHz bands, scheduled in December 2019.

noticeably different from 4G today[12]. At the same time, the maximum single carrier size for the 3.5 GHz band would be 100 MHz, which would allow a peak downlink throughput of 1750 Mbps[13] per user per cell. Notwithstanding the above, there was limited spectrum in the 3.5 GHz band, in particular for unrestricted spectrum use to provide pervasive outdoor coverage.

74. Balancing the various constraints and considerations, IMDA had proposed to facilitate the deployment of at least two nationwide, trusted and resilient networks in the initial years. More specifically, IMDA's proposal was to assign the 3.5 GHz band as (a) a 100 MHz lot comprising a 50 MHz unrestricted lot paired with a 50 MHz restricted lot (3450 - 3550 MHz); and (b) a 50 MHz unrestricted lot (3550 - 3600 MHz).

Industry and Public Response

75. IMDA received mixed responses on the 3.5 GHz band plan. Some Respondents agreed with IMDA's proposal of allocating at least two lots of 50 MHz unrestricted 3.5 GHz band, as this would increase network diversity, spur greater competition, encourage innovation, and provide more choices to wholesale customers and end-users. Most of these Respondents also requested to equalise both lots, such as expanding the second lot by 50 MHz restricted spectrum (e.g., pairing with 3600 – 3650 MHz or 3400 – 3450 MHz). On the other hand, a few Respondents proposed to only assign one lot of 100 MHz unrestricted 3.5 GHz band (i.e., 3500 - 3600 MHz) to maximise 5G throughput performance.

76. Additionally, many Respondents viewed that the 3400 – 3450 MHz (i.e., the remaining 50 MHz of restricted 3.5 GHz) should be paired with 3450 – 3500 MHz instead to make a 100 MHz lot, and some Respondents agreed that it would be less meaningful to issue 3400 – 3450 MHz on its own.

IMDA's Assessment & Decision

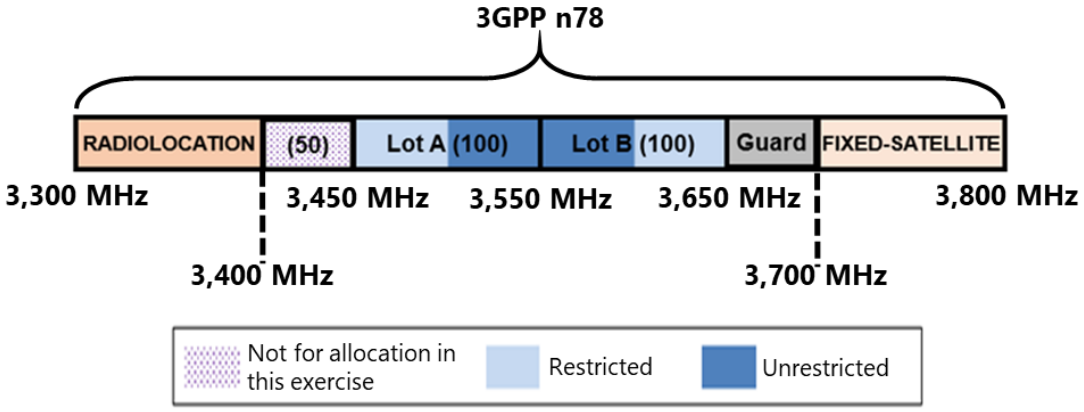
77. IMDA believes that competition at the infrastructure layer in the mobile market will continue to be important, in order to ensure that players in the market have the incentive to invest in new technology, innovate and compete for business. Thus, it will be important to have at least two nationwide networks as a start. This approach would better allow IMDA's policy outcomes to be realised.

[12] Based on the June 2019 Opensignal report, Singapore 4G networks had an average download speed of at least 35 Mbps. Based on IMConnected results that was published in the 2nd half of 2018, Singapore's 4G networks had a median throughput of about 30 Mbps and a peak throughput of more than 400 Mbps.

[13] 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.

78. Having taken in the Respondents' comments as well as IMDA's further technical studies that showed that it is possible to deploy mobile services in the 3600 – 3650 MHz range on a restricted basis, IMDA will facilitate the deployment of two nationwide networks. IMDA will do so by allocating two 3.5 GHz lots each comprising a 50 MHz unrestricted lot paired with a 50 MHz restricted lot, making it a total of 100 MHz (refer to Figure 2) [14]. This will allow two 100 MHz lots of contiguous 3.5 GHz band from 3450 – 3650 MHz, i.e., Lot A and Lot B. Given that the maximum carrier size is 100 MHz, it would not be meaningful to pair the 3400 – 3450 MHz with the two 100 MHz lots. Additionally, given its constrained deployment, it would not be meaningful to allocate 3400 – 3450 MHz on its own. Hence, IMDA will not allocate 3400 – 3450 MHz at this juncture, it will be held in reserve until there are clearer market developments that will allow its effective use. The 3.5 GHz band plan will be as follows:

Figure 2: 3.5 GHz Band Plan



mmWave Band Plan

Consultation Proposal

79. IMDA proposed to assign the mmWave band in blocks of 800 MHz to the MNOs and proposed three possible band plan options for the mmWave band.

Industry and Public Response

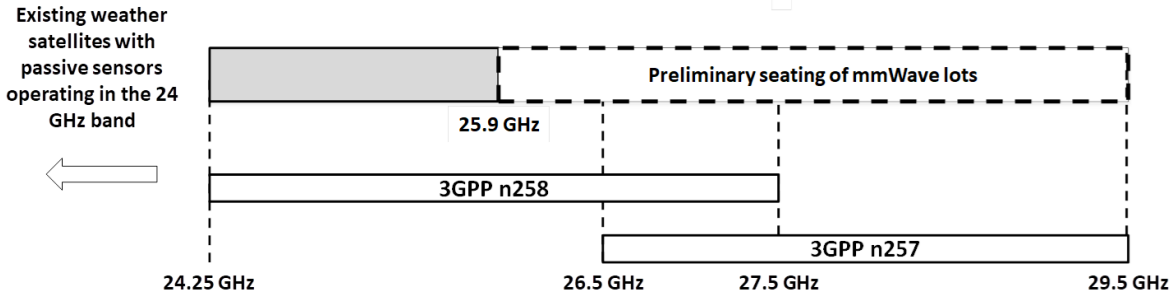
80. Some Respondents prefer the option that would give the most blocks of 800 MHz of mmWave lots for allocation.

[14] According to the ITU Radio Regulations, 3500 – 3700 MHz is allocated to both mobile (excluding aeronautical mobile) and FSS on a co-primary basis.

IMDA's Assessment and Decision

81. As the mmWave band plan is still subject to the deliberation outcomes at WRC-19, the exact band plan and specific spectrum ranges will be finalised later in end 2019. IMDA believes there is merit to give industry greater certainty after taking in the discussion outcomes at WRC-19 and will release the firm band plan later. Regardless, as mentioned above, IMDA will allocate 3.2 GHz of mmWave band to MNOs for 5G. A possible frequency range of the mmWave lots is as follows:

Figure 3: mmWave Band Plan



Initial Market Structure

Consultation Proposal

82. IMDA proposed to assign the 3.5 GHz and mmWave bands as a package, and to allocate two packages ("**Packages**") to MNOs. Additionally, IMDA proposed to reserve the remaining mmWave band, which could be opened up and paired with low/mid-bands when the latter are made available.

