Roadmap for C-band spectrum in ASEAN

August 2019

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About this study

This is a study for GSMA to assess the current use of the C-band (3.3-4.2 GHz) in the ASEAN region and to identify the roadmap and strategy to make available spectrum to support the deployment of 5G services while ensuring coexistence with other users in the band.

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Executive summary

Why 3.5 GHz?

The 3.5 GHz band (3.3 – 3.8 GHz) is a core spectrum band for 5G deployment. Over the last 24 months, many national regulators globally have either assigned this spectrum for mobile or have started preparations to do so. There is also a rapidly growing ecosystem of devices, setting the stage for successful rollouts.

Due to its propagation characteristics and the potential for large contiguous bandwidths, the 3.5 GHz band is an ideal frequency band for 5G as it is able to provide both capacity (the amount of data traffic it can support) and coverage (the distance the radio signals travel). High-speed enhanced mobile broadband services need to be capable of delivering peak download speeds of at least 20 Gbps, a reliable 100 Mbps user experience data rate in urban areas, and 4 ms latency. The 3.5 GHz band will be key for delivering eMBB and to enable good 5G service performance, 80 – 100 MHz of 3.5 GHz spectrum per mobile network operator is preferred.

In ASEAN, the 3.5 GHz band is used by different satellite and fixed services and its availability is less clear. Aside from the Philippines which has already assigned parts of the band for IMT, other countries in the region are looking into the release of 3.5 GHz to support 5G rollouts, with other frequency bands also being considered. To deliver on the promise of 5G and take advantage of its many benefits, it is important for the region's regulators to develop a roadmap for the release of as much as possible of the 3.5 GHz band. At the same time, the specific needs of current users in the band should be taken into consideration.

This report discusses the current use of the C-band in ASEAN, the different options to release the band for mobile use, and the factors that need to be taken into account in deciding on the appropriate way forward. Recommendations for developing the roadmap to release the 3.5 GHz band in ASEAN are then provided.

Current uses in the C-band

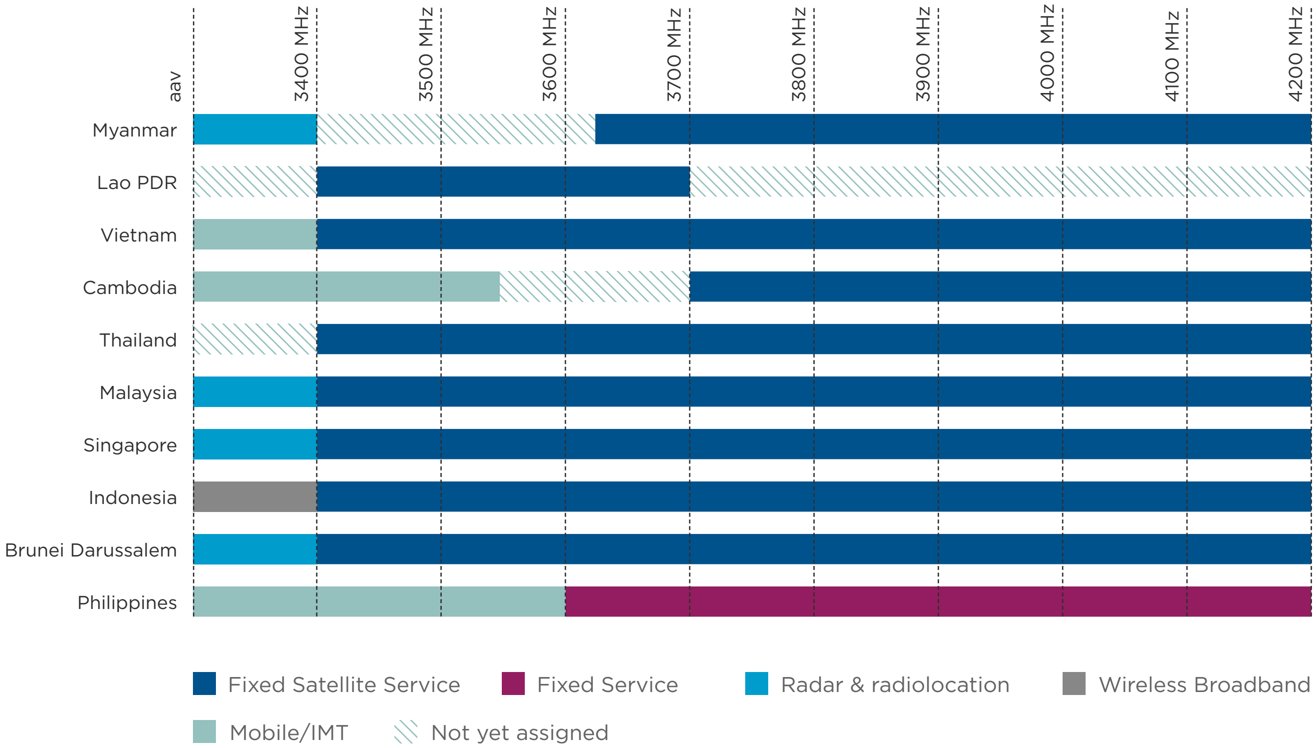
The current use of the C-band (3.3 – 4.2 GHz) band varies across the ASEAN region and by country. The main use is for fixed satellite service (space-to-Earth), although there is also use in parts of the band for radiolocation and fixed service (mainly point to multipoint or wireless broadband services). Figure 1 provides a summary of the current status.

The fixed satellite service (FSS) applications in the 3.4 GHz – 4.2 GHz range include:

- Large satellite earth stations which serve as a gateway that carry trunk or network traffic (feeder links) to and from satellite space stations
- Telemetry, tracking, and command (TT&C) stations used for communication between spacecraft and the ground.
- VSATs, which are small two-way satellite systems, primarily used by businesses, but also for military and government applications.
- Satellite Master Antenna Television (SMATV), a system that uses multiple satellite and broadcast signals to create a single integrated cable signal for distribution to a cabling network within a building (e.g. apartment block, hospital etc.).
- TV receive-only (TVRO), used for reception of broadcast signals such as free-to-air television.

Figure 1

Current status of 3.3 – 4.2 GHz in ASEAN countries (as of July 2019)



Source: Plum-WPC analysis based on information from national regulators.

Options to release 3.5 GHz spectrum

There are two general approaches to release the spectrum for mobile use, namely

1. Accommodate both mobile and existing users through sharing.

2. Clear the band (or parts of it) by migrating existing users to alternative bands or technologies.

The potential to share between IMT and incumbent users depends on the services themselves, the extent of their deployment and the type of sharing envisioned (co- or adjacent-channel) as shown in Figure 2.

Figure 2

Coexistence potential between IMT and incumbent services in 3300 – 4200 MHz band

Incumbent service	Co-channel	Adjacent channel
FSS (Limited FSS earth station deployment)	Yes, with detailed coordination / mitigation measures	Yes, with detailed coordination / mitigation measures
FSS (Ubiquitous FSS deployment, e.g. TVROs and VSATs)	No	Yes, with suitable guard band
FS (Limited FS deployment of point to point links)	Yes, with detailed coordination / mitigation measures	Yes, with detailed coordination / mitigation measures
FS (Ubiquitous FS deployment of point to point links)	No	Yes, with suitable guard band
FS (FS point to multipoint / BWA)	Yes, with mitigation measures e.g. synchronisation	Yes
Radiolocation / Radars	Possibly, with detailed coordination	Probably, with detailed coordination

There is no one 'correct' way to address potential interference issues. Instead, the solution is likely to be dependent on local conditions around the extent and nature of FSS usage in each country. A number of studies have been undertaken with different conclusions on the necessary guard band between the services, ranging from 20 MHz up to 100 MHz.

In addition to guard bands, other possible measures to ensure coexistence between IMT and FSS include;

- Earth station site shielding
- Restriction zones to protect FSS
- Improved FSS receivers
- Addition of filters to FSS receivers
- IMT base station location limits
- Reduced base station transmitter power
- Detailed coordination

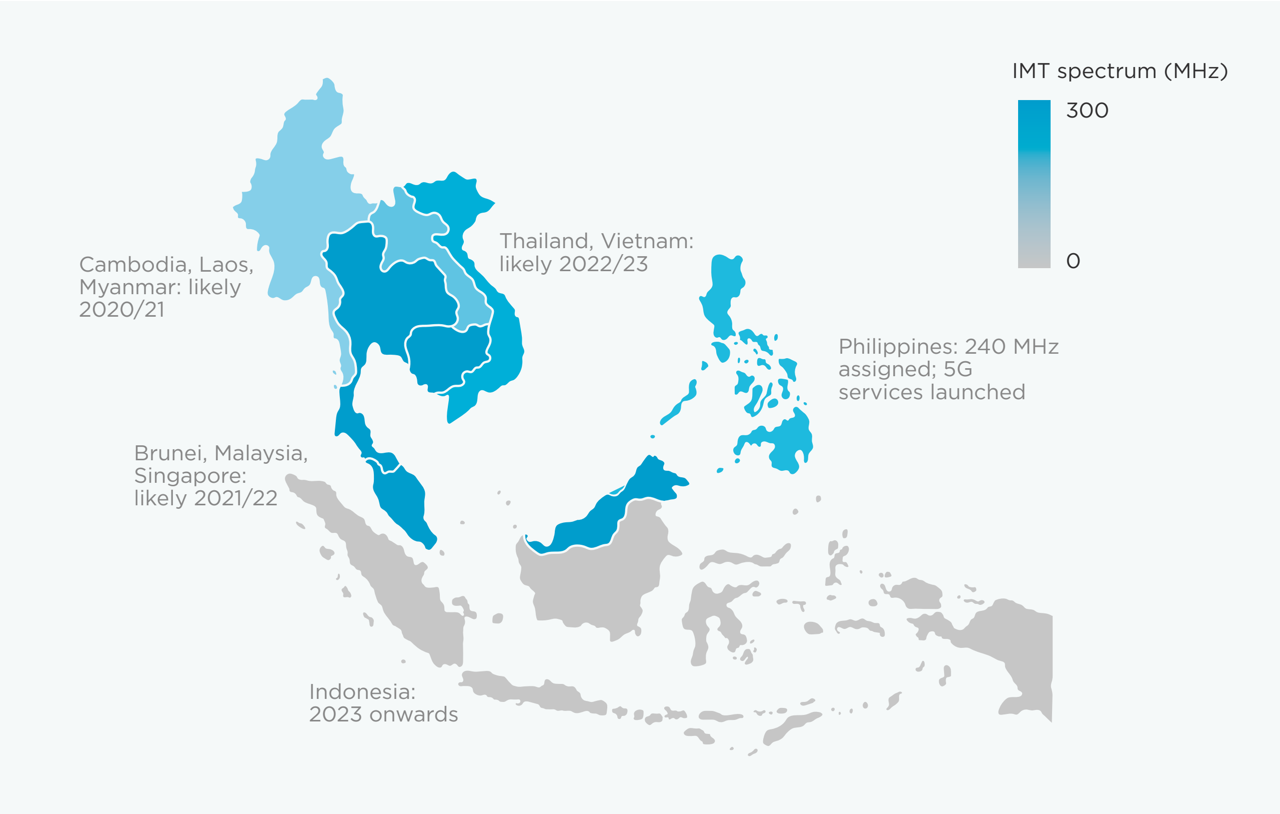
A cost-benefit analysis should be undertaken to assess the optimum approach for the release of 3.5 GHz for 5G. It should include the cost of implementing coexistence measures or a band clearance. In some cases, a hybrid of the two approaches may be appropriate. For example, in its plans for releasing the 3575-3700 MHz band, the Australian regulator ACMA decided to clear existing FSS and FS users in metro and regional areas over a transition period of up to seven years while specifying coexistence measures to protect incumbent users during this period.

The ASEAN roadmap for 3.5 GHz

Figure 3 shows the possible timing for the availability of the 3.5 GHz band in ASEAN based on the current plans and our analysis of the situation in each country. For Indonesia the heavy use of the C-band satellite services across the archipelago means there are particular challenges for releasing spectrum in the 3.5 GHz band.

Figure 3

Potential availability of the 3.3 – 3.8 GHz band for 5G



Source: Plum-WPC analysis based on information from national regulators.

The different timings have implications for cross-border agreements. Whilst agreements between mobile networks can be relatively easy to establish, different agreements will be necessary where IMT is deployed in one country and fixed satellite services, fixed services or radars in another. For coexistence between mobile and other services, it will be necessary to consider whether ubiquitous coverage is possible. Restriction or coordination zones as best fits the specific circumstances also have to be defined.

To get the best possible outcome, countries in the ASEAN region should work together to determine appropriate cross-border agreements. There are large borders in the region and decisions will impact on more than one country.

Not all ASEAN countries have currently identified the 3.5 GHz band for mobile and IMT use. At WRC-19, administrations should consider the inclusion of relevant footnotes[1] to reflect future planned use of the 3300 – 3700 MHz for mobile and specifically IMT.

1. Such as 5.432A, 5.432B and 5.433A currently.

Figure 4 shows a suggested roadmap for the release of the 3.5 GHz spectrum and the key steps that need to be undertaken by national regulators. As part of the planning process, ASEAN regulators should consider a moratorium on new C-band FSS and FS licences until a decision has been taken on the long-term future of the band.

Figure 4

Roadmap for releasing 3.5 GHz spectrum for 5G

STAGE 1:	PLANNING AND DECISION (ESTIMATED 12 MONTHS)
	• Review current use in 3.3 – 4.2 GHz • Assess potential for coexistence (co- and adjacent-channel) • Assess options available and conduct cost benefit analysis
STAGE 2:	IMPLEMENTATION (RANGE FROM SEVERAL MONTHS TO YEARS)
	• Co-channel – notify incumbents on measures and implementation timescale • Adjacent channel – notify incumbents of measures to minimise interference • Cross-border coordination and arrangements
STAGE 3:	AWARD SPECTRUM (6-12 MONTHS)
	• Determine technical conditions for released spectrum • Design appropriate award taking account of national objectives • Implementation of award

Lastly, having implemented the necessary coexistence measures, regulators should also:

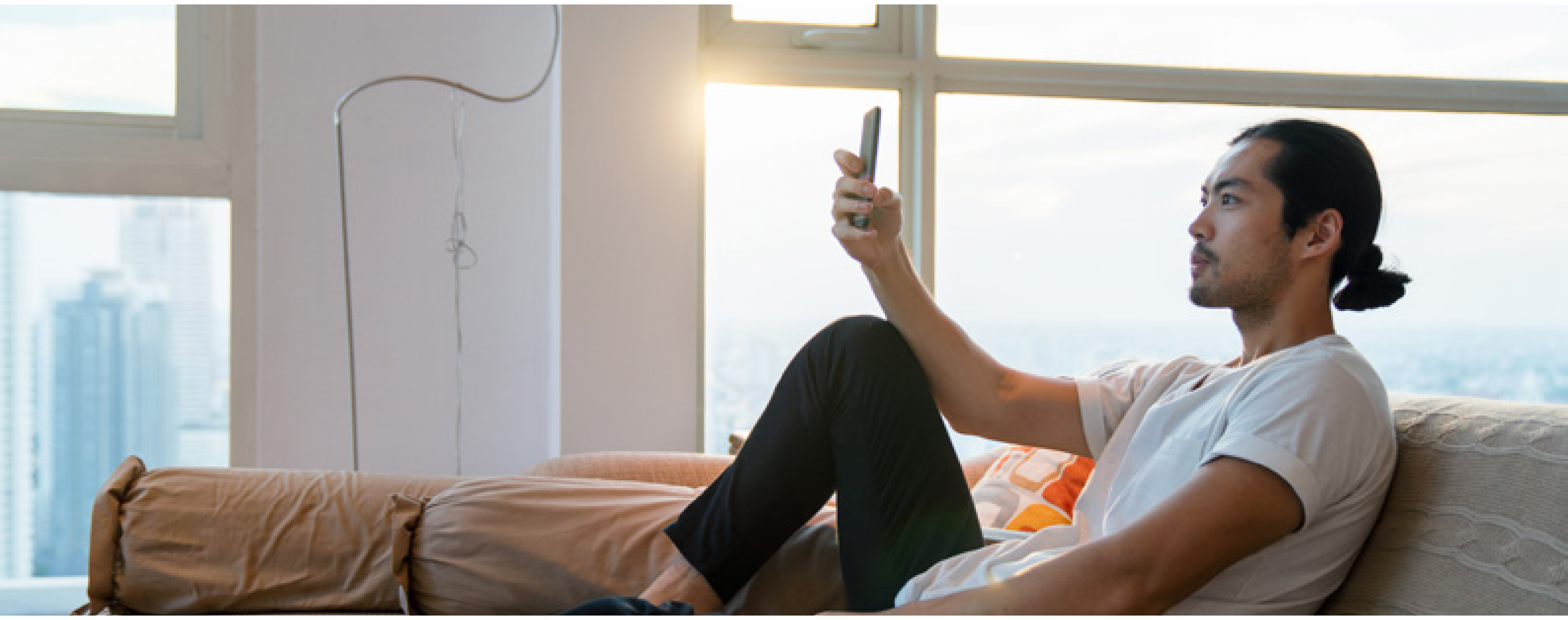
- Provide clarity on supply and timing – this allows greater certainty to the mobile industry and helps operators plan their 5G investments and network rollouts.
- Facilitate contiguous assignments – large contiguous bandwidths of 80 – 100 MHz are preferred for efficient 5G deployment. However, if there is a need for the 3.5 GHz band to be released in phases due to coexistence issues, measures should be in place for mobile operators to aggregate spectrum holdings at a later stage.
- Ensure the appropriate award mechanism is well designed, taking account of market specific conditions, non-financial aspects such as coverage, industry development, affordability and quality of service.

1. The importance of 3.5 GHz for 5G

The band 3.3 – 3.7 GHz was one of the main frequency bands identified for mobile use at the last World Radiocommunication Conference in 2015 (WRC-15) across all three ITU Regions. Since then, this has emerged as a core 5G band. A wide range of frequencies – low (sub-1 GHz), mid (1 – 6 GHz) and high (above 6 GHz) bands – will be required to support the variety of applications possible with 5G. These include enhanced mobile broadband service (eMBB), ultra-reliable and low-latency communications (URLLC) and massive machine type communications (mMTC).

High-speed eMBB services need to be capable of delivering peak download speeds of at least 20 Gbps, a reliable 100 Mbps user experience data rate in urban areas, and 4 ms latency.[2] The 3.5 GHz band is ideal as it is able to provide both capacity (the amount of data traffic it can support) and coverage (the distance the radio signals travel). The 3GPP specifications for 5G also allows this band to be used for 5G in tandem with existing LTE deployments.[3] The 3.5 GHz band has been an early focus of 5G development by equipment manufacturers. Over the last 24 months, many national regulators have either assigned the band for mobile or have started their preparations to do so.

Figure 1.1 shows the current status of IMT assignments in the 3.5 GHz band and administrations with plans to assign the band for IMT use. Progress in the assignment of the 3.5 GHz band is most advanced in Region 1, particularly in Europe where it has been identified as a pioneer 5G band.[4] In addition, there has also been activity in the 3.8 – 4.2 GHz band with several countries (e.g. Canada, UK, US) considering the potential release for 5G use while Japan assigned frequencies in the 3.8 – 4.1 GHz range in April 2019.



2. ITU. Minimum requirements related to technical performance for IMT-2020 radio interface(s). Report ITU-R M.2410-0. November 2017.
3. The 3GPP has also agreed upon a number of LTE-NR sharing combinations where the upload direction of some low frequency bands (e.g. 700, 800, 900, 1800 and 2100 MHz) are paired with the 3300 – 3800 MHz band.
4. The European Commission's Implementing Decision (EU) 2019/235) requires Member States to assign the 3400 – 3800 MHz for 5G services by 31 December 2020.

Figure 1.1

Status of 3.5 GHz IMT assignments globally, excluding ASEAN (as of June 2019)

Status	Region 1 (Europe, Middle East and Africa)	Region 2 (Americas)	Region 3 (Asia Pacific)
Completed	Ireland (May 2017) Czech Republic (July 2017) Slovakia (October 2017) UK (April 2018) Spain (July 2018) Latvia (September 2018) Finland (October 2018) Italy (October 2018) UAE (November 2018) Oman (December 2018) Qatar (January 2019) Switzerland (February 2019) Saudi Arabia (March 2019) Austria (March 2019)	–	South Korea (June 2018) Australia (December 2018) Japan (April 2019) China (June 2019)
Planned / consultation stage*	Czech Republic (2019) Estonia (2019) Greece (2019) Israel (2019) Romania (2019) Sweden (2019) Hungary (2020) Belgium (2019/2020) UK (2019/2020) Luxembourg (2020) France (2020) Norway (2020) Poland (2020) Slovenia (2020)	Canada (2020) Brazil (2020) Ecuador (2020) United States (2020) Peru (2020) Mexico (tbc)	Hong Kong (2019) Taiwan (2019) India (2019) New Zealand (2020)

Note: * published consultations.
Source: Plum analysis, national regulators

The number of 5G device announcements have increased significantly in the first half of 2019.[5] As of July 2019, there have already been a number of commercial launches for 5G using 3.5 GHz (e.g. Australia, Italy, South Korea, Spain, Switzerland and UK). These are expected to continue over the next year as more operators around the world launch 5G and the availability of 5G devices increase. Enhanced mobile broadband services will be a key driver of 5G demand. According to industry forecasts, over 10 million 5G subscriptions are projected by the end of 2019.[6] The pace of 5G adoption is expected to exceed that of 4G over the next five years and by 2024 5G subscriptions are forecast to make up 20 percent of all mobile subscriptions.

5. According to the GSA, there are 71 5G devices as of June 2019 and the 3.3-3.8 GHz band is the most well-supported 5G band with 20 devices. Currently the major chipset vendors for 5G include Huawei, Mediatek, Qualcomm and Samsung, and other vendors also have chipsets planned. Source: GSA. 5G Device Ecosystem. June 2019.
6. Ericsson Mobility Report. June 2019.

1.1 Progress in ASEAN so far

The current status of the 3.5 GHz band differs significantly across the ASEAN region. Aside from the Philippines which has already assigned parts of the band for IMT, there are ongoing activities in the other ASEAN countries looking into the release of the 3.5 GHz and other frequency bands to support 5G rollout. A brief summary of these developments as of July 2019 is provided below with more information available in Appendix A.

The **Philippines** is the first country in the ASEAN to assign the 3.5 GHz band; 240 MHz in 3.3 – 3.6 GHz has already been assigned for mobile and other wireless operators. On 1 July 2019, Globe Telecom launched the first commercial fixed 5G services to be known as "Air Fibre 5G" with up to 100 Mbps services and up to 2 TB post-paid packages in select areas of Pasig, Cavite and Bulacan. Globe Telecom are aiming to connect 2 million homes to 5G by 2020. In addition, PLDT is aiming to launch 5G services for select home and corporate customers by Q4, 2019.

Cambodia has allocated 3.4 – 3.7 GHz for IMT purposes for some time but for this band to be optimally used for 5G, the current mix of FDD and TDD spectrum allocations would need to be refarmed and reassigned. It is currently looking to develop a 5G White Paper to address these issues.

In **Myanmar** and **Singapore** regulators have issued consultation papers proposing the release of specific allocations (namely 120 MHz of spectrum in Myanmar and 200 MHz of spectrum in Singapore comprising 100 MHz of unrestricted spectrum and 100 MHz of restricted spectrum) of the 3.4 – 3.6 GHz band in 2020 and 2021 respectively. The spectrum being made available is reduced in size due to the need for guard bands to protect FSS. In Myanmar this 5G spectrum is likely to form part of an IMT spectrum auction to be run by the PTD while in Singapore a 'beauty contest' via call for proposals is currently favoured by the IMDA.

In **Vietnam** and **Thailand** consultation papers and trials on the use of the 3.5 GHz band for 5G have been issued by the ARFM and NBTC respectively with decisions on the way forward and whether any spectrum can be allocated to IMT purposes expected later in 2019.

Brunei has undertaken a study of the feasibility of coexistence of Fixed Satellite Service with IMT in the band 3.4 – 3.8 GHz and hopes, following migration of existing services, to allocate 200 MHz for IMT services from 3.4 – 3.6 GHz (including guard band) from 2022 or earlier.

In **Malaysia** and **Indonesia**, national 5G task forces have been created which will report later in 2019. The mandate of the 5G task forces includes spectrum band and bandwidth allocation required for services and use cases, guard bands and proposals for a 5G roadmap.

