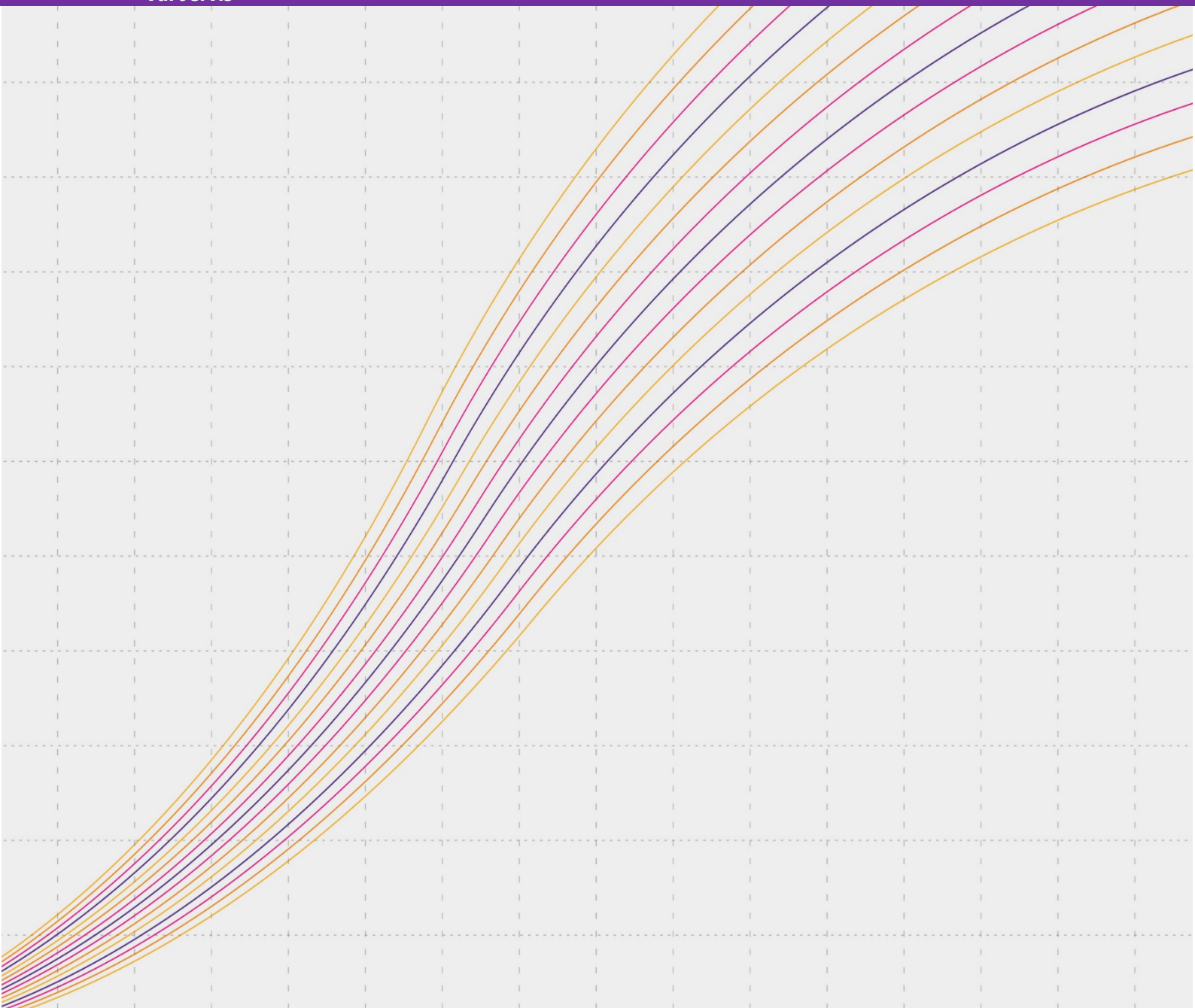


Coexistence of terrestrial and satellite services at 26 GHz

September 2019

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About Plum

Plum is an independent consulting firm, focused on the telecommunications, media, technology, and adjacent sectors. We apply extensive industry knowledge, consulting experience, and rigorous analysis to address challenges and opportunities across regulatory, radio spectrum, economic, commercial, and technology domains.



About this study

This study is undertaken for DCA and provides a critical review of sharing issues concerning the use of 27—27.5 GHz band by IMT services and their impact on FSS uplinks

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Summary

This report was commissioned by DCA to provide an independent assessment of the risk of interference to the NBN Co. Sky Muster satellite system from new spectrum assignments proposed by ACMA.

A detailed technical review of the ACMA modelling, and responses to it by NBN Co. has been undertaken.

The study concludes that the risk of interference is insignificant and that the mitigating licence conditions proposed by ACMA are appropriate, although these might impose modest constraints on some deployments.

1. Introduction

It is proposed, by the ACMA, to reallocate spectrum in the 26 GHz band for use by 5G wireless broadband services. Part of this spectrum (27.0-27.5 GHz) is currently used to provide uplinks from ten Australian Earth Stations to the two geostationary satellites forming the 'Sky Muster' network operated by NBN Co, 'NBN'.

Although ACMA modelling previously submitted to ITU-R Task Group 5/1 suggests that there is no risk of interference to the satellite uplinks from new terrestrial services, NBN have undertaken a separate analysis which indicated that such interference is possible.

The DCA has commissioned this study to review all relevant material, to make an independent assessment of the risk of interference to NBN's satellite services, and to comment on the proposed mitigating measures.

Plum Consulting have substantial experience in undertaking detailed statistical and deterministic modelling of complex spectrum sharing situations involving terrestrial systems and both GSO and NGSO satellite systems. These studies have been undertaken for regulators and for both terrestrial and satellite network operators. Plum staff were closely involved in developing the new propagation models (P.2108 and P.2109) used in the work of TG5/1, and have been undertaking propagation measurements at 26 GHz for several years.

1.1 Background

In September 2018, the ACMA published an Options Paper ('Wireless broadband in the 26 GHz band'¹). This formed the subject of a consultation that closed on 2nd November 2018.

The Options Paper noted that, if the 26 GHz band were to be released for wireless broadband services, a risk would exist of interference being caused to FSS uplinks operating above 27.0 GHz. Appendix 1 of the Paper notes that:

"Australia has [...] made a number of contributions to TG 5/1 in relation to coexistence between IMT-2020² and FSS³ (E-s). These contributions include a statistically-based sharing study, which considers the aggregate effect of IMT-2020 deployments at all locations across parts of the Earth that are visible to a satellite."

"The results of this Australian study indicate that the aggregate interference level will be at least 31 dB below the satellite system noise level, indicating that coexistence is feasible. These results are generally in line with other studies considering IMT-2020/FSS coexistence (as detailed in Table 6 below)."

In October 2018, a domestic working group was set up to study inter-service coexistence issues, particularly with respect to the (passive) EESS at 24 GHz and the FSS (uplink) above 27.0 GHz. This group worked largely by correspondence, concluding in February 2019.

One of the respondents to the consultation on the Options Paper was NBN Co, who operate the Sky Muster satellite system. This uses a pair of high-throughput satellites at locations on the GSO arc of 140°E and 145°E. Uplink (gateway) links to the satellite operate above 27 GHz from 10 Earth Station sites, located across Australia. NBN set out a number of concerns regarding the ACMA modelling submitted to TG5/1. The gist of the concerns is that (i) the parameters assumed for the FSS underestimate the

¹ <https://www.acma.gov.au/theACMA/-/media/15EF7BCEB00E4297B99953C9CDC27125.ashx>

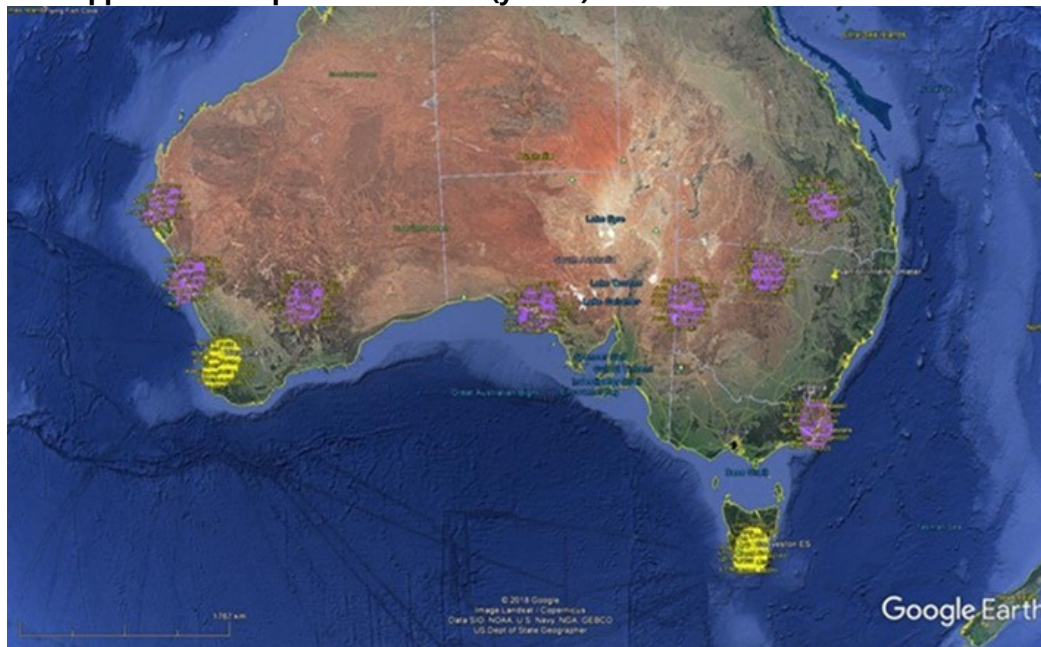
² IMT-2020; the formal ITU term for 5G technologies and systems

³ The 'Fixed Satellite Service', i.e. systems such as Sky Muster

sensitivity of the uplink to interference and (ii) that the characteristics used in modelling future broadband services at 26 GHz are not realistic. Undertaking their own modelling using revised parameters they asserted⁴ that interference may be significantly in excess of the satellite noise level, rather than 31dB below it.

In April 2019 a 'Decision paper' (*'Future use of the 26 GHz band—Planning decisions and preliminary views'*⁵) was released by the ACMA, proposing a strategy for the entire range 24.25–27.5 GHz (the 'wider 26 GHz band'). This set out an intention to licence the sub-band 25.1–27.5 GHz, by auction, in 34 geographical areas, and in 100 MHz blocks. Annex B of the document summarises the work of the group on inter-service sharing issues, while Annex C describes the ACMA response to the NBN's modelling; although ACMA continue to assert that the risk of interference is low, a number of additional mitigating measures relating to base station and fixed UE antenna pointing are proposed. Annex F sets out the two areas (southern Western Australia and Tasmania) where the additional conditions will apply to spectrum licences and the ten areas where such conditions will apply to apparatus licences.

Figure 1.1: Areas where additional conditions would apply to apparatus licences (purple) and to both apparatus and spectrum licences (yellow)



In May 2019, ACMA published a draft 'Reallocation Recommendation'⁶ and accompanying Written Notice. This Recommendation confirms the intention to apply the 'additional conditions' set out in the decision paper to licences in Tasmania and Southern Western Australia. The public consultation on these proposals for the band closed on 6th June 2019.

In the remaining sections, we consider the detail of the technical modelling undertaken, the choice of the parameter values suggested by each party and the appropriateness of the mitigating measures proposed by ACMA.

⁴ See documents: <https://www.acma.gov.au/-/media/Spectrum-Transformation-and-Government/Issue-for-comment/IFC-32-2018/NBN-submission-pdf.pdf> and <https://www.acma.gov.au/-/media/Spectrum-Transformation-and-Government/Issue-for-comment/IFC-32-2018/NBN-submission-attachment-pdf.pdf>

⁵ Future use of the 26 GHz band—Planning decisions and preliminary views

⁶ <https://www.acma.gov.au/theACMA/-/media/E32D8C7AA2A647E085F6D37C2E6503A0.ashx>

2. Analysis of key issues raised in NBN and ACMA technical studies

ACMA's first contribution to TG 5/1 regarding interference from IMT BS and UE transmitters into FSS satellite receivers was in September 2017. In the submission, ACMA undertook a detailed statistical simulation analysis to model the impact of aggregate interference using modelling parameters and analysis methodology agreed within TG 5/1. There were two subsequent submissions, in January and April 2018, providing updates on the analysis. ACMA's analysis results suggested that calculated I/N ratios were well below the assumed I/N threshold levels and significant protection margins existed. Therefore, it was concluded that the co-channel spectrum sharing within 27–27.5 GHz would be feasible between IMT and FSS networks. A more detailed overview of these submissions together with the summary of modelling assumptions is provided in [Appendix C](#).

The outcome of ACMA's TG 5/1 submissions were reflected in the 'Options' paper published in September 2018 which was the subject of a consultation closed in November 2018. NBN was one of the respondents and provided its views on the feasibility of sharing between its Sky Muster network and future IMT systems. In the same timescale, a technical Working Group was convened in which all interested parties (including NBN) were able to explore technical issues in detail.