83. IMDA encouraged network sharing amongst MNOs, and noted that IMDA would also facilitate services-based competition. In the same vein, IMDA also proposed to allow joint ventures and/or consortiums involving at least one existing MNO, or between two or more existing MNOs to jointly submit a proposal for a Package. Further, IMDA proposed to assign spectrum only to existing MNOs, given the spectrum constraints and the uncertainty in early use-cases. IMDA held the view that assignment to non-MNOs might fragment the market further, which would not help to realise its policy outcomes for 5G.

Industry and Public Response

84. There were strong views from Respondents to allocate the mmWave band to all MNOs in this round of allocation, as this would help drive greater competition and 5G service innovation in Singapore. Respondents noted that given the

short-range propagation of mmWave band, deployment using these bands would likely be localised, mainly for enterprise purposes, and with varying sets of service level agreements. As such, it would be challenging for nationwide operators to share or offer wholesale services over such mmWave deployments.

85. Additionally, a few Respondents also requested to allocate parts of the 3.5 GHz band and/or a block of 800 MHz of the mmWave band for private 5G use.

86. Regarding joint ventures and/or consortiums, some Respondents sought clarification on the ownership and control structure allowed such as between existing MNOs and non-MNOs, and between existing MNOs and foreign MNOs.

IMDA's Assessment and Decision

87. IMDA will maintain its position of assigning two Packages to MNOs, but the Packages will be revised such that each will comprise 100MHz of the 3.5 GHz band and 800 MHz of the mmWave band. This is to facilitate the deployment of two full-fledged 5G nationwide, trusted and resilient networks in the initial years.

88. With industry's confirmation that the market can indeed accommodate additional localised networks, IMDA will also make available the remaining two 800 MHz lots of mmWave band in this round of assignment to existing MNOs that have not been awarded the Packages. This approach will allow all interested MNOs to commence mmWave deployment earlier and facilitate greater service innovation to enterprise users.

89. As there is limited spectrum in the 3.5 GHz band and just sufficient spectrum in the mmWave band for existing MNOs, IMDA will maintain its position to assign the 5G spectrum to existing MNOs only.

90. IMDA would like to make clear that the 5G spectrum allocation exercise is not intended to facilitate any merger and/or acquisition of the MNOs nor allow the entry of a new MNO. Hence, on further consideration, any joint ventures applying for the Packages can only consist of the existing MNOs. IMDA encourages MNOs interested in a joint venture to seek IMDA's views on the control and ownership structure early.

91. Any change in ownership interests of the MNO(s) or joint venture(s) following the award of the Packages and mmWave-only lots will be subject to IMDA's regulatory frameworks such as the merger and acquisition framework.

Network Architecture of 5G Networks

Consultation Proposal

92. In the 2nd Public Consultation, IMDA noted that 5G NSA networks would be built on existing 4G networks and they would only result in incremental benefits in eMBB services. To realise the full potential of 5G, such as virtualisation and network slicing capabilities, IMDA proposed that operators would need to deploy SA networks from the start. This would also reduce disincentives to invest in network upgrades arising from the longer lifecycle of end-user devices.

Industry and Public Response

93. While some Respondents agreed that Singapore should deploy SA networks from the start to reap the full benefits of 5G, a number of Respondents asked for flexibility for both SA and NSA deployment. They highlighted that the NSA ecosystem was more mature, and it would improve coverage while reducing the time to market. In particular, some Respondents highlighted that the SA ecosystem for the mmWave band was still nascent, and it would not be feasible to deploy the mmWave band on SA basis from the start. Respondents had noted that SA and NSA deployments could coexist.

IMDA's Assessment and Decision

94. There is global industry consensus that only 5G SA networks can deliver full-fledged 5G capabilities such as network slicing, uRLLC and mMTC. This is opposed to 5G NSA networks, which are built over existing 4G networks and can only deliver faster speeds. While the equipment ecosystem for SA networks in the 3.5 GHz band is more developed, the roadmap for the mmWave SA equipment ecosystem globally remains uncertain.

95. To ensure Singapore's 5G networks are future-ready and can deliver full-fledged 5G capabilities, IMDA will require deployment of 5G SA networks over the 3.5 GHz band from the start. MNOs will have the flexibility to adopt the 3GPP Releases that best support the SA networks that meet their commercial needs and IMDA's regulatory requirements and policy objectives. MNOs who wish to deploy NSA networks in the 3.5 GHz band, over and above their SA networks, must seek IMDA's prior approval. MNOs must ensure that their NSA deployments will not compromise IMDA's policy outcome of achieving two 5G SA networks and capabilities within the stipulated timeframes.

96. As the roadmap for the mmWave SA equipment ecosystem is uncertain, IMDA will allow MNOs the flexibility to choose SA or NSA deployment for the mmWave band in the interim. For MNOs who choose to deploy NSA networks,

these operators must deploy SA networks within 24 months from when the ecosystem is ready. IMDA reserves the right to determine the commencement date of the 24 months.

Spectrum Right Duration

Consultation Proposal

97. In the 2nd Public Consultation, IMDA proposed 12 - 15 years for the duration of the spectrum rights to provide sufficient investment certainty for the MNOs. Additionally, IMDA proposed for the 3.5 GHz and mmWave spectrum rights to expire at the same time. As the 3.5 GHz spectrum rights would commence later, the mmWave spectrum rights would have a longer duration.

Industry and Public Response

98. Respondents provided feedback to commence the use of the spectrum rights as soon as possible. Some Respondents agreed 12 – 15 years was appropriate, while other Respondents requested to provide a longer spectrum duration (e.g., 20 – 25 years) to allow sufficient investment certainty, considering the denser deployment needed especially for mmWave deployment.

IMDA's Assessment and Decision

99. While IMDA agrees with the industry that MNOs need sufficient investment certainty, IMDA notes that 20 years would be too long considering the fast pace at which mobile technology moves. On balance, IMDA will provide a longer duration for spectrum rights for both bands. Accordingly, the 3.5 GHz spectrum rights will commence from 2021, after the completion of the migration exercise and will expire after 15 years. The mmWave spectrum rights will commence in 2020 after the Call for Proposal ("**CFP**") has concluded and will expire after approximately 16 years. Spectrum rights for both bands will expire at the same time. This is consistent with past 4G spectrum rights with durations ranging from 13 to 16 years.

100. Additionally, IMDA recognised that MNOs who are not granted the Packages may not wish to acquire mmWave band in the upcoming exercise. As such, IMDA will provide flexibility for such MNOs to apply for the mmWave band at a later stage (e.g., together with the Subsequent Tranche of 5G spectrum). The spectrum right commencement will shift accordingly, but the expiry of the mmWave spectrum right will remain the same.

Coordination between Spectrum Right Holders and Trial Spectrum Users

101. As mentioned in the section on **Building the 5G Ecosystem in Singapore**, IMDA is facilitating industry technical trials under the 5G Grant, which will include allowing selected MNOs undergoing trials ("**Trial Partner MNOs**") to deploy the 3.5 GHz and/or mmWave bands on a localised basis. To allow the trials to be meaningful, a longer duration for the trial use of the frequencies will be needed. At the same time, Respondents have requested to commence the use of the spectrum rights early.