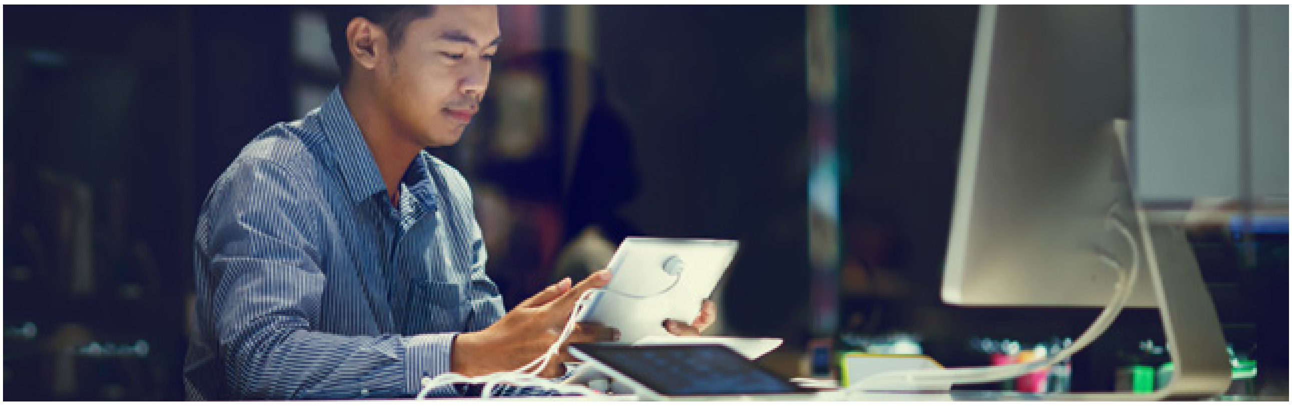
Lao PDR is preparing to move forward with 5G and is considering a timeline for the deployment of 5G networks and determining user demand. Currently, 3.3 – 3.4 GHz and 3.7 – 4.2 GHz are vacant and can be used for 5G as long as 5G signals do not cause interference with Lao PDR licensed FSS services.

2. Current uses in the C-band

The availability of the C-band (3.3 – 4.2 GHz) for 5G mobile use is constrained due to current use by other services which is particularly prevalent in ASEAN.

This section provides:

- An overview of the current frequency allocations in the C-band,
- The current services deployed in the individual ASEAN countries and
- The licensing approaches for these services and the implications for refarming to mobile use.



2.1 Frequency allocations in the 3.3 – 4.2 GHz band

At the 2015 World Radiocommunication Conference (WRC-15) agenda item 1.1 addressed the issue of additional spectrum for IMT services. There were a number of bands proposed between 3300 and 4200 MHz.

The outcome for 3400 – 3600 MHz was that it was more clearly identified for IMT, across Region 1 (Europe, Middle East and Africa) and Region 2 (the Americas) alongside specific technical requirements for the protection of fixed satellite services in neighbouring countries. The band was not identified for IMT in Region 3 (Asia Pacific), although some individual countries from that Region are included in country footnotes.[7]

The 3300 – 3400 MHz band which had been strongly pushed by some Asian countries in the preceding preparatory work, was identified for IMT in a number of African and South American countries, as well as in some Asia Pacific countries[8] through footnotes. The 3600 – 4200 MHz band is allocated to mobile (except aeronautical mobile) on a primary basis but is not identified for IMT in Region 3.

7. 3400 – 3500 MHz is allocated in Korea, Japan and Pakistan to mobile on a primary basis. The power flux density (pfd.) produced at 3 metre above the ground must not exceed -154.5dB(W/m².4kHz) for more than 20% of time at the border of any other administration.
3400 – 3500 MHz is allocated to mobile service on a primary basis and identified for IMT in Australia, Bangladesh, China, French overseas communities of Region 3, India, Iran, New Zealand, the Philippines and Singapore. The same pfd levels apply.
3500 – 3600 MHz is allocated to mobile service on a primary basis and identified for IMT in Australia, Bangladesh, China, French overseas communities of Region 3, Korea, India, Iran, Japan, New Zealand, Pakistan and the Philippines. The same pfd levels apply.
8. 3300 – 3400 MHz is identified for mobile on a primary basis in Papua New Guinea. In Cambodia, India, Lao PDR, Pakistan, the Philippines and Vietnam this is identified for IMT in accordance with RES.223. (Shall not cause harmful interference to, or claim protection from, systems in the radiolocation service).

In Region 3 the other services allocated in 3300 – 4200 MHz are shown in Figure 2.1.

Figure 2.1

Allocations in Region 3 between 3300 and 4200 MHz

Frequency	Region 3	Footnotes (ASEAN)
3300 – 3400 MHz	RADIOLOCATION Amateur	• MOBILE/FIXED – Brunei, Cambodia, Indonesia, Malaysia • IMT identification – Cambodia, Lao PDR, Philippines, Vietnam
3400 – 3500 MHz	FIXED FIXED SATELLITE (space-to-Earth) Amateur Mobile Radiolocation	• MOBILE – Philippines, Singapore • IMT identification – Philippines, Singapore
3500 – 3600 MHz	FIXED FIXED SATELLITE (space-to-Earth) MOBILE except aeronautical mobile Radiolocation	• IMT identification – Philippines
3600 – 3700 MHz	FIXED FIXED SATELLITE (space-to-Earth) MOBILE except aeronautical mobile Radiolocation	–
3700 – 4200 MHz	FIXED FIXED SATELLITE (space-to-Earth) MOBILE except aeronautical mobile	–

Source: ITU

2.2 Services in the 3.3 – 4.2 GHz band

The use of the 3.3 – 4.2 GHz band varies across the ASEAN region. In the 3.3 – 3.4 GHz band the main use is for radiolocation (radars).

In the 3.4 – 4.2 GHz band there is a range of different applications that come under the fixed satellite service (space-to-Earth) allocation including:

- Large satellite earth stations which serve as a gateway that carry trunk or network traffic (feeder links) to and from satellite space stations.
- Telemetry, tracking, and command (TT&C) stations used for communication between spacecraft and the ground. The stations receive information and transmit commands that allow, for example, the satellite's orbit to be adjusted, the solar panels to be realigned and system back-up to be performed from the earth.
- VSATs which are small two-way satellite systems and can send and receive data. These are used primarily for business, but also for military and government applications. The antennas are typically less than 3.6 metres in diameter and a Low Noise Block Downconverter (LNB) is used for receiving signals in the 3.4 – 4.2 GHz band.

- Satellite Master Antenna Television (SMATV), a system that uses multiple satellite and broadcast signals to create a single integrated cable signal for distribution to a cabling network within a building (e.g. apartment block, hospital etc.).
- TV receive only (TVRO), used for the reception of broadcast signals such as free to air television signals.

Fixed services (FS) are also in use in the 3.4 – 4.2 GHz range although it appears the main use is for point to multipoint (wireless broadband services) rather than individual point to point links.

2.3 Licensing approaches by service and implications for refarming

The licensing approach adopted for the incumbent services in the C-band will have implications on the potential for coexistence and refarming of frequencies for 5G use.

2.3.1 Fixed Satellite Service

FSS receiving earth stations operate in the space-to-Earth direction in the 3400 – 4200 MHz frequency band. These earth stations can generally be grouped into four categories:

- Earth stations deployed ubiquitously and/or without individual licensing or registration;
- Individually licensed earth stations;
- Telemetry earth stations; and
- Earth stations that are feeder links for mobile-satellite systems.

In the case of large FSS earth stations and feeder link earth stations they are generally licensed on an individual basis and as part of the licences the location is specified in the licence along with other information such as antenna pointing and characteristics. These earth stations do not transmit in the 3.4 – 4.2 GHz band and so will not cause harmful interference to new uses (IMT) in the band.

If the earth stations are to coexist with IMT then there will be a need for formal coordination between the new licensees and satellite services. Coexistence may be facilitated by, for example, site shielding of the earth station or even relocation to geographic areas where there may be less or no demand for the spectrum for mobile services as proposed in Australia. Similarly, TT&C earth stations will receive telemetry data in the band, and their locations are known. The licences will also normally specify the frequencies that are used at the earth station but often the whole band may be included rather than the actual frequencies. Specifying the precise frequencies may also facilitate coexistence.

The approach adopted for licensing of VSATs varies by country and can either be individual licences, as for large earth stations, or licence exempt. In the case of the latter, the location of the VSAT terminal is not known (unless there is a requirement for registration of all VSAT terminals) and there is no protection provided from interference. This means it is difficult to consider coexistence on a co-channel basis especially as typically VSAT networks are likely to consist of hundreds of terminals.

A similar situation exists with receive only satellite use such as TVRO systems, of which there may be thousands, as these are licence exempt and their locations are not generally known. There is also no protection provided from interference for the satellite services. Sharing on a co-channel basis between IMT and FSS is not feasible in the same geographical area since no minimum separation distance can be guaranteed.

In the case of licence exempt use of the spectrum by VSATs and TVROs or ubiquitous deployments, the only options are to continue to make the spectrum available for FSS or to migrate all users from the band as co-channel coexistence is not feasible.

There is extensive use of the 3.4 – 4.2 GHz band for FSS with a number of countries having their own national satellites as well as foreign satellites providing coverage and services. Appendix C provides a list of national satellites for the ASEAN countries.

2.3.2 Fixed Service

Fixed services will both transmit and receive within the 3.4 – 4.2 GHz band. Point to point links are normally licensed on an individual link basis and will be coordinated with other users in the band. Point to multipoint and multipoint to multipoint (wireless access) do not tend to be licensed individually but spectrum blocks are awarded for the provider to self-manage and coordinate.

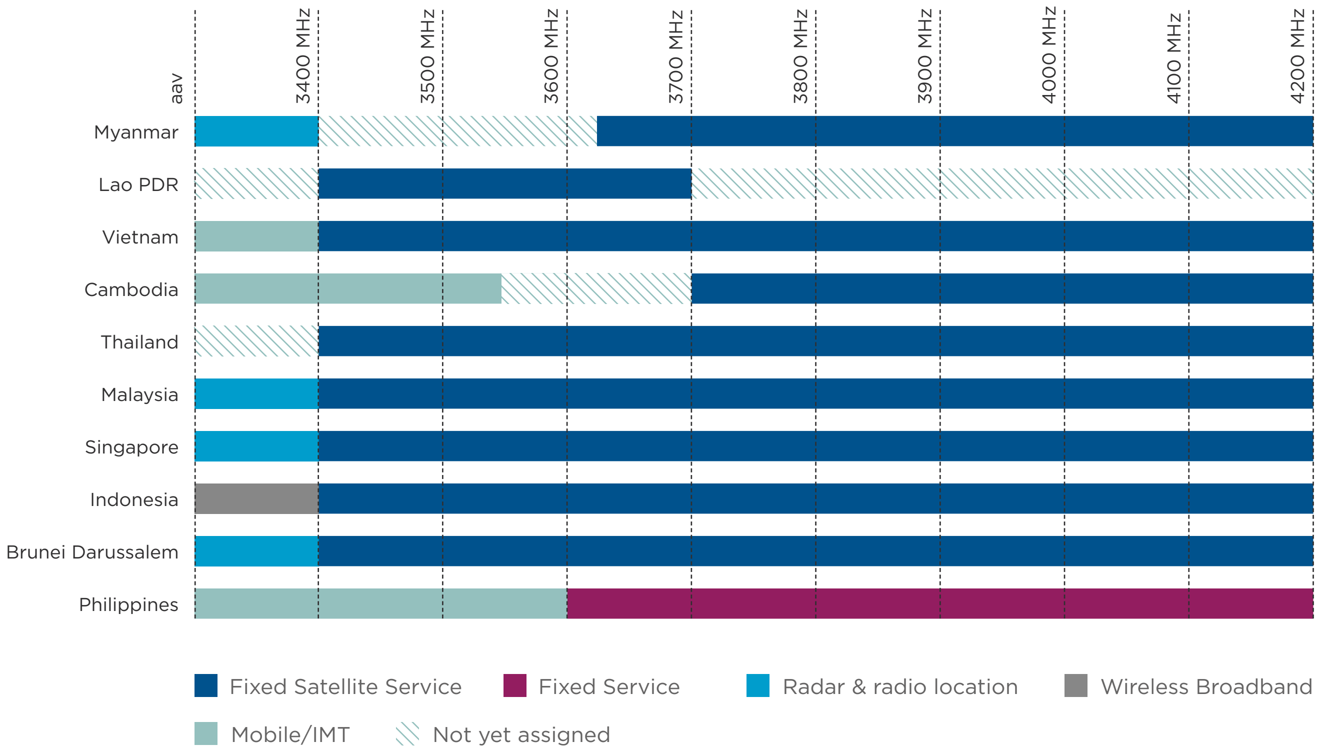
Point to point links are directional and if there are a limited number it may be possible to coexist on a co-channel basis with IMT service. However, this is not likely to be feasible for multipoint systems, typically used for broadband wireless access, with more extensive coverage but there is the potential for broadband wireless access to be deployed in adjacent geographic areas depending on the technology deployed.

2.4 Current status in ASEAN

Figure 2.2 provides an overview of the current status of allocation of the 3.3 – 4.2 GHz frequencies across the ASEAN countries. This comprises the current allocations and also takes account of the planned allocations for 5G as described in Section 1.1.

Figure 2.2

Current status of 3.3 – 4.2 GHz in ASEAN countries (as of July 2019)



Source: Plum-WPC analysis based on information from national regulators.

There are significant differences across the ASEAN countries in terms of current uses and the potential frequencies that could be released for 5G. While it looks likely that the majority of countries may be able to release at least some parts of the 3.3-3.8 GHz band, the amount of bandwidth available will vary considerably. In some countries such as Lao PDR and Vietnam, there is substantial FSS use in 3.4-3.7 GHz which restricts the amount of spectrum that can be released for 5G in that band in the short to medium term (at least until mid-2020s if not later). Indonesia's heavy use of the C-band satellite services across the archipelago means that there are particular challenges in releasing spectrum in the 3.5 GHz band (except 3.3-3.4 GHz) for 5G services.

For 3.8-4.2 GHz, these frequencies are unlikely to be made available for 5G use in most ASEAN countries, perhaps with the exception of the Philippines where they are currently used for wireless backhaul by mobile operators although any refarming for mobile use is unlikely to be feasible in the near term. Thus, the potential for 5G use in 3.8-4.2 GHz is low although there may be opportunities in the longer term for sharing on a limited area basis.

3. Options to release spectrum

The presence of existing uses and users in the C-band presents national regulators with a significant challenge in making spectrum available in this band for IMT use, specifically 5G. There are a number of considerations that need to be taken into account when determining what spectrum can be identified:

- How will spectrum in the 3.5 GHz band be used for 5G?
- Is incumbent use such that it is feasible to consider sharing (co-channel and adjacent channel) through coexistence/coordination measures? This might be on a short term or long-term basis.
- What coexistence/coordination measures should be specified and implemented?
- How to migrate incumbents from the identified spectrum? For example, refarming on the basis of licence expiry or removal of protection of incumbents.
- What is the impact of cross border spectrum use? How will this impact on spectrum availability near the borders and what mitigation measures can be implemented to maximise spectrum use?

Some of these considerations are addressed in the following sections based on the case studies in Appendix B and sharing studies undertaken to assess the potential for coexistence between the different incumbent services in the C-band and IMT in Appendix C.

3.1 How will 3.5 GHz spectrum be used for 5G?

As discussed in Section 1, the 3.5 GHz band is a prime band for the initial phase of 5G deployment globally. Mobile operators see it as an ideal band for the provision of enhanced mobile broadband services given its propagation characteristics and the potential availability of large, contiguous bandwidths. The current deployments of 5G around the world are predominantly based on eMBB.

The 5G eMBB use case means that deployments will likely have to be on a wide geographic area, possibly nationwide or close to that. Besides eMBB, the C-band (3.3 – 4.2 GHz) could also be used to support local networks in sectors including industrial Internet of Things (IoT), enterprise, logistics, mining and agriculture. Such deployments are expected to be on a smaller scale, and possibly indoors, which may be easier to accommodate with incumbent users already in the band.

In the ideal situation, each mobile network operator should have 80 – 100 MHz of contiguous bandwidth as this provides a number of advantages:

- Increased data rates to support eMBB usage with typical user experience of 100 Mbps,
- Reduced terminal front-end complexity and power consumption (compared with carrier aggregation using non-contiguous channels); and
- Cost effective rollout with the ability to support new services such as URLLC, and capabilities such as simultaneous wireless backhauling and front-hauling to 5G New Radio (NR) base stations.[9]

The need for contiguous spectrum on a nationwide basis to accommodate eMBB use is an important consideration. Based on the current situation among most ASEAN countries as described in Section 2.4, there is limited unused spectrum in the C-band which can be readily released to support 5G. This suggests that some form of sharing with incumbent users may be needed.

9. ECC Report 287. Guidance on defragmentation of the frequency band 3400-3800 MHz. 26 October 2018. https://www.ecodocdb.dk/download/3a143dbe-7cbc/ECCRep287.pdf

3.2 Is sharing feasible with incumbent services using mitigation?

The potential to share between IMT and incumbent users depends on the services themselves, the extent of their deployment and the type of sharing envisioned (co- or adjacent-channel). The ITU has conducted several studies on the feasibility of sharing between IMT and various incumbent users during the run-up to WRC-15. These are summarised in Appendix C. There has been considerable debate since about the FSS protection criteria that have been used and the applicability of both long term and short term criterion. In practice it is expected that the separation distances between IMT and FSS will be considerably shorter.

The approach adopted by individual countries may vary from the ITU criteria as evidenced in recent examples on the introduction of IMT in the 3.5 GHz band. For example, in the UK, in the 3600 – 3800 MHz band it was decided that mobile deployment would be significantly constrained by satellite earth stations in some densely populated areas including greater London where mobile services would be deployed. Also, coordination procedures are burdensome and could slow mobile roll out. Therefore, both satellite and fixed links were migrated from the band. In Singapore it has been decided to define restriction zones around TT&C earth stations. In Australia in the 3575 – 3700 MHz band there has been a transition period of seven years for earth stations and satellite operators being encouraged to move their earth stations to remote geographic areas where there will be less or little demand for C-band IMT spectrum.

In the case of VSAT and particularly TVRO services countries such as Australia and Hong Kong have adopted the approach that as they are licence exempt, no protection will be provided from interference.

Potential adjacent channel interference from IMT into satellite receivers, such as TVROs and VSATs, is an important consideration. There have been a number of studies undertaken with a range of different conclusions on the necessary guard band and these are shown in Figure 3.2.

Figure 3.2

Proposed guard bands between IMT and FSS receivers (e.g. TVRO, VSAT)

Country	Guard band	Comment
Brazil	25 MHz	Filter needed for low quality TVRO receivers
Hong Kong	100 MHz	Worst case assumptions used in analysis
Singapore	100 MHz	Ongoing studies to identify final value for guard band
Taiwan	44 MHz	Filter needed for FSS receivers in adjacent band; exclusion zone of 150 m to protect receivers
US	20 MHz	Determined by satellite operators in proposed approach to undertake private auction

Source: national regulators, industry submissions

In addition, Qualcomm has undertaken studies that have been submitted as input into the APT Wireless Group meeting in July 2019. The studies consider a number of different scenarios and the likely separation distances or separation distances and filtering requirements for a range of different guard bands. The findings are summarised in Appendix C and guard bands of 20 MHz and 41 MHz, based on the assumptions made in the studies, are feasible with minimal separation distances. Finally, a Transfinite study[10] concludes that an 18 MHz guard band is sufficient to mitigate co-frequency interference.

What is clear is that there is no one 'correct' answer to this issue and the solution is likely to be dependent on local conditions around the extent and nature of FSS usage in each country.

10. https://www.transfinite.com/papers/Report_for_GSMA_on_3.4-3.8_GHz_Compatibility.pdf

3.3 What measures are feasible?

In addition to the mitigation measures mentioned above to facilitate coexistence there are a number of other options that can be considered on a case by case basis.

Figure 3.3 provides a range of different options and how attractive they may be in terms of providing a viable solution for coexistence between 5G and fixed satellite services. The considerations of efficiency, time to implement and cost for the different options are assessed at a high level and expressed in relative terms for comparison purposes only.

Figure 3.3

Interference mitigation measures for fixed satellite service

Interference mitigation measures	Incumbent service					
	FSS (limited deployment)			FFS (ubiquitous deployment)		
	Efficiency	Time to implememt	Cost	Efficiency	Time to implememt	Cost
FFS earth station site shielding	✓✓✓	⌛⌛	$$	N.A.	N.A.	N.A.
Restriction zones to protect FSS	✓✓✓	⌛	$	N.A.	N.A.	N.A.
Improved FSS receivers	✓✓	⌛	$$	✓✓	⌛⌛	$$$
Additional of filters to FSS receivers	✓✓	⌛⌛	$$	✓✓	⌛⌛⌛	$$$
IMT base station location limitations	✓✓	⌛	$	✓✓	⌛⌛	$$
IMT base station antenna pointing/ down-tilt*	✓✓	⌛	$	✓✓	⌛⌛	$$
Reduce base station transmitter power	✓✓	⌛	$	✓✓	⌛⌛	$$
Detailed coordination	✓✓✓	⌛⌛⌛	$$	N.A.	N.A.	N.A.
Guard band 100 MHz	N.A.	N.A.	N.A.	✓	⌛	$$$**
Guard band < 50 MHz	N.A.	N.A.	N.A.	✓✓	⌛	$$**

Notes:
✓ to ✓✓✓ in terms of increasing efficiency and desirability.
⌛ to ⌛⌛⌛ in terms of increasing time to implement.
$ to $$$ in terms of increasing cost of implementation (** based on opportunity cost)
* As part of the IMT network planned deployment, the siting of IMT base stations and pointing of sectors are determined based on the location of existing FSS receivers.

For fixed links the coexistence measures are shown in Figure 3.4.

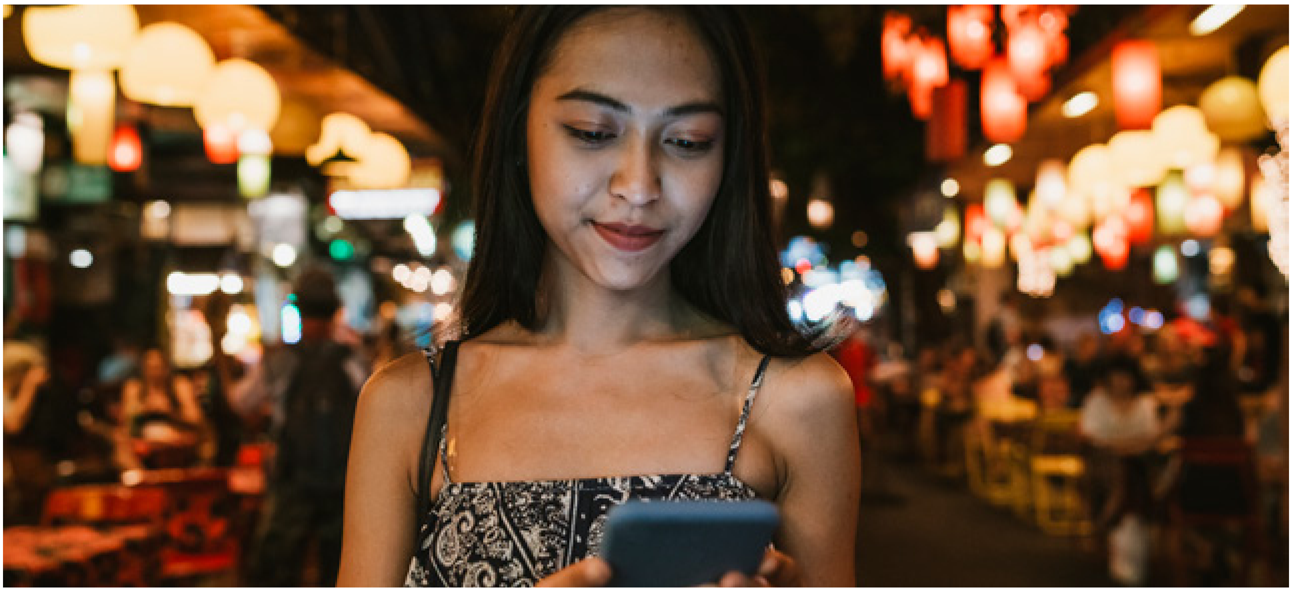
Figure 3.4

Interference mitigation measures for fixed service

Interference mitigation measures	Incumbent service					
	FSS (limited deployment)			FFS (ubiquitous deployment)		
	Efficiency	Time to implememt	Cost	Efficiency	Time to implememt	Cost
IMT base station location limitations	✓✓	⌛	$	✓✓	⌛⌛	$$
IMT base station antenna pointing/ down-tilt*	✓✓	⌛	$	✓✓	⌛⌛	$$
Reduce base station transmitter power	✓✓	⌛	$	✓✓	⌛⌛	$$
Detailed coordination	✓✓✓	⌛⌛⌛	$$	N.A.	N.A.	N.A.