In its formal submission in response to the consultation, NBN primarily argued that studies submitted to TG 5/1 were generic and did not reflect the NBN's Sky Muster network characteristics. It was also argued that the implications of IMT network parameters differing from those assumed in TG 5/1 studies needed to be examined when assessing the potential for sharing. Consequently, NBN submitted its own analysis based on re-running the ACMA compatibility model studies with revised ('re-baselined') parameters for NBN's Sky Muster system and performing sensitivity analyses with different IMT parameter values. The results of NBN's analysis showed that the protection margin calculated in ACMA's TG 5/1 submissions would be reduced significantly (from 32 dB to 10 dB) if the re-baselined satellite parameters were incorporated. Furthermore, it was shown, as part of the sensitivity analysis, that sharing would not be feasible with certain modified IMT system parameters (it was predicted that the assumed I/N criterion would be exceeded by a significant margin of 11 dB).

In the remainder of this section, a comparison of modelling assumptions and results is provided. This is followed by the analysis of key points identified from both set of calculations.

2.1 Comparison of ACMA and NBN analysis assumptions and result

Table 2.1 provides the list of assumed key parameter values together with the calculated protection margins based on ACMA's analysis and NBN's response.

Table 2.1: Assumed parameters and calculated margins

Parameter	ACMA (Study E in TG 5/1 Document 5- 1/478)	NBN (Response to ACMA's consultation on Options Paper) ⁷	Comments
Key parameter assumptions	-		
Satellite Receive Antenna Gain	46.6 dBi		
Noise temperature	400 K	-	
Satellite G/T	20.6 dB/K	30 dB/K	[G/T = Ant Gain (dBi)—10 x log (Noise temp)] NBN argued that current and future very high throughput satellites will have higher gain.
Satellite Receiver Protection Criterion (I/N)	-6 dB, -10 dB, -12.2 dB	-12.2 dB	NBN argued that ACMA's assumed -10 dB criterion associated with 20% of time translates to -12.2 dB to be exceeded for 50% of time.
IMT BS / UE hotspot deployment density	30 BSs/km ² (urban) 10 BSs/km ² (suburban) 1 BS/km ² (suburban open) 100 UEs/km ² (urban) 30 UEs/km ² (suburban and suburban open)	100 BSs/km ² 400 UEs/km ²	NBN argued that its figures are based on small cell forum research and accommodates uncontrollable and unpredictable nature of IMT deployments.
IMT BS transmit power	2 dBm/MHz	10 dBm/MHz	ACMA's figure is based on power per antenna element = 10 dBm/200 MHz, ACMA's assumed antenna configuration = 8 x 8 (i.e. 18 dB), array ohmic loss = 3 dB and bandwidth correction = 23 dB NBN argued that 10 dBm/MHz figure aligns more closely with the 3GPP standards and systems trialed and licensed in Australia.

⁷ See documents: <https://www.acma.gov.au/-/media/Spectrum-Transformation-and-Government/Issue-for-comment/IFC-32-2018/NBN-submission-pdf.pdf> and <https://www.acma.gov.au/-/media/Spectrum-Transformation-and-Government/Issue-for-comment/IFC-32-2018/NBN-submission-attachment-pdf.pdf>

Parameter	ACMA (Study E in TG 5/1 Document 5- 1/478)	NBN (Response to ACMA's consultation on Options Paper) ⁷	Comments
Average UE transmit power	-6.1 dBm/MHz (urban and suburban hotspots) -3.6 dBm (suburban open space hotspots)	-	ACMA's average UE values are based on the implementation of ITU-R M.2101 power control algorithm in the simulation methodology explained in detail in ACMA's first contribution to TG 5/1, Document 117 (Sept 2017)
IMT UE body loss	4 dB	0 dB	
Polarisation isolation	3 dB	1.5 dB	
Network loading factor (Average BS activity)	20%	50%	
BS TDD activity factor	80%	60%	NBN argued that upload intensive applications can exist.
BS Antenna height (a.g.l.)	6 m (urban/suburban hotspots) 15 m (suburban open space hotspot)	30 m	NBN argued that existing infrastructure can be used.
IMT BS and UE antenna array size	8 x 8 (BS) 4 x 4 (UE)	4 x 4 (BS) 2 x 2 (UE)	NBN argued that smaller antenna arrays will result in higher sidelobes towards the GSO arc.
Results			
Total Aggregate Interference	-151.8 (dBm/MHz)	-	ACMA's total aggregate interference figure corresponds to aggregation of average BS and UE interference from the satellite's visible area (145o E) plus the main beam coverage area over Sydney ⁸ . The results in Table E-8 in Attch. 3 to Annex 3 of Document 478 show that, for the assumed BS and UE densities, contributions to the total aggregate interference from interferers assumed to be operating within the wide satellite visible area and the small spot main beam area over Sydney are of the same order of magnitude.

⁸ ACMA's analysis is based on satellite antennas pointing towards Sydney and Tokyo both of which have higher populations than NBN's beams covering gateway Earth stations.

Parameter	ACMA (Study E in TG 5/1 Document 5- 1/478)	NBN (Response to ACMA's consultation on Options Paper) ⁷	Comments
I/N	-39.2 dB	1 dB	N = -112.6 dBm/MHz (T=400 K) NBN's I/N = 1 dB figure is based on their calculation of -11 dB margin compared to the ACMA's assumed I/N threshold level of -10 dB and combines the impact of assumptions in re-baselining and sensitivity analysis outlined in NBN's response to ACMA's consultation.
Protection Margin	33.2 dB for I/N = -6 dB, 29.2 dB for I/N = -10 dB, 27 dB for I/N = -12.2 dB	-7 dB for I/N = -6 dB, -11 dB for I/N = -10 dB, -13.2 dB for I/N = -12.2 dB	

The assumptions and analysis results presented in Table 2.1 show significant differences. The NBN's calculated implicit I/N value of +1 dB in the presence of BS and UE interferers within their satellite main beam is approximately 40 dB higher than that calculated by ACMA for aggregating BS and UE interference from Sydney (which was used, with Tokyo, as an example large population centre for the purposes of modelling) plus the remaining visible area to the satellite assumed to be operating at 1450 E.

The following sections summarise the positions of both parties on their assumptions, together with an outline of Plum's opinion. More detailed discussion is provided in [Appendix E](#).

2.1.1 General modelling issues

The ACMA modelling approach is based on Monte Carlo methods, and calculates an average interference level at the satellite receiver from a single IMT sector which is randomly located within the area visible to the satellite. The random location of the IMT sector takes account of the density of populated areas at different latitudes to make the simulation runs more realistic. At each location, the interference power at the satellite is calculated by taking appropriate BS and UE power and antenna gain towards the satellite (allowing for dynamic power control), clutter and building entry losses, and satellite antenna gain towards the IMT sector. The calculated interference levels at each random location are then averaged separately to determine the mean BS and UE interference power at the satellite receiver.

Using the assumed BS and UE density figures, network loading and uplink/downlink ratios together with calculated BS and UE average interference levels, total aggregate interference levels are then determined for each deployment environment (e.g. suburban and rural).

In order to take specific account of the impact of interferers located within the satellite main beam, aggregate interference levels that would result from satellite beams aligned with Sydney and Tokyo have also been calculated separately and added to the total aggregate interference levels calculated from the wide area interference modelling outlined above. This approach will lead to some 'double-counting', but this is minimal as transmitter densities in such hotspots are so much greater than the background densities. In the final ACMA calculations, the 'hotspot' contribution and the 'background' contributions were found to be almost equal. It is worth noting that this model is significantly more pessimistic than the actual situation, where the only large urban settlement falling within a -3dB footprint is Perth, with less than half the population of Sydney.

There seems to have been a significant discussion as to whether the interference seen by a satellite receiver can be considered to be ergodic (i.e. that observations of a large range of spatial distributions are equivalent to observation over a long time), and if not, whether the simulation method can provide an accurate assessment of risk.

Without knowing the actual distribution and performance of all IMT terminals within each footprint, this question cannot be resolved. Having undertaken a very wide range of interference simulations involving dynamic terrestrial networks and aggregations over large areas we would, however, have confidence that the ACMA calculations are robust, given that the latest iteration takes explicit account of terminals within the 3dB footprint contour.

2.1.2 Satellite G/T

The initial ACMA modelling used the parameters adopted in TG5/1, assuming a 46.6dBi gain and noise temperature of 400K, giving a G/T figure of 20.6dB/K. NBN proposed a revised value of 30dB/K as being more representative of the actual Sky Muster system, and ACMA adopted this value in their later modelling.

Based on our own assessment of the stated spot-beam footprints and current satellite technology, Plum consider the 30dB/K figure to be appropriate and representative.

2.1.3 Satellite receiver protection criterion

Initial ACMA modelling assumed an interference criterion of $I/N = -10\text{dB}$, and this does not appear to have been explicitly associated with a particular probability. In the final model submitted to TG5/1, ACMA assessed interference against three I/N limits; -6dB , 10dB and -12.2dB .

NBN submitted that the -10.0dB value relates to 20% time, and that the -12.2dB value represents the translation of this value for 50% time, and should be used.

Reviewing the advice of WP4A and the derivation of the limits, we believe that an I/N criterion of -10.8dB is the appropriate value against which average interference values should be assessed. For near-worst-case single entry values, the figure of $I/N = 0\text{dB}$ is appropriate.

In the submission from NBN, it is noted that they do not accept that interference will be ergodic. It is our opinion that, given plausible IMT parameters, the limiting interference to the uplink will be due to the aggregation of a very large number of rather weak sources and will be essentially invariant. The use of the long-term criterion to assess the impact of interference is therefore appropriate and unlikely to give over-optimistic conclusions.

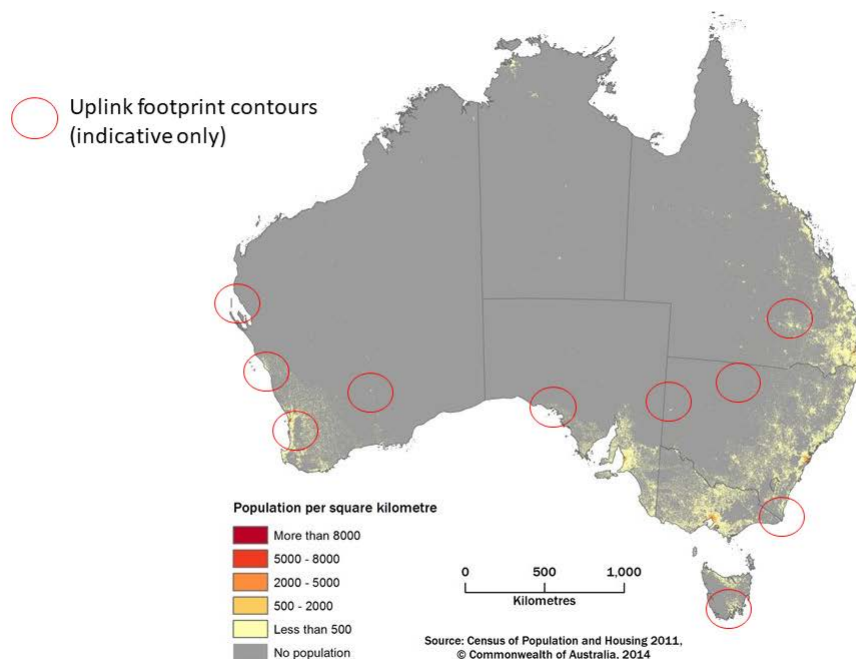
2.1.4 IMT hotspot deployment density

The ACMA modelling assumption is that there may be an urban density of 30 BS/km² and 100 UE/km². NBN consider that this is an under-estimate, noting that "research conducted by the small cell forum indicates that many operators will aim for BS densities of 100 to 350 per square kilometre". They therefore propose an urban density of 100 BS/km² and 400 UE/km².

While some other studies support such high deployment densities, it is also clear that they would be restricted to a few hotspot areas, and would require the use of antennas with significantly better directionality than assumed in the present studies. The deployment characteristics in terms of base station height and local clutter would also tend to minimise uplink interference.

We also note that, with the exception of the Geeveston (Hobart) and Waroona (Perth) Earth stations, the other Sky Muster gateway receive footprints fall in areas of very low population density.

Figure 2.2: Population density and gateway uplink beam contours (Source Australian Bureau of Statistics with Plum overlay)



NBN have indicated that they consider there to be a significant risk from future rural deployment of 5G millimetre wave systems, perhaps associated with mining industry operations. We are of the opinion that such use would be unlikely to require spectrum licences in the 27.0-27.5 GHz portion of the band, but would operate below 25.1 GHz under class or apparatus licences.

We therefore conclude that the ACMA's IMT density assumptions are appropriate when considering aggregate interference within a whole satellite beam. The densities suggested by NBN may be appropriate for modelling of hotspots, as essentially single-entry cases from geographically-limited clusters of small extent.

2.1.5 IMT BS and UE transmit power

ACMA modelling assumes a BS transmit power of 2dBm/MHz (25 dBm/200 MHz), based on ITU-R SG5 recommendations. NBN propose a figure 8dB higher "to align more closely with the standards under development and systems already trialled and licensed in Australia".

The 8dB increase in base station power, for instance, would imply a total conducted power in the 200 MHz base station bandwidth of 2W, which may be excessive for high-density deployments and the relatively large antenna arrays being developed for this band.

We consider the ACMA figure for BS transmit power appropriate for the majority of foreseen deployments. The enhanced power modelled by NBN may be required for some applications, although these are likely to be of lower density.