102. Considering the shorter propagation characteristics of the mmWave band and the localised nature of such trials, IMDA will allow trials using the mmWave band to continue until December 2020, and the trials using the 3.5 GHz band to continue up until June 2021. This means that there may be some overlap in the period when the trials end and the commencement of the spectrum rights. Where overlapping spectrum has been awarded to a different Trial Partner MNO and spectrum right holder, IMDA will require both parties to coordinate the use of the said spectrum. IMDA will inform the spectrum right holders of the Trial Partner MNOs and the location(s) of the trial(s).

Key Obligations and Requirements for Nationwide and Localised 5G Networks

Network Rollout and Performance

Consultation Proposal

103. In order to ensure the timely deployment of nationwide 5G networks in Singapore, IMDA had proposed some key requirements for spectrum right holders in the consultation. One of the key obligations is the extent of 5G coverage and speed of network rollout. IMDA had proposed a minimum coverage obligation of 5G SA networks with >50% coverage within 24 months for the 3.5 GHz band and put-to-use requirement within 12 months for the mmWave band. Spectrum right holders may use a combination of spectrum to meet the 50% coverage requirement.

Industry and Public Response

104. Some Respondents were of the view that the minimum coverage obligations were fair and achievable. However, some Respondents believed that the minimum obligations would be challenging and greater visibility of the ecosystem readiness would be required before any commitments could be made.

105. Several Respondents had proposed for IMDA to consider supporting a phased deployment approach and allow spectrum right holders to determine their preferred network coverage and deployment areas. Considering the initial availability of the 3.5 GHz band in Singapore, one Respondent suggested for IMDA to allow MNOs to utilise their existing spectrum holdings to complement the 3.5 GHz 5G coverage gaps.

106. On the applicability of the Quality of Service ("**QoS**") requirement for 5G networks, Respondents' views were mixed. Some Respondents suggested for the QoS obligations to be imposed from the start while some were of the view that the QoS requirements could be considered when more sub-6 GHz spectrum were available.

107. There were several recommendations on the methodology and measurement criteria for the coverage obligations. Most of the proposed parameters were generally similar to the existing methodology for 3G/4G coverage and signal strength measurement. This included the reference signal received power ("**RSRP**"), signal to interference plus noise ratio ("**SINR**"), call setup time, call drop rate and call setup successful rate. Some Respondents proposed to conduct drive and walk tests to gather some of these parameters. In addition, one Respondent noted that the methodology to measure other 5G attributes such as uRLLC, and mMTC were still under development. Another Respondent encouraged IMDA to conduct closed discussions with the 3.5 GHz spectrum right holders on the coverage methodology.

108. As part of the consultation process, IMDA has also engaged MNOs for deeper discussion on the measurement methodology for the coverage obligation.

IMDA's Assessment and Decision

109. For the definition of 5G, IMDA will reference the standards and specifications of 5G as defined in 3GPP Release 15 and beyond, or standards/specifications recognised by ITU for IMT-2020.

110. IMDA understands that the deployment of 5G networks by MNOs will mainly be driven by demand and use-cases. Taking this into consideration and noting that the current methodology for 4G QoS may not be suitable for 5G in the initial phase, IMDA agrees with the feedback provided by the industry. Accordingly, IMDA will not impose 5G QoS obligations for a start. However, IMDA reserves the right to do so in the future.

111. Based on views from the industry and at the same time, bearing in mind IMDA's policy objectives, IMDA has assessed that MNOs must minimally achieve at

least 50% outdoor[15] SA coverage using the 3.5 GHz band within 24 months from the commencement of the 3.5 GHz spectrum right in 2021, i.e., end 2022. IMDA will provide more details to the MNOs on the coverage measurement methodology.

112. As for nationwide coverage, IMDA understands that 5G network deployment will be more challenging compared to 4G which took 18 – 24 months, and may require a longer deployment timeframe. The relatively shorter propagation characteristic of the 3.5 GHz and mmWave bands means denser deployments will be needed. In view of IMDA's policy outcomes, IMDA's preference is for 3.5 GHz spectrum right holders to aim to achieve nationwide outdoor 5G coverage within 5 years from the commencement of the 3.5 GHz spectrum right, i.e., by end 2025. The MNOs may propose a reasonable timeline to achieve nationwide coverage (see section on **CFP Evaluation Criteria**). This approach will give the MNOs the flexibility to determine the areas for 5G rollout during the ramp-up period, while ensuring that Singapore will get to enjoy the full-fledged benefits of 5G.

113. For road and MRT tunnel coverage, IMDA notes the deployment challenges involved and that the equipment ecosystem is still nascent. As such, IMDA will not stipulate any requirement for 5G coverage in road and MRT tunnels at this juncture. However, IMDA reserves the right to do so in the future.

114. Separately, for the mmWave spectrum right holders, MNOs must put the spectrum to use within 12 months from the commencement of the mmWave spectrum right.

115. Noting the uncertain mmWave SA equipment ecosystem, IMDA will allow flexibility in choosing SA or NSA deployment for the mmWave band only, until such time that the mmWave SA ecosystem becomes mature. More specifically, the spectrum right holders shall deploy the mmWave band on SA basis within 24 months of when the ecosystem is ready, i.e., availability of commercial products by the spectrum right holders' chosen vendors. IMDA reserves the right to determine the commencement date of the 24 months. For MNO(s) who apply for the mmWave band at a later stage, IMDA reserves the right to determine the timeline to deploy the mmWave band on SA basis[16]. For clarity, IMDA will allow the spectrum right holders to continue supporting the mmWave NSA deployment in parallel with the mmWave SA deployment.

[15] Exclusion zones will not be included as part of the assessment of MNOs' outdoor 5G coverage.
[16] This may include requiring the MNO(s) to deploy the mmWave band on SA basis from the outset.

Network Design and Resilience

Consultation Proposal

116. IMDA firmly believes that the 5G networks need to be designed for resilience and security at the outset to provide a strong foundation for the delivery of 5G services, with assurance on the ability to support eMBB, uRLLC and mMTC type of useful and critical applications. Key 5G features such as SDN, NFV, distributed networks and Cloud Computing, will also bring about a new paradigm of threat landscape. As such, it is paramount that 5G networks be equipped with the ability to support continuous enhancement of their resilience and cybersecurity posture.

117. Thus, IMDA proposed that the 5G networks should minimally meet IMDA's regulations relevant to resilience and security, and best practices and technical specifications from relevant standards bodies and forums, such as 3GPP, Internet Engineering Task Force ("**IETF**"), European Telecommunications Standards Institute ("**ETSI**") and Institute of Electrical and Electronics Engineers ("**IEEE**").

118. In addition, IMDA proposed that operators should ensure the performance and reliability of equipment purchased from vendors meet their commercial operational needs and regulatory requirements, including those pertaining to quality of service, resilience and security.

Industry and Public Response

119. In general, Respondents agreed with IMDA that the 5G networks should be resilient and secure. Some Respondents concurred that a security-by-design approach should be adopted to ensure the necessary considerations would be incorporated from the start.

120. However, some Respondents highlighted challenges, both financial and to a certain extent technical, that they would face should IMDA impose overly onerous resilience and cybersecurity requirements. They asked IMDA to consider the cost of new network deployment against the level of resilience and security required for the 5G networks. Furthermore, the demand for 5G is currently use-case driven. Any specific resilience and security requirements from the customers should be commercially negotiated.