Notes:
✓ to ✓✓✓ in terms of increasing efficiency and desirability.
⌛ to ⌛⌛⌛ in terms of increasing time to implement.
* As part of the IMT network planned deployment, the siting of IMT base stations and pointing of sectors are determined based on the location of existing FSS receivers.
$ to $$$ in terms of increasing cost of implementation (** based on opportunity cost)

More novel techniques for sharing spectrum such as licensed shared access (LSA) and dynamic spectrum access (DSA) could also be potential solutions. These involve active control of interference through the use of geolocation databases and sensing technologies. Examples of initiatives involving such techniques include the use of the Citizen Band Radio Service (CBRS) in the 3.5 GHz band in the US and the LSA framework in the EU. There is still a degree of scepticism over these sharing models at present and more confidence and trust will be required for these to become mainstream in future. With 5G, use cases will be more varied along with their spectrum requirements and deployments are expected to be more localised. As 5G evolves, there may be a bigger role for more flexible sharing frameworks.



3.4 Clearance of incumbents

Another possible option to release 3.5 GHz is to migrate existing users to clear parts of the band for 5G. However, the feasibility of band clearance and timescales involved are dependent on a number of factors, including;

- The type of service and number of users – for example, the number of consumers using DTH satellite TV is likely to be many times that of enterprise users of VSAT data communications.
- The possible impact on consumers and how this can be managed if there is a need to replace or upgrade equipment to maintain services (e.g. for DTH users etc.).
- The availability of alternatives for users to maintain their current service output, e.g. through alternative frequencies or wired technologies.
- The cost of migration to alternatives identified above and measures which need to be put in place to address potential disruption to services.

Typically, a cost benefit analysis will be undertaken to assess if clearance of the band is the optimum approach or if other options such as coordination measures discussed in the previous section are more appropriate. Note that a combination of coexistence and clearance could be another a possible option.

As noted earlier in the case of licence exempt use of the spectrum, where no interference protection is provided for existing users, it can be sufficient to provide notice that the risk of interference will increase on deployment of mobile networks. This approach has been adopted in a number of countries including Australia and Hong Kong. See Appendix B.

Satellite earth stations can potentially be restricted to operate only in the spectrum identified for fixed satellite service going forward. Also, as satellites reach the end of their lifetime,[11] there may be the potential to replace with satellites operating in parts of the standard C-band spectrum or higher frequency bands (for example Ku band).

Fixed point to point links can be migrated to higher frequency bands and alternative bands identified for point to multipoint or broadband wireless access (BWA) use.

It will be important to consider the appropriate timescales for clearance. In Australia a seven-year transition period was provided for existing licensees (fixed satellite service and fixed links). Other considerations may include when a licence was awarded and whether there has been the potential for a licensee to recoup the cost of their investment – this is particularly relevant for point to multipoint (BWA) networks.

Figure 3.5

Ease of clearing incumbents

Incumbent service	Comparative difficulty of clearance	Comments
Satellite receivers – licence exempt (e.g. VSATs, TVRO)	+	Need to consider implications to users of interference on services
Satellite earth stations – licensed	+++	Will depend on lifetime of associated satellites
VSATs – licensed	+++	Will depend on number of receivers – can be large
Fixed point to point links	++	Alternative frequency bands available that should be able to support high capacity links
Point to multipoint / BWA	++	Potential to identify alternative frequency bands or deliver services using 5G if awarded frequencies
Radiolocation	+++	Costs prohibitive. Difficult if maritime radars.

Note: + to +++ in terms of increasing difficulty for band clearance.

11. See Appendix E which provides information on satellites providing services in ASEAN.

3.5 Cross border considerations

While the ideal situation is to adopt harmonised arrangements across the whole ASEAN region, it is not likely to be feasible given the differences in terms of the availability of the 3.5 GHz band and the timing of this. Where harmonised arrangements are not feasible it will be necessary to define suitable cross border agreements to ensure that the deployment of IMT in one country does not cause interference to existing use in neighbouring countries. This is likely to require the definition of restriction zones or coordination zones where a specified power flux density cannot be exceeded over a given frequency range.

In the case that the same frequencies can be deployed for IMT either side of a national border, then synchronising the networks can facilitate coexistence. This approach has been adopted for the 2.3 GHz band between Myanmar and Thailand where the operators on both side of the border adopt the same up link to down link ratio. A tripartite agreement also exists between Indonesia, Malaysia and Singapore covering such synchronisation issues. This is a similar approach to that adopted between networks deployed on a regional basis nationally where it is necessary for the mobile operators to agree the uplink to downlink ratio between themselves, perhaps with regulator guidance or a determination when no consensus can be reached.

Further information on synchronisation is provided in Appendix D.

4. The ASEAN roadmap for 3.5 GHz

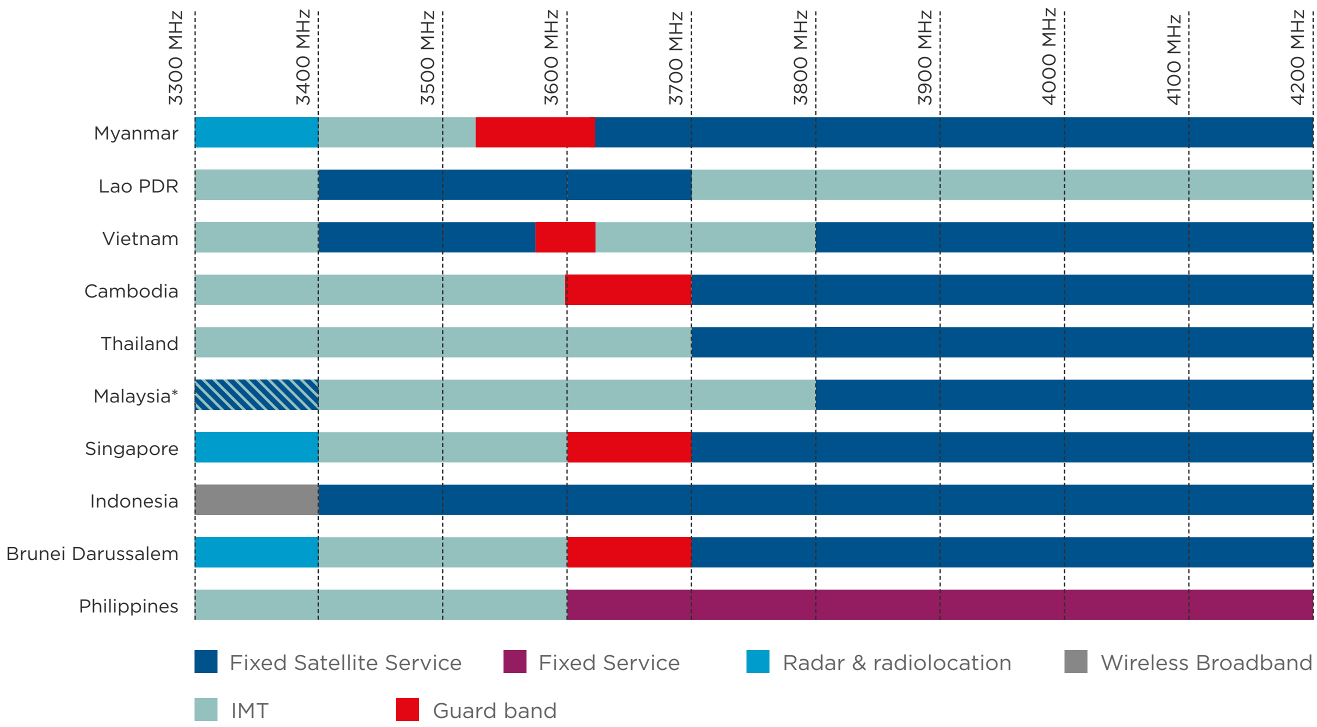
This section provides a summary of current plans for 3.5 GHz in the ASEAN region, the recommendations on the key steps towards release of the 3.5 GHz band for 5G use and the issues to consider for the spectrum award.

4.1 Current plans for 3.5 GHz band

The current plans for IMT spectrum allocation in the C-band (3.3 – 4.2 GHz) in ASEAN countries are focused mainly on the 3.3 – 3.8 GHz range and are as shown in Figure 4.1. These are based on recent and ongoing consultations and may be subject to change.[12]

Figure 4.1

Current or planned spectrum allocations for 5G (as of July 2019)



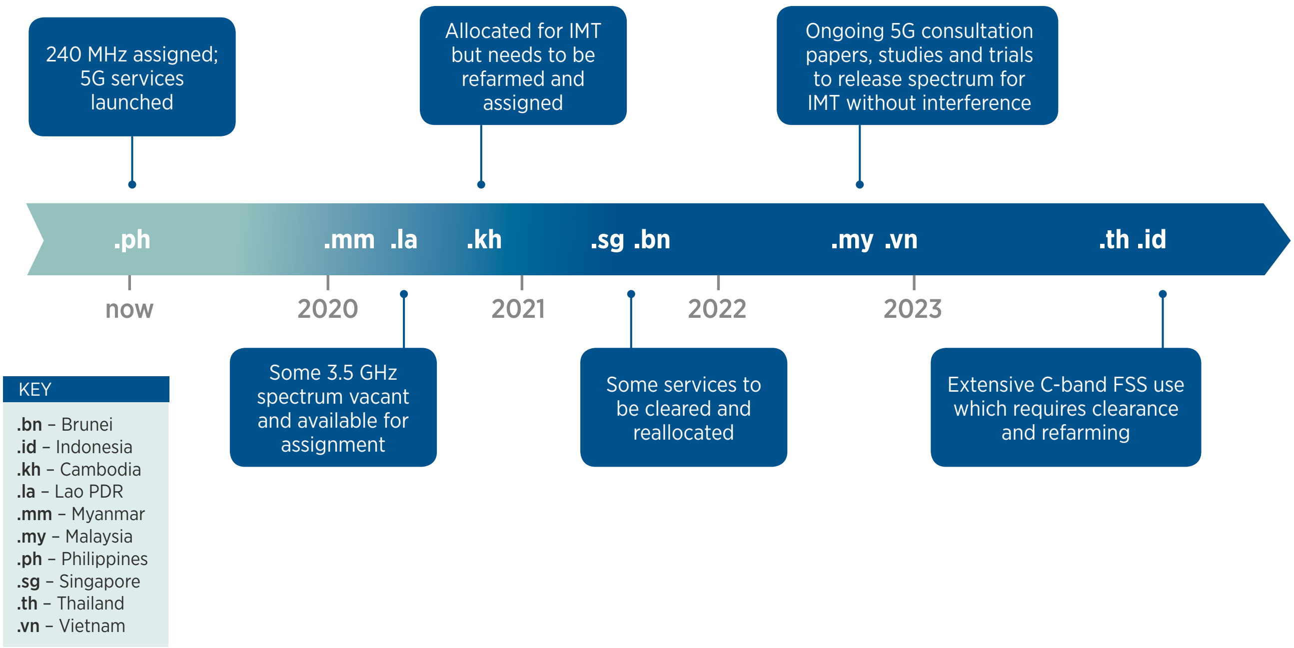
Note: * Malaysia – 3.3 – 3.4 GHz allocated to radar use and IMT indoor-only use. Singapore – 3.4 – 3.5 GHz to be allocated "restricted" use basis, where deployments may have to be limited to indoors and underground.

It can be seen that there is limited harmonisation of spectrum between the countries. The implications are discussed below. The timescales for availability of these frequencies will also vary as illustrated in Figure 4.2.

12. For countries where there are ongoing consultations, the guard bands proposed by the regulator are indicated in Figure 4.1. For countries where there are no proposals yet (e.g. Lao PDR, Malaysia, Thailand), these are not shown but note that guard bands are likely to be required.

Figure 4.2

Potential timescales for availability of 3.5 GHz band for 5G



4.1.1 Implications of plans

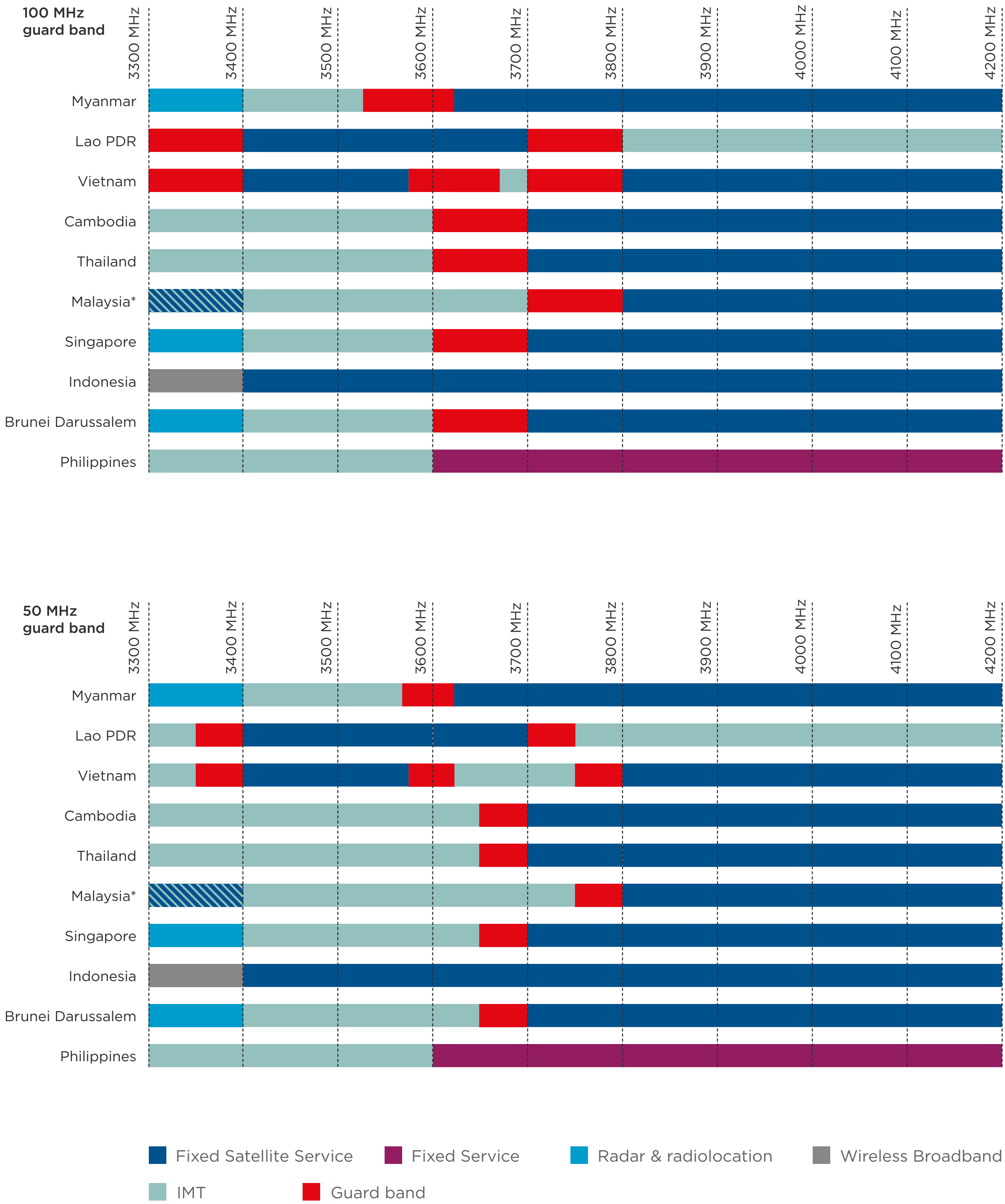
The amount of available spectrum in the 3300 – 4200 MHz band for IMT varies. In a number of countries, it is necessary to implement a guard band between IMT and fixed satellite service spectrum to minimise the risk of adjacent channel interference. As noted in Section 3.2, there are a number of different guard band options proposed ranging from 20 MHz to 100 MHz. Figure 4.3 summarises the implications of three different scenarios for different guard bands different guard bands (i.e. 20 MHz, 50 MHz and 100 MHz).[13]

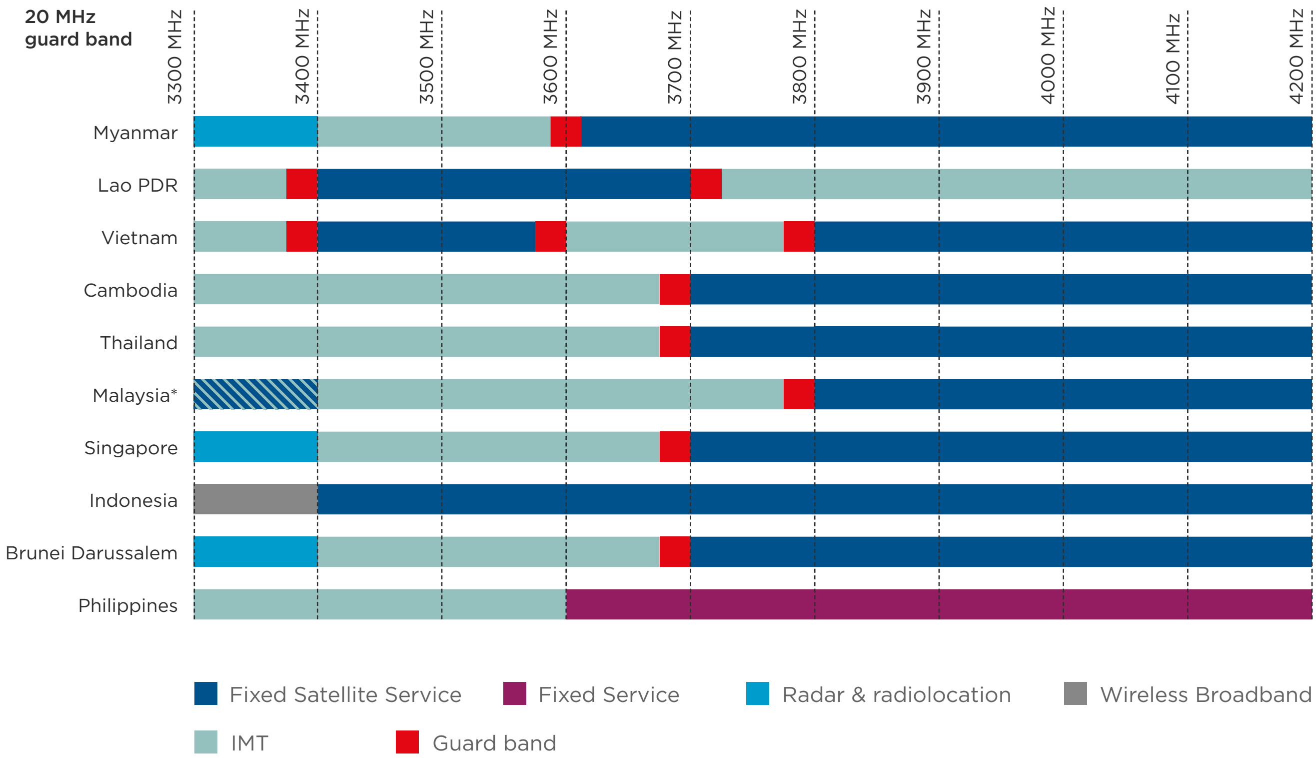
Ideally between 80 and 100 MHz per mobile network operator should be awarded to support the services that can be provided over 5G networks such as eMBB. The size of the guard band is the key factor which determines the amount of 3.5 GHz spectrum available for 5G, and therefore how many operators can be accommodated. For most ASEAN markets, due to the incumbent FSS use, a 100 MHz guard band scenario would severely restrict the amount of 3.5 GHz spectrum available; only the scenarios of 20 MHz or 50 MHz guard bands would allow more than two operators in the C-band. It is important to recognise that if only a limited amount of spectrum can be released, there are other frequency bands such as 2.3 GHz (n40), 2.6 GHz TDD (n41) and 4.4-5 GHz (n79) which are potential substitutes in the mid-band range in the future. It is therefore not necessary to accommodate all mobile operators in the same band by reducing the spectrum per operator, although the ecosystem readiness may be different in the short term as 3.5 GHz is more advanced than other bands at present.

13. These are based on current understanding of the situation and the exact frequencies available for IMT and the guard bands adopted may be subject to change depending on the outcomes of ongoing technical work and regulatory decisions.

Figure 4.3

Comparison of impact of different guard bands (100, 50, 20 MHz)





Notes: * Malaysia 3.3 – 3.4 GHz allocated to radar use and IMT indoor-only use.
IMT assumptions are for the short/medium term and involves implementation of appropriate mitigation measures; analysis based on current understanding of situation and may be subject to revision.
For Indonesia it is not possible to identify specific frequencies for IMT in C-band at present.
Source: Plum-WPC analysis.

The different timings anticipated for use of available spectrum per country and the different spectrum that will be allocated has implications for cross border agreements. Whilst cross border agreements between mobile networks can be relatively easy by establishing synchronisation between networks, similar to regional sharing, different agreements will be necessary where IMT is deployed on one side of the border and fixed satellite services, fixed services or radars on the other.

In the case of the latter it will be necessary to consider whether there will be ubiquitous or limited deployment of 5G and define restriction or coordination zones as best fits the specific circumstances. The risk of such requirements is that deployment of IMT networks may be substantially limited close to borders and for those countries, such as Singapore, that are of limited geographic area, this could impact considerably on the rollout of 5G.

4.2 Recommendations for release of 3.5 GHz

Whilst there is work ongoing in many countries in the ASEAN region to identify suitable spectrum in the C-band for 5G, it is recommended that administrations adopt the roadmap shown in Figure 4.4.

Figure 4.4

Roadmap for releasing 3.5 GHz spectrum for 5G

STAGE 1: PLANNING AND DECISION (ESTIMATED 12 MONTHS)

- Review current use in 3.3 – 4.2 GHz
- Assess potential for coexistence (co- and adjacent-channel)
- Assess options available and conduct cost benefit analysis

STAGE 2: IMPLEMENTATION (RANGE FROM SEVERAL MONTHS TO YEARS)

- Co-channel – notify incumbents on measures and implementation timescale
- Adjacent channel – notify incumbents of measures to minimise interference
- Cross-border coordination and arrangements

STAGE 3: AWARD SPECTRUM (6-12 MONTHS)

- Determine technical conditions for released spectrum
- Design appropriate award taking account of national objectives
- Implementation of award

Figure 4.5 shows the indicative timeline for the availability of the 3.5 GHz band for 5G services in each country based on the current status of incumbent use and the estimated timescales for the implementation of various mitigation measures discussed in Section 3. Note that these may be subject to change as consultations and technical studies are currently ongoing.

Figure 4.5

Indicative timeline for availability of 3.5 GHz band in ASEAN (as of July 2019)

Country	C-band incumbent service	Estimated availability of 3.5 GHz for IMT/5G
Myanmar	Vacant and FSS	Now – 3.4 – 3.52 GHz
Lao PDR	Vacant and FSS	Now – above 3.7 GHz depending on IMT demand
Philippines	IMT and FS	Now – 3.3 – 3.6 GHz. 240 MHz assigned and 5G services launched.
Brunei Darussalam	IMT and FSS (VSATs)	2020/21 – 3.4 – 3.6 GHz depending on IMT demand
Cambodia	IMT and FSS	2020/21 – 3.3 – 3.7 GHz following refarming of BWA licences
Singapore	FSS	2021/22 – 3.4 – 3.6 GHz following migration of TVROs
Vietnam	FSS (ubiquitous – VSATs)	2022/23 – 3.3 – 3.4 GHz and 3.62 – 3.8 GHz
Malaysia	FSS (ubiquitous – VSATs)	2022/23 – 3.4 – 3.8 GHz
Thailand	FSS (ubiquitous – TVROs)	Post-2023 – 3.4 – 3.7 GHz, depending on expiry of satellite licences
Indonesia	FSS (ubiquitous – VSATs)	Post-2023 – Specific frequencies unclear at present.

Stage 1: planning and decision

Key steps:

- **Obtain a clear understanding of the current use of the 3300 – 4200 MHz frequencies.** While it should be relatively easy to identify licensed users (fixed links, land based radars, satellite earth stations, including TT&C) and the geographic location of deployments, it will be considerably more challenging to obtain information on those uses that are licence exempt such as VSATs and TVROs.

- **Address the potential for IMT coexistence with the incumbent usage.**

  – Co-channel: this might be on a short- or long-term basis where the incumbent use may impose limited restrictions, for example satellite earth stations may be able to remain based on suitable restriction or coordination zones. The appropriate mitigation measures such as proposed in Figure 3.3 should be considered as well as options for migration of incumbent users.

  – Adjacent channel: it is important to consider what mitigation measures are necessary. Where feasible, the use of guard bands between IMT and fixed satellite services should be minimised to maximise spectrum available for IMT.[14] Other measures such as upgrading satellite receivers should also be considered.

- **Undertake cost benefit analysis of options for both co- and adjacent channel coexistence**, taking into account their impacts on all affected parties (incumbent and new users) and future needs. The analysis will then feed into the decision on the optimum approach for releasing the band.