2.1.6 IMT UE body loss

The ACMA studies assume 4dB body loss (screening of IMT user terminals) in line with ITU-R assumptions.

NBN suggest that this parameter is 'speculative' with no clear reason for the value used. They also note that there are numerous 5G use cases that involve no body (i.e. fixed wireless access (FWA) or autonomous vehicles) and a consequently increased potential for interference.

Plum's opinion is that the 4dB figure represents a pragmatic value if interference is primarily from a large number of handheld user terminals. There is a realistic possibility, however, that future IMT use of the 27 GHz band may be dominated by other terminal types, and a 0dB figure should also be considered.

2.1.7 Polarisation isolation

For aligned antennas, a 3dB polarisation loss between circular and linear polarisation is theoretically expected. NBN argue that this figure is only valid under 'ideal circumstances'.

Our opinion is that it is highly unlikely that linearly-polarised fields will be coupled to the circularly-polarised satellite antenna with a smaller loss, and the 3dB value is appropriate.

2.1.8 IMT Network loading factor / average BS activity

ACMA assume a 20% loading factor for IMT networks, while NBN suggest a value of 50%.

From our experience, and following the guidance given in ITU-R texts, we would note that terrestrial networks are unlikely to be able to maintain stability if average activity approaches 50%. We consider an assumption closer to 20% to be more representative of average activity.

2.1.9 IMT BS TDD activity factor (Uplink to downlink ratio)

ACMA assume that downlink traffic will dominate, at 80% of the total. NBN comment that "It is difficult to state conclusively that upload-intensive applications will not exist, or that the proportion of upload traffic will not vary with time", and propose a value of 60%.

The comments by NBN are reasonable, in that a definitive statement can be made. In any case, the impact on interference of changing the ratio is not straightforward and will depend on many other parameters.

In the course of work for the European Commission, we have recently reviewed a very wide range of potential 5G millimetre-band use cases. On the basis of this review, we are inclined to favour the assumption that most applications that can be foreseen, downlink traffic will continue to dominate and the 80% figure is appropriate.

2.1.10 IMT BS antenna height

ACMA assume 6m, in line with the relevant ITU-R Recommendation. NBN suggest that "the standard 30-metre height of many communications infrastructure platforms is a reasonable assumption to make for the purpose of conducting sensitivity analyses".

The few existing deployments of mobile networks using millimetre-waves (e.g. in Chicago and Minneapolis) employ base stations mounted on street furniture, such as lamp-posts, and embedded in urban clutter. While it might be an interesting parameter to flex, we **do not believe that a 30m base station height is plausible** for the majority of millimetre wave, with the exception, perhaps, of FWA in which case better antenna performance and a fixed down tilt may be assumed.

2.1.11 IMT BS and UE antenna array size and grating lobes

This parameter is important because larger arrays will tend to generate sharper beams with less power transmitted in undesired directions.

The ITU and ACMA assume that the base station antenna will be composed of an array of 8x8 elements and that for the UE of 4x4 elements.

NBN suggest that, while the 8x8 figure for base stations is plausible, these will often be used as smaller, independent, sub-arrays. Their review of standardisation activities also suggests the likely use of 4-element (1x4 or 2x2) arrays on user terminals.

Our research indicates that the majority of existing base station antenna designs employ a minimum of 8x8 elements and are often larger. On the other hand, the only known operational UE antenna design uses a 1x4 element design.

We conclude that the 8x8 assumption for base stations is appropriate, but that UEs may be better represented by 1x4 antennas.

2.2 Implications for I/N predictions

While we find the majority of the ACMA and ITU-R assumptions to be reasonable, we agree (as ACMA have already done) that a significantly higher (56 dBi–46.6 dBi = 9.4 dB) value should be assumed for the satellite antenna gain, but that the long-term interference criterion should be slightly relaxed ((-12.2 dB)–(-10.8) dB = 1.4 dB).

This brief study does not allow the re-running of the detailed statistical simulations, but we would note that the increase in satellite gain is offset by the consequent reduction in footprint area. The overall impact on interference levels will then depend on the geographic distribution of IMT terminals (if most are clustered near the footprint centre interference will increase, if the distribution is skewed to the edge of coverage it will decrease). When ACMA re-ran their simulation with the increased gain, and accounted explicitly for urban IMT sites within the satellite main beam, the interference margin fell from 32.0 dB to between⁹ 27.0 dB and 25.4 dB.

While we consider the ACMA predictions to be robust, we have highlighted a number of parameters that may need to be re-evaluated when considering explicitly worst-case scenarios; base station densities as high as 100/km² should be considered and it is possible to conceive of situations where little or no body loss is encountered. The array gain for the UE antennas may also be smaller than currently assumed, with four rather than 16 elements. Taken together, these factors could give an increase in interference of around 15 dB in a worst case. Even if evaluated against the ‘average’ interference criterion of I/N = -10.8 dB, rather than the worst case criterion of 0 dB, a good margin still exists.

⁹ The picture is slightly confused because the increased gain value, taken from the NBN filing, is associated with the noise temperature of 1200K specified in that filing which is, surprisingly, higher than the ITU assumption of 400K.

2.3 Deterministic calculations

In their response to the ACMA consultation, NBN provided predictions of interference based on single-entry calculations.

Plum undertook similar single-entry calculation based on the ACMA assumptions and shared these with NBN, who added columns highlighting the impact of their 're-baselining' for current and next-generation Sky Muster satellites and varying the assumed IMT2020 parameters. Following our review of parameters, detailed above and in [Appendix E](#), Plum have themselves updated some assumptions. The NBN and Plum results are compared in Table 2.2 below.

Table 2.2: Single-entry interference analysis (Plum and NBN assumptions)

	Units	PLUM	NBNCo 1 st gen	NBNCo 2 nd gen
Interference criterion				
k	Constant	1.38E-23	1.38E-23	1.38E-23
T	K	400.0	400.0	400.0
B	Hz	1000000	100000	100000
Sat Rx noise	dBW/MHz	-142.6	-142.6	-142.6
I/N	dB	-10.8	-12.2	-12.2
I max	dBW/MHz	-153.4	-154.8	-154.8
Path loss				
f	Hz	27000000000	27000000000	27000000000
v	m/sec	300000000	300000000	300000000
Lambda	m	0.0	0.0	0.0
FSPL	dB	212.6	212.6	212.6
Polarisation loss	dB	3.0	0.0	0.0
Body loss (for UE only)	dB	0.0	0.0	0.0
EIRP towards satellite				
IMT BS TX Downtilt	degrees	10.0	10.0	10.0
IMT BS Ant Element Gain	dBi	5.0	5.0	5.0
IMT BS No of Ant Elements	8x8	64.0	64.0	64.0
IMT BS Array Ohmic Loss	dB	3.0	3.0	3.0
IMT BS Conducted Power per Element before Ohmic Loss	dBm/200MHz	2.0	10.0	10.0
IMT BS Conducted Power per Element before Ohmic Loss	dBW/MHz	-51.0	-43.-	-43.0
IMT BS Off-axis Relative Gain (Assumed)	dB	-15.0	0.0	0.0
IMT B EIRP towards Satellite	dBW/MHz	-27.9	-4.9	-4.9
Set Ant Gain				
Satellite RX Ant Max Gain	dBi	56.0	56.0	60.5
Feeder Loss	dBi	0.0	0.0	0.0

	Units	PLUM	NBNCo 1 st gen	NBNCo 2 nd gen
Sat RX Ant Gain (incl Feeder Loss)	dBi	56.0	56.0	60.5
Single entry interference				
Interference at Sat RX input	dBW/MHz	-187.5	-161.5	-157.0
Margin to Int Criterion	dB	34.1	6.7	2.2
Permissible no of interferers (Base Station only considered)		2578.0	4.0	1.0

It should be borne in mind that this analysis is simplistic and cannot be compared directly with the much more complex, statistical model developed by ACMA, but it can serve to give an 'order of magnitude' feel for the issues and an understanding of the sensitivities to certain assumptions.

Under the Plum assumptions, some 2,600 base stations could be accommodated in the area covered by a single uplink footprint, while the NBN calculations would only permit 4 (or 1 with the increased gain of the next-generation Sky Muster antenna¹⁰).

One obvious criticism of Table 2.2 is that it does not account for interference from user terminals. The final ACMA modelling estimates that aggregate interference due to UEs is 7.1 dB greater than that from BS; accounting for UE interference will therefore reduce the permissible population of base stations significantly. These calculations can be used, with 'representative', or average values to understand the IMT population that might be permissible before the long-term interference limit ($I/N = -10.8\text{dB}$ or -12.2dB) is exceeded. Alternatively, the parameters can be set to represent 'worst-case' values and assessed relative to the low-probability (0.02%) limit of $I/N = 0\text{dB}$. This gives the results indicated in Table 2.3 below.

Table 2.3: Worst-case single-entry calculations

	Units	PLUM
Interference criterion		
k	constant	1.38E-23
T	K	400.0
B	Hz	1000000
Sat Rx noise	dBW/MHz	-142.6
I/N	dB	0.0
I max	dBW/MHz	-142.6
Path loss		
f	Hz	27000000000
v	m/sec	300000000
Lambda	m	0.0
FSPL	dB	212.6
Polarisation loss	dB	3.0

¹⁰ although this increased gain will also reduce the area covered by the beam, reducing the number of possible contributors to the interference

	Units	PLUM
Body loss (for UE only)	dB	0.0
EIRP towards satellite		
IMT BS TX Downtilt	degrees	10.0
IMT BS Ant Element Gain	dBi	5.0
IMT BS No of Ant Elements	8x8	64.0
IMT BS Array Ohmic Loss	dB	3.0
IMT BS Conducted Power per Element before Ohmic Loss	dBm/200MHz	10.0
IMT BS Conducted Power per Element before Ohmic Loss	dBW/MHz	-43.0
IMT BS Total Power Transmitted	dBW/MHz	-27.9
IMT BS Max Composite Gain	dBi	23.1
IMT BS Max EIRP	dBW/MHz	-4.9
IMT BS Off-axis Relative Gain (Assumed)	dB	0.0
IMT B EIRP towards Satellite	dBW/MHz	-4.9
Set Ant Gain		
Satellite RX Ant Max Gain	dBi	56.0
Feeder Loss	dBi	0.0
Sat RX Ant Gain (incl Feeder Loss)	dBi	56.0
Single entry interference		
Interference at Sat RX input	dBW/MHz	-164.5
Margin to Int Criterion	dB	21.9
Permissible no of interferers (Base Station only considered)		155.0

In this calculation, it is assumed that the main beam of a base station, operating at the higher power level suggested by NBN, is pointing directly at the satellite. To reflect the small probability of such an alignment, the less stringent interference criterion recommended by WP4A is applied, with the interference remaining more than 20dB below this level.

3. Licence conditions and proposed mitigation

3.1 Licensing approach

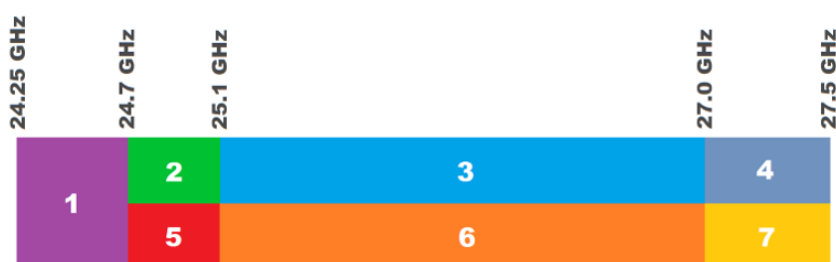
ACMA, in their document “Future use of the 26 GHz band. Planning decisions and preliminary views. April 2019” identified three broad categories of potential wireless broadband use when identifying the licensing approach for the 26 GHz band:

Figure 3: Categories of wireless broadband use

Category	Description	Licensing approach
Type 1	Traditional subscriber-based wide-area mobile or fixed network operator deployments	Spectrum licence
Type 2	Smaller market/local subscriber-based networks	Apparatus licence
Type 3	Uncoordinated ad hoc deployments within the confines of private premises or property	Class licence

The 24.25—27.5 GHz band was divided by frequency and licensing approach as shown below, taking into account any sharing considerations that might apply:

Figure 4: Planned arrangement for wireless broadband services in the 26 GHz band



- 1 Class-licensing for indoor use (Australia-wide).
- 2 Class-licensing for indoor and outdoor use (Australia-wide).
- 3 Spectrum licensing defined areas. Includes additional conditions to protect SRS earth stations.
- 4 Spectrum licensing with additional FSS coexistence conditions within certain areas.
- 5 Apparatus licensing (Australia-wide).
- 6 Apparatus licensing (Australia-wide, except defined areas). Includes additional conditions to protect SRS earth stations.
- 7 Apparatus licensing with additional conditions to protect FSS uplinks (Australia-wide except defined areas). New FSS earth stations will also be permitted, on a first-in-time coordinated basis with apparatus licensed wireless broadband services.

It can be seen that both spectrum and apparatus licences will be available at 27.0-27.5 MHz. Spectrum licences are intended for more dense geographic areas where there will be greater demand for wireless broadband so there is only an overlap with NBN gateway footprint in Perth, Hobart and to a much lesser extent Canberra. It is proposed that these licences will be for a duration of 15 years. In the case of the other NBN gateway footprints they will be covered by apparatus licences and subject to 1-5 year licence terms.