121. The Respondents also proposed areas that may enhance the resilience and security of the 5G networks. For example:

    i) Follow best practices and comply with international standards;

ii) Use of network monitoring and data analytics on information collected from various sources, and implement systems to detect anomalies;

iii) Have redundancy (including geographically) in critical network equipment and elements and path diversity;

iv) Implement overlapping coverage; and

v) Enhance the physical security of edge and access networks.

IMDA's Assessment and Decision

122. IMDA has reviewed the Respondents' suggestions and decided that the design of 5G networks should (i) meet key resilience and security requirements stipulated in the relevant IMDA Codes of Practice (and to exceed such requirements where possible); and (ii) be architected based on the following principles, at the outset:

i) Defence-in-Depth[17]: Adopt security-by-design principles by implementing various defence mechanisms which are secure and scalable (e.g., capability to turn on encryption upon request);

ii) Zero-trust Environment[18]: Ensure that the 5G network is always secure and trusted through deployment of network security solutions (e.g., implementing a "demilitarised zone" and other relevant measures);

iii) Network Element Assurance: Ensure that a risk assessment strategy and policy will be applied to the 5G infrastructure (e.g., policy compliance to the Network Equipment Security Assurance Scheme currently being defined by 3GPP and Global System for Mobile Communications ("**GSMA**"), and demonstrate how security assurance is achieved such as security testing of equipment);

iv) Resilience by Outcome: Demonstrate end-to-end network resilience to minimise outages and impact;

v) Minimise dependency: Configure network, to the extent feasible, to minimise instances where a failure of the (a) fibre network used to provide broadband services, and/or (b) infrastructure used to provide other mobile services in a geographical area, could also affect 5G services in the same geographical area; and

[17] A series of defensive mechanisms that are multi-layered with redundancies to increase the security of a system and address different attack vectors.
[18] An organisation should not trust anything inside or outside the perimeters of its networks and systems and must verify everything trying to connect to its networks and systems before granting access.

vi) Adopt technology: Use of advanced technologies for resilience purpose, e.g., automation and machine learning to detect, respond and recover from service disruption expeditiously.

123. Additionally, any 5G NSA deployment should, to the extent possible, meet all resilience and security requirements, unless such requirements are only supported on 5G SA networks. This would include the underlying 4G networks used to support 5G NSA networks.

Wholesale Arrangements

Consultation Proposal

124. In the 2nd Public Consultation, IMDA proposed that spectrum right holders would be required to provide 5G wholesale services to other mobile service providers, specifically to any MNO and/or mobile virtual network operator ("**MVNO**"), upon request. In addition, IMDA noted that 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 ("**Negotiation Principles**") remained relevant. As such, IMDA proposed to update and apply the updated Negotiation Principles for 5G wholesale services.

Industry and Public Response

125. IMDA notes that a majority of the Respondents were supportive of reviewing the Negotiation Principles that guide the wholesale arrangements for the 3G/4G mobile market, or even reviewing the regulatory approach itself for application to 5G services. A summary of the feedback received is as follows:

i) Some Respondents agreed that the Negotiation Principles were sufficient for the provision of 5G wholesale services;

ii) Some Respondents were of the view that the Negotiation Principles on their own were insufficient to facilitate the provision of 5G wholesale services. Some recommended for the current light-touch regulatory approach, but IMDA should enhance the Negotiation Principles to better facilitate the provision of 5G wholesale services;

iii) Some Respondents suggested a change of regulatory framework governing the provision of 5G wholesale services. Specifically, IMDA should consider a neutral 5G wholesaler. This could be achieved through imposing structural and/or operational separation requirements; and

iv) One Respondent called for IMDA to regulate the provision of 5G wholesale services through a three-ring model, at the core network, RAN, and spectrum level.

126. There were suggestions to (i) codify and enforce the Negotiation Principles; (ii) regulate wholesale prices such as a cost-plus wholesale pricing or fixed price; and (iii) allow the 5G wholesaler to determine the services that should be provided on a wholesale basis.

IMDA's Assessment and Decision

127. IMDA notes the interest from the industry to explore wholesale arrangements and shares similar views that wholesale arrangements for 5G services is important, especially in the initial phase where there are likely only two 5G nationwide networks. Hence, to facilitate market entry and promote competition in the 5G retail market, IMDA maintains its position to mandate the wholesale of 5G capacity, where 5G networks are deployed.

128. Nonetheless, IMDA notes the challenges of sharing or offering wholesale services over the mmWave band as it will be deployed for localised use, mainly for enterprise purposes, and will be deployed with varying sets of service level agreements, and it is likely that all MNOs will be allocated the mmWave band. Therefore, IMDA will only impose the mandatory requirements on the 3.5 GHz deployment (i.e., mandatory requirements will not be imposed on the mmWave band in the initial phase). For the avoidance of doubt, MNOs can still enter into commercial negotiations to offer wholesale services over the mmWave deployments.

129. IMDA has taken in the feedback and separately issued an industry consultation on 9 September 2019 to MNOs and MVNOs on the proposed framework governing the wholesale arrangements for 5G, and how it would apply to existing wholesale arrangements for 3G and 4G services. The consultation proposed specific enhancements to the existing Negotiation Principles to better facilitate 5G market entry.

130. Given that the industry consultation is ongoing, the current Negotiation Principles will continue to apply for the wholesale arrangements for mobile services, including 5G services until the revised framework comes into effect.

IMDA and Agencies' Facilitation for Rollout of 5G Networks

Infrastructure Access

131. As 5G is likely to utilise the high frequency bands that 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 (e.g., lampposts and bus stops).

132. In view of this, a coordinated 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. 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., the Land Transport Authority and the Housing & Development Board) to facilitate 5G deployment.

Network Sharing Possibilities

Consultation Proposal

133. In view of the spectrum constraints in the initial years of 5G deployment, coupled with the anticipated large-scale deployment of small cells, network sharing could be an effective means for MNOs to reduce the cost of building and operating a mobile network infrastructure, thereby accelerating the rollout of 5G services in Singapore. While MNOs would be encouraged to explore sharing beyond the existing models (i.e., in-building and in-tunnel antenna systems), IMDA also recognised the complexity of sharing active network components and the potential impact on network resilience, cybersecurity risks and service differentiation. Considering these issues, IMDA had requested MNOs to propose the potential infrastructure sharing models for Singapore and conduct technical trials to determine the feasibility of such models.

Industry and Public Response

134. Most of the Respondents had supported infrastructure sharing among the MNOs. However, some of these Respondents had also highlighted the need for extensive coordination between the MNOs (e.g., complex technical and commercial arrangements) to facilitate active sharing. Several Respondents were of the view that deeper sharing might result in the reduction of network diversity, service differentiation and technology innovation. Considering both

the potential benefits and complexities of infrastructure sharing for 5G networks, some Respondents had suggested for infrastructure sharing to be based on commercial arrangements between the MNOs such that each MNO had the flexibility to decide on its preferred infrastructure sharing arrangement.