As part of the planning process, ASEAN regulators should consider a moratorium on new C-band FSS and FS licences until a decision has been taken on the long-term future of the band.[15]

It is understood that there are already ongoing technical studies in several ASEAN countries including Malaysia, Singapore, Thailand and Vietnam, to assess the possible options for releasing spectrum for 5G in the 3.5 GHz band. In determining the appropriate way forward, regulators will need to take account of the feasibility of the possible options in terms of their effectiveness, implementation timescales and associated cost. This is not straightforward as there will be trade-offs amongst these aspects and implications on the amount and timing of availability of spectrum for 5G.

Stage 2: implementation

This will be based on the outcome of Stage 1 and the key steps involve:

- Discuss with and notify co-channel incumbents of measures to be implemented – these may include mitigation measures to remain in the band or a migration plan from the 3.5 GHz spectrum. Appropriate timescales and approaches for the implementation need to be established. For example, this may require alternative spectrum to be identified by the administration for incumbents. It is also important to consider impact on users as well as technical and licensing issues.

- Notify adjacent channel incumbents of measures that will need to be implemented to minimise potential for interference when IMT networks are deployed.

- Discuss and agree with neighbouring administrations appropriate cross border agreements. These might be short term and long term to take account of planned release of IMT spectrum on a per country basis. By default, there may be a need to define restriction or coordination zones within the neighbouring country where the use differs from that over the border. See Figure 4.2 on potential timescales for making spectrum available in ASEAN region.

Depending on the option adopted, the implementation stage can range from a matter of months to several years, particularly if there are many existing users which need to be migrated. Where a long-term migration plan is required, clear targets and milestones should be set and monitoring procedures put in place to ensure that the progress is being made towards the targets.

14. With this aim in mind consideration should be given to accepting the potential for interference to a percentage of existing users
15. Where there are expiring FSS and FS licences, decisions on renewals should be considered on a case-by-case basis taking into account the potential reallocation of the band.

Stage 3: spectrum award

Having implemented the necessary measures, the final stage involves the award of spectrum which will involve:

- Determine necessary technical conditions for award of released spectrum based on above considerations.
- Ongoing informal and formal consultations with stakeholders leading to the award of the identified available spectrum.
- Development of Information Memorandum and carrying out the award process.

Given the likely disparity in the amount of spectrum available and the timing for its release, there are a number of implications which need to be taken into account in the award of the 3.5 GHz band for 5G. These are discussed below in Section 4.3.

4.3 Implications on spectrum award

Providing clarity on supply and timing

The first issue is that there may be insufficient spectrum in the 3.5 GHz band to accommodate all mobile network operators in a market, particularly in the near term, if limited amount of spectrum (e.g. less than 200 MHz) can be readily released. Aside from Brunei, the rest of the ASEAN markets consist of three or more mobile network operators. As large, contiguous bandwidths of 80 – 100 MHz per operator is preferred for 5G, it may not be possible to support all network operators in the market during the initial phase of 5G rollout.

In designing the award of the 3.5 GHz spectrum, it will be important for national regulators to take account of this requirement and avoid undesirable outcomes where limited 3.5 GHz spectrum is split across multiple operators with sub-optimal bandwidths which do not enable the delivery of 5G performance. At the same time, national competition in the supply of 5G services should be ensured. It may be the case that not every network operator in the market will be able to have access to the 3.5 GHz band, particularly in the near-term. Based on such considerations there should be a minimum bandwidth of 50 – 60 MHz per network operator.[16, 17] This should help ensure good quality and competitive provision of 5G services in the near term while further work to release more mid-band spectrum continues. Due to the potential limitation in the amount of 3.5 GHz spectrum available in some ASEAN countries, setting aside spectrum in this band specifically for industrial uses[18] may not be appropriate, especially if demand for such uses is uncertain.[19] For the 3.5 GHz band national licences would be more suitable from an efficiency perspective.

Governments and regulators should provide a clear roadmap on the availability of 5G spectrum across the different frequency ranges – low, mid and high. While there is clear and growing momentum behind the 3.5 GHz band (n78), the 2.3 GHz (n40), 2.6 GHz TDD (n41) and 4.4 – 5 GHz (n79) bands are potential alternatives in the mid-band range which can also support 5G deployment, particularly in countries where these bands are not currently licensed.[20] Where there may be a necessity to release the 3.5 GHz band in stages to enable the implementation of coexistence measures, there should be clarity on timescales and amount of spectrum that can be released. This will help provide more certainty for network operators and other potential 5G users.

Facilitating contiguous assignments

In countries where there is extensive incumbent use (e.g. ubiquitous FSS deployment), the potential frequencies available for 5G could be in non-

16. This in line with the outcomes of recent 3.5 GHz awards in Australia, Germany and the UK.
17. See ECC Report 287 for more information on the benefits of large contiguous blocks in 3400-3800 MHz for 5G and the implications of different bandwidths on network performance. https://www.erodocdb.dk/download/3a143dbe-7cbc/ECCRep287.pdf
18. This approach has been taken in some European countries. For example, the German regulator Bundesnetzagentur has set aside 100 MHz (3700-3800 MHz) to be assigned on a local area basis for industrial applications while the Swedish Post and Telecom Authority is adopting a similar approach with 80 MHz (3720-3800 MHz).
19. An alternative option for promoting industrial applications and innovative use is to facilitate shared access for these uses to other IMT bands through local licensing on a low or medium power basis. Ofcom's approach to local licensing is one example. Source: Ofcom. Enabling wireless innovation through local licensing. Statement, 25 July 2019. https://www.ofcom.org.uk/consultations-and-statements/category-1/enabling-opportunities-for-innovation
20. With 5G NR it is possible to use alternative frequency bands (e.g. those currently used for 4G) for supplemental uplink which can enable more efficient use of the 3.5 GHz spectrum and better coverage.

contiguous ranges within the 3.3 – 3.8 GHz band (e.g. Lao PDR and Vietnam). While 5G NR systems can be configured for any sub-band within a tuning range, e.g. 3.3 – 3.8 GHz (n78), it would be preferable to facilitate assignments in contiguous rather than non-contiguous blocks as the former avoids the need for intra-band carrier aggregation (CA) which reduces complexity and power consumption, and improves spectrum efficiency and network performance.

If a phased approach to 3.5 GHz spectrum release is taken, then there should be some flexibility in the licensing framework or measures for operators to aggregate their holdings within the 3.5 GHz band and avoid fragmentation where possible. It should also be noted that 3.5 GHz band assignments should be consistent with the supported channel bandwidths for 3.3 – 4.2 GHz (n77/n78).[21]

Using appropriate award mechanism to meet objectives

Auctions are widely considered to be the appropriate and most transparent approach to assign spectrum where demand exceeds supply. However, there are undesirable outcomes from poorly designed auctions which should be avoided.[22] There is growing recognition that high spectrum fees can discourage deployment, and this is a particular concern with 5G on the horizon. The capital expenditure on 5G will be significant and this will put more pressure on mobile operators whose revenue growth has been flat or declining in recent years due to intense competition. To encourage 5G rollout and facilitate industry growth, the 3.5 GHz spectrum needs to be priced at reasonable and sustainable levels.

While auctions have become the default award mechanism for mobile spectrum in the last 20 years, there have been signs of a move towards more "managed" award mechanisms such as comparative tenders which place more emphasis on non-economic objectives.[23] While there is no one correct award mechanism for spectrum, there are advantages associated with a comparative tender such as

- the ability to deliver contiguous spectrum of appropriate bandwidth,
- the speed of the process which facilitates rapid 5G deployment,
- it tends to make obligations more palatable, and
- reduced investment risks for MNOs.

With the 3.5 GHz being the key band for the first wave of 5G deployment, it is important to ensure that the award of this band is designed to meet objectives that support the development of 5G and maximise benefits to users.

21. The options for 5G NR channel bandwidth in the 3400 – 3800 MHz range are 10, 15, 20, 30, 40, 50, 60,70, 80, 90, 100 MHz. Source 3GPP.
22. Poorly designed auctions could be due to factors such as high reserve prices, artificial spectrum scarcity and auction rules which prevent price discovery or flexible bidding amongst others. See GSMA. Auction Best Practice. May 2019. https://www.gsma.com/spectrum/wp-content/uploads/2019/05/Auction-Best-Practice.pdf
23. For example, Japan recently awarded spectrum in several 5G bands (3.7, 4.5, 28 GHz) through a comparative tender. The IMDA is also proposing a similar approach.

4.4 Conclusion

The 3.5 GHz band has emerged as an early 5G band globally and is crucial for the delivery of enhanced mobile broadband services. Many countries around the world have assigned spectrum in this band for 5G or preparing to do so over the next 12 months. In the ASEAN region the availability of this band is complicated by heavy use by incumbent users, particularly FSS, in parts of the band.

To secure a timely release of 3.5 GHz spectrum for 5G rollout while also ensuring adequate protection for existing applications where required, national regulators should

1. Carry out a detailed review of the 3.3 – 4.2 GHz band and map out the current usage in terms of number of licensees and their characteristics.

2. Identify and assess the potential options and measures to facilitate 5G use in the band, taking account of their feasibility in terms of effectiveness, implementation timescales and associated costs. There should be a moratorium on new C-band FSS and FS licences until a decision has been made on the future of the band.

3. Develop a clear 5G spectrum roadmap for the band and with realistic timescales for the implementation of coexistence measures or migration plans as necessary.

4. Prepare for the 3.5 GHz award by consulting with all stakeholders and ensuring that adequate spectrum and conditions are in place to meet industry needs and national objectives.

To ensure better coordination on an ASEAN level, it is also recommended:

- The ASEAN region works together to determine appropriate cross border agreements. There are large borders in the region and decisions will impact on more than one country. This process can be achieved through regular forums to allow exchange of views and relevant information such as study findings and best practices.

- At WRC-19 further ASEAN countries are added to the relevant footnotes[24] to reflect future planned use of the 3300 – 3700 MHz for mobile and specifically IMT.

24. Such as 5.432A, 5.432B and 5.433A currently.

Appendix A: ASEAN Member States

A.1 Brunei Darussalam

While AITI initially planned to have field trials it engaged a local vendor to conduct desktop study/ simulations on the feasibility of coexistence of Fixed Satellite Service with IMT in the band 3.4 – 3.8 GHz. The study took into consideration:

- Adjacent Channel Interference between IMT and FSS; and
- Co channel interference between IMT and FSS.

The outcome of the studies showed that given Brunei Darussalam's geographical nature, it is not feasible to have co channel arrangement and a guard band of 100 MHz is required. In the efforts of making the band available for IMT by 2022 or earlier, the following actions needs to be taken by AITI:

- Brunei will cease assignment of VSAT services in the bands 3.4 – 3.7 GHz; and
- Migrate existing users out of 3.4 – 3.7 GHz or introduce mitigation techniques.

The challenges which AITI foresees include the migration of existing users and introduction of mitigation techniques in order to secure C-Band spectrum for IMT use. See Figure A.1.

Figure A.1

Proposed AITI future spectrum planning for the C-Band

Bands	Current	Planned for future use
3400 – 3500 MHz	–	IMT
3500 – 3700 MHz	VSAT (space-to-earth)	IMT (3600 – 3700: guard band)
3700 – 4200 MHz	VSAT (space-to-earth)	Fixed Satellite Service

AITI also advises that ideally it would like to make two lots of 100 MHz available for its two MNOs subject to protecting FSS services. Its current thinking is a guard band of 100 MHz will be required.

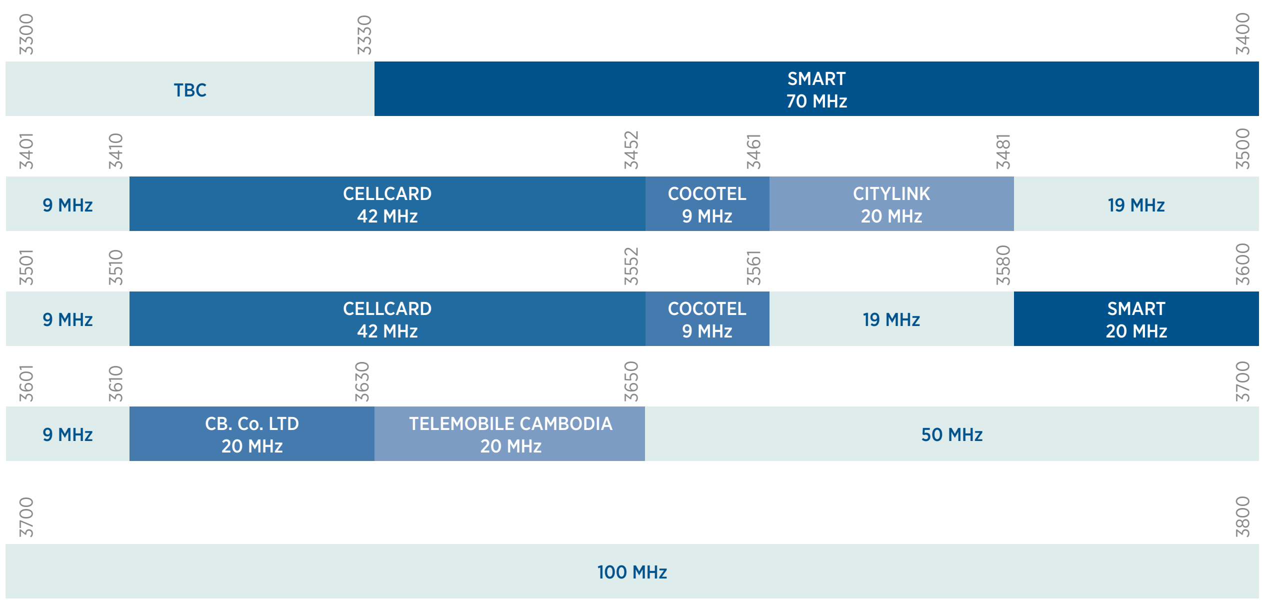
A.2 Kingdom of Cambodia

Cambodia's Frequency Band Plan for 2020 for the medium band (which includes the C-band), includes granting 100 MHz to each MNO and enhancing nationwide broadband speeds to achieve target speeds of more than 100 Mbps. In July 2019, 5G trials have taken place in the country including with Smart Axiata and Viettel Cambodia while Cellcard has announced plans to deploy 5G technology.[25]

Although many licenses in the 3.3 – 3.7 GHz band are designated for wireless broadband (refer to Figure A.2) during the World Radiocommunication Conference in 2015, Cambodia together with Vietnam, Thailand and Lao PDR proposed a plan to revoke wireless broadband licenses to allow for 5G use within the band. However, there is uncertainty regarding the progress of this plan to date.

Figure A.2

Current allocation in 3.3 – 3.8 GHz in Cambodia



Source: Industry sources, 2019

There is some satellite usage in Cambodia within the 3.7 – 4.2 GHz band, though there have not been recent studies to gather updated data on this band. It is currently looking to develop a 5G White Paper.

Overall, the MPTC is committed to freezing the C-band for 5G use, but in order to carry out its plans and ensure harmonization across the region, cross-border coordination with Vietnam, Thailand and Lao PDR will be crucial.

25. Nikkei Asian Review. Cambodia joins the 5G race despite concerns over cost and viability, 20 May 2019. https://asia.nikkei.com/Spotlight/5G-networks/Cambodia-joins-the-5G-race-despite-concerns-over-cost-and-viability

A.3 Republic of Indonesia

The extended C-band (3400 – 3700 MHz) and standard C-band (3700 – 4200 MHz) are heavily used by satellite services in Indonesia given the geography of the archipelago.

National satellites operating on the C-band include:

1. The PALAPA D, which was launched on 31 August 2009, and will be in operation for 10 years;
2. The TELKOM 3S, which was launched on 14 February 2017, and will be in operation for 15 years;
3. The BRISAT, which was launched on 18 June 2016, and will be in operation for 15 years;
4. The TELKOM-4, which was launched on 7 August 2018, and will be in operation for 15 years; and
5. The NUSANTARA SATU, which was launched on 22 February 2019, and will be in operation for 15 years.

Given the heavy satellite usage, with an estimated total of more than 100,000 VSAT services in operation, a considerable amount of time and effort will be needed to optimize the use of the 3.5 GHz band for 5G, particularly in major cities and industrial complexes.

Indonesia is studying the possibility of adopting the policy of geographical separation for VSAT and cellular backhaul in the rural area while restricting the use of DTH and TVRO in the extended C-band.

On the other hand, the 3.3 – 3.4 GHz band is currently being used for broadband wireless access and could be available for 5G use subject to some technical and regulatory measures, including a guard band in order to protect the 3.4 – 3.7 GHz FSS earth stations.

5G trials have been ongoing since 2017 with XL Axiata, Telkomsel, and Indosat Ooredoo conducting indoor and outdoor trials. More trials are planned for 2019 and include end-to-end live-network trials.

In terms of the regulatory framework preparation for 5G, the four focus areas are agile spectrum policy, supporting infrastructure including the infrastructure sharing policy, the 5G business model and legal review of the existing regulations. Specific considerations being taken into account include balancing spectrum fees so as to not inhibit 5G roll outs; streamlining local government policies related to the access to street-side public infrastructure and building premises; evaluating the needs of specific allocation bands for 5G local/private networks deployment; and anticipating the new roles cellular operators may take on including as network developers and service creators.

In May 2019, a national 5G task force was initiated and is currently drafting terms of reference for all sub working groups within the task force. The drafting of the terms of reference is scheduled to be completed by July/August 2019.

A.4 Lao PDR

Lao PDR is preparing to move forward with 5G and is considering a timeline for the deployment of 5G networks and determining user demand.

Since November 2015, part of the C-band (3.4 – 3.7 GHz) has been used for FSS by the satellite LAOSAT-1. The main business services of LAOSAT-1 are DTH, Television Production Centre (TVPC), VSATs, and the National Emergency Communication Network (NECN).

However, 3.3 – 3.4 GHz and 3.7 – 4.2 GHz are vacant and can be used for 5G as long as 5G signals do not cause interference with the Lao Satellite network and no other solutions or any regulations for 5G use and MSS on the C-band are identified.

In preparation for 5G, operators, telecom vendors and departments of the Ministry of Posts and Telecommunications (MPT) held a workshop in 2019. A key takeaway from the discussions was that operators are interested in investing in 5G networks but are unsure about the actual demand for 5G services.

A.5 Malaysia

A national 5G task force group was formed in November 2018 and consisted of 110 members as of 30 May 2019. The taskforce must prepare a report to the Minister by Q4, 2019 covering (a) proposed solutions to resolve regulatory impediments, (b) proposed plan for timely availability of spectrum resources; (c) support for infrastructure, services and devices; and (d) measures for consumer protection.

Two current aims of the Spectrum Group of the 5G Task Force are to identify the spectrum band and bandwidth allocation required for services and use cases, and to propose a 5G roadmap based on 5G ecosystem readiness. In April 2019, the preliminary recommendation by the Spectrum Group of the 5G Task Force was to allocate the 3.3 – 3.4 GHz band for limited indoor use; the 3.4 – 3.8 GHz for 5G usage, and the 3.8 – 4.2 GHz for satellite usage. It was noted that a guard band would be needed between the 5G and satellite usage. It is expected that in August 2019 there will be a public consultation paper on the 5G Task Force recommendations. Recommendations should be finalised in October 2019 when the final report is delivered to the Malaysian Communications and Multimedia Commission.

Regarding satellite usage in the C-band, there are currently three existing satellites:

- The Africasat-1a, which was launched on 7 February 2013 and is using the 3.7 – 4.2 GHz band. Its end of life is expected in H2 of 2028;
- The MEASAT-3a, which was launched on 21 June 2009 and is also using the 3.7 – 4.2 GHz band. Its end of life is expected in H2 of 2027; and
- The MEASAT-3, which was launched on 11 December 2006 and is also using the 3.7 – 4.2 GHz band. Its end of life is expected in H1 of 2023.

The MEASAT-3d is another satellite that is expected to launch in H2 of 2021 and will be using the 3.4 – 4.2 GHz band. Its end of life is expected to be beyond 2036. Furthermore, there is currently some radar use in the 3.3 – 3.4 GHz band in Malaysia, but there are no fixed links in the 3.7 – 4.2 GHz band, but it is heavily used by VSATs.

In addressing interference issues, the national task force plans to conduct both indoor and outdoor field trials and will be able to assess coexistence interference issues and mitigation techniques between FSS and 5G (C-band and mmWave).

Malaysia's 2.3 GHz TDD synchronization agreement with neighbouring countries maybe used as a model for future 5G services in the 3.5 GHz band.

In July 2019 the MCMC released a public consultation on the allocation of the 700 MHz, 2300 MHz and 2600 MHz bands for mobile broadband.[26] It is anticipated that these bands would still be used for 4G (LTE) provision in the near term which means the 3.5 GHz band and its availability will be important for 5G rollout in Malaysia.

A.6 Republic of the Union of Myanmar

Myanmar has reserved the 3.4 – 3.6 GHz band for IMT/5G usage. Satellite use starts from 3625 MHz in Myanmar, with an allocation to Intelsat while other satellite companies only use bands above 3.7 GHz. It should be noted that, the 3.3 – 3.4 GHz band is currently being used for military radar, but this band could be considered for indoor usage in the future.

In an industry consultation on the future IMT Spectrum Roadmap[27] the use of the C-Band for IMT purposes issued by the Posts and Telecommunications Department (PTD) received a number of submissions from the satellite industry that were strongly critical of the release of spectrum in the C-band (3.5 GHz) for IMT services. They highlighted inter alia potential harmful interference, the need for 100 MHz guard bands, and exclusion zones. Other submissions from inter alia MNOs, vendors etc were highly supportive of the release of C-Band spectrum for IMT purposes.

It should be noted that while the satellite industry argues that to a large number of users in Myanmar including TVROs, the PTD has only issued nine spectrum licenses with the lowest frequency to Intelsat starting at 3625 MHz.

26. MCMC. Public Inquiry on Allocation of Spectrum Bands for Mobile Broadband Service. 1 July 2019.
27. PTD, Consultation Paper: Review of IMT Aspects of Myanmar's Spectrum Roadmap, 8 March 2019

The PTD's preliminary position which is to be confirmed by the Ministry after a second round of public consultation which started on 25 June 2019,[28] is for the release of 120 MHz of spectrum (in 2 lots of 60 MHz) commencing from 3.4 GHz as part of a major auction of IMT capacity spectrum in 2020. Initially, a conservative 105 MHz guard band will be imposed from IMT services to FSS which may be reduced to 45 to 55 MHz post 2023 if demand exists and once all of the regional interference testing etc is completed.

A.7 Republic of the Philippines

Unlike many of its ASEAN neighbours, the Philippines does not currently use the C-Band between 3.4 to 3.6 GHz band for satellites. As a result, the full 200 MHz of bandwidth has been able to be allocated to MNOs. For more information on the frequency assignments within the 3.3 – 3.6 GHz band, see Figure A.3.

Figure A.3

3.3 – 3.6 GHz frequency assignment in the Philippines

Company name	Frequency assignment	Bandwidth
Mislatel	3300 – 3400 MHz	100 MHz
Smart/Digitel	3400 – 3460 MHz	60 MHz
Globe/Innove/Bayantel/Altimax	3540 – 3600 MHz	60 MHz
Mislatel	3480 – 3520 MHz	40 MHz
Be	3460 – 3480 MHz	20 MHz
NOW	3520 – 3540 MHz	20 MHz
Total assigned bandwidth	3300 – 3600 MHz	240 MHz

Mislatel is the Philippines new market player which has recently been approved by the Philippines Congress[29] and has 140 MHz of spectrum allocated to it in the 3.3 – 3.4 GHz band.

By comparison the current major players Smart and Globe Telecom have 60 MHz of 3.5 GHz spectrum each. On 1 July 2019, Globe Telecom launched the first commercial fixed 5G services using the 3.5 GHz spectrum to be known as "Air Fibre 5G" with up to 100 Mbps services and up to 2 TB post-paid packages in select areas of Pasig, Cavite and Bulacan. Globe Telecom is aiming to connect 2 million homes to 5G by 2020. In addition, PLDT is aiming to launch 5G services for select home and corporate customers by Q4, 2019. Other players like NOW have also made public announcements on 5G services.

The 3.6 – 3.8 GHz and 3.8 – 4.2 GHz bands are being extensively used by Philippine MNOs for their microwave backbones nationwide with configuration as high as 7 + 1. The possibility of clearing these bands for 5G is very remote as of this time. This will depend on the MNOs' plan to fibre up their backhaul/backbone networks.