In the case of the apparatus licences as they are valid for a shorter timescale and deployments can be, if necessary, limited to avoid the risk of interference into NBN's network they are considered to be less of an issue to NBN. The main concern is the spectrum licences. However, it is important to recognise that some of the potential applications raised by NBN, such as mining or industrial use in a localised area, may not be served through spectrum licences but by apparatus or even class licences available below 27.0 GHz.

3.2 Licence duration

NBN are concerned that future satellites will operate with a G/T at around 30 dB/K, not the current 26 dB/K and the existing satellite fleet will need replacement by 2032. This should not be a problem for the apparatus licences that are for a 5 year duration and could, if necessary, be renewed with different licence conditions to protect satellite uplinks. The 5 year duration of these apparatus licences should also provide the opportunity to develop a better understanding of likely wireless broadband applications and deployments.

However, the licence duration might be an issue for the spectrum licences as the 15 year duration proposed will be later than any satellite replacement. Depending on the licence conditions adopted for the spectrum licences it may not be appropriate or feasible to make them more stringent. Of course, if NBN decide to use alternative frequencies for the replacement satellites this would not be an issue, but Plum has understood that this is not likely to be the case. Another option might be to reduce the duration of the spectrum licences to align them with the NBN satellite fleet replacement e.g. 12 years. This would be a very short licence duration considering the investment required by the wireless broadband operators. Industry has been lobbying for longer duration licences and, for example, in Europe the recent European Electronic Communications Code¹¹ in Article 49 (2) requires individual rights of use for these radio frequencies to be valid for a duration of at least 15 years, and where the licence duration is not valid for at least 20 years the right of use must include a right of extension so as to ensure regulatory predictability for a period of at least 20 years.

3.3 Licence conditions

It is important that any licence conditions that are included in the apparatus and spectrum licences are realisable and measurable to ensure efficient spectrum use, while at the same time minimising the risk of interference. Generally, licence conditions are intended to be the least restrictive. In the case of apparatus licences it is generally easier to set case-by-case conditions relevant to each individual deployment. In the case of spectrum licences, conditions typically apply to all use of the spectrum and can include requirements such as maximum transmitter power, block edge masks to protect adjacent channel services, power flux density at boundaries where coordination is to be undertaken for cochannel and adjacent channel deployments and limitations on antenna pointing for fixed deployments.

¹¹ On 20 December 2018, Directive (EU) 2018/1972 of the European Parliament and of the Council of 11 December 2018 establishing the European Electronic Communications Code ("EECC") entered into force.

The ACMA's preliminary view, provided in their document "*Future use of the 26 GHz band. Planning decisions and preliminary views. April 2019*" is that "*the following additional licence conditions should apply to spectrum and apparatus licensed services in the range 27–27.5 GHz operating within NBN FSS gateway footprint areas (-3 dB contour) specified in Annex F:*

- *outdoor base stations must have mechanical down tilt equal to or greater than 0*
- *outdoor base stations must not direct antenna beams (via electrical steering) to elevation angles greater than 5° above the horizon for more than 5% of time*
- *outdoor fixed UEs must not direct their antenna beam (via electrical steering) to within 1.5° of the geostationary orbit (GSO) arc*
- *reduced base station TRP limit of 25 dBm/200 MHz."*

The ACMA notes that the "additional conditions act as a safeguard to ensure that NBN gateway uplinks will be protected from the operation of wireless broadband deployments in that frequency segment. The effect of the conditions is to ensure that wireless broadband networks in these areas are designed and optimised to serve user equipment below the base station. It should be noted that power limitations are usually included in all spectrum licence technical frameworks."

Considering each condition in turn:

- The requirement for a mechanical down tilt should have little or no impact on wireless broadband deployments as most high density applications envisaged would, in any case, use a down tilt of around 10 degree. It is also anticipated that it may be a requirement from the World Radio Conference to have a mechanical down tilt of around 10 degrees.
- The requirement on base stations not to direct antenna beams above a set elevation angle for a percentage of time may be difficult to apply. However, the expectation is there would be very few incidents where the UE is above the horizon and such a requirement is unlikely to impact on the mobile operators network deployment.
- The requirement for fixed UE's not to direct the antenna beam to within 1.5° of the geostationary orbit (GSO) arc is unlikely to impact on network deployment. It is questionable whether fixed UEs will have an antenna system with electrical steering. For example, for fixed wireless access it is most likely the UE will have a fixed antenna beam.
- The limitation on base station transmitted radiated power may have an impact on network deployments and may even limit use in those geographic areas where they are imposed. There are currently two options for transmitted radiated power proposed in the CPM text¹² one proposal is for the option of 37, 40, 46 dBm and the other 25, 28, 31, 37 dBm in a 200 MHz bandwidth. The GSA, GSMA and operators are not expecting to be able to deliver the full benefits of 5G (data rates, number of users, coverage) at hot spots with the lower transmitted radiated power levels and have therefore supported the higher levels. It is likely that the actual value will be agreed at the WRC.

There would be the potential to relax all the proposed licence conditions later, but it would be very difficult to make them more stringent once networks are being rolled out. Plum is not aware of any examples where changes have been made retrospectively to technical licence conditions which would have an impact on the network deployment and require re-engineering.

¹² CPM text 2/1.13/4.1.2.5

4. Conclusions and recommendations

Plum have reviewed the assumptions made by the ACMA in modelling interference to the FSS, both within the TG5/1 process and following consultation with other national stakeholders.

We consider the modelling to be essentially robust; although the modelling has a large stochastic element we consider that interference is likely to be due to a sufficiently large number of sources as to be considered stationary; if this is not the case, the interferer population is likely to be too small to cause interference issues, even assuming a few worst-case contributions.

The mitigating measures proposed in the ACMA document “Future use of the 26 GHz band. Planning decisions and preliminary views. April 2019” seem to strike an appropriate balance between safeguarding the critical NBN infrastructure and imposing conditions on new spectrum entrants that are not too onerous.

Once networks are rolled out and it is possible to determine more accurately likely deployments it may be possible to retrospectively relax the licence conditions.

Appendix A—The 'Sky Muster' satellite system

The Sky Muster I (NBN-Co 1A) and Sky Muster II (NBN-Co 1B) satellites are owned by NBN Co Limited. They are located at 140o E and 145o E, respectively. They were manufactured by Space Systems/Loral, based on the SSL 1300 platform¹³ and launched in October 2015 and 2016. They are designed for a minimum 15 years life-span to provide broadband services for rural areas in Australia. They provide download speeds of up to 25 Mbit/s, and upload speeds of 5 Mbit/s.

Each Sky Muster uses 101 Ka-band spot beams¹⁴. Beams can overlap, and more than one spot beam can cover certain areas¹⁵.

Figure A.1: Sky muster downlink footprints

(Source: <https://www.nbnco.com.au/blog/the-nbn-project/five-questions-with-nbns-satellite-program-director>)



Sky Muster Earth Station Gateways are connected by redundant fibre cable to Sydney. All traffic from the Earth Station Gateways is aggregated by NBN at Eastern Creek in Sydney where the various Sky Muster providers interconnect. There are 9 active and one standby gateways, geographically spread across Australia, with the standby in Wolumba, NSW. The standby is capable of assuming control for any of the other ground stations.

¹³ http://sslmlda.com/html/1300_series_platform.php

¹⁴ https://www.wikiwand.com/en/Sky_Muster

¹⁵ <https://birrraus.com/2016/06/05/what-are-sky-muster-spot-beams/>

Figure A.2: Correspondence between downlink beams and gateway earth stations(Source: <https://birrraus.com/2016/06/05/what-are-sky-muster-spot-beams/>)**The relationship between SkyMuster beams and Earth Station Gateways**

Once your SKY MUSTER beam is established, this chart identifies your Earth Station Gateway

Bourke NSW	Broken Hill NSW	Carnarvon WA	Ceduna SA	Geeveston TAS
Beam 3—Whitsundays, QLD	Beam 4—Maxwelton, QLD	Beam 7—Mackay, QLD	Beam 1—Cairns, QLD	Beam 6—Mount Wyatt, QLD
Beam 14—Goomally, QLD	Beam 22—Bollon, QLD	Beam 11—Rockhampton, QLD	Beam 12—Blackall, QLD	Beam 8—Longreach, QLD
Beam 24—Toowoomba, QLD	Beam 30—Ceduna, SA	Beam 28—Tamworth, NSW	Beam 15—Gladstone, QLD	Beam 46—Horsham, VIC
Beam 26—Bourke, NSW	Beam 33—Mudgee, NSW	Beam 32—Dubbo, NSW	Beam 47—Shepparton, VIC	Beam 51—Melbourne, VIC
Beam 52—Wilson, Promontory, VIC	Beam 44—South Adelaide, SA	Beam 39—Hay, NSW	Beam 72—Christmas Is	Beam 53—Orbost, VIC
Beam 55—Launceston, TAS	Beam 48—Victorian Alp, VIC	Beam 40—Griffith, NSW	Beam 76—Wyndham, WA	Beam 62—Mt Magnet, WA
Beam 58 -Top End (small beam), NT	Beam 54—Burnie TAS	Beam 73—Macquarie Is	Beam 84—Southern Gulf of Carpentaria, QLD	Beam 67—Narrogin, WA
Beam 60—Meekatharra, WA	Beam 82—Victoria River, NT	Beam 79—Cape York, QLD	Beam 98—Cocklebidy, WA	Beam 74—Lord How Is
Beam 61—Geraldton, WA	Beam 87—Newman, WA	Beam 85—Cooktown, QLD	Beam 100—Broken Hill, NSW	
Beam 70—Esperance, WA	Beam 88—Gibson Desert, WA	Beam 86 - Carnarvon, WA		
Beam 71—Cocos Is, Cocos	Beam 91—Hughenden, QLD	Beam 96—Birdsville, QLD		
	Beam 95—Oodnadatta, SA	Beam 99—Ceduna, SA (large beam)		
	Beam 97—Ravensthorpe, WA	Beam 101 -Cobar, NSW		

Geraldton WA	Kalgoorlie WA TT&C Site	Roma QLD	Warroona WA	Wolumla NSW TT&C Site
Beam 05—Torrens Creek, QLD	Beam 10—Clermont, QLD	Beam 09—Galilee Basin, QLD	Beam 2—Townsville, QLD	Standby site
Beam 21—Cunnamulla, QLD	Beam 13—Mantuan Downs, QLD	Beam 18—Roma, QLD	Beam 16—Bundaberg, QLD	Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure

Geraldton WA	Kalgoorlie WA TT&C Site	Roma QLD	Warroona WA	Wolumla NSW TT&C Site
Beam 23 Goondiwindi, QLD	Beam 20—Gympie, QLD	Beam 29—Coffs Harbour, NSW	Beam 17— Charleville, QLD	Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 25—Brisbane, QLD	Beam 24—Forster, NSW	Beam 35—Port Lincoln, SA	Beam 19— Chinchilla, QLD	Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 27— Lightning Ridge, NSW	Beam 36—Whyalla, SA	Beam 37— Adelaide, SA	Beam 38—Mildura VIC	Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 31—Port Augusta, SA	Beam 43— Kangaroo Island, SA	Beam 50— Warrnambool, VIC	Beam 41— Canberra, ACT	Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 42—Sydney, NSW	Beam 56—Hobart, TAS	Beam 57 —Bamaga, QLD	Beam 66—Perth, WA	Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure

Geraldton WA	Kalgoorlie WA TT&C Site	Roma QLD	Waroon WA	Wolumla NSW TT&C Site
Beam 45— Bordertown, SA	Beam 64—Koorda, WA	Beam 59—Fitzroy Crossing, WA	Beam 69—Albany, WA	Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 49— Merimbula, NSW	Beam 68—Augusta, WA	Beam 63— Cervantes, WA	Beam 75—Norfolk Island	Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 77—Top End, NT (Large Beam)		Beam 65—Leonora, WA		Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 78— Northern Gulf of Carpentaria, NT		Beam 80—Port Headland, WA		Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 89—Alice Springs, NT		Beam 81—Derby, WA		Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure

Geraldton WA	Kalgoorlie WA TT&C Site	Roma QLD	Waroona WA	Wolumla NSW TT&C Site
Beam 90—Mt Isa, QLD		Beam 83— Newcastle Waters, NT		Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 92—Mt Magnet, WA (Large Beam)		Beam 93— Goldfield Region, WA		Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure
Beam 94—North West, SA				Wolumla near Merimbula, can assume control of beams from any other Earth Station, in order to provide service in the event of catastrophic failure

Telemetry, tracking, and command (TT&C) site monitors and control the spacecrafts health and location.

The temperature value listed on the NBN's satellite network filings is 800 K and 1200 K.

Our understanding is that NBN's existing satellites need to be replaced by 2032. It is envisaged that these satellites will be high throughput multibeam satellites with high gain antennas leading to a G/T value of 30 dB/K which is 4 dB higher than the G/T level of current NBN satellites.

Appendix B—Terrestrial use of 26 GHz

B.1 Introduction

It is important to recognise that the 26 GHz band is one of a number of frequency bands that have been identified for 5G. Other key bands include 700 MHz and 3.5 GHz and over time other frequencies will become available either through re-farming from other services or through the operators upgrading their technologies.