135. With regard to the recommended infrastructure sharing model for Singapore, some Respondents had proposed either a Multi-Operator Core Network ("**MOCN"**) or Multi-Operator Radio Access Networks ("**MORAN**") sharing model due to its spectral efficiency and higher cost savings as compared to passive site and antenna sharing. This form of sharing would also allow MNOs to maintain and have control over their core networks. Several Respondents had also indicated preference for a hosted (wholesale) model in which MVNOs would get access to the full range of shared infrastructure elements. However, it was also noted that such sharing arrangement would imply that there would be a single-point-of-failure for both the shared core and RAN networks.

IMDA's Assessment and Decision

136. Among the various possible infrastructure-sharing models, IMDA understands that the industry prefers the MOCN/MORAN and the hosted (wholesale) models. A MOCN/MORAN model allows MNOs to reduce cost of deployment while maintaining their independent core networks. However, it is also noted that such arrangements are highly complex and will take time as MNOs need to come to a commercial sharing agreement (e.g., deployment sites, coverage objective). It may also be difficult to dissolve such sharing arrangements subsequently.

137. Taking into account that each MNO has its own business strategy, commercial objective and deployment plans, IMDA will not impose sharing requirements at a network wide level. In the event of exceptional circumstances where multiple deployments may not be feasible, IMDA will reassess the need to require sharing as part of its regulatory measures to resolve any industry-related issues. This is no different from the existing framework where IMDA will identify bottleneck facilities, designate them as critical support infrastructure, and require sharing amongst operators. MNOs are encouraged to consider the possible network sharing models that could potentially help to facilitate 5G deployment in Singapore. Interested MNOs have the flexibility to engage their preferred MNO partners and come to a commercial agreement on the ideal infrastructure-sharing model based on the use-cases and service offerings, so long as they continue to comply with their regulatory obligations including network resilience and cybersecurity.

Synchronisation of TDD Networks

Consultation Proposal

138. IMDA sought views on the synchronisation approach (i.e., synchronised or unsynchronised networks) for 5G TDD networks in a multi-operator environment for the 3.5 GHz and mmWave bands, the adoption of suitable measures to mitigate interference between unsynchronised networks, and the need to have regulatory intervention or operator-to-operator coordination to manage interference between networks.

139. In the 2nd Public Consultation, IMDA shared the view that the 3.5 GHz network deployments should be fully synchronised for more efficient use of spectrum as it would expect the networks to be pervasive to provide both indoor and outdoor 5G services. On the other hand, the limited propagation characteristics of the mmWave band meant that full synchronisation might not be necessary which could afford greater flexibility to operators when deploying in the mmWave band. IMDA also shared that interference between 5G base stations that made use of non-Active Antenna Systems ("**non-AAS**") could be mitigated through the specification of Block Edge Mask ("**BEM**") using external customised filters. However, it would be a challenge to implement the same for AAS base stations.

Industry and Public Response

140. Respondents who commented were generally supportive of a synchronised network in the 3.5 GHz band to maximise the use of the spectrum. However, views were mixed for the mmWave band with some Respondents proposing that synchronised networks might be required to reduce the likelihood of interference although its limited propagation characteristic would reduce such susceptibility. A few Respondents commented that no additional BEM requirement would be needed for 5G AAS and non-AAS base stations when the networks would be fully synchronised and comply with the unwanted emission specifications stated in the 3GPP TS 38.104. Some Respondents also suggested that semi-synchronisation could be available by 2020 to allow more independent configuration of each network.

141. With respect to mitigation measures between unsynchronised networks, some Respondents shared that the common mitigation measures include guard bands, geographical separation and installation of external customised filters for mobile base stations, but were not in favor of having them implemented.

142. There were several TDD configurations (i.e., frame alignment/structure and uplink/downlink ratio) being proposed which highlighted the global mainstream deployments and their suitability for different types of 5G deployments.

Respondents were generally of the view that mobile operators could coordinate amongst themselves the TDD deployment and parameters. However, operators would be expected to engage in further discussions amongst themselves and with the vendors before determining the values to be implemented. In the event where agreement could not be reached amongst the local mobile operators or with neighbouring countries' operators, some Respondents suggested that IMDA could step in and regulate or ensure that proper coordination would be achieved.

IMDA's Assessment and Recommendation

143. As mentioned above, IMDA is inclined for the 3.5 GHz band to be fully synchronised while affording operators the flexibility on the choice of synchronisation for the mmWave band. However, IMDA notes the mixed responses proposed for the mmWave band. Given that coordination amongst operators on the use of spectrum remains essential even if the networks are fully synchronised, IMDA will continue to impose the requirement for operators to coordinate with one another, operators of other networks and systems, or neighbouring countries' operators, where required.

144. On the issue of synchronisation, as a start, IMDA will not mandate the synchronisation approach for both the 3.5 GHz and mmWave bands. IMDA will allow operators to coordinate amongst themselves in the first instance. In the event of disputes amongst operators, IMDA may require operators to synchronise and comply with certain parameters in order to minimise interference between the networks on a case-by-case basis. Similarly, for cross-border coordination, IMDA will also facilitate coordination with our neighbouring countries on the TDD synchronisation in order to avoid cross-border interference.

Fixed Wireless Services

Consultation Proposal

145. IMDA noted in the 2nd Public Consultation that with technology advancement, industry had expressed interest in using mobile spectrum bands for fixed-wireless services. Hence, IMDA proposed to allow MNOs to use existing and upcoming 5G spectrum rights for fixed-wireless services, as long as the spectrum would be primarily used for the intended mobile service.

Industry and Public Response

146. IMDA noted that majority of the Respondents were either supportive of or had no strong preference/views on IMDA's proposal to allow the use of 5G or other

mobile spectrum bands for Fixed-Wireless Access ("**FWA**") services. Most of the Respondents provided the view that FWA should be allowed for new innovative usages and services. While some Respondents were of the view that there was little need for FWA given the pervasiveness of Singapore's Nationwide Broadband Network ("**NBN**"), they remained open to the opportunities for FWA to support niche markets.

147. Only one Respondent was not in favour of FWA and was of the view that the NBN would suffice in supporting the last mile access of fixed services in Singapore. Furthermore, given the space constraints within buildings for telecommunication network, such space should be used optimally, and redundancies should be reduced.

IMDA's Assessment and Decision

148. IMDA notes that 5G possesses the ability to support high-speed connections, and is a potential alternative to fixed services. While there is little need to introduce an alternative fixed-wireless network with the same level of pervasiveness as that of the NBN, IMDA agrees with the majority of Respondents that there are opportunities for the FWA to complement the NBN. IMDA also believes that the industry should not be unduly restricted from offering innovative services that are beneficial to consumers and businesses. IMDA notes from some Respondents that there exists capabilities that are able to support FWA.

149. In view of the above, IMDA will allow the industry to leverage mobile spectrum for the deployment of FWA to support the last mile access of fixed services, subject to the following conditions:

i) As radio frequency spectrum for mobile services are scarce, it should be used predominantly for the provision of 5G mobile services;

ii) IMDA will treat fixed services that are provisioned over FWA in the same manner as any other fixed services provided over a fixed network. As such, existing regulations and obligations imposed on fixed services will be similarly applied, e.g., quality of service requirements on fixed line telephone service will apply, regardless whether the service is provided using FWA or a fixed network such as fibre;

iii) The prices, terms and conditions of the fixed service should be the same, regardless of whether the service is provisioned using FWA or via existing network, e.g., NBN. In addition, end-users should be made aware upfront, at the point of service sign-up, that the fixed service is

provided over FWA, where applicable, including any related restrictions or potential constraints on service quality; and

iv) Providers of FWA should exercise flexibility to allow end-users to switch to existing/alternative network, e.g., NBN, should the FWA solution fail to support the fixed services with reasonable service quality.