28. PTD, Consultation Paper. Myanmar's IMT and 5G Spectrum Roadmap preliminary positions, 25 June 2019. See www.ptd.gov.mm/Uploads/News/Attach/62019/89126152562019_Consultation%20paper%20for%20Myanmar%27s%20IMT%20
29. See https://www.telegeography.com/products/commsupdate/articles/2019/05/23/mislatel-takeover-by-china-telecom-dennis-uy-consortium-approved-by-congress/

A.8 Republic of Singapore

The 3.5 GHz band is currently used extensively for satellite communications in Singapore, as is the case for many countries in the Asia Pacific region. In Singapore, most of the key FSS operations today operate in the 3.7 – 4.2 GHz range of the C-band, while the extended C-band in the 3.4 – 3.6 GHz range is generally used for the purpose of receiving satellite signals for TVRO stations to individual sites (e.g., hotels, hospitals).

The Info-communications Media Development Authority of Singapore (IMDA) published its second 5G consultation.[30] After carefully considering the interests of all stakeholders, the ongoing efforts to enable 5G mobile services in Singapore, and the continuing the use of satellite operations in the C-band, the IMDA decided that:

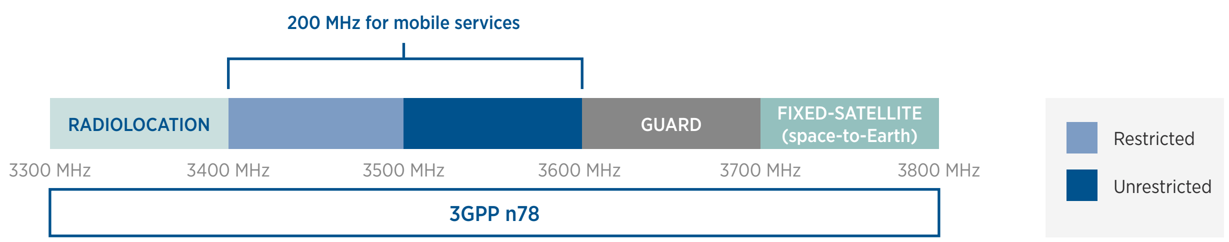
- The primary allocation of the 3.4 – 3.7 GHz band will be changed from FSS (space-to-Earth) to mobile service, and
- The primary allocation of the 3.7 – 4.2 GHz band will be retained as FSS (space-to-Earth).

Taking all technical constraints into consideration, IMDA plans to make available 100 MHz of spectrum for outdoor, indoor and underground ("unrestricted") use within the 3.5–3.6 GHz band for 5G telecommunication systems and services in the immediate term.

Additionally, while IMDA notes that more restrictions will be required for mobile service usage within the 3.4–3.5 GHz band, it intends to make available up to 100 MHz spectrum within this band on a "restricted" use basis, where deployments may have to be limited to indoors and underground. See Figure A.4 for an overview of the available spectrum in the 3.5 GHz band. Due to the constraint in spectrum supply, the IMDA's proposals is to limit the spectrum to two operators.

Figure A.4

Available Spectrum in the 3.5 GHz Band



Source: IMDA, May 2019

To avoid potential radio interference in the future 5G rollout, IMDA will assist and work closely with affected FSS users in the 3.4–3.7 GHz band to migrate their services to other suitable spectrum bands such as the 3.7–4.2 GHz range of the C-band. IMDA is looking at approximately 18 months until end 2020 to complete this migration. Existing users will also be expected to undertake necessary measures to mitigate the potential for interference from 5G including retrofitting band pass filters.

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

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

30. IMDA. Second consultation on 5G mobile services and networks. 7 May 2019 https://www2.imda.gov.sg/regulations-and-licensing/Regulations/consultations/Consultation-Papers/2019/Second-Public-Consultation-on-5G-Mobile-Services-and-Networks

IMDA is currently considering assigning the spectrum in two packages – one a 50 MHz unrestricted lot and the other a 100 MHz lot consisting of a 50 MHz unrestricted lot paired with a 50 MHz restricted lot (this will be contiguous spectrum).

MNOs have also been preparing for 5G by conducting performance trials including trials relating to radio coverage/propagation characteristics, end-to-end-latency, data throughput, and non-standalone architecture. Industrial trials are also planned with smart ports, smart factories, and smart estates being considered as possible places to begin testing out 5G technology.

To encourage these 5G trials, IMDA has waived the frequency fees associated with 5G technical and market trials from May 2017 to December 2019.

A.9 Kingdom of Thailand

Among all the Thaicom satellites, only ThaiCom5 operates in 3.4 – 3.7 GHz range. ThaiCom5's licence expires in 2020, but Thaicom launched a booster and asked for a five-year extension, which the Government is currently considering. It should also be noted that satellite earth stations on 3.5 GHz are not deployed in urban areas. Given that the concession timing of ThaiCom5, the earliest availability of the 3.5 GHz spectrum for 5G in Thailand is likely to be in three years' time.

While 5G usage is not possible within the 3.7 – 4.2 GHz band, the 3.3 – 3.4 GHz band is a possible candidate for use in Thailand for given it is not being used for radar.

In preparation for 5G, a field trial organised by the NBTC for sharing and compatibility in the 3.5 GHz focusing on the adjacent band case started in early 2019. Figure A.5 details the types of frequency usage for the trial in the 3.4 to 4.2 GHz band.

Figure A.5

The types of frequency usage for the trial in frequency band 3.4 – 4.2 GHz

Type of frequency usage	Scenario #	Frequency range		Guard band size
		3.4 – 3.7 GHz	3.7 – 4.2 GHz	
Co-channel	1	3400 – 3700 MHz	3700 – 4200 MHz	–
Adjacent Channel	2.1	3400 – 3700 MHz	3700 – 4200 MHz	0 MHz
	2.2	3400 – 3690 MHz	3700 – 4200 MHz	10 MHz
	2.3	3400 – 3680 MHz	3700 – 4200 MHz	20 MHz
	2.4	3400 – 3660 MHz	3700 – 4200 MHz	40 MHz
	2.5	3400 – 3640 MHz	3700 – 4200 MHz	60 MHz
	2.6	3400 – 3600 MHz	3700 – 4200 MHz	100 MHz

5G FFS Guard band

Source: NBTC, May 2019

The trials are expected to be completed by Q3 of 2019 and the results will inform the NBTC and the Government whether 3.5 GHz can be used for 5G and if so, under which conditions.

A.10 Socialist Republic of Vietnam

The ARFM is planning for 4G usage to continue until 2023 or 2024 before 5G usage becomes more widespread. Vietnam is planning for the early deployment of 5G in Vietnam in 2020. The focus is on rolling out eMBB during this first phase.

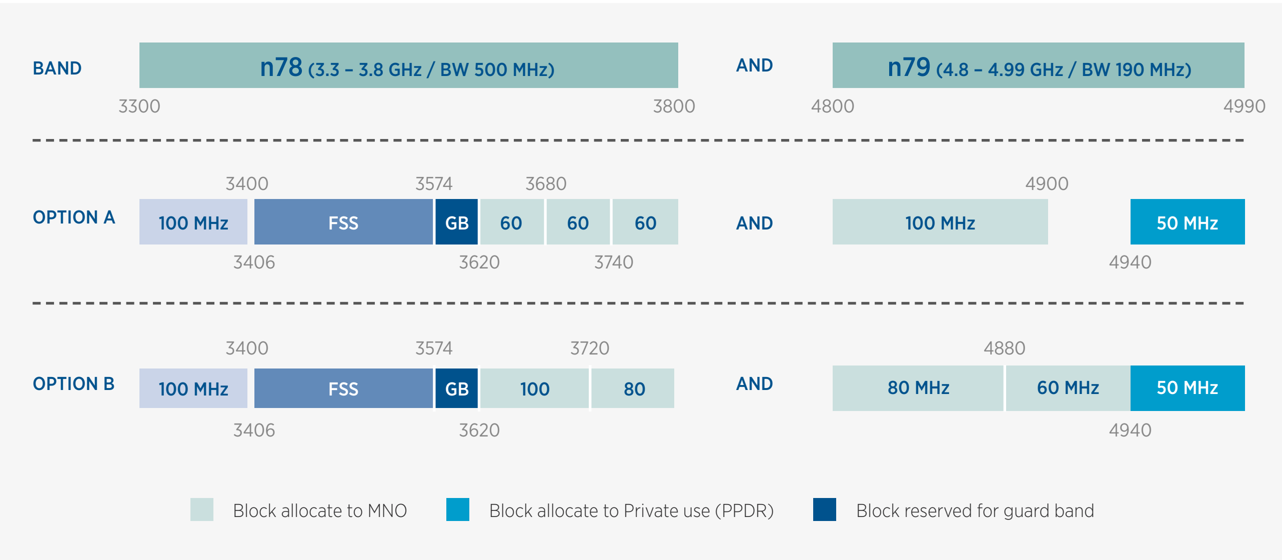
In preparation for 5G, licenses for field trials have been granted, the first of which was granted in January 2019. Furthermore, there are plans to survey potential use cases, identify network rollout challenges, prepare spectrum for 5G usage, and utilise IPv6 resources to determine the default protocol for 4G/5G. On 11 June the ARFM issued a 5G consultation paper seeking input on a range of questions on the 700 MHz, 3.5 GHz and 26/28 GHz in Vietnam.

ARFM is trying to release spectrum of 3.3 – 3.4 GHz and 3.62 – 3.8 GHz in conjunction with 4.8 – 4.99 GHz for 5G with two options, A and B, to provide four spectrum blocks in mid-band range.

Regarding the band n78, taking into account two satellite TT&C stations using frequencies around 3.70 GHz which require a protection zone to avoid co-channel interference, the ARFM is considering two options (option A with three blocks of 60 MHz and option B with two block of 100 MHz + 80 MHz). Regarding the band n79, taking into account PPDR reservation in the band 4.94 – 4.99 MHz, the ARFM is considering two options (option A with one block of 100 MHz and option B with two blocks of 80 MHz + 60 MHz). See Figure A.6.

Figure A.6

Proposed ARFM band plan for n78 and n79



Source: ARFM, June 2019

The ARFM Consultation paper also queries whether TDD synchronization (Up-down ratio) should be pre-defined by the regulator or based on agreement between MNOs, and in the case of it being predefined by the regulator, what frame structure (Up-down ratio) should be used.

Figure A.7 summarises the current situation in Vietnam.

Figure A.7

Summary of C-Band/3.5 GHz availability for 5G in Vietnam

Frequency	Comments
3.3 – 3.4 GHz	• Available but depending on the measures necessary to protect the incumbent services in the adjacent bands.
3.4 – 3.8 GHz:	• The frequencies in this band are likely to be difficult to be released for IMT unless the coexistence measures between 5G and FSS can be specified. • Currently used by Vietnam satellite/Vinasat 1, which is expected to retire in year 2023. But may be extended for a further 5 years. • Vinasat 1 C-band transmissions are assigned to the frequency range 3.4 – 3.7 GHz. • There are two TT&C sites: one in area surrounding Hanoi, and the other near HCMC. • 3.7 – 3.8 GHz could be considered for 5G but similar to above, with coexistence measures between 5G and FSS that would need to be specified
3.8 – 4.2 GHz:	• The availability of this spectrum band for IMT services is to be determined and will depend on the measures necessary to protect the incumbent FSS services in the adjacent bands.

Source: Industry sources, ARFM discussions, 2019

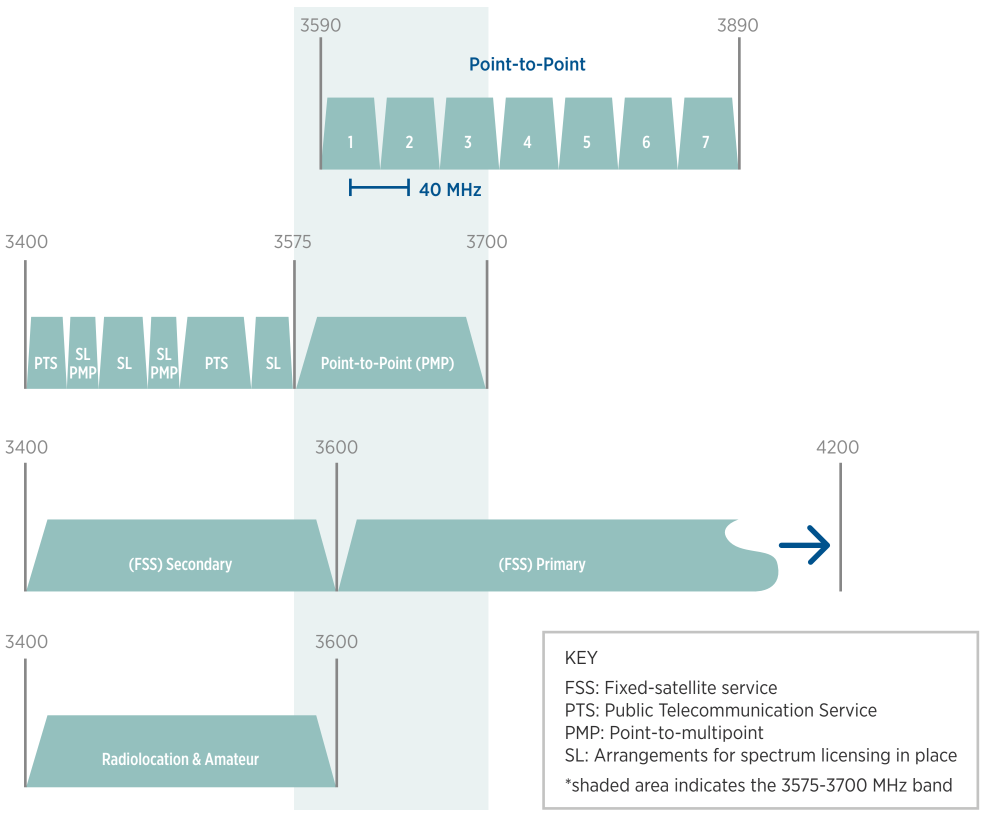
Appendix B: International case studies

B.1 Australia

Australia awarded spectrum between 3575 and 3700 MHz on a regional basis[31] in December 2018 through an auction. The services that utilised the spectrum prior to the award included satellite earth stations, point to multipoint (licensees included Wireless Internet Service Providers), point to point links and radio amateurs as shown in Figure B.1 and Figure B.2.

Figure B.1

Use of 3.6 GHz Band



Source: ACMA

31. There were 15 regions: 13 regions of 125 MHz, Perth upper of 45 MHz and Perth lower of 80 MHz.

Figure B.2

Services licensed on 1 May 2017

Services	Number of licences	Number of licensees
FSS – Earth receive	19	5
FS – Point to multipoint	413	57
FS – Point to point	47	5
Amateur – repeater	2	2

Source: ACMA. Future use of the 3.6 GHz band – Options paper, June 2017

In the case of point to point links there had been an embargo on new licences since 2005 to allow the use of the band for site-based broadband wireless access services – only existing licences could be renewed – and this had reduced the number of links. An embargo on new point-to-multipoint licences has been applied since November 2016 in all capital cities and regional areas.

In the case of fixed satellite services earth stations, the majority use the 3700 – 4200 MHz band. TV receive only (TVRO) use is unlicensed and not afforded protection. There may be around 200,000 TVRO systems in the 3400 – 4200 MHz band.

In determining the way forward for the band ACMA undertook analysis to determine the highest value use of the band – it concluded that this was wide-area broadband deployments (fixed / mobile) in metro and regional areas. A key consideration of the analysis was the mitigation options identified by ACMA including:

- Extended transition period for incumbents of seven[32] years. During this period no new licences would be allowed but the incumbents would be protected until their licences are cancelled. There would also be the possibility for incumbents to make commercial agreements with the new licensees to remain for longer.
- Alternative spectrum at 5.6 GHz for point to multipoint services, and
- Identifying geographic location(s) for relocation of satellite earth stations from metropolitan areas and ensuring long-term protection of earth stations. ACMA identified potential locations away from capital cities in areas of low population density where they could protect an area around these sites, while freeing up spectrum in highly populated areas for use by terrestrial services. Developments such as the expansion of optical fibre networks throughout Australia mean there is no longer an overwhelming requirement to maintain or establish all earth stations within capital cities.[33]

On 5 March 2018, following consideration of the ACMA's recommendation, the minister made three spectrum reallocation declarations, based on 3575–3700 MHz being reallocated by issue of spectrum licences. The three declarations provide for different reallocation periods (which commenced on 30 March 2018) as follows:

- Adelaide, Brisbane, Canberra, Melbourne, Sydney: two years
- Perth: five years, and
- Regional Australia: seven years.

The new licensees were required to protect incumbents during the transition period which might lead to restrictions on deploying services in some locations and frequencies.[34]

The amount of spectrum obtained per operator[35] typically varied between 30 and 60 MHz depending on the availability in each region. The spectrum was awarded in 5 MHz blocks.

32. The transition period of seven years was based on "providing sufficient time for earth station operators to relocate (periods up to six years had been proposed by industry) and would provide the point to multipoint operators a minimum of around 8 years to recoup investment on installed infrastructure".
33. The ACMA has recognised the value of locating earth stations in areas of low population density and has already established an earth station protection zone around Mingenew in Western Australia.
34. ACMA. 3.6 GHz band auction guide. August 2018 https://www.acma.gov.au/-/media/Spectrum-Licensing-Policy/Information/pdf/3-6-GHz-auction-2018-Auction-guide-pdf.pdf?la=en
35. There were also instances of award of a single 5 MHz block to one bidder and 75 MHz (15 blocks) to another.

Spectrum awarded: 3575 – 3700 MHz

Incumbent services: Satellite Earth Stations, TVRO, point-to-multipoint, point to point

Approaches for release of spectrum:

- Satellite Earth Stations – Transition period of 7 years to allow relocation to remote geographic areas
- TVRO – Licence exempt so not afforded protection. Move to above 3700 MHz
- Point to multipoint – Transition period of 7 years. Alternative spectrum identified at 5.6 GHz
- Point to point – Embargo on new links since 2005 so numbers substantially reduced. Potential for links users to make commercial agreements with new licensees.

Importantly, ACMA commenced a further process for the release of additional 3.5 GHz band spectrum with the release process of an options paper in April 2019 for optimising the arrangements in 3400 – 3575 MHz.[36] The 3400–3575 MHz band is subject to a mix of spectrum and apparatus licensing arrangements across Australia. These arrangements authorise a variety of services, including wireless broadband (both fixed and mobile), fixed satellite, radiolocation and amateur services. ACMA's objective is to consolidate the different licence arrangements for wireless broadband in this band in order to increase the efficient use of spectrum and reduce network deployment costs.

36. Refer to https://www.acma.gov.au/theACMA/optimising-the-3400-3575-mhz-band

B.2 Brazil

In Brazil the regulator Anatel carried out studies to verify the coexistence conditions between LTE-Advanced systems installed in the 3400 – 3600 MHz band with the TVRO application in the range of 3625 – 4200 MHz.[37]

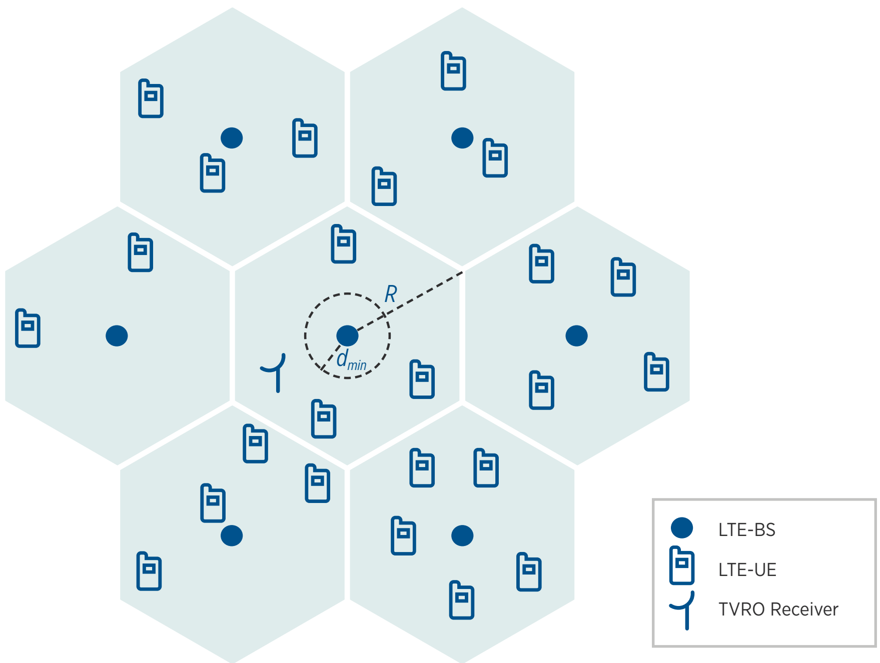
The 3400 – 3600 MHz band has been allocated to wireless broadband applications since 1999 and it was expected that this would be used for IMT, specifically LTE. The 3600 – 4200 MHz band was allocated for fixed satellite services but in practice the satellite services operated above 3625 MHz band. The satellite services in use are VSAT operating under a "blanket licensing procedure", licensed stations with known geographical locations and TVRO systems with around 20 million users. The TVRO stations typically use low cost and low quality equipment without appropriate filtering. Use of the band is exempted from licensing and no protection provided from harmful interference.

The study investigated and defined operational constraints for deploying LTE-Advanced in the 3400 – 3600 MHz band adjacent to the TVRO receivers. The study used Monte Carlo modelling to undertake the interference analysis. The problem was identified to be mainly due to the low noise block converter (LNB) used in the receiver which does not have a C-band filter and so responds across the full band of 3400 – 4200 MHz leading to the potential for overloading the TVRO.

The modelling simulations investigated overloading and used the characteristics of IMT systems provided in Rep. ITU-R M.2292-0 and considered a range of scenarios (suburban macrocell, urban macrocell and an outdoor small cell).

Figure B.3

Simulation using a 7-cell network and showing relative positions between TVRO and LTE-A



Source: Fernandes ad Linhares (2017)

37. The output of the studies can be found in the paper by LC Fernandes and A Linhares titled "Coexistence conditions of LTE-advanced at 3400 – 3600 MHz with TVRO at 3625 – 4200 MHz in Brazil". The paper was published on 19 June 2017 in the Wireless News.

The simulation checked for overload of the TVRO (overload threshold exceeded) which is randomly located inside the LTE network with a minimum distance (*dmin*: assumed to be 10 metres) from the base station. The modelling also assumed that 5% of TVRO receivers experiencing interference is acceptable. It was found that filtering in the C-band with at least 30 dB would be a solution for the overload problem.

It was also found that if the minimum distance between the LTE base station and the TVRO receiver was increased then both systems could co-exist in some situations without a C-band filter.[38]

However, it was concluded that in all cases using an adequate C-band filter coexistence is possible for all scenarios. Assuming a 25 MHz gap (guard band) between the beginning of the FSS frequency band and the end of the LTE-A frequency coexistence would depend on the availability of suitable filters with the necessary decay. Initially these may not be cost effective but the study noted that "a mixed solution could be used considering a filter with an intermediate decay, robust LNB (specifically the first LNA), better antenna and reducing the EIRP of the base station". In some cases, particularly small cells, deploying the LTE-Advanced base stations at a minimal distance from the TVRO receivers can mitigate the overloading of the TVRO receivers. In such circumstances it is possible to identify the location of the TVRO antennas through visual inspection.

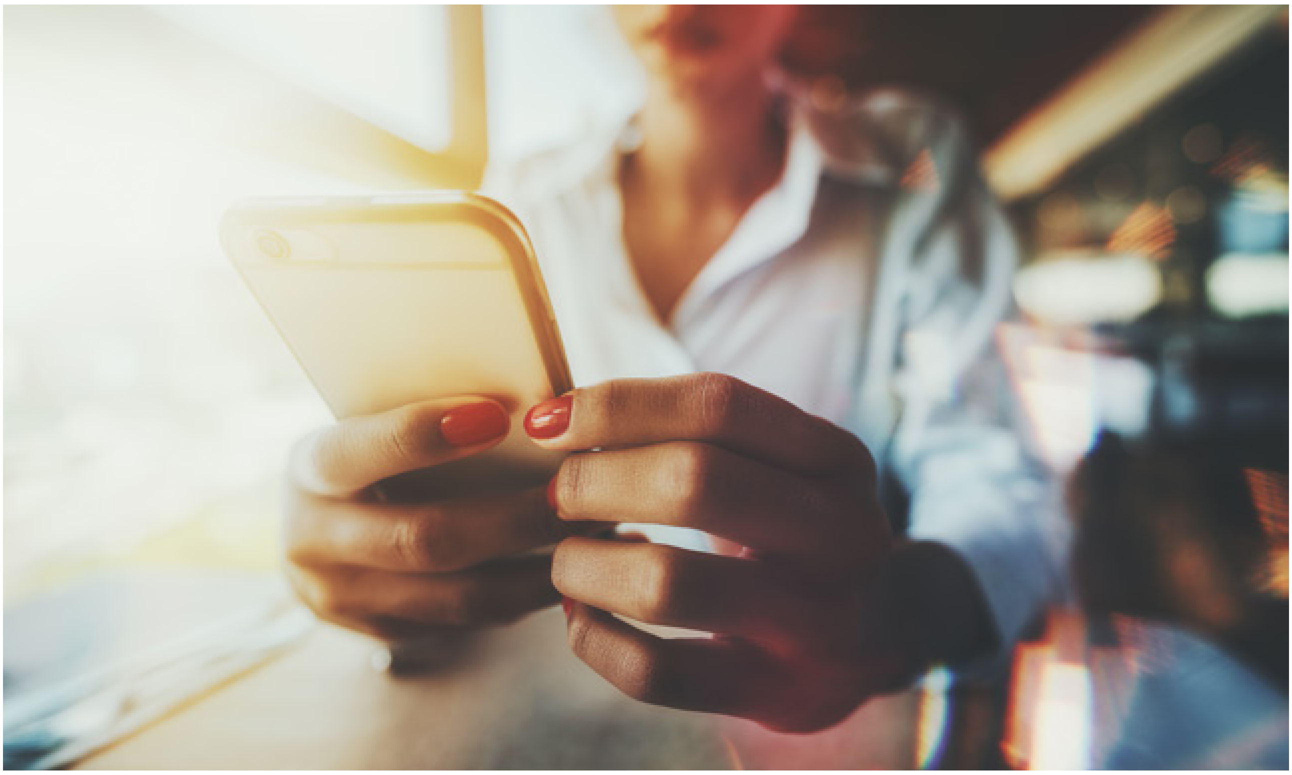
The overall conclusion of the study was that "the use of a better antenna and an optimized LNB, with adequate separation distance between interferer-interfered can significantly mitigate the overload problem". A 25 MHz guard band could be sufficient for the development of a suitable filter for those lower quality TVRO receivers.