Millimetre wave bands are seen as providing services at hot spots, in addition to the other frequency bands, as they can support higher bandwidth. It is not expected that millimetre wave bands will be used over a wide geographic area due to the small cell size and lower density of population making it less economic for operators. Business case modelling assumes that mobile demand will be mainly consumed indoors with, for example, predictions of 80% of mobile demand being indoors¹⁶.

The main use case areas include the provision of Enhanced Mobile Broadband (eMBB) based-services for high capacity applications and services dedicated to vertical sectors. Public safety and backhauling applications are also potential areas for the use of mm-wave bands including the 26 GHz band.

B.2 eMBB services

The following potential use cases can be considered as examples of the mm-wave deployment scenarios.

- Urban / suburban hotspots;
- Stadiums/arenas and other indoor venues with ultra-high density of users;
- Airports, railway stations and other transport hubs with very high user concentrations; and
- Rural areas for fixed wireless access.

In the scenarios outlined above, expected example services and applications include.

- High data rate video and media delivery; and
- Virtual Reality (VR) / Augmented Reality (AR) applications;

ONE5G¹⁷ is a European Commission funded project where eMBB use cases have been considered. One of the use cases considered is 'outdoor hotspots and smart offices with AR/VR and media applications'¹⁸. The use case is mainly characterised by a high throughput demand and the use of services like augmented reality (AR), virtual reality (VR), high-quality video streaming or file transmissions in smart offices and stadiums/arenas. In the outdoor hotspot scenario, the scenario assumes that macro cells are deployed around 4 GHz band with a 200 m inter site distance. It is further assumed that there could be up to three micro cells assumed to be operating around 30 GHz band and clustered around per macro cell. BS antenna arrays of up to 256 x 256 elements and UE antenna arrays up to 32 x 32 elements are suggested. Connection densities of 200—2500 km² are defined.

¹⁶ Schneir et al (2019) 5G business case in dense urban areas.

¹⁷ <https://one5g.eu/project/>

¹⁸ Deliverable D2.1 Scenarios, KPIs, use cases and baseline system evaluation, <https://one5g.eu/documents/>

B.3 Services for vertical sectors

There are a range of vertical sectors that could potentially make use of mm-wave bands. Some examples include:

- transportation including autonomous vehicles (V2X: Vehicle-to-everything) and 5G on trains and buses;
- medical applications;
- manufacturing and industrial automation; and
- smart cities.

V2X use cases encompass vehicle communications with other vehicles (V2V), pedestrians (V2P), road infrastructure (V2I) and the internet (V2N). It is however worth noting that much of autonomous vehicle standardisation activities to date (within ETSI and IEEE 802.11p) are in the unlicensed 5.9 GHz band (i.e. 5.85—5.925 GHz). Similarly, vehicle information and entertainment use cases mainly target below 6 GHz bands and a limited number of mm-wave band use cases (e.g. Wi-Fi hotspot backhauling, video streaming with increased definition and high-resolution navigation maps downloading) can be considered, for example, when a car is parked or in very dense urban areas. In the case of 5G on public transport systems (e.g. trains and buses), mm-wave bands could provide high-bandwidth backhaul links between base stations on tracksides / roadsides and access units on vehicles. However, establishing links with high speed vehicles in mm-waves is very challenging and a limited number of use cases are likely to be realised in early years of 5G deployments.

Potential medical application use cases include remote monitoring of patient health, asset management (e.g. real time tracking of wheelchairs, ECG monitors and drugs), intervention management (e.g. surgery planning activities), remote surgery (e.g. use of robotics) and smart medication (e.g. applying medication through embedded connected devices). The use of mm-wave bands in such use cases could provide capability of handling high throughputs which may result from low-latency real time data gathering from many devices or performing remote surgery.

In the manufacturing and industrial automation area, a smart factory concept is an example use case and includes the use of 3D real-time technologies and virtual reality in the design and engineering phase; the integration of the entire shop floor in an ICT-controlled system; the use of mobile devices, wearables and augmented reality to enhance operator abilities; the ubiquitous deployment of sensors on the shop floor, the use of tracking technologies to follow goods along production cycles and 3D scanners for quality control; and the production process using advanced prediction technologies and decision-support systems.

Smart cities make use of extensive sensor and Wi-Fi technologies. Backhauling of these is a potential use case for mm-wave bands. One example is improved video surveillance systems with high resolution cameras. A further example is the provision of video based outdoor advertising especially in urban areas.

B.4 Public safety

Public service use cases include requirements like real time video and high-quality picture transmissions in typical scenarios including disaster recovery, rescue and relief operations; routine or “day-to-day” operation; large and/or planned event operation; and critical assets protection. The use of mm-wave can help to satisfy associated high bandwidth and low latency requirements.

4.2 Backhauling

High data rates of 5G radio access links increase bandwidth requirements for backhauling significantly. When there is no fibre availability in-band backhauling using mm-wave spectrum could be an option.

Appendix C—Overview of TG5/1 studies

C.1 Input assumptions (terrestrial)

IMT system parameters intended for sharing and compatibility studies in the frequency range between 24.25 GHz and 86 GHz were provided by a liaison statement from WP 5D to TG 5/1¹⁹. These parameters include system characteristics and deployment scenarios.

In terms of potential deployment environments, the following options are considered in the liaison statement.

- **Outdoor suburban hotspot**—corresponding to ‘local office centres, commercial & shopping precincts/malls, railway stations, airports, public venues & central parks’ where ‘base station antennas are typically wall- or pole-mounted a few metres above ground level and users are mostly outdoors’.
- **Outdoor suburban open space hotspot**—corresponding to ‘a small portion of locations such as shopping precincts/malls, railway stations, public venues & central parks in suburban areas, where a high density of users may occur in the open spaces surrounding or within those locations. Operators may use sites at the edge of roof of low-rise buildings within such venues or adjacent to them. Such sites may be standalone or complementary to an outdoor suburban hotspot deployment’.
- **Outdoor Urban hotspot**—corresponding to ‘densely populated areas, such as high-rise central business districts, and the surroundings of crowded locations (for example: city/town squares/plazas, railway stations, airports and open-air malls) where base station antennas are typically wall- or pole-mounted a few metres above ground-level and users are mostly outdoors’.
- **Indoor**—where ‘base stations and user terminals are indoors’.

The methodology recommended for examining sharing scenarios involving IMT systems is described in ITU-R Recommendation M.2101.

Table C.1 below shows IMT parameters relevant to the key IMT—FSS sharing scenarios (i.e. outdoor deployments) examined within TG 5/1 for the frequency range 24.25—27.5 GHz.

Table C.1: IMT parameters (Document 5-1/36, February 2017)

Parameter	Value
Duplex method	TDD
Channel bandwidth (MHz)	200 (90% of this value is signal bandwidth)

¹⁹ Document 5-1/36, February 2017

Table C.1A: IMT Parameters (Base Stations)

	Outdoor suburban open space hotspot	Outdoor suburban hotspot	Outdoor urban hotspot
Parameter			
Density (per Sq. km) See NOTE 1	0 or 1 ²⁰	10	30
Frequency re-use	1	1	1
Antenna height (a.g.l.) (m)	15	6	6
Sectorisation	1	1	1
Downtilt (degrees)	15	10	10
Antenna deployment	Roof edge	Below roof top	Below roof top
Average BS activity ²¹ (Network loading factor) (%)	20, 50	20, 50	20% 50
BS TDD activity factor (%)	80	80	80
Antenna Pattern	Rec. M 2101	Rec. M 2101	Rec. M 2101
Polarisation	Linear (+/-45 degrees)	Linear (+/-45 degrees)	Linear (+/-45 degrees)
3 dB beamwidth for single antenna element (degrees)	65 (for Horizontal and Vertical)	65 (for Horizontal and Vertical)	65 (for Horizontal and Vertical)
Antenna front to back ratio (dB)	30 (for Horizontal and Vertical)	30 (for Horizontal and Vertical)	30 (for Horizontal and Vertical)
Antenna element gain (dBi) See NOTE 2	5	5	5
Antenna array	8x8 elements	8x8 elements	8x8 elements
Antenna array Ohmic loss (dB)	3	3	3
Conducted power per antenna element before Ohmic loss (dBm in channel bandwidth)	10	10	10
Maximum coverage angle in horizontal plane (degrees)	120	120	120

²⁰ The liaison statement states that 'the modelling of this deployment environment is optional. For potential studies, one possible scenario assumes the overall number of deployed base stations to be negligible (zero BS/km²). Another possible scenario assumes 1 BS/km² in outdoor suburban open space hotspot'.

²¹ According to the liaison statement '20% would normally represent a typical/average value for the loading of base stations across a network and therefore can be used for wide area analysis (province, national or larger satellite footprint, for example). In order to provide adequate quality of service, IMT networks are dimensioned to avoid undue congestion, such that, over all cells in a network, most of the cells are not heavily loaded simultaneously and only a small percentage of cells being heavily loaded at any specific point in time. For studies involving only a smaller area (e.g. within a local area), a maximum value of not more than 50% for BS/network loading may be used. For worst-case studies involving a single IMT base station/cell, a loading of 100% may be used'.

Table C.1B: IMT Parameters (User Equipment)

	Outdoor suburban open space hotspot	Outdoor suburban hotspot	Outdoor urban hotspot
Parameter			
Density (per Sq. km) (Simultaneously transmitting terminals)	30	30	100
Body loss (dB) (Resulting from proximity effects) ²²	4	4	4
Indoor terminal usage (%)	5	5	5
UE TDD activity factor (%)	20	20	20
Antenna Pattern	Rec. M 2101	Rec. M 2101	Rec. M 2101
Polarisation	Linear (+/-45 degrees)	Linear (+/-45 degrees)	Linear (+/-45 degrees)
3 dB beamwidth for single antenna element (degrees)	90 (for Horizontal and Vertical)	90 (for Horizontal and Vertical)	90 (for Horizontal and Vertical)
Antenna front to back ratio (dB)	25 (for Horizontal and Vertical)	25 (for Horizontal and Vertical)	25 (for Horizontal and Vertical)
Antenna element gain (dBi) See NOTE 2	5	5	5
Antenna array	4x4 elements	4x4 elements	4x4 elements
Antenna array Ohmic loss (dB)	3	3	3
Conducted power per antenna element before Ohmic loss (dBm in channel bandwidth)	10	10	10
Maximum output power (dBm) (PCMAX) See NOTE 3	22	22	22
Target transmit power per 180 kHz (dBm) (PPUSCH)	-95	-95	-95
Power control model	Rec. M 2101 ($\alpha=1$)	Rec. M 2101 ($\alpha=1$)	Rec. M 2101 ($\alpha=1$)

NOTE 1: The BS (sector) density must be translated into the Inter-Site Distance (ISD) according to the network topology for use as input in Recommendation ITU-R M.2101. Dense urban environments are likely to be served by single sector small cells.

NOTE 2: The antenna pattern for base station or user equipment depends on the antenna array configuration and the antenna element pattern and gain. For example, the antenna array composed of 8x8 identical antenna elements with 5 dBi gain each produces a maximum 23 dBi main beam antenna gain for base stations and an antenna array composed of 4x4 identical antenna elements with 5 dBi gain each produces a maximum 17 dBi main beam antenna gain for user terminal.

²² According to the liaison statement 'although preliminary studies suggest that the impact of proximity effects/body loss will in most cases be in excess of 4 dB, a value of 4 dB has been selected as a typical value'.

Antenna gain in directions other than the main beam is reduced according to the antenna model described in Recommendation ITU-R M.2101.

The use of antenna array configurations other than those indicated in the table above should not lead to an increase of interference to other services to which the bands are currently allocated and should not increase the EIRP, by adjusting the other relevant parameters.

NOTE 3: Maximum user terminal output power depends on the antenna array configuration and conducted power (before Ohmic loss) per antenna element. For example, the antenna array composed of 4x4 identical antenna elements with conducted power per antenna element 10 dBm produces 22 dBm maximum user terminal output power. The reduction of maximum user terminal output power resulting from power control model is applied to each element within antenna array; i.e. conducted power (before Ohmic loss) per antenna element is reduced to same extent as PPUSCH reduced compared to PCMAX.

It is argued that the deployment density figures given in Table C.1 are for hotspots and applicable for studies considering an area of a single hotspot or a small cluster of cells as described in Recommendation ITU-R M.2101. If sharing studies consider deployments in wider areas (e.g. city, county or region) where hotspot areas represent only a small percentage of the total area, as would be in the case of IMT—FSS uplink sharing scenarios, the density figures given in Table C.1 need to be multiplied by 'Ra' and 'Rb' which are ratio of hotspot areas to areas of cities/built areas/districts and ratio of built areas to total area of region considered in the study, respectively. The values recommended for 'Ra' are 7% for urban and 3% for suburban. The value suggested for 'Rb' is 5%. These values appear to be adopted in the sharing studies submitted to TG 5/1.

C.2 Input assumptions (satellite)

A WP 4A liaison statement²³ to TG 5/1 provides a 'streamlined' version of FSS/BSS technical parameters developed earlier for sharing studies undertaken under the World Radio Conference 2019 agenda item 1.13²⁴.

In the uplink direction, the parameters list includes three example carriers, named Carrier 13, 14 and 19, in the band 27-27.5 GHz. Table C.2 below shows the parameter values provided for all three carriers²⁵.