Views on 5G Health Matters

Industry and Public Response

150. IMDA received a number of responses from individuals, expressing concerns about the potential effects Radio Frequency ("**RF**") radiation might have on health. While some Respondents recognised that the public is exposed to emissions from existing wireless services (e.g., Wi-Fi, 3G/4G, etc.), there were concerns that 5G would compound the existing problem and raise the health hazard to an unprecedented level.

151. Some Respondents highlighted that the International Commission on Non-Ionizing Radiation Protection ("**ICNIRP**") guidelines that the National Environment Agency ("**NEA**") and IMDA took reference from, could be outdated as they were last updated in 1998. Some Respondents had also cited some examples of countries adopting guidelines that were 100 times lower then ICNIRP, and there were also countries that had taken steps in delaying their 5G deployment to take a closer look at radiation concerns.

152. Moving ahead, some Respondents had suggested conducting further studies on the safety of 5G and also developing guidelines for the MNOs to ensure that the mobile base stations were placed a safe distance away from the schools or areas with children.

IMDA's Assessment and Decision

153. It is recognised that the transmission from mobile networks, including those used by 5G, are forms of non-ionising radiation. The ICNIRP, an international organisation formally recognised by the World Health Organisation ("**WHO**"), has developed safety guidelines on public exposure to RF radiation that are widely adopted by many countries, including Singapore. The WHO has also found no conclusive scientific evidence of adverse health effects from very low RF exposures.

154. Based on measurements conducted by NEA, the ambient level of RF radiation in Singapore is very low, typically below 0.7% of the ICNIRP guidelines. With the establishment of 5G trial sites in Singapore, IMDA will be conducting

measurements specifically for emissions from mobile networks, to ensure that the RF radiation levels continue to be well within the ICNIRP guidelines.

155. IMDA is committed to ensuring that Singaporeans will have high quality mobile services that are safe and secure. We will continue to closely monitor developments and consult health experts as appropriate.

Chapter 4: Approach to Assignment of 5G Spectrum to MNOs

5G Spectrum Assignment Approach

Call for proposal ("CFP")

Consultation Proposal

156. IMDA proposed to assign the spectrum via a call for proposal ("**CFP**") approach instead of the auction mechanism. This was in recognition that the auction mechanism will not be able to bring about the desired policy outcomes in this first wave of spectrum assignment. MNOs would have to compete based on the merits of their proposals that can best deliver future-ready 5G networks to meet IMDA's policy objectives.

157. IMDA would score and rank the proposals based on the proposed evaluation criteria. IMDA would award the two Packages to the two applicants with the highest scores. The two successful applicants of the Packages would be assigned the mmWave lots based on their desired sitting.

Industry and Public Response

158. Respondents agreed that the proposed CFP approach would better meet IMDA's policy objectives of facilitating early rollout of trusted and resilient 5G SA networks that deliver strong performance and capabilities, while balancing the spectrum constraints and nascent business case.

IMDA's Assessment and Decision

159. Given industry's response, IMDA will allocate the Packages through the CFP approach. For the remaining mmWave lots, IMDA would administratively allocate them. IMDA will issue the CFP documents to all MNOs on a confidential basis.

160. In view that both Packages are now equal in size, interested applicants shall submit only one proposal for a Package. Applicants' proposals must detail their 5G network design and deployment plans using both spectrum bands in the Package, and how they would meet the various requirements described in the above **Key Obligations and Requirements for Nationwide and Localised 5G Networks**. Proposals must also include the price that applicants are willing to pay for the 3.5 GHz band, which must be higher than the base price set by IMDA ("**Offer Price**").

161. IMDA will score and rank the proposals based on the evaluation criteria (see **Evaluation Criteria** section). IMDA will award the Packages to the two applicants with the highest scores.

162. The successful applicants will be allowed to discuss and select their preferred 3.5 GHz and mmWave lots. Thereafter, the remaining MNO(s) who wish to obtain the mmWave lots in this exercise will be allowed to discuss and select their preferred mmWave lots from the remaining lots[19]. Where there is a contest on the frequency assignment at any stage, a one-time sealed bid will be conducted for the relevant band(s). In this case, IMDA will further inform the MNOs of the auction parameters where needed.

163. Proposals submitted by the successful applicants will be binding on the applicants and shall form part of their licence. Successful applicants are required to submit a performance bond amounting to 5% of its budgeted capital expenditure and shall be tied to key performance milestones and commitments as set out in the proposals.

164. IMDA reserves the right not to assign one or both Packages if the proposals are assessed to be unable to bring about IMDA's policy outcomes and/or fully meet IMDA's key regulatory obligations.

Base Price & Offer Price

Consultation Proposal

165. For the 3.5 GHz band, IMDA considered taking reference from international benchmarks of base and final bid prices for similar bands auctioned globally between 2017 and 2019. As for the mmWave band, given that there was excess supply, there would be no spectrum premium payable. However, spectrum right holders will need to pay the application and annual charges for both bands, as specified in the Telecommunications (Radio-communication) Regulations.

Industry and Public Response

166. Respondents had generally requested to price the 3.5 GHz band low or issue it for free, and to waive the annual charge for the mmWave band. Accordingly, some Respondents proposed to reduce or remove the Spectrum Offer Price criterion weight.

[19] If an MNO subsequently applies for an mmWave lot after the CFP, the mmWave lot will be allocated on a first-come-first-served basis.

IMDA's Assessment and Decision

167. The principles of setting the base price and the Spectrum Offer Price criterion weight are to incentivise MNOs to put in an offer price close to their valuation, balanced against the MNOs' overall business case and allowing MNOs to focus on proposing a network that maximises the value of 5G for Singapore.

168. To arrive at the base price for the allocation of the 3.5 GHz lots, IMDA considered the following: (i) intrinsic value [20] of 3.5 GHz band; (ii) the international benchmarks of reserve and clearing bid prices for similar bands in recently concluded spectrum auctions; (iii) the clearing prices for the spectrum allocated in past auctions in Singapore; and (iv) IMDA's econometric assessment of Singapore's mobile market.

169. Based on this set of assessment, the base price for one 3.5 GHz lot is set at $55 million, excluding Goods and Services Tax, which shall be separately borne by successful applicants in accordance with the relevant tax requirements[21]. As such, applicants shall propose an offer price for one 3.5 GHz lot that is higher than $55 million. Applicants will be required to submit bank guarantee(s) securing $55 million as part of its CFP proposal.

170. For the mmWave band, IMDA maintains that there will be no spectrum premium payable except where there is a contest at the frequency assignment stage as described in the section above. As stated in the 2nd Public Consultation, spectrum right holders will need to pay the applicable one-time application and processing ("**A&P**") fee, and the annual charge for the duration of the spectrum rights for both bands, as specified in the Telecommunications (Radio-communication) Regulations.