Spectrum identified for IMT: 3400 – 3600 MHz

Incumbent services: Satellite services 3625 – 4200 MHz (Earth stations, VSATs, TVRO)

Approaches for release of spectrum:

Mixed solution to protect TVROs above 3625 MHz – Guard band of 25 MHz between FSS and IMT, optimised LNB, addition of filters to TVRO receivers, IMT base station site location.



38. For example, with low quality TVRO receivers a minimum distance of 80 metres is sufficient for coexistence in the urban small cell scenario.

B.3 Hong Kong

In Hong Kong, the Communications Authority (CA) is proposing to award spectrum in the 3300 – 3400 MHz and 3400 – 3600 MHz bands in 2019 providing a total of 300 MHz for IMT. In addition, the CA is proposing to award spectrum at 4.9 GHz.

B.3.1 3300 – 3400 MHz

In July 2018, the CA updated the Spectrum Release Plan ("SRP")[39] to include 100 MHz of spectrum in the 3.3 GHz band for indoor use only. This spectrum will be made available in 2019 for the provision of public mobile services, including the fifth generation mobile ("5G") services. In addition, another 100 MHz of spectrum in the 4.9 GHz band is to be released which may be used in any locations of the territory.

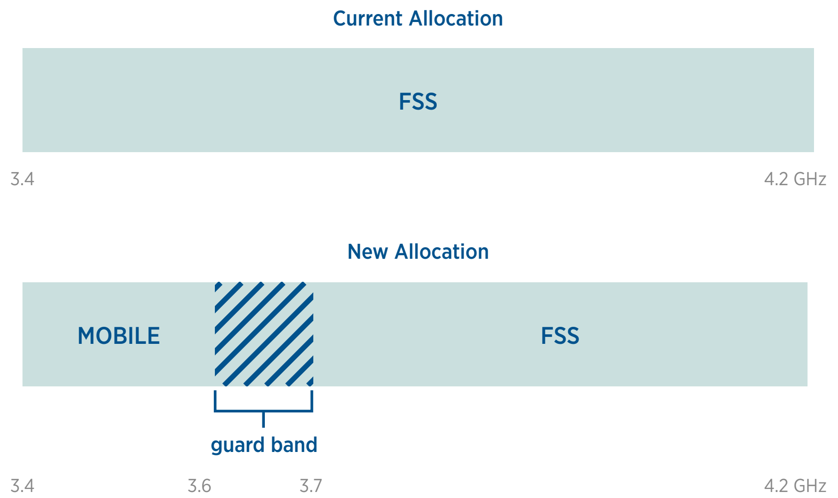
In the CA statement[40] regarding these bands it notes that the "CA considers that the proposed use of the 3.3 GHz band will unlikely cause any harmful interference to fixed satellite service operating in the 3.4 – 4.2 GHz band. This is because the use of the 3.3 GHz band for indoor use only will be limited to low transmitting power and such use cannot cause interference to the incumbent radiolocation services operating outdoors".

B.3.2 3400 – 4200 MHz

In a March 2018 statement[41] the CA decided to change the allocation in the 3.4 – 3.7 GHz band from fixed satellite service (space-to-Earth) to mobile service (MS) for the provision of public mobile services with effect from 1 April 2020. This is shown in Figure B.4.

Figure B.4

Current and new allocations of C-band in Hong Kong



Source: Communications Authority

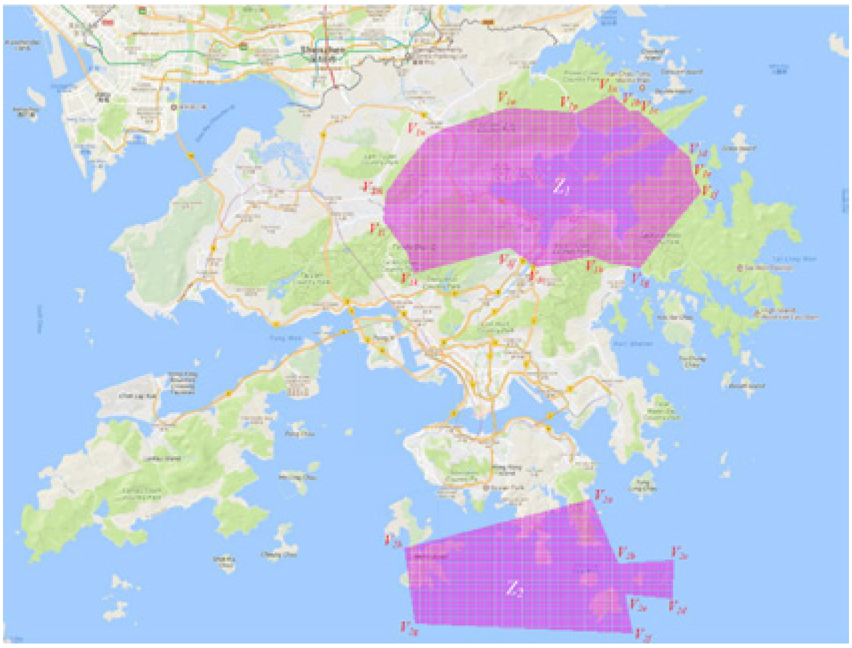
39. OFCA. Spectrum Release Plan for 2018-2020. 26 July 2018. https://www.coms-auth.hk/filemanager/en/content_613/spectrum_plan2018_en.pdf
40. Joint Statement of the Communications Authority and the Secretary for Commerce and Economic Development. Arrangements for Assignment of the Spectrum in the3.3 GHz and 4.9 GHz Bands for the Provision of Public Mobile Services and the Related Spectrum Utilisation Fee. 13 December 2018. https://www.coms-auth.hk/filemanager/statement/en/upload/482/joint_statement_st_072018.pdf
41. Statement of the Communications Authority. Change in the Allocation of the 3.4 –3.7 GHz Band from Fixed Satellite Service to Mobile Service. 28 March 2018. https://www.coms-auth.hk/filemanager/statement/en/upload/441/ca_statements20180328_en.pdf

In the 3400 – 3600 MHz band the existing FSS users were:

- Telemetry, Tracking and Command (TT&C) station receivers used to control satellites. It was decided that the two stations at Tai Po and Stanley should be protected by the restriction zones as shown in Figure B.5. The zones were developed based on worst case scenario by simulating a hypothetical deployment of mobile base stations and ensuring the received signal power at the Earth Station does not overload or desensitise the receiver. Account was taken of actual terrain, clutter and buildings in the surrounding area. It was noted by mobile network operators (MNOs), in response to the CA's public consultation, that the restriction zones could be reduced by adding shielding to the TT&C stations, careful location and pointing of mobile base station antennas and even moving TT&C Stations to more remote areas.

Figure B.5

Restriction Zones around Tai Po and Stanley



Source: Communications Authority

- Licensed systems of Satellite Master Antenna Television (SMATV), external fixed telecommunications network service (EFTNS) and self-provided external telecommunication systems (SPETS), operating in the 3.7 – 4.2 GHz band are required to implement mitigating measures to avoid interference caused by mobile base stations operating in the 3.4 – 3.6 GHz band. It was also noted that "EFTNS and SPETS licensees may need to lease FSS downlink capacity in the 3.7 – 4.2 GHz band to maintain the existing systems". In the case of SMATV a subsidy scheme was proposed by the CA, to be administered by the prospective spectrum licensees, to cover the one-off cost of upgrading SMATV systems.[42]
- TV Receive Only (TVRO) systems are exempted from licensing and "are not entitled to protection from any harmful interference from prospective public mobile services".

A notice of two years was provided to the affected licensees.

Figure B.4 shows a guard band of 100 MHz which is required under worst case (Minimum Coupling Loss) assumptions. However, it was noted that if a statistical approach is used to establish the size of guard band this could be considerably smaller, e.g. if it is accepted a small percentage of satellite receivers may be interfered

42. The maximum amount of subsidy will be capped at HK$20,000 per SMATV system.

and, in those cases, mitigation is required in the form of either a new more blocking resilient LNA, a filter or both. The deployment of IMT is anticipated to be of relatively limited cell size in urban areas so antennas will in most cases not be located above rooftop, such a deployment will reduce the number of interference cases to satellite receivers which for line of sight are most often roof top mounted.

However, the above mitigation measures alone may not be sufficiently resilient in dealing with some special circumstances. For instance, if a mobile base station installed on a rooftop is located higher than a SMATV antenna, and their respective antennas are facing each other in close proximity, significant interference to the SMATV system might occur. Given that Hong Kong is geographically located in the northern hemisphere and that geostationary satellites are orbiting over the equator, SMATV antennas in Hong Kong are naturally pointing south at various azimuths and elevation angles. With this in mind, the Consultancy Study report[43] recommends taking specific mitigation measures against this by the adjustment of the direction of the mobile base station antenna or relocation of the mobile base station to another building, preferably in the eastern or western direction in respect of the SMATV antenna concerned. On the whole, mobile network coverage will not be compromised even with such mitigation measures, as the required separation between the upgraded SMATV system and the mobile base station is in the order of 65 metres under the worst-case scenario.

Spectrum identified for IMT: 3300 – 3400 MHz

Incumbent services: Radiolocation, FSS above 3400 MHz

Approaches for release of spectrum:

- Indoor only IMT deployment as unlikely to cause interference to incumbents

Spectrum identified for IMT: 3400 – 3700 MHz

Incumbent services: TT&C earth stations, SMATV, EFTNS, TVRO

Approaches for release of spectrum:

- TT&C earth stations – identified restriction zones around the 2 sites
- TV receivers – Guard band of 100 MHz to FSS band, more blocking resilient LNA, addition of filters, IMT base station location
- 2-year notice provided to licensees
- Subsidy of HK$20,000 per SMATV system

43. Rohde & Schwarz. Assessments on and Recommendations to Enable the Electromagnetic Compatibility between Public Mobile Services and Fixed Satellite Service Operating in the C-Band. Consultancy Report, 28 March 2018. https://www.ofca.gov.hk/filemanager/ofca/common/reports/consultancy/cr_201803_28_en.pdf

B.4 UK

Ofcom, in the UK, awarded the 3410 – 3480 MHz and 3500 – 3580 MHz spectrum in April 2018. Ofcom is also planning to award the 3600 – 3800 MHz spectrum later in 2019.[44] Ofcom has also consulted on the potential release of the 3800 – 4200 MHz band on a shared basis.

B.4.3 3400 – 3600 MHz

The spectrum awarded (3410 – 3480 and 3500 – 3580 MHz) was released by the MOD (ministry of Defence) as part of the Public Sector Spectrum Release Plan. UK Broadband already held 40 MHz in the band (3480 – 3500 MHz and 3580 – 3600 MHz). The main sharing considerations were in respect to civil maritime radar and aeronautical radar close to the 3.4 GHz band and coexistence with satellite services.[45] It was concluded that coordination is needed between 3.4 GHz LTE and aeronautical radar, but not with civil maritime radar or satellite services. Coexistence was needed with some naval systems and there were coordination zones around a number of key military locations. The spectrum was awarded on a TDD basis.

The 150 MHz of spectrum in the 3.4 GHz band was awarded by auction with 40 MHz in the 2.3 GHz band (2350 – 2390 MHz). The four incumbent mobile operators (3UK, EE, O2 and Vodafone) each won between 20 MHz and 50 MHz.[46]

B.4.4 3600 – 3800 MHz

The use of the 3600 – 3800 MHz band in the UK includes:

- Fixed satellite downlinks in 3600 – 4200 MHz. It is used by receive-only satellite earth stations holding grants of Recognised Spectrum access and by satellite earth stations transmitting at 5825 – 6725 MHz. This band is used by several earth stations across the UK for broadcast contribution and monitoring, data communications and other services.
- UK Broadband licensed to use 3605 – 3689 MHz 3925 – 4009 MHz to provide wireless data capacity, equipment and services to customers and to the telecoms industry, service providers, and the public sector.
- Fixed link licences which operate in 3695 – 3875 MHz paired with 4015 – 4195 MHz.

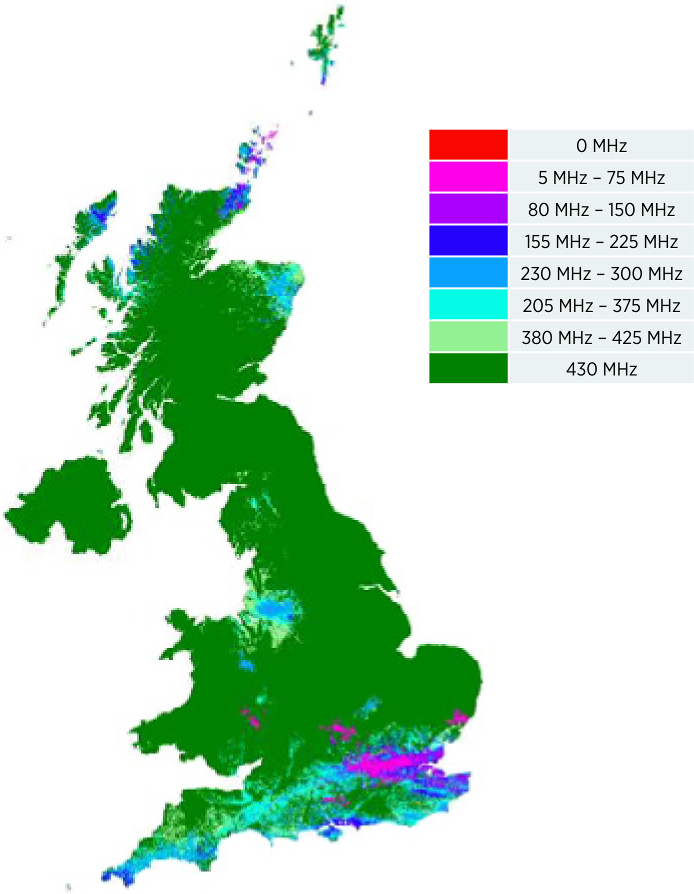
Ofcom undertook a number of sharing studies to assess the potential for spectrum sharing between IMT and fixed links and satellite services.[47]

A study undertaken by Transfinite considered small cell sharing and identified that there was the possibility to share on a geographic basis taking into account the location of the satellite and fixed links stations.[48] Figure B.6 shows the amount of available spectrum for IMT small cell deployment in the 3.6 – 4.2 GHz band in the UK.

44. Ofcom. Award of the 700 MHz and 3.6 – 3.8 GHz spectrum bands. Consultation, 18 December 2018. https://www.ofcom.org.uk/consultations-and-statements/category-1/award-700mhz-3.6-3.8ghz-spectrum
45. Ofcom. Public Sector Spectrum Release: Award of the 2.3 and 3.4 GHz spectrum bands. Statement and Consultation, 26 May 2015. https://www.ofcom.org.uk/__data/assets/pdf_file/0027/68337/Public_Sector_Spectrum_Release_statement.pdf
46. Ofcom. Award of 2.3 and 3.4 GHz spectrum bands. 13 April 2018. https://www.ofcom.org.uk/__data/assets/pdf_file/0018/112932/Regulation-111-Final-outcome-of-award.pdf
47. Ofcom. Improving consumer access to mobile services at 3.6 GHz to 3.8 GHz, Statement and Consultation, 28 July 2017. https://www.ofcom.org.uk/__data/assets/pdf_file/0017/103355/3-6-3-8ghz-statement.pdf
48. Transfinite Systems, Geographic Sharing in C-band, Final report, May 2015. https://www.ofcom.org.uk/research-and-data/technology/radio-spectrum/c-band-sharing

Figure B.6

Spectrum available for small cell mobile deployment considering geographic sharing with satellite and fixed services



Source: Transfinite Report on Geographic Sharing in C-Band

Ofcom also undertook an internal study considering the impact of large-scale macrocell deployment at 3.6 GHz to 3.8 GHz. The study indicated that coexistence could be very challenging – for example a large-scale macrocell deployment in London would affect the benchmark spectrum quality at several different earth station sites (including Chalfont, Bedford, Crawley Court, Crowsley Park and Brookmans Park). So, whilst "small cell deployments could enable a greater degree of coexistence, this would be likely to require significant deployment planning and site engineering to manage interference impacts; dense small cell deployment near satellite earth stations would be particularly challenging". (p.29, Ofcom July 2017 statement)

Similarly, for fixed links coexistence with small cells and macrocell base stations "could be very challenging in densely populated areas, such as the links in the south-east of England". (p.29, Ofcom July 2017 statement) Also, macrocells could cause interference to fixed links in rural areas.

Ofcom concluded, based on further studies and responses to consultations that (p.32, Ofcom July 2017 statement):

- "Coexistence between mobile and the satellite earth stations and fixed links users based on the existing coordination approach would be very challenging and could significantly impact and constrain mobile deployments across large parts of the UK as a result of the large separation distances which would be required to maintain existing users' benchmark spectrum quality".
- "The impact of the required separation distances to maintain current levels of benchmark spectrum quality would vary across regions. There are many areas of the UK in which mobile deployment would be relatively unconstrained. However, owing to the location of current registered users, mobile deployment would be significantly constrained in some densely populated areas including greater

London, where we would expect there to be particularly strong demand for new mobile services including 5G".

- "Current coordination procedures are burdensome and would slow mobile roll out".

It was concluded that nationwide deployment of future mobile services including 5G could not coexist with the coordination approach and current benchmark spectrum quality provided to registered users of the band. Ofcom therefore decided to revoke all fixed link licences[49] and issued notices with an effective date of 23 December 2022.[50, 51]

In the case of the receive Earth Stations they would still be able to receive signals in the band on a licence exempt basis but would have to adjust to an expectation of lower spectrum quality. Some of these, if away from urban areas, might be able to continue receiving in the band without suffering service impacting levels of interference from future mobile services. It would be the responsibility of the satellite operator to introduce mitigation from interference (e.g. through natural or artificial shielding) and reach any agreements with the mobile licensees. Following Ofcom's decision, 12 Permanent Earth Station licences and three grants of RSA were therefore modified, with an effective date of 1 June 2020 and one grant of RSA with an effective date of 1 September 2020. This would provide access to some of the band by the new licensees from June 2020.

B.4.5 3800 – 4200 MHz

Ofcom has also consulted on opportunities for innovation in the 3.8 to 4.2 GHz band having identified it as a candidate for spectrum sharing by new mobile users with the current incumbent services of fixed satellite service (earth stations), fixed links and fixed wireless access.[52] It is expected that the spectrum could support deployment of local networks in sectors including industrial Internet of Things (IoT), enterprise, logistics, mining and agriculture, as well as help to improve the quality of coverage in poorly served areas.

Under its proposed sharing approach, access to new users would be provided on a per location basis and Ofcom would carry out technical coordination to minimise the risk of interference between new and incumbent users. The main steps in the proposed application process are:

1. Users to apply for the location(s), band(s) and bandwidth(s) that they need to provide a service;
2. Ofcom to assess requests with regards to interference to and from other licensees in the band;
3. Ofcom to grant individual licence(s) for the requested location(s), band(s) and bandwidth(s) on a first come first served basis, where there is no undue interference to other users; and
4. Cost-based licence fees to recover the cost of Ofcom managing the licence, where spectrum demand does not outstrip supply (consistent with our established pricing principles).

Spectrum awarded: 3600 – 3800 MHz

Incumbent services: Earth stations, BWA, point to point links

Approaches for release of spectrum:

- Ofcom concluded that sharing was too difficult and would limit mobile deployments.
- Earth stations – Recognised Spectrum Access (RSA) licences revoked. Can remain but no protection from interference. Potential to make agreements with mobile licensees
- Point to point links – Notice provided of revocation of all fixed links licences (effective date December 2022)
- BWA – No action necessary and licensee remains in the band

Spectrum identified for IMT: 3800 – 4200 MHz

Incumbent services: Earth stations, BWA, point to point links

Approaches for release of spectrum:

- Licences for innovative applications on a location, frequency band and bandwidth basis.
- Awarded on first come first served basis. Interference analysis undertaken by Ofcom with incumbent services.

49. There were only around 26 links remaining in the band.
50. Ofcom. Improving consumer access to mobile services at 3.6 GHz to 3.8 GHz. Statement, 26 October 2017. https://www.ofcom.org.uk/__data/assets/pdf_file/0019/107371/Consumer-access-3.6-3.8-GHz.pdf
51. Ofcom. Improving consumer access to mobile services at 3.6 GHz to 3.8 GHz. Update on timing of spectrum availability, 2 February 2018. https://www.ofcom.org.uk/__data/assets/pdf_file/0018/110718/3.6GHz-3.8GHz-update-timing-spectrum-availability.pdf
52. Ofcom. Enabling opportunities for innovation. Consultation, 18 December 2018. https://www.ofcom.org.uk/consultations-and-statements/category-1/enabling-opportunities-for-innovation

B.5 Europe

On 21 May 2008, the European Commission adopted the 3.4 GHz Decision for the 3400 to 3600 MHz band, this decision required Member States, within six months of the 3.4 GHz Decision's entry into force, to designate and make available the band, on a non-exclusive basis, for terrestrial electronic communications networks, in compliance with a number of technical parameters set out in the annex to the 3.4 GHz Decision. On 2 May 2014, the European Commission adopted Decision 2014/276/EU3 which amended the 3.4 GHz Decision, primarily the technical conditions, set out in the annex. It stated that the preferred mode of operation in the 3.4 to 3.6 GHz sub-band shall be Time Division Duplex (TDD). Since the Decision, the Radio Spectrum Policy Group (RSPG) has identified the wider 3.4 to 3.8 GHz band as the "primary band suitable for the introduction of 5G use in Europe even before 2020".

In January 2019 the European Commission amended the Decision for the 3400 – 3800 MHz band[53, 54] for the future use with 5G. It noted that the use of the band, since the original decision in 2008, had been low with only a limited number of licences issued. With the identification of the 5G band as a primary pioneer band for 5G in the European Union the amendment updates the technical conditions to make them 5G-ready. The amended Decision also noted the preference for large contiguous bandwidths of 80 – 100 MHz to facilitate the efficient deployment of 5G wireless broadband services.

No exclusive use for 5G is mandated in the 3.6 GHz band – use is technology and service neutral – but it was viewed that 5G will rely in its progressive deployment on the other two pioneer bands in the Union (700 MHz and 26 GHz) until 2020 as well as on further spectrum – both in existing EU-harmonised bands below 6 GHz and new spectrum in the so-called mmWave bands.

B.6 US

In the US the FCC has proposed to expand the flexible use of mid-band spectrum, 3.7 – 4.2 GHz, and issued an Order and Notice of Proposed Rulemaking, FCC 18-91, that was adopted on 12 July 2018.[55] FCC proposed to add a mobile, except aeronautical mobile, allocation to the band and to seek comment on transitioning all or part of the band to terrestrial wireless broadband services.

The 3.7 – 4.2 GHz band is currently allocated for fixed satellite services (space-to-Earth) and fixed services. Fixed services use 20 MHz paired channels and there are only around 115 licences in the band now after a significant decrease in licences since 1997. For fixed satellite service the band is used to provide downlink signals of various bandwidths to licensed transmit-receive, registered receive-only, and unregistered receive-only earth stations throughout the United States. Uses include delivery of programming content to television and radio broadcasters, as well as the backhaul of telephone and data traffic. Satellites operating in the C-band typically have 24 transponders, each with a bandwidth of 36 MHz. The 24 transponders use the full 500 MHz available at any orbital slot and re-use spectrum to achieve the necessary 864 MHz of spectrum. Space stations are authorised for all 500 megahertz exclusively at any orbital slot, but non-exclusively in terms of geographic coverage. The band is also used for TT&C to control the satellites.