Table C.1: FSS uplink parameters (Document 5-1/89, May 2017)

Parameter	Carrier 13 and 14	Carrier 19
Frequency range (GHz)	24.65-25.25 and 27-27.5	24.65-25.25 and 27-27.5
Noise bandwidth (MHz)	20—100	20—250
Maximum receive antenna gain (dBi)	46.6	33
Antenna pattern	Section 1.1 of Annex 1 in Rec. ITU-R S.672-4 (Ls = -25 dB)	Section 1.1 of Annex 1 in Rec. ITU-R S.672-4 (Ls = -20 dB)
Beamwidth (degrees)	0.8	3 x 7 (elliptical)
System receive noise temperature (K)	400	900

²³ Document 5-1/89, May 2017

²⁴ WRC-19 Agenda Item 1.13 considers identification of frequency bands for the future IMT systems, including possible additional allocations to the mobile service on a primary basis.

²⁵ A further liaison statement (Document 5-1/183, November 2017) provides corrected ES parameters. The satellite receiver parameter values are the same as those provided in Document 5-1/89.

The liaison statement notes that ‘... the interference protection criterion requires, as a matter of urgency, further analysis for the bands under study under WRC-19 agenda item 1.13’. There have been long discussions within WP 4A on the protection criteria issue with no clear decision emerging during the sharing studies submitted to TG 5/1. The key discussion points have included

- Whether the allocation of 6% of clear sky satellite system noise temperature to interference from other co-primary services to provide long term interference protection corresponds to I/N of -12.2 dB or I/N of -10.5 dB (for FSS systems not implementing frequency re-use) or -10.8 dB (for FSS systems implementing frequency re-use)²⁶;
- Whether the percentage time associated with the long term I/N criterion level should be 20% or 50%;
- Whether the long term I/N criterion should be further apportioned to accommodate multiple co-primary services; and
- Whether short term effects need to be taken into consideration and what should be the appropriate short-term protection criteria.

Table C.3 below provides the list of assumed protection criteria within studies submitted to TG 5/1 to address the IMT uplink interference into FSS satellite receivers operating in the 27.0—27.5 GHz band.

Table C.2: Assumed FSS protection criteria (Attachment 3 to Annex 3 to TG 5/1’s final Chairman’s report, Document 5-1/478, September 2018)

Study	Assumed FSS protection criteria (I/N)
A	-10.5 dB
B	-12.2 dB 20%
C	0 dB 0.02%, -6 dB 0.6%, -10.5 dB 20%
E	-6 dB, -10 dB, -12.2 dB
F	-10.5 dB
H	-10 dB
I	0 dB 0.02%, -6 dB 0.6%, -10.5 dB 20% (Further apportionment of 3 dB is also considered)
J	-12.2 dB (Further apportionment of 3 and 4.7 dB is also considered)
K	0 dB 0.02%, -6 dB 0.6%, -10.5 dB 20%
L	-12.2 dB (Further apportionment of 3 dB is also assumed)
M	-10.5 dB (Further apportionment of 3 and 4.7 dB is also considered)
N	-12.2 dB
P	No criterion is specified to compare against the calculated I/N of -28 dB for FSS NGSO system
Q	-10.5 dB 20%
R	-10.5 dB 20% (for FSS NGSO system)

²⁶ The main issue here is whether N is referring to FSS space station receiver system noise (which includes antenna, feeder and receiver noise) or FSS total system noise (which includes antenna, feeder and receiver noise as well as external interference from other FSS systems).

In July 2018, a reply liaison statement from WP 4A to TG 5/1 included the following I/N criteria agreed for the 24.65—25.25 GHz and 27.0—27.5 GHz bands²⁷:

- I/N = 0 dB to be exceeded for 0.02% of time, probability or location;
- I/N = -6 dB to be exceeded for 0.6% of time, probability or location; and
- I/N = -10.5 dB to be exceeded for 20% or I/N average of time, probability or location.

The liaison statement notes that “The noise N in the I/N criteria as specified above is the system receiver noise (i.e. thermal noise) and is equal to the receiver antenna noise plus the receiver noise referred to the antenna as contained in the technical parameters liaised to Task Group (TG) 5/1 by WP 4A. Hence studies conducted by TG 5/1 should only use the values presented above when evaluating the compliance with the protection criteria.”

It is further noted that “For interference analysis where the degradation is due to atmospheric attenuation, which varies as a function of time, it is appropriate to specify protection criteria based on a percentage of time. However, sharing studies conducted between satellites and IMT systems under WRC-19 agenda item 1.13 may involve far more complex considerations and calculations, based on additional variables which are not a function of time. These studies may include geographical locations in the space domain associated to the IMT position. As such, the definition of the protection criteria cannot be expressed simply in terms of values against a percentage of time. Therefore, as depicted in Table 1, the percentage is expressed as a percentage of time, location or probability (for example, for Monte Carlo simulations, the percentage can be expressed in terms of a number of snapshots).”

It is also stated that the apportionment of the I/N criterion should be implemented on a case-by-case basis.

Finally, it is noted that the work on developing short term criteria is ongoing, the current values are provided to complete the work for WRC-19 agenda item 1.13 and they may evolve in future.

C.3 Modelling

The TG 5/1 chairman’s final report (Document 5-1/478) includes Attachment 3 to Annex 3 where studies on the analysis of sharing and compatibility of the FSS and IMT operating in the 24.25—27.5 GHz frequency range are provided. In the attachment, there are 15 studies (Studies A to R) examining the impact of IMT uplink interference into FSS satellite receivers. An extensive summary of the studies outlining modelling assumptions, methodology and results is also presented in the attachment.

An overview of these studies is provided below in terms of the modelling assumptions, analysis methodology applied and study outcomes.

²⁷ Document 5-1/411, July 2018

C.3.1 Input assumptions

Studies have mainly adopted the IMT and FSS parameters outlined in the preceding two sections. Propagation effects, clutter loss and building entry loss have been modelled using ITU-R Recommendations P.619, P.2108 and P.2109, respectively. Parameters where there have been differences in assumed values are as follows.

- The assumed number of BS and UE transmitters show variations depending on assumptions related to the satellite orbital position and populated areas within the satellite receiver footprint. Two studies have considered the impact of BS interferers only.
- The normalisation of IMT transmitter antenna has been considered in the majority of studies to ensure that the total integrated gain is 0 dBi as outlined in Section 16 of Annex 1 to the final TG 5/1 chairman's report.
- The cross-polarisation loss value of 3 dB has been applied to aggregate interference in most of the studies.

C.3.2 Methodology

A statistical modelling approach based on Monte Carlo analysis has been commonly adopted in the studies by using elements of the simulation methodology described in ITU-R Rec.2101. The approach is based on an aggregation of interference from a population of BS and UE interferers assumed to be deployed in populated areas covered within the satellite receiver visibility. Typical suburban and urban deployment scenario parameters have been used to model IMT interferers. Statistics of IMT BS and UE antenna gain, UE transmit power, clutter and building entry losses have been taken into account to derive aggregate interference levels at the victim satellite receiver.

A more detailed summary of the adopted methodology is provided in Section C.3.4 as part of the review of ACMA's submissions.

C.3.3 Outcome

The study outcomes have been presented as I/N ratios which are then compared against the assumed I/N long-term threshold levels to determine the protection margins. In most cases, the calculated I/N ratios are well-below the assumed thresholds and large protection margins (> 10 —20 dB) exist. The exception is one study (Study M) where while baseline modelling results show protection margins of 4—6 dB these are 'consumed' in the sensitivity analysis which assumes an increased IMT base station interferer power, antenna array, number of sectors and network loading resulting in an exceedance of 6–8 dB compared against the assumed -10.5 dB I/N threshold value.

C.3.4 ACMA Submissions to TG 5/1

In this section, we have provided a more detailed review of ACMA's submissions to TG 5/1 as these were used to establish NBN's counter arguments.

ACMA made three submissions to TG 5/1 on sharing between FSS and IMT in the 24.25—27.5 GHz. The key points identified from the review of these submissions are summarised below.

C.3.4.1 Document 5-1/117 (September 2017)

This is the first and main submission where the methodology is described in detail. The modelling assumptions are based on those summarised earlier in Sections C.1 and C.2.

The interference analysis methodology is based on calculating an average interference level at the satellite receiver from a single IMT sector which is randomly located within the area visible to the satellite. The random location of the IMT sector takes account of the density of populated areas at different latitudes to make the simulation runs more realistic. At each location, the interference power at the satellite is calculated by taking account of maximum BS power / average UE power; average IMT BS / UE antenna gain towards the satellite; clutter and building entry losses; path loss; and satellite antenna gain towards the IMT sector. Calculated interference levels at each random location are then averaged to determine the average interference power at the satellite receiver. The calculations are implemented separately for both IMT BS and UE transmitters and for assumed two satellite pointing directions: Sydney and Tokyo.

Using the BS and UE density figures, network loading and uplink/downlink ratios together with calculated BS and UE average interference levels, total aggregate interference levels are then determined for each deployment environment (e.g. suburban and rural). The results are compared against an assumed interference threshold level of I/N of -10 dB to determine if the sharing is feasible.

In order to take account of the impact of BS / UE interferers located within the satellite main beam, aggregate interference levels from Sydney and Tokyo have also been calculated separately and added to the total aggregate interference levels calculated from the wide area interference modelling outlined above.

The wide area simulation results show that the total aggregate interference levels are -147.1 dBm/MHz for the satellite antenna pointing towards Sydney and -135.5 dBm/MHz for the satellite antenna pointing towards Tokyo. These are well below the assumed maximum interference level of -122.6 dBm/MHz.

It is stated that the aggregate level in the Tokyo example is larger than that of the Sydney example because the satellite antenna is pointing at a northern latitude where there is a higher probability of more IMT 2020 deployments closer to the main beam of the satellite antenna as there are more major cities in the northern hemisphere.

When the aggregate interference through the main beam pointing towards Sydney and Tokyo are added to the wide area simulation results it is shown that the total aggregate interference levels are increased by 1.4 dB for the Sydney example and 0.4 dB for the Tokyo example. Both levels are still well below the assumed permissible level.

C.3.4.2 Document 5-1/193 (January 2018)

The document has provided 'updates' to the analysis presented in Document 5-1/117. It appears that the key update is a correction factor applied to the IMT antenna pattern to normalise the total integrated gain to 0 dBi.

It is suggested that the total aggregate interference levels are -155.1 dBm/MHz for the Sydney example and -145.4 dBm/MHz for the Tokyo example in the case of wide area simulations. These are approximately 8 and 10 dB lower than those provided in the original submission. It is also shown that when the main beam interference from Sydney and Tokyo are added to the wide area simulation results the total aggregate interference levels are increased by 3.3 dB for the Sydney example and 1.8 dB for the Tokyo example. These results indicate that the total aggregate plus main beam interference levels are still

39.2 dB (for the Sydney example) and 31 dB (for the Tokyo example) below the satellite system noise level (-112.6 dBm/MHz).

C.3.4.3 Document 5-1/290 (April 2018)

The third submission has provided 'further updates' to address the editor notes associated with the January 2018 submission. In this context, the details of the number of iterations used in simulations and a description of the percentage of locations used to calculate clutter and building entry loss are added to the previous submission. An assessment against a range of protection criteria (i.e. I/N values of -6, -10 and -12.2 dB) is also included.

It is shown that, for the assumed I/N protection levels of -6 dB, -10 dB and -12.2 dB, the calculated protection margins are 32.3 dB, 28.3 dB and 26.1 dB, for the Sydney example, and 25 dB, 21 dB and 18.8 dB, for the Tokyo example, respectively.

It is noted that this submission has been incorporated into the TG 5/1 Chairman's final report (Document 5-1/478) as Study E.

Appendix D—Brief on Europe and North America

The implications of interference aggregation from terrestrial networks deployed in the millimetre-wave bands into satellite receivers have also been considered in Europe and North America.

In Europe, CEPT Report 68²⁸ on the harmonised technical conditions for the 24.25-27.5 GHz frequency band was published in July 2018. The report concludes that “Studies have shown that coexistence with FSS satellites is feasible (aggregate interference from 5G base stations to GSO FSS satellites will likely fall within the protection criteria for GSO FSS with a large margin) when considering the assumed technical and operational characteristics for 5G. CEPT intends to assess the evolution of Wireless Broadband Electronic Communications Service (WBB ECS) system characteristics, including network deployments, in a 5-year timeline, so as to be able to provide additional confidence that such evolution will continue to ensure the adequate protection of other services, in particular space services.” The report further notes that “the harmonised technical conditions include a general provision requiring that outdoor base station deployments shall ensure that the antenna beam is normally below the horizon and outdoor base station shall not have mechanical pointing above the horizon. This would help preventing having 5G base stations with antenna pointing directly towards the sky which, in case there are many such deployments, would significantly increase the interference potential to FSS.”

In line with the above conclusions, ECC decision 18(06)²⁹ on the harmonised technical conditions for Mobile/Fixed Communications Networks (MFCN) in the band 24.25-27.5 GHz was approved in July 2018 where it is stated that “most sharing studies have shown that Fixed-Satellite Service (FSS) and the Inter-Satellite Service (ISS) would be protected with a margin of more than 12 dB, based on agreed assumptions, and it will be necessary to ensure that these services remain protected ” and “the pointing elevation of the main beam (electrical and mechanical) should normally be below the horizon for outdoor base stations”.