Table 4: One-time A&P Fees and Annual Charges

Spectrum	One-time A&P fee	Annual charge
3.5 GHz band: 100 MHz	$6,000	$154,000
mmWave band: 800 MHz	$48,000	$1,232,000

[20] Intrinsic value refers to the IMDA estimated economic value of the spectrum arising from technical factors such as its propagation characteristics, applications and the harmonisation of spectrum internationally, as well as commercial factors such as the expected market demand for 5G going forward.

[21] Applicants shall comply with the relevant tax treatment and requirements prescribed by the Inland Revenue Authority of Singapore in relation to all payments to be made for the upcoming spectrum auction exercise.

CFP Evaluation Criteria

Consultation Proposal

171. IMDA sought views on the proposed evaluation criteria and weights assigned: Network Design and Resilience (40%); Network Rollout and Performance (30%); Spectrum Offer Price (15%); and Financial Capability (15%); and Wholesale Services (mandatory).

Industry and Public Response

172. As mentioned above, some Respondents proposed to reduce or remove the Spectrum Offer Price criterion weight. One Respondent suggested evaluating the proposals based on certain key performance indicators such as proposed launch date, number of base stations deployed, and commitments on number of engineers to be trained for 5G services etc. One Respondent also suggested setting up a lab to audit the MNOs' compliance to their network performance obligations.

IMDA's Assessment and Decision

173. IMDA notes the feedback from the industry. For the Spectrum Offer Price criterion weight, IMDA will maintain the weight as explained in the sections above.

174. Bearing in mind IMDA's desired policy outcomes in facilitating the deployment of 5G, and the suggestion from the industry to focus more on network and service performance indicators, the rollout and performance of 5G networks in Singapore is critical. In this spirit, IMDA will increase the weight of the Network Rollout and Performance criterion and adjust the weight of another criterion or other criteria accordingly.

175. IMDA will provide greater clarity on the specific evaluation criteria in the CFP document that IMDA will issue to the MNOs. A summary of the evaluation criteria and the revised weights are set out in Table 5.

Table 5: Evaluation Criteria

Evaluation Criteria	Details
Network Design & Resilience (40%)	This criterion will assess whether the applicants' proposed 5G networks come with designs that (i) not only meet but also exceed key resilience and security requirements stipulated in the relevant IMDA Codes of Practice, and (ii) are architected based on the following principles, at the outset: - Defence-in-Depth - Zero-Trust Environment - Network Element Assurance - Resilience by Outcome - Minimise dependency - Adopt technology
Network Rollout and Performance (35%)	This criterion will look at the applicants' proposed network rollout and performance potential. For example, IMDA will consider the extent of 5G coverage, timeline/speed of network rollout (including achieving nationwide outdoor coverage), capabilities of the proposed 5G system, including its ability to support use-cases, and performance standards beyond the key requirements set by IMDA.
Spectrum Offer Price (15%)	This criterion will look at the offer price submitted beyond the base price. Applicants shall also submit bank guarantee(s) equivalent to the base price.
Financial Capability (10%)	This criterion will assess whether the applicants have the financial ability to fund their proposed 5G network rollout and meet their projected costs.
Wholesale services	Mandatory compliance, in line with IMDA's framework.

176. The indicative timeline for the CFP is provided below:

Table 6: Indicative timeline for CFP

Milestone	Indicative Timeline
Issuance of CFP	By October 2019
Submission deadline to the CFP	21 January 2020
Decision on CFP/ Notification of award	Mid-2020

Chapter 5: Summary of Key Points of Policy and Regulatory Framework

177. IMDA maintains its vision for Singapore to be a front-runner for innovation in trusted and resilient 5G applications and services. IMDA will continue to support and prime the 5G ecosystem for innovation and development across a span of 5G applications and services.

178. A robust policy design and regulatory framework will be needed to facilitate deployment of resilient and secure 5G systems, in order to support the development of Singapore's 5G innovation ecosystem. Accordingly, IMDA's key policy objectives for the deployment of 5G networks in Singapore are to:

i) Maximise value of 5G for the economy and welfare for the consumers;
ii) Facilitate efficient allocation of scarce spectrum resources;
iii) Bring about 5G networks that are secure and resilient; and
iv) Support the growth of Singapore's telecommunications sector.

179. The key features of Singapore's 5G policy and regulatory framework are as follows:

i) Two nationwide, trusted and resilient networks as a start, using 100 MHz of 3.5 GHz band and 800 MHz of mmWave band for each network;

ii) IMDA will assign two Packages (each comprising 100 MHz of 3.5 GHz band and 800 MHz of mmWave band) in the initial phase, via a CFP process;

iii) Allow localised deployment by MNOs using only 800 MHz of mmWave band for each network for those who did not secure the Package. These MNOs can apply for the remaining two mmWave lots in the same exercise;

iv) MNOs with the 3.5 GHz band shall deploy SA from the outset. Those who wish to also deploy NSA networks in the 3.5 GHz band to meet early demand must seek IMDA's prior approval. MNOs with the mmWave band may deploy SA or NSA in the interim, but shall deploy SA within 24 months of when the SA ecosystem is ready.

v) The spectrum will only be assigned to existing MNOs and any joint ventures applying for the Packages or mmWave band can only consist of the existing MNOs; and

vi) The 3.5 GHz and mmWave spectrum rights will commence from 2021 and 2020 respectively, and will have approximately 15- and 16-year duration. Both spectrum rights will expire on the same date.

180. To participate in the CFP, applicants will have to submit detailed proposals that meet IMDA's key obligations and requirements:

i) Provide 5G SA networks with at least 50% coverage within 24 months from the commencement of the 3.5 GHz spectrum right;

ii) Put to use the mmWave band within 12 months from assignment;

iii) Design of the 5G networks should (a) meet key resilience and cybersecurity requirements stipulated in the relevant IMDA Codes of Practice (and to exceed such requirements where possible); and (b) be architected based on principles such as Defence-in-Depth and Zero-Trust Environment, at the outset;

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

v) The applicants shall also indicate their offer price for one lot of 3.5 GHz band, which must be higher than $55 million, and submit bank guarantee(s) equivalent to the base price of $55 million.

181. The proposals will be evaluated based on the following criteria:
i) Network Design & Resilience (40%);
ii) Network Rollout and Performance (35%);
iii) Offer Price (15%); and
iv) Financial Capability (10%).

182. IMDA will score and rank the proposals, and will assign the Packages to the two applicants with the highest scores. The successful applicants will then select their preferred 3.5 GHz and mmWave lots, followed by the remaining applicants.

183. Proposals from the successful applicants will be binding and shall form part of their licence. Successful applicants are required to submit a performance bond amounting to 5% of its budgeted capital expenditure and shall be tied to the key performance milestones and commitments in the proposals.

184. With more spectrum to be availed by IMDA in the longer term, there will be growth opportunities for future network build and technology upgrade for MNOs to be able to effectively respond to future technology and market dynamics.