In adjacent bands to 3.7 – 4.2 GHz there are:

- 3.55 – 3.7 GHz: Citizens Broadband Radio Service for shared wireless broadband.
- Below 3.7 GHz: Reception of telemetry signals transmitted by satellites (TT&C).
- 4.2 – 4.4 GHz: Aeronautical radionavigation (radio altimeters and wireless avionics systems).

As part of the Order and Notice the FCC has requested information on current deployments in the band because it "lacks sufficient information regarding incumbent operators, including those of earth station licensees and registrants" which is vital for deciding

53. European Commission. Commission decides to harmonise radio spectrum for the future 5G. News article, 24 January 2019. https://ec.europa.eu/digital-single-market/en/news/commission-decides-harmonise-radio-spectrum-future-5g
54. European Commission. Commission Implementing Decision (EU) 2019/235 of 24 January 2019. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1549615962331&uri=CELEX:32019D0235
55. FCC. Expanding flexible use of the 3.7 to 4.2 GHz band. Order and Notice of Proposed Rule Making, 12 July 2018. https://docs.fcc.gov/public/attachments/FCC-18-91A1.pdf

on modifying any use of the band.[56] In April 2019 a new docket (GN Docket no 18-22) was opened that announced a temporary freeze from April 19, 2018, on the filing of new or modified applications for earth station licenses, receive only earth station registrations, and fixed microwave licenses in the 3.7 – 4.2 GHz whilst information was collected and evaluated.

The FCC proposes to licence the 3.7 – 4.2 GHz band for flexible mobile use on an exclusive and geographic area basis. Whilst it has asked for inputs on protection criteria for FSS earth stations from mobile, the FCC has also proposed possible options to clear incumbent users from the band. One is a market-based approach where a cooperative entity of satellite operators would negotiate with mobile users to clear and repack the spectrum. Satellite operators (C-band Alliance) have proposed a plan to turn over 200 MHz to wireless providers for 5G development in 18 to 36 months through a private spectrum auction.[57] This would include 180 MHz (3700 – 3880 MHz) to be released for 5G use with a 20 MHz guard band at 3880 – 3900 MHz. The spectrum would be released in two tranches – 60 MHz within 18 months; the rest after 36 months – and 300 MHz would be retained for satellite. The satellite companies have argued they should be able to keep any returns from trading their spectrum.

Another approach would be to auction the spectrum and four possible approaches have been suggested: an overlay auction, an incentive auction, a capacity auction or a combination of these. Input on the economic benefits of the different plans and implications for incumbent protection have been requested.

Spectrum identified for IMT: 3700 – 4200 MHz for flexible mobile use on exclusive and geographic basis.

Incumbent services: Fixed satellite services and fixed services (limited numbers of links); CB radio systems and TT&C below 3700 MHz; Radionavigation above 4200 MHz

Approaches for release of spectrum:

- Currently investigating approaches for sharing and options for clearance. One clearance option under consideration is private spectrum auction by satellite users of 3700 – 3880 MHz for mobile and 20 MHz guard band with spectrum above 3900 MHz retained for satellite.

B.7 Taiwan

The Taiwan regulator NCC commissioned a study to investigate 5G and IoT developments and related spectrum issues. This included a compatibility study between IMT and FSS in the 3.5 GHz band. TTC carried out a measurement study to establish the parameters needed to accommodate IMT services in the 3.5 GHz band.[58]

Three mitigation measures to address IMT-FSS coexistence were proposed, namely

- Guard band between IMT and FSS – 44 MHz (3570 – 3614 MHz)
- Use of exclusion zones – 150 metres between 5G base stations and FSS terminals above 3614 MHz
- Installation of band pass filters (BPF) on FSS terminals to improve receiver performance

Reference was made to the Hong Kong study carried out by Rohde and Schwarz for OFCA which recommended a 100 MHz guard band, installation of BPFs on FSS terminals and 5G base station parameters. A comparison between the Taiwan and Hong Kong studies is shown in Figure B.7.

56. In addition to 4,700 earth stations it is believed there may be thousands of unregistered receive only earth stations.
57. C-band Alliance. Filing, 21 May 2019. https://ecfsapi.fcc.gov/file/10521277644574/CBA%20-%20Band%20Plan%20Ex%20Parte.pdf
58. NCC. New generation mobile and IoT technology developments, spectrum sharing models and ultra-wide band technology. Research report (in Chinese), December 2018. https://www.ncc.gov.tw/chinese/files/19011/4007_40876_190110_1.pdf

Figure B.7

Comparisons of 3.5 GHz measurements carried out in Taiwan and Hong Kong

	Taiwan	Hong Kong	Notes
Current usage status			
Satellite receiver antenna size	>90% 3m/3.7m dishes (main users are TV distributers)	Various sizes (including individual DTH use)	–
Geographical distribution of receivers	One per 53.82 sq.km (or 7.33km by 7.33km) [excluding mountainous regions, 70% of land area]	One per 1.72125 sq.km (or 1.31km by 1.31km) [including rural parts of Hong Kong]	Less than 200 receive terminals in Taiwan compared to 1600 in Hong Kong
Relative height distribution of IMT base stations and FSS stations	IMT base stations mainly lower than FSS ground station; majority are NLOS	Evenly distribution in height – high, medium, low; mainly LOS	Due to density of satellite receivers in Hong Kong, hard to eliminate possibility of any scenario
Frequency considerations			
Extended C-band satellite usage	Retain portion of ST-2[59] transponders	Reduce/migrate to 3.7 – 4.2 GHz	–
Guard band	Ideally less than 50 MHz	100 MHz (3.6 – 3.7 GHz)	–
Empirical testing			
Band pass filter specifications	• Pass band: 3.61 – 3.71 GHz (for ST-2) • 3.4 – 3.61 GHz: Out-of-band emission limit 60dB (using 40 MHz) • Insertion loss: 0.5dB	• Pass band: 3.7 – 4.2 GHz • 3.4 – 3.6 GHz: Out-of-band emission limit 55dB (using 100 MHz) • Insertion loss: 0.5dB	• Hong Kong uses standard BPF which is easier to obtain from market • For Taiwan, due to specific frequencies used by ST-2, BPF needs to be specially ordered
Measurement set-up and steps	• DVB-S signal generator • Spectrum analyser • Source of interference: signal generator	• DVB-S signal generator • Spectrum analyser Source of interference: signal generator	Approach is roughly similar
Key measurement items	• IMT/FSS protection distance (one/two sources of interference) • BPF performance test	• IMT/FSS protection distance (one/two sources of interference) • BPF performance test • LNB performance	• 5G NR interference sources of different bandwidths and signal strength of macrocell considered • BPF testing based on lab and outdoor environments • Hong Kong recommended mandatory installation of BPF but no requirement to upgrade to better LNB

Source: NCC report Figure 2.7, pp.29-30.

59. ST-2 is Singtel-Chunghwa satellite operating the C and Ku bands https://www.singtel.com/about-Us/news-releases/singtels-second-commercial-satellite-st-2-soars-orbit

Based on the findings, the NCC is planning to award 270 MHz of spectrum in 3300 – 3570 MHz by auction in December 2019, along with the 28 GHz band and residual 1800 MHz spectrum.[60]

Spectrum identified for IMT: 3300 – 3570 MHz

Incumbent services: FSS above 3600 MHz (TV production, headends)

Approaches for release of spectrum:

- Guard band between IMT and FSS – 44 MHz
- Use of exclusion zones/separation distances – 150 metres between 5G base stations and FSS terminals
- Installation of band pass filters (BPF) on FSS terminals to improve receiver performance.

60. http://www.taipeitimes.com/News/taiwan/archives/2019/06/20/2003717254

Appendix C: Sharing studies

In the following sections studies undertaken in the ITU and CEPT are summarised and provide information on the potential for different incumbent services to share spectrum with IMT on a co and adjacent channel basis.

C.1 ITU

C.1.1 Sharing between FSS and IMT

In the preparations for the World Radiocommunication Conference 2015 (WRC-15) a number of coexistence studies were undertaken between FSS and IMT that are summarised in ITU-R Report S.2368-0.[61] The outcome of these studies provides separation distances to protect FSS earth stations associated with in-band and adjacent band emissions for a number of different scenarios. The outcome of the studies is summarised as follows in the ITU Report.

"The required separation distances to protect FSS receiving earth stations are summarized as follows with respect to the following different interference mechanisms.

C.1.2 In-band emissions

In the case of IMT-Advanced suburban/urban macro-cell deployment scenarios:

- For the long-term interference criterion, the required separation distances are at least in the tens of kilometres. For the short-term interference criterion, the required separation distances, including when the effects of terrain are taken into account, exceed 100 km for most of the cases. Both the long-term and short-term interference criteria would have to be met.
- In some cases, the required separation distances are larger, up to 525 km. In other cases, the required separation distances could be reduced by taking into account additional effects of natural and artificial shielding. However, these effects are site specific.

In the case of IMT-Advanced small-cell outdoor deployment scenarios:

- For the long-term interference criterion, the required separation distances are in the tens of kilometres. For the short-term interference criterion, the required separation distances, including when the effects of terrain and clutter are taken into account, are around 30 km in typical IMT-Advanced small-cell deployment using low antenna height in urban environments. In some cases, the required separation distances were found to exceed 100 km. Both the long-term and short-term interference criteria would have to be met.

In the case of IMT-Advanced small-cell indoor deployment scenarios:

- The required protection distance for an indoor small cell deployment was smaller relative to small cell outdoor due to the fact that some degree of building attenuation was assumed, as well as lower base station EIRP and antenna height.
- For the long-term interference criterion, the required separation distances vary from about 5 km to tens of kilometres. For the short-term interference criterion, the required separation distances vary from about 5 km to tens of kilometres, and in some instances up to 120 km. Both the long-term and short-term interference criteria would have to be met.

61. ITU. Report ITU-R S.2368-0(06/2015). Sharing studies between International Mobile Telecommunication – Advanced systems and geostationary satellite networks in the fixed satellite services in the 3400 - 4200 MHz and 4500 – 800 MHz frequency bands in the WRC study cycle leading to WRC-15.

- The wide range of distances is a consequence of earth stations in a variety of terrain conditions, assumed clutter loss, and different assumptions for the building penetration loss (0 to 20 dB).

The above-mentioned separation distances were derived assuming an IMT Advanced deployment limited to indoor. If a percentage of IMT-Advanced UE are used outdoors, the required separation distances would normally be larger.

FSS earth station receivers that are deployed with low elevation angles require a path between space and earth to and from the satellite that is clear of ground clutter. For this reason, it should not be assumed that clutter is available to attenuate emissions from an IMT-Advanced device that is located in the azimuth of the main beam of the FSS earth station receiver, especially those that have been installed with low elevation angles.

C.1.3 Adjacent band emissions

Adjacent band compatibility between IMT-Advanced systems in the bands or parts of the bands 3300 – 3400 MHz / 4400 – 4500 MHz / 4800 – 4990 MHz and FSS systems in the bands 3400 – 4200 MHz / 4500 – 4800 MHz have been studied.

- Using the long-term interference criteria, the required separation distance is from 5 km up to tens of km for IMT-Advanced macro-cell and from 900 m to less than 5 km for IMT-Advanced small-cell outdoor deployments, respectively, with no guard band.
- In the case of IMT-Advanced deployment in the adjacent band, the separation distance between IMT Advanced base stations and a single FSS receiver earth station could be reduced by employing a guard band between the edge of the IMT-Advanced emission and FSS allocation.
- For a specific macro-cell deployment scenario studied, the required separation distances from the edge of the IMT-Advanced deployment area are in the range of 30 km to 20 km with an associated guard band of 2 MHz to 80 MHz respectively. Likewise, for a specific small-cell deployment studied, the required separation distances from the edge of the IMT-Advanced deployment area are in the range of 20 kilometres to 5 km with an associated guard band of 1 MHz to 2 MHz respectively.

One study shows that the use of a common representative FSS receive LNA/LNB front-end RF filter provides an insignificant decrease in the required separation distance to protect the FSS earth station receiver from adjacent band emissions. Moreover, inclusion of an RF filter provides little additional rejection of adjacent band emissions over what is already provided by the IF selectivity of the tuner.

C.1.4 LNA/LNB overdrive

The results show that emissions from one IMT-Advanced station can overdrive the FSS receiver LNA, or bring it into non-linear operation, if a macro cell deployment is closer than a required protection distance that ranges from 4 km to 9 km to an earth station in the band 3400 – 4200 MHz and 4500 – 4800 MHz. The required protection distance to prevent overdrive of the FSS receiver by IMT-Advanced emissions ranges from one hundred metres to 900 m for the case of small cell deployments.

C.1.5 Intermodulation

The required protection distance to prevent intermodulation interference produced in the receiver of the FSS earth station from being caused by multiple IMT-Advanced stations ranges from 2 km to 8 km in the case of macro cell deployments. The required protection distance in the small cell deployment scenario to limit the possibility of intermodulation interference being caused into the earth station receivers in the band 3400 – 4200 MHz and 4500 – 4800 MHz is at least 100 metres to as high as half a kilometre.

C.1.6 Conclusions on FSS and IMT sharing

It is concluded in the ITU-R Report that sharing is feasible with FSS earth stations when their location is known, and separation distances can be derived to protect each individual earth station. In the case of earth stations which are ubiquitous and not subject to individual licensing sharing in the same geographical areas is not feasible as it is not possible to specify separation distances. It is also noted that deployment of IMT-Advanced would constrain the deployments of future FSS earth stations in the bands.

C.1.7 Sharing between FS and IMT

In ITU-R Report F.2328-0[62] the outcome of studies into sharing between FS and IMT are provided. The report provides the required separation distances, as shown in Figure C.1, for co-channel coexistence assuming the IMT base station or user terminal is pointing towards the FS receive station.

Figure C.1

Co-channel separation distance

Scenario	Environment	Separation distance
IMT BS into FS receive station	Macro suburban	50.4 – 92 km
	Macro urban	41.7 – 81 km
	Small cell outdoor	13.4 – 45 km
	Small cell indoor	1 – 10 km
IMT UE into FS receive station	Macro suburban	1 – 24 km
	Macro urban	1 – 31 km
	Small cell outdoor	1 – 25 km
	Small cell indoor	< 1 km

62. ITU. Report ITU-R F.2328-0 (11/2014). Sharing and compatibility between international mobile telecommunication systems and fixed service systems in the 3400 – 4200 MHz frequency range.

It can be seen that for co-frequency deployment the required separation distance can range from less than one kilometre to nearly 100 km, depending on the interference scenario and deployment environment. The report notes that the "results are based on worst-case assumptions including the pointing direction of the IMT station and the application of the propagation model."[63] Where there is a limited deployment of fixed links it can be seen that there is the potential for the mobile operators to identify suitable base station locations to meet required separation distances.

In the case of adjacent channel coexistence, the report considers the impact of aggregate interference into a FS receive station. It calculates the necessary rejection necessary for the different environments and scenarios and determines the required frequency separation, assuming different separation distances, based on the OOB emissions and adjacent channel selectivity of the FS receiver. The results are provided in Figure C.2.

Figure C.2

Separation distances and frequency separations results for various interference scenarios and development environments

Scenario	Environment	FS Pointing Angle	Frequency Separation				
			1.0 km	5.0 km	10.0 km	20.0 km	30.0 km
IMT BS into FS receive station	Macro suburban	180 deg 90 deg	– 27.7 MHz	– 9.0 MHz	– 9.0 MHz	– 9.0 MHz	– 9.0 MHz
	Macro urban	180 deg 90 deg	– 25.4 MHz	– 9.0 MHz	– 9.0 MHz	– 9.0 MHz	– 8.9 MHz
	Small cell outdoor	180 deg 90 deg	– 9.0 MHz	25.8 MHz 8.8 MHz	19.8 MHz 8.3 MHz	9.0 MHz 6.2 MHz	9.0 MHz 0.9 MHz
	Small cell indoor	180 deg 90 deg	6.3 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz
IMT UE into FS receive station	Macro suburban	180 deg 90 deg	6.3 MHz 0.0 MHz	5.7 MHz 0.0 MHz	3.2 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz
	Macro urban	180 deg 90 deg	8.2 MHz 0.0 MHz	7.3 MHz 0.0 MHz	5.4 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz
	Small cell outdoor	180 deg 90 deg	6.6 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz
	Small cell indoor	180 deg 90 deg	6.0 MHz 0.0 MHz	2.2 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz	0.0 MHz 0.0 MHz

Note: Frequency separation is the channel centre to channel centre separation and not guard bands.
Source: ITU-R F.2328-0

The adjacent channel results show that in the worst-case scenarios (FS receive station pointing directly toward a macro deployment of IMT base stations (180 degrees)) the separation distance needed to protect the FS station exceeds 30 km. However, there is the potential to mitigate by using a mix of frequency and geographic separation and separation distances can be reduced to a few kilometres with frequency separation of "about one or two channel bandwidths".

In the case of small cell indoor use, the requirements are significantly reduced. The results also show that the interference from the IMT UE is relatively low. It is noted that "certain assumptions such as FS receive station placement and direction, use of propagation model, etc. overestimate interference from the IMT network".

63. Calculations used ITU-R. P.452-14 which is a conservative approach – assumes smooth Earth terrain profile.

C.1.8 Summary

Figure C.3 provides a summary of the findings based on the ITU studies

Figure C.3

Coexistence potential between IMT and incumbent services in 3300 – 4200 MHz band

Incumbent service	Co-channel	Comment	Adjacent channel	Comment
FSS (Limited ES deployment)	Yes	Where the location and technical characteristics are known for earth stations there is the potential to coordinate on an individual ES basis. Whilst ITU studies estimated separation distances between 5 and tens of kms for IMT small indoor cells and separation distances of tens of kms up to 525 kms for outdoor IMT deployments. Distances can be reduced if there is natural and artificial shielding of a site. If protection is only for long term interference separation distances are less.	Yes	Where the location and technical characteristics are known for earth stations there is the potential to coordinate on an individual ES basis. ITU studies estimated separation distances of between 900m and 5 km for IMT small cell outdoor deployments and tens of kms for macrocell deployments. There is the possibility of introducing guard bands that can reduce the necessary separation distance.
FSS (Ubiquitous deployment, e.g. TVRO and VSATs)	No	There will be a significant number of receivers (e.g. TVRO and VSATs) with the majority of locations unknown. Impossible to define any coordination and mitigation measures.	Yes	Coordination not feasible but potential to coexist with the use of mitigation measures, including: Guard bands, Improved performance receivers, Addition of filters to satellite receivers IMT base station practical deployment (e.g. location, antenna pointing and downtilting)
FS (Limited deployment of point to point links)	Yes	No single coexistence parameters can be defined so will need to coordinate on case by case basis.	Yes	No single coexistence parameters can be defined so will need to coordinate on case by case basis.
FS (Ubiquitous deployment of point to point links)	No	Impossible to derive generic coordination to allow for overlapping channel sharing in same geographic area.	Yes	Coordination is not feasible if there are large numbers of fixed links. There may be the potential to use frequency separation if fixed links can be migrated to part of the frequency band. Where there are 1 for n systems where n is a large number and therefore the majority of frequencies are being utilised this is unlikely to be a feasible option. Geographic sharing might be an option depending on the geographic spread of fixed links.
FS (Point to multipoint / BWA)	Yes	Only feasible on a geographic sharing basis and will depend on technologies deployed. e.g. WiMAX and IMT networks can share. Will need to define technical licence conditions such as BEMs and synchronisation between networks.	Yes	Should be feasible without guard bands depending on technologies deployed.
Radiolocation / Radars	Possibly	Separation distances can be large even with mitigation (e.g. improved radar receiver performance and decreased IMT emissions). Coexistence only possible if small number of radars and their location is known so detailed coordination can be undertaken. Potential for remediation of radar receivers to improve coexistence. Indoor deployment of IMT may be feasible.	Yes	Likely to require separation distance around radars as adjacent channel interference into IMT BSs from radars may be experienced at distances of tens of kms. Alternatively could use a guard band of around 20 MHz. However shielding and other mitigation measures such as avoiding pointing towards radars can significantly reduce likely impact.

Source: ITU-R Report S.2368-0, June 2015

C.2 CEPT / ECC

ECC Report 203[64] considers the necessary, least restrictive, technical sharing conditions between Mobile / Fixed Communications Networks (MFCN) and defines different Block Edge masks (BEMs) depending on whether MFCN networks are synchronised (see Appendix D). Additionally, the report includes coexistence studies for other services for both in-band and out-of-band scenarios. The in-band (co-channel) services considered are FSS, FS and BWA and the out-of-band (adjacent channel) services are civil and military Radiolocation.

C.2.1 BWA

In the case of BWA it is assumed that these are MFCN networks and that sharing can be facilitated through the use of BEMs and synchronisation. For example, it is possible for WiMAX and IMT networks to share on a geographic basis.

C.2.2 Fixed Services

In the case of FS systems their deployment and technical characteristics vary so using a single coexistence parameter (separation distance, guard band or signal strength) is not practical. It is necessary to undertake analysis on a case-by-case basis which may not be feasible if there is significant use of these systems. In ECC Report 203 a number of general observations were made based on the interference analysis (mobile service into point to point links and vice versa):

- Overlapping channel sharing is not feasible in the same geographic area and with larger frequency separation and distances coordination is needed based on the actual characteristics of the two services.
- Coexistence may be more difficult if there are multiple interferers.
- Interference from FS systems to mobile systems may exceed the acceptable interference level.

However, in the case of point to multipoint systems it was considered that coexistence between mobile to mobile adjacent channel coexistence was similar to mobile to multipoint. In the case of base station to base station interference measures such as frequency separation and / or additional filters may be necessary. Ensuring that the MFCN BS does not interfere with FS is sufficient to guarantee protection of the FS from MFCN user equipment.

C.2.3 Fixed Satellite Service

FSS earth stations have a range of deployments and characteristics so it is not considered possible to define a single separation distance, guard band or signal strength limit to ensure coexistence with MFCN. Coordination is necessary on a case by case basis.

The report includes some general observations on coexistence between MFCN and FSS:

- Separation distances for coexistence vary considerably depending on type of equipment and deployment (e.g. tilt and clutter) but can be large.
- MFCN user equipment (UE) impacts earth stations less than base stations, so separation that prevents interference from base stations will also protect earth stations from UE interference.
- There are several mitigation techniques that can be applied, in particular site shielding of earth stations.
- Interference from FSS satellites to MFCN may exceed the acceptable interference level, but in most cases only by a small margin.

Figure C.4 shows the outcome, upper and lower bounds, of analysis undertaken for a range of different studies making different assumptions about FSS ES antenna elevation angles, propagation models, interference apportionment, BS down tilt, etc.

64. "Least Restrictive Technical Conditions suitable for Mobile / Fixed Communications Networks (MFCN) including IMT in the frequency bands 3400 – 3600 MHz and 3600 – 3800 MHz. 14 March 2014.

Figure C.4

Separation distances (km) for generic (flat terrain) interference analysis

	Macro BS	Micro BS	Mobile Station
Co-channel Long-term Single interferer	33 – 70	15 – 50	0 – 1.5
Co-channel Long-term Aggregate interference	51 – 61	46 – 58	0 – 1.5
Co-channel Short-term Single interferer	34 – 430	N.A.	1.5
Adjacent channel Long-term Single interferer	0.07 – 80	2 – 51	0.5 – 32.5
Adjacent channel Long-term Aggregate interference	0.35 – 45	4 – 35	N.A.
LNA/LNB saturation Long-term Single interferer	10 – 30	0.6 – 2	0.17 – 0.55

Mitigation techniques that were investigated included:

- Base station sector disabling in direction of earth station,
- Use of MIMO antennas at base station (also potential now to use beam forming antennas),
- Earth station shielding,
- Base station antenna down tilting, and
- Dynamic spectrum allocation using, for example, a database.

C.2.4 Radiolocation

Again, due to the varying characteristics of radars and their deployment coexistence needs to be determined on a case by case basis.

General observations in the report include:

- Separation distances due to interference from MFCN to radars can be large but may be limited to a few kilometres if there is sufficient frequency separation to enable roll-off for MFCN unwanted emissions and radars have good selectivity.
- There are mitigation techniques which can reduce the separation distance or frequency separation required. In particular, for adjacent channel/ adjacent band interference, improved radar receiver performance and decreased MFCN unwanted emissions can be a solution.
- With regard to blocking of radars by mobile systems it may be necessary to increase the separation between the radar and the mobile service base station or improve the radar performance.
- Regarding interference from radars to MFCN networks, it is concluded that adjacent channel interference may be experienced by MFCN stations at distances of up to tens of kilometres.