In the US, FCC has published a series of documents³⁰ outlining its approach on regulating the use of spectrum bands above 24 GHz for mobile radio services. As far as the aggregate interference into satellites is concerned, FCC has decided that the potential for aggregate interference rising to the level of harmful interference is unlikely and therefore there is no need to establish any regulatory limit on aggregate power levels. FCC has also stated that “The Commission retains the authority to monitor developments and intervene to prevent unacceptable interference to satellites if that becomes necessary, but there is no evidence to date that suggests that any such intervention will be necessary.”

In June 2019, Innovation, Science and Economic Development (ISED) Canada decided that³¹ “there will be no mandated limit on the aggregate emissions produced by flexible use systems operating in the 27.0-28.35 GHz band.” ISED also noted that “However, if necessary, ISED may review whether to apply technical measures to ensure coexistence between flexible use systems and FSS systems in this frequency band in the future.”

²⁸ <https://www.ecodocdb.dk/document/3358>

²⁹ <https://www.ecodocdb.dk/document/3361>

³⁰ <https://docs.fcc.gov/public/attachments/FCC-16-89A1.docx> ; <https://www.federalregister.gov/documents/2018/07/20/2018-14806/use-of-spectrum-bands-above-24-ghz-for-mobile-radio-services> ; and <https://www.federalregister.gov/documents/2019/05/13/2019-09426/use-of-spectrum-bands-above-24-ghz-for-mobile-radio-services>

³¹ <https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf11510.html>

Appendix E—Detailed discussion of parameter assumptions

E.1 Satellite G/T figure

The ACMA studies follow the assumptions made in the ITU-R by assuming a satellite G/T value of 20.6dB/K, based on satellite characteristics given in ITU-R Document 5-1/89, "FSS/BSS technical [parameters for sharing studies under WRC-19 agenda item 1.13", liaised to TG5/1 from WP4A.

That document gives two options for the relevant uplink band. The first, used by ACMA, has a 46.6dBi gain antenna (giving a 0.8° beamwidth) and a system temperature of 400K; the second, unused option, has 33dBi gain and relates to an elliptical beam of 3° x 7° and a 900K temperature. These beamwidths would correspond to a footprint of around 600 x 400km in the first case and coverage of all Australia in the second.

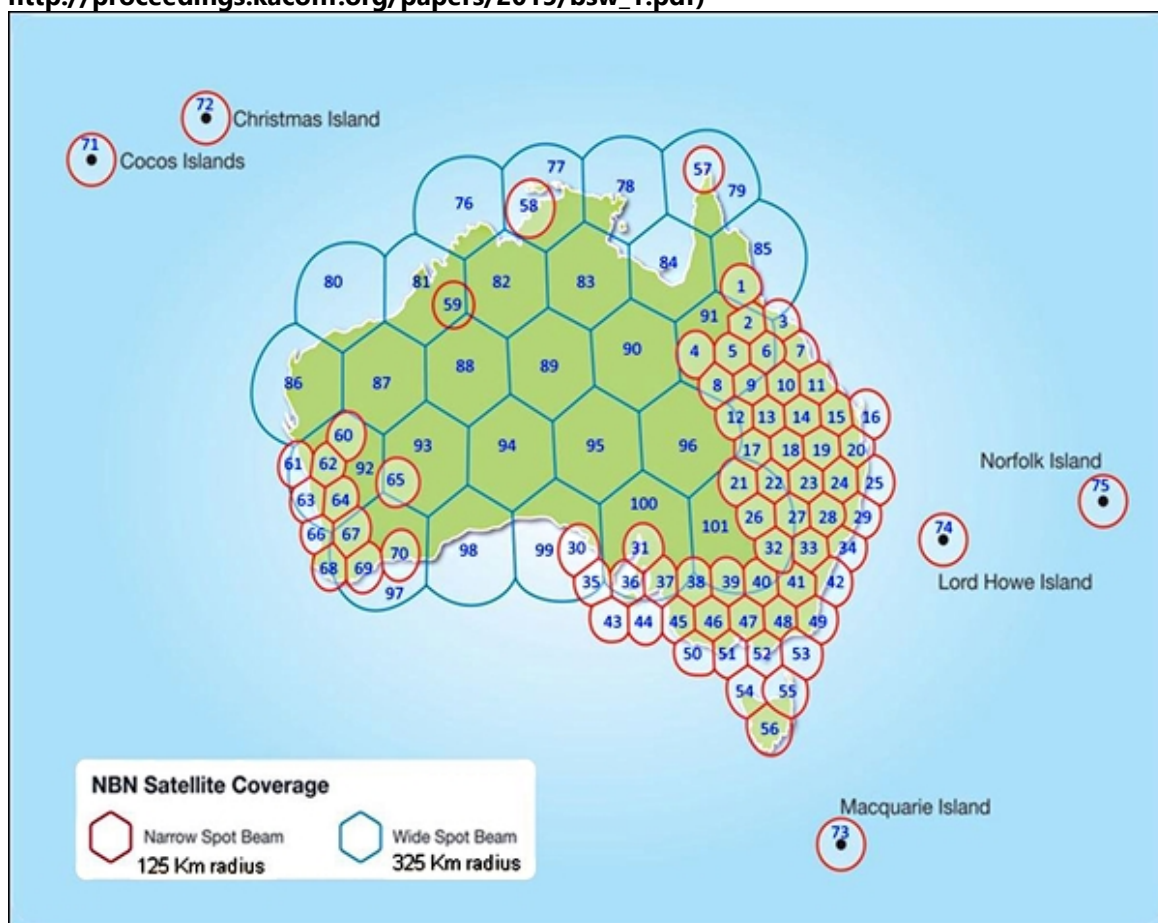
We have not been provided with detailed information on the actual Sky Muster satellite uplink characteristics, Figure 6 of the ACMA 'Reallocation Recommendation' shows the approximate 3dB footprints of the uplink spot beam for Waroona, near Perth, which would seem to correspond to a beamwidth in the order of 0.3°. This would imply a gain of 54.7 dBi and an antenna diameter of around 2.3m³². Assuming the same receiver noise temperature, this would correspond to a G/T of 29dB/K,

In their submission, NBN propose a revised value of 30dB/K as being "more representative of current and future Very High Throughput³³ Satellite (VHTS) system characteristics". This is broadly in line with the figure obtained above.

³² At 27 GHz, assuming a 0.7 efficiency

³³ Traditional FSS satellites will have footprints covering thousands of kilometres across, with the available bandwidth shared between all users, High-Throughput Satellites are characterised by the use of multiple high-gain 'spot beams', used to create a cellular pattern of footprints in the target area. A high degree of frequency re-use ensures that much greater bandwidth is simultaneously available to each user

Figure E.1: : Showing different Sky Muster spot-beam sizes (source: http://proceedings.kaconf.org/papers/2015/bsw_1.pdf)



A pre-launch image of the satellite suggests that the larger antennas, used to generate the 'narrow' spot beams, may have an aperture smaller than 2.3m (by comparison with the personnel in the picture below), so this performance may not reflect the current deployment.

Figure E.2: Pre-launch image of Sky Muster satellite (launch (source:

<https://www.gizmodo.com.au/2016/04/nbn-has-launched-its-sky-muster-broadband-service-for-regional-areas/>)



In their submission, NBN note that “Lower-gain satellites are much less susceptible to interference than high throughput satellites”. The accuracy of this statement depends on the spatial distribution of the interference; if the majority is via the main beam of the satellite, the statement holds, but if this is outweighed by the aggregation of a very large number of interferers entries at off-axis angles, a low-gain antenna may be more susceptible (because the antenna will be less directive).

E.2 Protection criteria

The initial ACMA modelling assumed an interference criterion of $I/N = -10\text{dB}$, and this does not appear to have been explicitly associated with a particular probability. In the final model submitted to TG5/1, ACMA assessed interference against three I/N limits; -6dB , 10dB and -12.2dB .

NBN submitted that the 10.0dB value relates to 20% time, and that the -12.2dB value represents the translation of this value for 50% time, and should be used.

The advice from WP4A to TG5/1 was that the -12.2dB figure should be used at both 20% and 50% probabilities. Criteria are also provided for interference impact at lower probabilities; -6dB at 6% and $+8\text{dB}$ at 0.02%.

In the submission from NBN, it is noted that they do not accept that interference will be ergodic (i.e. that observations of a large range of spatial distributions are equivalent to observation over a long time). Our understanding is that the issue is not, strictly, one of ergodicity, but rather whether the overall interference at the satellite will be aggregated from so many sources that it can be considered essentially invariant with time (the basis of ACMA modelling) or whether the interference will be dominated by a few dominant sources that could give rise to high levels of interference with low probability. If the latter is the case, interference must be assessed at both long-term (-12.2dB) and short-term (-6dB or 0dB) limits.

It is our opinion that, given plausible IMT parameters, the limiting interference to the uplink will be due to the aggregation of a very large number of rather weak sources and will be essentially invariant. The use of only the long-term criterion is therefore very unlikely to give over-optimistic conclusions (particularly bearing in mind the fact that the short-term limit is up to 12.2dB more relaxed than that used by ACMA).

As an aside we would also note that there seems to be some confusion regarding whether the 400K value used for the satellite represents thermal noise (as it should for G/T calculations) or system noise, including all interference or 'external' noise as would be appropriate for the application of the -12.2dB criterion. The heading in the WP4A tables in Document 5-1/89 implies the latter.

The initial modelling submitted to TG5/1 by ACMA noted that WP4A had not yet specified interference criteria for the band and that they would, tentatively, assume a criteria of I/M=-10dB. "It is further noted that Australia supports using an I/N of -10 dB as protection criteria for FSS satellite receivers in this band."

Within the ITU-R, and elsewhere, there has been significant discussion of the appropriate limits. The starting point for these discussions is Recommendation S.1432, which states that interference to the FSS from other primary services should be limited to 6% of the overall satellite receiver system noise. This is equivalent to a level 12.2dB below that system noise.

The receiver system noise is the sum of the thermal noise (from receiver and antenna) and the 'external noise' due to all forms of interference. For an FSS system employing frequency re-use, such as Sky Muster, the external noise should comprise 27% of the overall system noise and the thermal noise 73%. The thermal noise is, therefore, to be -1.4 dB with respect to the system noise.

This implies that, if interference from other primary services should be 12.2dB below the system noise, they should, equivalently, be $12.2 - 1.4 = 10.8$ dB below the thermal noise. It is this thermal noise that is used in the G/T calculations discussed above (i.e. 400K).

Towards the end of the work of TG5/1, WP4A contributed a Liaison Statement (Document 5-1/411, July 2018) which specified the following I/N criteria for their studies, where the percentages may represent temporal, spatial or other probabilities:

- -10.5dB for 20% or average;
- -6.0dB for 1%; and
- 0.0dB for 0.02%.

The -10.5dB figure is derived in the same way as the -10.8dB figure, but for FSS networks not employing frequency reuse.

This LS contains the following note:

Note 1: The noise N in the I/N criteria as specified above is the system receiver noise (i.e. thermal noise) and is equal to the receiver antenna noise plus the receiver noise referred to the antenna as contained in the technical parameters liaised to Task Group (TG) 5/1 by WP 4A. Hence studies conducted by TG 5/1 should only use the values presented above when evaluating the compliance with the protection criteria.

The definition of I/N appears to exclude 'external' (i.e. interference) noise from the N term, which would imply that the 10.5/10.8dB value should be used.

It is assumed that the number of IMT interferers is sufficiently large that the interference can be assessed on the basis of the average value and judged against a 50% time criterion is therefore appropriate.

Although Recommendation ITU-R S.1432 apportions 6% of the degradation to other in-band primary services it is assumed that the only sharing service will be IMT, so no apportionment is made to other services.

E.3 IMT terminal density

The biggest, and unavoidable, source of uncertainty in any modelling of interference to satellite receivers is due to the assumptions that must be made about the distribution and density of terrestrial interference sources. Both the ITU and Small Cell Forum have produced estimates of likely deployment density, but these must come with the caveat that few operational, commercial 26 or 28 GHz IMT mobile networks exist at present. Informal discussions with operators and regulators suggest that there is, as yet, little operator demand for such networks, with most millimetre-wave deployment initially likely to focus on private networks in industrial settings and on FWA (Verizon is planning to provide fixed wireless of 1 Gbps speeds at ranges of up to 600 meters and looks confident in its ability to find a sustainable business model for 5G fixed wireless access³⁴).

One exception is the Verizon network in Chicago; this is clearly in a very early stage of deployment and consists of a small number of low-height base stations mounted on street furniture, providing hotspot coverage in the dense urban centre³⁵.

The ACMA modelling assumption is that there may be an urban density of 30 BS/km² and 100 UE/km². NBN consider that this is an under-estimate, noting that “research conducted by the small cell forum indicates that many operators will aim for BS densities of 100 to 350 per square kilometre” They therefore propose an urban density of 100 BS/km² and 400 UE/km².

The most demanding 5G applications in terms of data rate, according to ETRI, will be spherical view holography. For which the data rate could surpass 1 Gbps.