Annex A: List of Respondents

1. Advanced Wireless Technology Group Ltd (AWTG)
2. Alissa
3. Arete M Pte Ltd
4. Asia Satellite Telecommunications Company Limited (Asiasat)
5. Association of Telecommunication Industry of Singapore (ATIS)
6. Cara Yousry
7. Chua Choon Hiang
8. CLOP Technologies Pte Ltd
9. David Skinner
10. Dr A. Skinner
11. Dr Mona Board
12. Dr Timothy Ng and Henry Yue
13. Emma Paris
14. Ericsson Telecommunications Pte Ltd
15. Eutelsat Asia Pte Ltd
16. Federated Wireless Inc
17. Gabrielle Muenkel
18. Global Mobile Suppliers Association (GSA)
19. Global Satellite Coalition (GSC)
20. Global System for Mobile Communications (GSMA)
21. Huawei International Pte. Ltd
22. Inmarsat
23. Intelsat Singapore
24. Jakkolab Pte Ltd
25. Jenny Castelino
26. Joanna
27. Juniper Networks (Singapore) Pte Lt
28. Katharine Tan-Sinha
29. Keysight Technologies
30. Kinney Workman
31. Kwan Xiuwen
32. Lauren Ullman
33. Liberty Wireless Pte. Ltd. (Circles.Life)
34. M1 Limited
35. Martin Lim
36. Mavenir Systems Inc
37. Measat
38. Melanie Kao
39. Motorola Solutions
40. MyRepublic Group Limited
41. NetLink Trust
42. Nokia
43. Palo Alto Networks
44. Peter Chan

45. Qualcomm Inc.
46. Rohde & Schwarz Regional Headquarters Singapore Pte Ltd
47. Rosemary Pattison
48. Samsung Electronics Co. Ltd
49. Seah Guan Hai
50. SES World Skies Singapore
51. Singapore Telecommunications Limited
52. ST Engineering and SP Telecom
53. StarHub Mobile Pte Ltd
54. Suhana
55. Tan Teng Hai
56. Telesat
57. Thoo Hoi Thian
58. TPG Telecom Pte Ltd
59. US Asean Business Council (USABC)
60. Vahidha Shaik Naina
61. Viasat
62. Weina Li
63. ZTE Singapore Pte Ltd

ANNEX B: DEPLOYMENT GUIDELINES OF 5G MOBILE NETWORK EQUIPMENT OPERATING IN THE 3400 - 3700 MHz C-BAND

1. This Annex provides the guidelines for the deployment of 5G mobile network equipment operating in the 3.5 GHz band.

2. In the frequency migration exercise to make available the 3.5 GHz band for the deployment of 5G mobile networks, existing FSS users are advised to take the necessary preparatory steps such as retrofitting an appropriate BPF to protect the signal reception of their FSS System/Systems. Based on a technical study commissioned by IMDA, it is recommended that the BPF should have a rejection of at least 45 dB at 3650 MHz, and should have a frequency response, which continues to fall below this, so as to provide a reasonable amount of protection to the FSS System/Systems. The type of BPF and its specifications are dependent on the FSS users' own technical assessment.

3. IMDA will provide, to the MNOs awarded with the radio frequency spectrum in the 3.5 GHz band the list of existing FSS locations to facilitate their 5G deployment and site planning. The MNOs may be required to coordinate directly with the FSS users to mitigate the risk of interference.

4. The mobile base stations shall at least comply with the unwanted emission limits specified for Wide Area Base Station (Category B) prescribed in the 3GPP TS 38.104 v15.6.0, including the latest version.

5. In order to minimise any radio frequency interference to FSS users whose FSS System/Systems receive in the frequency range of 3.7 – 4.2 GHz band, the MNOs are to adhere to the following requirements within the specified zones:

   <u>Exclusion zones – for areas that house critical FSS operations</u>

   i) There shall not be any use of radio frequency in the 3.4 – 3.7 GHz band to provide service, through the deployment of any 5G base station located within the exclusion zones. IMDA has designated two (2) exclusion zones (**refer to Areas F and G(i) in Annex B1**) to protect licensed FSS used for critical operations.

Precautionary zones - for areas with relatively high density of FSS Systems

ii) For the deployment of 5G base stations within the precautionary zones (refer to **Areas A, B, C, D, E and G(ii)** in **Annex B**), the following shall be observed:

a) No 5G base station shall be operated within +/- 45 degrees of the bore-sight of a FSS System;

b) Local Area (indoor and outdoor) 5G base stations are allowed; and

c) For Wide Area Base Stations (e.g., macro cells at rooftop) and Medium Range Base Stations (e.g., small cells at six (6)-meter height), there must be sufficient shadowing/cluttering between the 5G base stations and FSS Systems.

6. For avoidance of doubt, please refer to section 4.4 of 3GPP TS 38.104 v15.6.0 for the definitions of “Wide Area Base Stations”, “Medium Range Base Stations” and “Local Area Base Stations”.

7. If interference is caused to any existing FSS operations, the MNOs must:

i) Verify that the FSS System/Systems has been installed with an appropriate BPF;

ii) If an appropriate BPF has been installed, the MNOs must undertake mitigation actions to resolve interference issues; and

iii) The total power (per operator) reaching the FSS System does not overdrive the LNA/LNB.

8. IMDA reserves the right to, at any time and in its sole and absolute discretion amend, supplement and/or vary any element of the 5G deployment guidelines in the course of monitoring the deployment of 5G network equipment in the first two (2) years of the network rollout by the MNOs. In the event that any changes are made to these guidelines, IMDA will provide advance notice to the industry and may consult industry players where necessary.

Annex B1

Zones with guidelines for 5G deployment in the C-Band

Two (2) exclusion zones and six (6) precautionary zones are defined as follows:

Figure B1: Exclusion zones and precautionary zones

Each of the zones is represented by a polygon/circle using the Decimal Degrees coordinates format.

Zone	Definition of zone	Latitude (°N)	Longitude (°E)	Category
A	Circle of radius 400 metres from given coordinate	1.33921	103.75116	Precautionary zone
B	Polygon with vertices at given coordinates in sequence	1.29947	103.79240	Precautionary zone
		1.29239	103.79901	
		1.28868	103.79467	
		1.29556	103.78821	
C	Polygon with vertices at given coordinates in sequence	1.35586	103.85896	Precautionary zone
		1.35199	103.86499	
		1.34840	103.86246	
		1.35229	103.85645	
D	Polygon with vertices at given coordinates in sequence	1.31706	103.81578	Precautionary zone
		1.31351	103.82889	
		1.30372	103.84155	
		1.31674	103.83927	
		1.32773	103.84334	
		1.31465	103.85470	
		1.32168	103.86641	
		1.28798	103.86311	
		1.28976	103.84791	
		1.27789	103.85403	

Zone	Definition of zone	Latitude (ºN)	Longitude (ºE)	Category
		1.27140	103.84519	
		1.27702	103.83124	
		1.29954	103.83161	
		1.30288	103.82873	
		1.29190	103.81541	
E	Polygon with vertices at given coordinates in sequence	1.38635	103.96688	Precautionary zone
		1.38746	103.99928	
		1.37451	104.00430	
		1.33375	103.98756	
		1.34096	103.97160	
		1.36472	103.98216	
		1.37047	103.96991	
F	Circle of radius 500 metres from given coordinate	1.35232	103.79071	Exclusion zone[22]
G	(i) Circle of radius 650 metres from given coordinate	1.39693	103.83435	Exclusion zone
	(ii) Circle of radius 1000 metres from given coordinate, excluding the exclusion zone defined in G(i)			Precautionary zone

[22] IMDA will review the exclusion zone status after 31 December 2022.