C.3 Qualcomm submission to APT

Qualcomm has undertaken three separate studies to inform coexistence for potential frequency arrangements for 5G NR where there is extensive use of the 3400 – 3600 MHz band such as in Vietnam. These have been submitted for information to the APT Wireless Group for its meeting, 1-5 July 2019.[65]

Study 1 considers the coexistence requirements at the 3400 MHz boundary when 3300-3400 MHz is used for 5G NR and FSS DL operates in the 3400-3700 MHz band, using 36 MHz bandwidth transponders. The interference mechanism is unwanted out of band emissions from the NR transmitters into the FSS receivers. The minimum protection distance, and where necessary additional mitigation, is calculated for a number of different scenarios:

- Different guard bands between the two services of 0 MHz (5G NR uses full 100 MHz bandwidth), 10 MHz (5G NR uses 90 MHz bandwidth) and 16 MHz (5G NR uses 90 MHz bandwidth and FSS transponder centre frequency provides additional 6 MHz guard band).
- Different types of 5G NR base stations: macro, micro and pico cell.
- Different protection criteria for FSS: 6% and 1% allowed interference to FSS.

The outcome of this study is shown in Figure C.5. It can be seen that in some scenarios to reduce the separation distances to below 1 km it is necessary to fit BS transmitter filters or alternatively reduce the BS transmitted power to reduce the filter requirement. Figure C.6 shows the trade-off between separation distances between BS and FSS receiver and required isolation from BS transmitter filter. Site shielding around FSS earth stations can also reduce the need for filters as potentially it can provide up to 33 dB isolation.[66]

Figure C.5

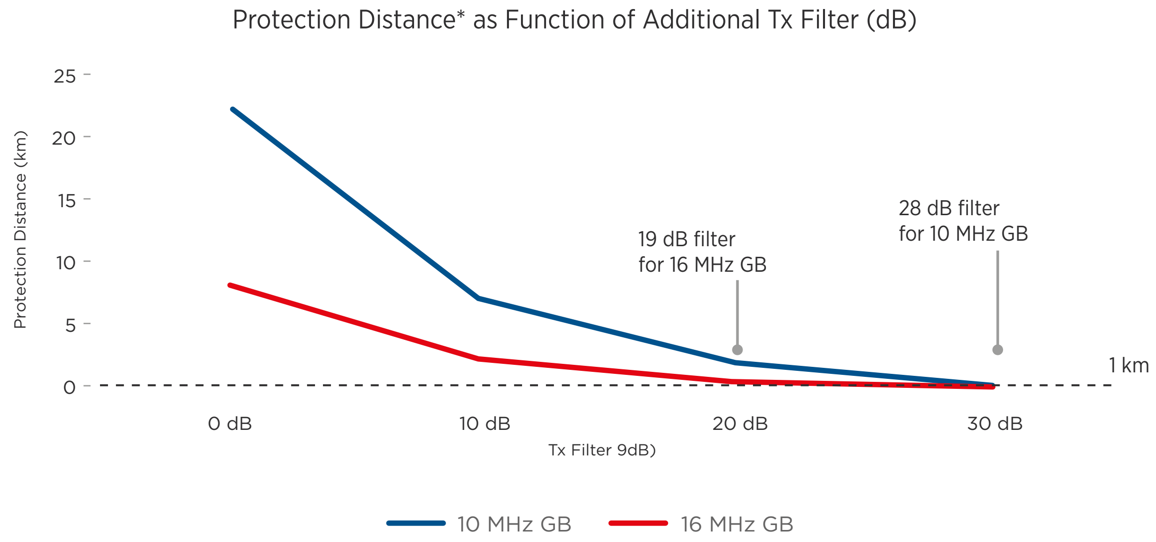
Protection distances and isolation needed from BS transmitter filter to provide protection to FSS

5G NR BS class	FSS error protection 6% degradation			FSS error protection 1% degradation		
	0 MHz guard-band	10 MHz guard band	16 MHz guard band	0 MHz guard band	10 MHz guard band	16 MHz guard band
Macro call		<1 km separation plus 3 dB Tx filter	8.34 km separation, or <1 km separation plus 19 dB Tx filter		<1 km separation plus 35 dB Tx filter	20.5 km separation, or <1 km separation plus 29 dB Tx filter
Micro cell	<1 km separation plus 3 dB Tx filter	0.6 km separation			1.4 km separation, or <1 km separation plus 4 dB Tx filter	
Indoor / pico cell		0.1 km		0.13 km	0.1 km	

65. Qualcomm. Coexistence analysis between 5G NR and FSS in different scenarios in the 3300-4200 MHz band. Submission to 25th meeting of the APT Wireless Group, 1-5 July 2019.
66. Based on ITU-R SF.1486.

Figure C.6

Impact of transmitter filter deployment on necessary protection distances between BS and FSS



*6% degradation of FSS protection criteria
Source: Qualcomm

Study 2 considers the 3600 MHz boundary between 5G NR in the band 3700-4200 MHz and FSS DL in 3400-3600 MHz (transponders with 36 MHz bandwidth). The study calculates the minimum protection distance necessary to avoid impact of BS unwanted emissions on FSS LNA/LNB receivers for a number of different scenarios:

- Different guard bands, reducing the spectrum available to 5G NR, of 100 MHz, 41 MHz and 20 MHz.
- Different LNA gain of 50 dB or 60 dB.
- Different types of 5G NR base stations: macro (50 dBm /100 MHz and 24 dBi antenna gain), micro (31 dBm/100 MHz and 12 dBi antenna gain) and pico cell (24 dBm/100 MHz and 5 dBi antenna gain).

The outcome of the analysis is summarised in Figure C.7. It can be seen that the size of the guard band does not affect the separation distances required to avoid saturation of the LNB. Necessary protection distances are less than 1 km for micro and indoor / pico base stations. In the case of macro base stations, the separation distances can be reduced to below 1 km by the addition of filters (BS transmitter and FSS Rx). Reducing the BS transmitter power can reduce any filter requirements.

Figure C.7

Protection for coexistence between single carrier 100 MHz 5G NR radio and FSS earth station

5G NR BS class	Protection for unwanted emission (separation distance)			Protection for LNB saturation – LNA gain of 50 dB (separation distance)			Protection for LNB saturation – LNA gain of 60 dB (separation distance)		
	20 MHz GB	41 MHz GB	100 MHz GB	20 MHz GB	41 MHz GB	100 MHz GB	20 MHz GB	41 MHz GB	100 MHz GB
Macro	7.89 km (Note 1)	0.01 km	0.01 km	1.02 km (Note 2)			3.21 km (Note 2)		
Micro	0.56 km	0 km	0 km	0.02 km			0.05 km		
Indoor / pico cell	0.06 km	0 km	0 km	0 km			0 km		

Note 1: Separation distance can be reduced to less than 1 km by 18 dB BS NR transmitter filter.
Note 2: Separation distance can be reduced to less than 1 km by addition of front-end-filter at FFS Rx ES of 5 dB for LNA gain of 50 dB and 15 dB for LNA gain of 60 dB.

Where two carrier BSs are used they need to take account of aggregate power and protection distance will increase. Protection distances in such cases can be reduced by the addition of front-end filters to the FSS Rx station.

Study 3 addresses the specific situation of FSS TT&C operating on frequencies 3694.5 and 3695.5 MHz co-channel with 5G NR. The study calculates a minimum isolation of 145 dB necessary between macro NR and FSS, which required more than 20 km isolation distance. In the case of micro and pico-cells the distance is significantly lower (1.73 km to 0.19 km). As for the other studies mitigation such as lower BS transmitter power and FSS receiver site shielding can reduce the necessary separation distances.

Appendix D: Synchronisation between mobile networks

With 5G TDD systems operating in the 3.5 GHz band there are two levels of synchronisation which are needed, namely inter-operator synchronisation within a country and synchronisation across borders.

Firstly, inter-operator synchronisation within a country is needed. If 5G macro-cell networks are not synchronised, arguably an additional guard band and improved filtering of transceivers would be required. This is problematic in the ASEAN context given the limited C-Band/3.5 GHz spectrum which is available. Thus, synchronisation of 5G macro-cell networks becomes the best way to avoid interference. In this way, efficient spectrum usage is ensured – no additional guard band is required – and network equipment costs can be reduced. This has been the approach adopted in Australia, China, the European Union,[67] Japan and South Korea.

Secondly, in relation to synchronisation across borders, synchronisation comprises three elements, clock synchronisation, slot synchronisation and frame structure synchronisation (i.e. the same frame structure).

In relation to clock synchronisation there are two options for the MNOs - Type 1: distributed synchronisation scheme based on satellite (i.e. GPS) which is used in Japan and other countries or Type 2: centralised synchronisation scheme based on IEEE 1588V2 system (which is used in Europe). It is also possible to use a combination of methods in order to improve reliability (e.g. China). If the MNOs use the same frame structure, then frame structure is synchronised.

The most difficult aspect is the slot synchronisation, which defines the time that each slot begins and ends. As it may not be feasible to have neighbouring countries across ASEAN synchronise their slots, the full synchronisation across border might not be feasible though it is optimal. If full synchronisation is not possible, it is preferable if the same frame structure is adopted in neighbouring ASEAN countries. Adopting the same frame structure results in less interference and hence requires less regional coordination efforts.

When unsynchronised TDD networks are deployed on either side of a border (regional or national) detrimental base station to base station, base station to user terminal, user terminal to base station and user terminal to user terminal co-channel interference paths can occur. In such deployment scenarios, coordination threshold requirements are mainly determined by base station to base station interference as the height and EIRP of base stations are higher than those of user terminals. To provide the necessary protection it is necessary to define exclusion zones or coordination requirements within which detailed coordination needs to be implemented.

A number of mitigation measures can be deployed to minimise base station to base station interference, such as:

- Antenna shielding,
- Antenna pointing away from borders,
- Reducing antenna heights,
- Reducing transmitter power,

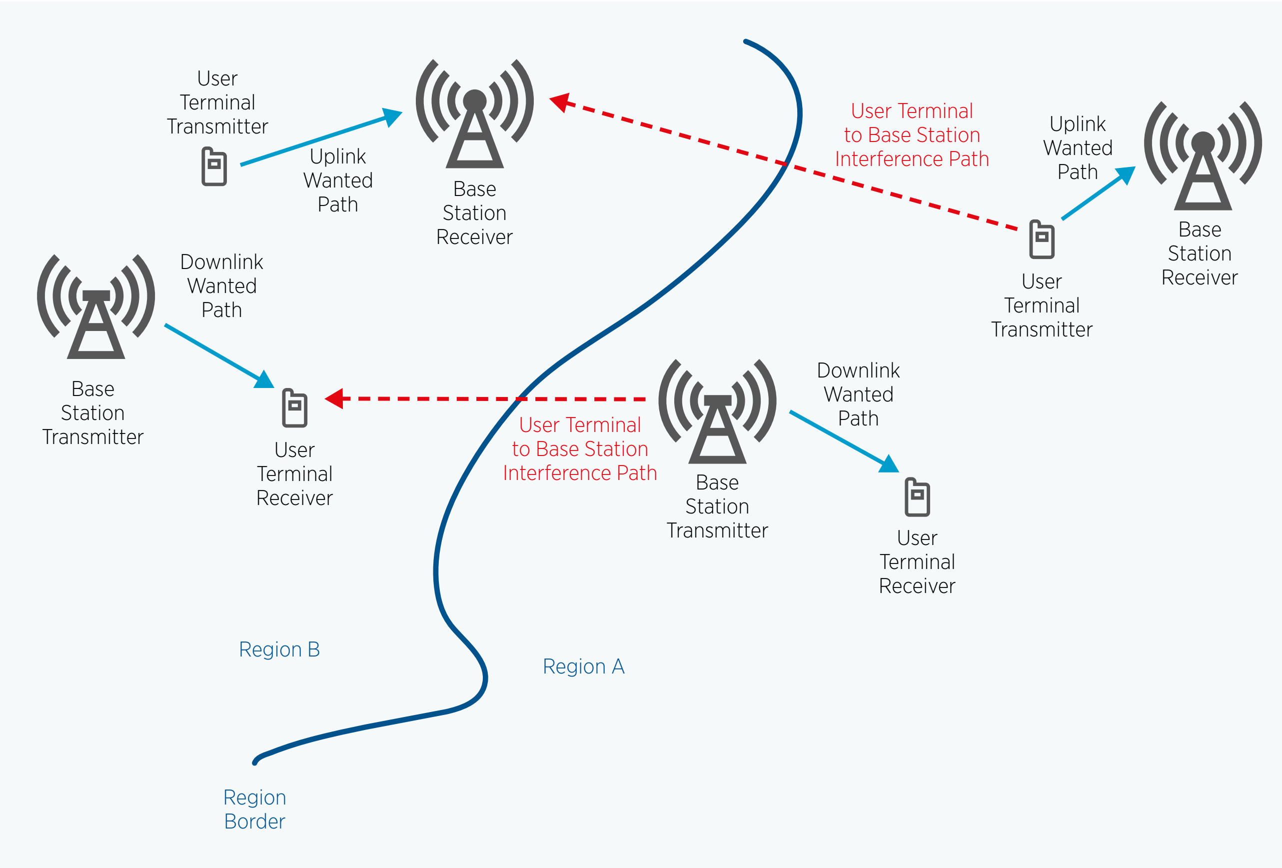
67. See ECC Report 296, National synchronization regulatory framework options in 3400-3800 MHz: a toolbox for coexistence of MFCNs in synchronised, unsynchronised and semi-synchronised operation in 3400-3800 MHz, Approved 8 March 2019

- Antenna downtilting,
- Use of directional, smart antennas, and
- Deployment of heterogenous networks close to the border (i.e. deploy micro and pico base stations)

However, another approach as noted above, involving synchronisation of networks on either side of the border will eliminate base station to base station interference paths and coordination threshold conditions are driven by interference paths between base stations and user terminals as shown in Figure D.1.

Figure D.1

Interference from Region A into Region B when synchronised TDD networks are deployed



The benefits of synchronisation for geographically adjacent operation are scenario dependent. As well as terrain practical network planning can limit the potential for interference. For example,

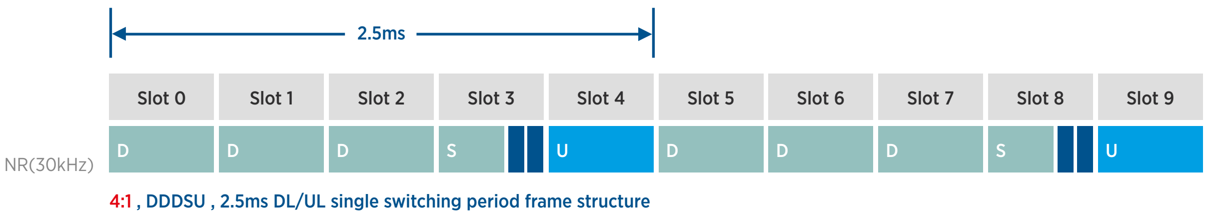
- Mobile terminal receivers may be deployed indoors or in the clutter so additional losses may apply and allow base stations to be deployed closer to the border.
- Mobile terminal receivers are generally not at a single location over any considerable period of time so the probability of interference and the impact will be less than for fixed wireless access systems.
- When mobile receivers are on the edge of coverage, and most prone to interference from a neighbouring base station transmitter, it is likely that they will automatically use a different frequency as mobile terminals are multi-band devices.
- In the case of fixed terminal receivers, they use directional antennas so can be located on buildings to minimise the potential for interference.

D.1 Frame Structure

It is expected that DL traffic will continue to dominate mobile data traffic in 5G networks in ASEAN, in particular for eMBB applications it may go beyond 90 percent of the overall mobile data traffic. Anticipating this trend, we recommend for C-band 5G only macro-cell networks a 2.5 ms single DL/UL switching period frame structure (DDDSU)[68] for its high system capacity and efficiency as shown in Figure D.2 below. The other advantage of the 4:1 is that it facilitates future evolution to URLLC scenarios as it has a lower reduced round trip time (RTT).[69]

Figure D.2

Recommended National Frame Structure



If synchronisation is not deployed, then this requires more stringent block edge masks to be deployed to limit base station to base station interference. For example, in the UK Ofcom identified two options for release of the 3400 – 3600 MHz band.[70]

- Option 1: Mandate a TD-LTE frame alignment[71] but leave it up to individual licensees whether to adopt the specified frame structure. This would allow a degree of flexibility. If a licensee chose not to adopt a specified structure, they would need to use a restrictive block edge mask.

- Option 2: Mandate synchronisation and define the full technical configuration compatible with TD-LTE, including the frame alignment and frame structure. In this case, all licensees would be able to use a permissive mask.

Ofcom adopted option 1 to provide maximum flexibility for the operators. In contrast, the South Korean Ministry of Science, ICT and Future Planning (MSIP) in the June 2018 auction of 5G spectrum determined that synchronisation in the bands 3.5 GHz and 28 GHz will use the same frame structure of DDDSU as recommended above. Japan's Ministry of Internal Affairs and Communications (MIC) in relation to the 3.4 – 3.6 GHz band requires synchronisation between all of Japan's domestic MNOs and a 3:1 DL:UL ratio. China's MIIT is actively organising MNOs and relevant stake holders to negotiate a single frame structure for synchronisation of 5G networks in 3.5 GHz band

In Australia on 17 June 2018 following industry consultation,[72] the then Minister of Communications on advice from ACMA issued the *Australian Communications and Media Authority (Radiocommunications Licence Conditions—3.4 and 3.6 GHz Bands Interference Management) Direction 2018*.[73] The direction also specified the adoption of a common frame structure (or equivalent in terms of duration and timing of downlink and uplink segments) if and when required to support the synchronisation fall-back solution. The frame structure specified supports a 3:1 downlink-to-uplink ratio, with the arrangements taking affect from 30 March 2020.[74]

68. Down link dominant special slot.
69. Note this is different for TDD 2.6 GHz where there is 5G coexistence with LTE TDD network. In such circumstances, a 5 ms frame structure of 8:2 (DDDDDDDSUU) should be adopted in order to be compatible with LTE TDD network.
70. Refer to https://www.ofcom.org.uk/__data/assets/pdf_file/0027/68337/Public_Sector_Spectrum_Release_statement.pdf
71. Refer to http://niviuk.free.fr/lte_tdd.php
72. Refer to ACMA, *3.4 GHz and 3.6 GHz band spectrum licence technical framework— Outcomes and response to submissions* August 2018
73. Available at https://www.legislation.gov.au/Details/F2018L01045
74. In Australia, Telstra has argued for more extensive synchronisation (or refarming of the 3.5 GHz band) due to its view that "*TDD technology has a "ripple" effect when it comes to synchronisation and frame structures. Different base stations on the same frequency in the same area have to use identical frame structures and timing. This impacts all the surrounding co-channel areas, which also need to fall into line. And then, due to imperfect out-of-band emissions and interference rejection, the frequency adjacent services also need to align, and the services next to them need to align. And so on, across all networks and sites." See Telstra, Optimising Arrangements for the 3400-3575 MHz band, Public submission to ACMA, 31 May 2019*. Available at https://www.acma.gov.au/-/media/Spectrum-Transformation-and-Government/Issue-for-comment/IFC-12-2019/Telstra-submission_IFC12_2019-pdf.pdf

Appendix E: ASEAN C-band national satellite use

Brunei, Cambodia and the Philippines are the only countries not to have one or more national satellites operating in the 3.4 – 4.2 GHz band. Figure E.1 provides a list of national satellites for each ASEAN country.

Figure E.1

Overview of national satellites in ASEAN countries

Country	Satellite	Frequencies (MHz)	Launch date	Expected lifetime	Transponders	Services
Lao PDR	LaoSat 1	3400 – 3700	Nov. 2015	15 years	14 C-band 8 Ku-band	TV channels 3435-3655 MHz
Indonesia	Palapa D1	3400 – 4200	Aug. 2009	10 years	24 C-band 11 extended C-band 5 Ku-band	TV channels 3429-4194 MHz
	BRIsat	4000 onwards	June 2016	15+ years	36 C-band 9 Ku-band	TV channels from 4058 MHz Secure banking communications for >10,600 operational branches, 237,000 electronic channel outlets, nearly 53m customers
	Telkom 3S	3400 – 4200	Feb. 2017	15+ years	24 C-band 8 extended C-band 10 Ku-band	TV channels 3404-4196 MHz
	Telkom 4 (Merah Putih)	3800 upwards	Aug. 2018	15+ years	60 C-band	TV channels 3827-3977 MHz
	PSN 6 (Nusantara Satu)	3400 – 4200 MHz	Feb. 2019	15+ years	38 C-band 18 Ku-band	Voice & data comms., broadband Internet, video distribution

Country	Satellite	Frequencies (MHz)	Launch date	Expected lifetime	Transponders	Services
Myanmar	Intelsat 39 (planned)	3625 – 4200 MHz	2019	15+ years	C-band and Ku-band	Planned to provide broadband and video distribution. (Replaces Intelsat 92)
Vietnam	Vinasat 1	3400 – 3700	April 2008	15+ years	8 C-band 12 Ku-band	TV channels 3451-3590 MHz Voice, video and internet
Singapore	ST-2		May 2011	15 years	10 C-band 41 Ku-band	TV channels 3590-3671 MHz
Thailand	Thaicom5	3400 – 4200	May 2006	19+ years (extended from 12 years) 25 C-band 14 Ku-band	25 C-band 14 Ku-band	TV channels 3408-4160 MHz. Internet
	Thaicom6	3700 – 4200	Jan. 2014	15 years	18 C-band 8 Ku-band	TV channels 3711-4169 MHz
Malaysia	MEASAT 3	3400 – 4200	Dec. 2006	18+ years (till 2023)	24 C-band 25 Ku-band	TV channels 3423-3652 MHz
	MEASAT 3a	3700 – 4200	June 2009	18+ years (till 2027)	12 C-band 12 Ku-band	TV channels 3705-4164 MHz DTH broadcasting
	Africasat 1a	3700 – 4200	Feb. 2013	15+ years (till 2028)	24 C-band 12 Ku-band	TV channels 3715-4163 MHz
	MEASAT 3D (planned)	3400 – 4200	H2 2021 (expected)	18+ years (expectation from prior assignments)	TBC	

Source: Satbeams, Lyngsat industry

Appendix F: Glossary

Term	Description
3.5 GHz	3.3-3.8 GHz
5G	Fifth Generation (mobile network)
ACMA	Australian Communications and Media Authority
AITI	Authority for Info-communications Technology Industry (AITI)
Anatel	National Telecommunications Agency (Brazil)
APT	Asia Pacific Telecommunity
ARFM	Authority of Radio Frequency Management (Vietnam)
ASEAN	Association of Southeast Asian Nations
BEM	Block edge mask
BPF	Band pass filter
BS	Base station
BWA	Broadband wireless access
CA	Communications Authority (Hong Kong)
CB	Citizen Band
C-band	3.3 - 4.2 GHz
CBRS	Citizen Band Radio Service
CEPT	European Conference of Postal and Telecommunications Administrations
dB	decibel
DL	downlink
DSA	Dynamic Spectrum Access
DTH	Direct-to-home satellite TV
DVB-S	Digital Video Broadcasting - Satellite
ECC	Electronic Communications Committee
EFTNS	External fixed telecommunications network service
EIRP	Equivalent isotropic radiated power
eMBB	Enhanced Mobile Broadband
ES	Earth Station
FSS	Fixed-Satellite Service
HCMC	Ho Chi Minh City
IMDA	Infocomm Media Development Authority (Singapore)

Term	Description
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU	International Telecommunication Union
LNA	Low Noise Amplifier
LNB	Low Noise Block Downconverter
LOS	Line-of-sight
LSA	Licensed Shared Access
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MCMC	Malaysian Communications and Multimedia Commission
MFCN	Mobile / Fixed Communications Networks
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine-Type Communications
MNO	Mobile network operator
MS	Mobile service
MSS	Mobile Satellite Service
NBTC	National Broadcasting and Telecommunications Commission (Thailand)
NCC	National Communications Commission (Taiwan)
NECN	National Emergency Communication Network
NLOS	Non-line-of-sight
NR	New Radio
Ofcom	Office of Communications (United Kingdom)
pfd	Power flux density
PTD	Posts and Telecommunications Department (Myanmar)
RF	Radio frequency
RSA	Recognised Spectrum Access (for receive-only earth stations)
RTT	Round trip time
SMATV	Satellite Master Antenna Television
SPETS	Self-provided external telecommunication systems
TDD	Time Division Duplex
TD-LTE	Time-Division Long-Term Evolution
TT&C	Telemetry, tracking, and command
TVPC	Television Production Centre
TVRO	Television Receive Only
TVWS	Television White Space

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