Table E.1: Data rates for different video applications

Service	Data rate
360 view with 4K resolution	65 Mbits/s (H.265) and 130 Mbits/s (VAR for peak).
360 view with 8K resolution	258 Mbits/s (H.265) and 516 Mbits/s (VAR for peak).
Spherical view for holography	4 to 8 times more than 360 views

Source: ETRI

Connection density for various areas are given in the table below:

Table E.2: Connection density for different areas

Teledensity	Number of devices per area	Activity factor	Connection density
Overcrowded area	1-4 / m ²	90%	225 000 / km ²
Dense urban area	5-100 / m ²	70%	35 000 / km ²
Urban area	20-10000 / m ²	50%	2 500 / km ²

Source: ETRI

³⁴ Study on using millimetre wave bands for the deployment of the 5G ecosystem in the Union—SMART 2017/0015

³⁵ see <https://www.cnet.com/news/testing-verizons-early-5g-speeds-was-a-mess-but-im-still-excited-about-our-data-future/>

Similarly, the collaborative European project 'One5G' considers hotspot deployments³⁶, aimed at serving applications such as virtual reality, with connection densities of 200—2,500/km². To support such densities, however, it is assumed that at least 1 GHz of bandwidth is used and that base stations will require antenna arrays of up to 256 x 256 elements and UE antenna arrays of up to 32 x 32 elements. Scaling for the 200 MHz bandwidth being modelled, brings this value down to a maximum of some 500 connections/km².

A recent research paper³⁷ notes that current microcell density is 10-20/ km². A density of 32 base stations/km² offers 97% coverage, with network self-interference setting a density limit at around 96/km². The NBN suggestion would therefore seem to represent an absolute upper bound for a few urban areas. To achieve these densities would also seem to require BS and UE antennas with significantly better performance (larger arrays, lower sidelobes) than those assumed by either ACMA or NBN. These densities would also imply deployment at low height within urban clutter, with consequently greater levels of screening due to diffraction loss.

The discussion above concerns mobile networks offering 'enhanced mobile broadband' (eMBB) services. A less speculative application of 5G millimetre-wave is to provide fixed wireless access (FWA) or 'last-mile connectivity' in suburban or rural areas. Considering the entirety of housing and office locations falling within the individual satellite uplink beams, it is likely that many of the dense areas will already have, or be close to, fibre connectivity. In the suburban and rural areas where the business case for FWA is strongest, deployment densities are likely to remain very low.

E.4 IMT BS and UE transmit power

ACMA modelling assumes a BS transmit power of 2dBm/MHz, based on ITU-R SG5 recommendations. NBN propose a figure 8dB higher "to align more closely with the standards under development and systems already trialled and licensed in Australia". No reference to specific standards or licences is given.

The relevant 3GPP specification (TS 38.104) does not define a maximum EIRP for Type 2-O base stations

The 8dB increase in base station power, for instance, would imply a total conducted power in the 200 MHz base station bandwidth of 2W, which may be excessive in light of envisaged deployments and likely antenna beamforming gain.

The Motorola 'Moto Mod' 28 GHz handset uses four 1x4 element antenna arrays³⁸, only one of which is active at any time. These arrays have a nominal per-port power of +8dBm. With all ports active, and considering both (orthogonal, linear) polarisations, a total power of +17dBm is therefore available.

³⁶ Deliverable D2.1 Scenarios, KPIs, use cases and baseline system evaluation,
<https://one5g.eu/documents/>

³⁷

<http://epubs.surrey.ac.uk/849644/1/Capacity%20and%20Costs%20for%205G%20Networks%20in%20Dense%20Urban%20Areas.pdf>

³⁸ <https://fccid.io/IHDT56XL1/RF-Exposure-Info/PD-Simulation-report-0213-4170293#download>

E.5 IMT UE body loss

The ACMA studies assume 4dB body loss (screening of IMT user terminals) in line with ITU-R assumptions.

NBN suggest that this parameter is 'speculative' with no clear reason for the value used. They also note that there are numerous 5G use cases that involve no body (i.e. fixed wireless access (FWA) or autonomous vehicles) and a consequently increased potential for interference

The reason, however, that this value is used is that it is specified in the TG5/1 document ('Annex 1 to Document 5-1/478) on 'System parameters...to be used in ... sharing studies', where it is noted that "The body loss provided in Document 5-1/36 (4 dB) is considered as a fixed value without a distribution".

The fact that it is specified by TG5/1 does not, however, mean that it is necessarily appropriate in the present context: there is certainly a case for assuming no body loss as (i) many user terminals may be fixed wireless access (FWA) terminals and (ii) at typical elevation angles of 40° or higher, the user's body may often not obstruct the path.

Given the high attenuation likely at 26 GHz, it would be better perhaps, to model this by discarding a certain number of interferers rather than applying an average loss, but for a large population the two will give the same results. Attachment 2 to 5-1/36 states (footnotes 5,7,9 & 11) "Although preliminary studies suggest that the impact of proximity effects/body loss will in most cases be in excess of 4 dB, a value of 4 dB has been selected as a typical value". No reference is given for the 'preliminary studies'.

Plum's opinion is that the 4dB figure represents a plausible value if interference is primarily from a large number of handheld user terminals. There is a realistic possibility, however, that future IMT use of the 27 GHz band may be dominated by other terminal types, and a 0dB figure should also be considered.

E.6 Polarisation discrimination

The ACMA modelling assumes a discrimination between linear and circularly polarised antennas of 3dB

In their submission, NBN state that "Off-axis to off-axis polarisation loss is zero. On-axis to on-axis emissions can be as high as 3 dB but usually lower", and propose that modelling be undertaken using an intermediate value of 1.5dB.

As the most significant interference will couple to the main beam of the satellite antenna, we can expect that the axial ratio of that antenna will be close to unity. There will not be many geometries where the discrimination between a linear array and the CP antenna would be significantly less than 3dB.

E.7 IMT Network loading factor / average BS activity

ACMA assume 20%, but NBN state "It does not appear reasonable to state conclusively that, at all times, no more than 20% of cells will be active", and assume a 50% value.

This factor is not, presumably, stating that 'at all times no more than 20% are active', but will rather be the average of active cells over a day.

The 20% ACMA figure comes from Doc 5-1/478, where it is stated to be appropriate for wide-area interference into satellites. The document also proposes a 50% value 'for studies involving a small area where there are only a few IMT transmitters', but notes that "In a small area with a few IMT transmitters, if the loading is approaching 50%, then the IMT network performance will not be sufficient... every MNO will try to avoid local situations ... where loading is greater than 20%".

From experience with terrestrial network planning we would concur that a network cannot maintain stability if the network loading over larger areas approaches 50 %. In a local area a few BSs (5-10) can exceed 50 % for shorter periods; the network is designed for such a situation and individual BSs may approach a 100 % loading for shorter periods of time. For aggregated interference for an area of a radius of 250 km it is not practical to get to more than 20 % averaged over the area.

E.8 IMT BS activity factor (Uplink to downlink ratio)

ACMA assume 80%, while NBN state: "It is difficult to state conclusively that upload-intensive applications will not exist, or that the proportion of upload traffic will not vary with time" and propose a value of 60%.

It isn't implausible that usage will become more symmetrical, though there is no current evidence of this—AR and VR applications are still dominated by the downlink. Real-time, multiple video/radar streams from driverless vehicles might be an alternative example. A recent research paper³⁹ by David Wiseley (BT) notes "Downlink traffic continues to dominate existing networks and most of the applications proposed for eMBB are highly asymmetric with a preponderance of downlink traffic. Thus we have chosen TDD, with a DL:UL ratio of 10:1". The impact of changing this assumption depends on the balance between UE and BS interference at the satellite, which, in turn, depends on geometry, clutter and antenna patterns.

For hot spots in urban and suburban areas the areas covered will also be covered by sub-6GHz BS so the hot spot effectively serves as a Secondary Downlink (SDL). Where used for FWA it is less clear that 80 % download is correct based on synchronisation ratios adopted for lower frequency bands (e.g. 3:1 adopted by the ACMA in the 3.5 GHz band). However, the number of FWA with fixed antennas seem likely to be a small fraction of the UEs served by urban/suburban hot spots.

The services currently identified for 5G mmWave tend to be downlink centric as demonstrated for automotive services.

Table E.1: Requirements for automotive services

Service	Quantity of data to transmit (per month)	Latency	Data rate	Traffic direction
Infotainment	Up to 20 GB per month	Low latency (< 10 ms)	> 100 Mbps	Downlink
WiFi hotspot	Tens of GB	Low latency for critical applications (video mainly or e-commerce)	> 100 Mbps	Downlink
Software updates	Tens of GB	Not really a real-time issue (on-demand)	> 100 Mbps	Downlink
Autonomous vehicles	-	A maximum network end-to-end delay (including device detection, connection setup and radio transmission) of 5 ms	> 100 Mbps	Downlink and uplink

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<http://epubs.surrey.ac.uk/849644/1/Capacity%20and%20Costs%20for%205G%20Networks%20in%20Dense%20Urban%20Areas.pdf>

Source: IDATE

Table E.2: Technical requirements for manufacturing / Industrial automation

Service	Quantity of data to transmit (per month)	Latency	Data rate	Traffic direction
WiFi hotspot	In TB	Low latency for critical applications (video mainly or ecommerce)	The more the better (1 Gbps)	Downlink mainly
Video surveillance	Depending on the system	Low latency	> 50 Mbps	Uplink
Remote operation	Variable	Low latency	The more the better (1 Gbps)	Both downlink and uplink

Source: IDATE

Table E.3: Requirements for smart city services

Service	Quantity of data to transmit (per month)	Latency	Data rate	Traffic direction
Digital signage	Up to 5 GB per month	n.a.	> 100 Mbps	Downlink
WiFi hotspot	In PB	Low latency for critical applications (video mainly or ecommerce)	The higher the better (1 Gbps)	Downlink mainly
Video surveillance	Depending on the system	Low latency	> 100 Mbps	Uplink

Source: IDATE

E.9 IMT BS antenna height

ACMA assume 6m, but NBN comment: "The standard 30-metre height of many communications infrastructure platforms is a reasonable assumption to make for the purpose of conducting sensitivity analyses". A height of 30m is therefore proposed.

Given the limited range of 26 GHz cells, it is unlikely that antennas would be located so far (vertically) from the user. The overwhelming majority of the literature posits a 'street furniture' deployment for eMBB use.

For FWA applications, the 30m figure is more plausible. The implication of the increased BS height is that UEs would be pointing with a greater elevation angle. If the network is FWA, however, the UEs themselves will be higher.

Urban hot spots will be limited by the surrounding streets and the people/cars and other street furniture; with a maximum coverage distance of around 100-120 m, a 6 m antenna height is more than adequate. This is confirmed by the height of the 28 GHz base stations in Chicago, seen in the video at www.cnet.com/news/testing-verizons-early-5g-speeds-was-a-mess-but-im-still-excited-about-our-data-future/.

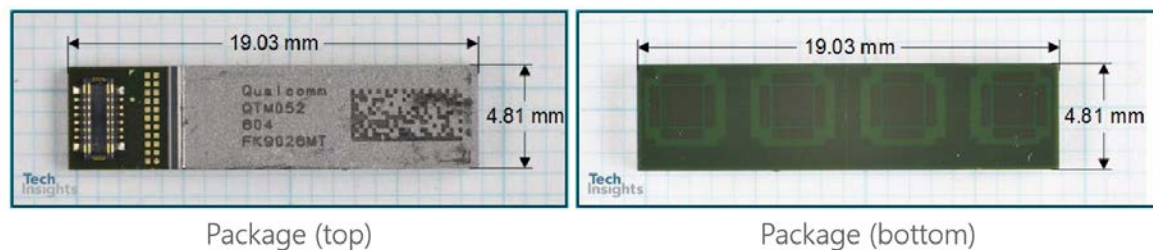
FWA would use higher antennas, perhaps still less than 30 m but the fixed antennas on the dwellings will be close to roof heights in most cases and the distances typically involved will tend to ensure that the antenna alignments are close to horizontal in most cases.

IMT BS and UE antenna array size and grating lobes

ACMA assume a UE antenna with 4x4 elements, while NBN state “A review of 5G standardisation activities indicates that the most likely implementation of phased arrays on UE terminals will include a total of four elements, either 1 x 4 or 2 x 2”. “This would result in a ‘double hit’ of interference through more transmitted power and worse antenna performance”. They propose using a 2x2 (UE) assumption.

The only known antenna module commercially available for 28 GHz (Qualcomm QTM052), as used in the Motorola ‘Moto Mod’ 5G add-on transceiver unit, and this features a 1 x 4 array.

Figure E.1: Qualcomm QTM052 module, showing 1 x 4 antenna elements (source Techinsights.com, <https://osch.oss-cn-shanghai.aliyuncs.com/blogContentFile/1562306596954.pdf>)



A brief review of other (academic) literature shows no examples of 2x2 arrays—minimum found is 2x4 for UE with 4x4 and 8x8 also suggested. In turn, between 2–8 of such modules are assumed to be embedded in a handset to avoid hand-screening and to allow MIMO.

Developments in antenna fabrication would seem to make it more, rather than less, likely that larger number of antenna elements will be employed

Table E.3 shows some commercial TDD Massive MIMO systems of today and the number of transmit/receive ports versus maximum number of multiuser MIMO supported.

Table E.1: Typical Commercial TDD mMIMO Base Stations

Tx/Rx	Antenna elements (row x column x polarization)	Tx/Rx	Maximum number of layers (Lm)
64T64R	128 (8x8x2)* 196 (12x8x2)	64	16
32T32R	64 (8x4x2)*	32	8
16T16R	32 (4x4x2)* 96 (12x4x2)**	16	8

Note (*): Every set of radiating elements makes up an antenna subarray (in this case 2 or 3) and is connected to a separate RF input signal.

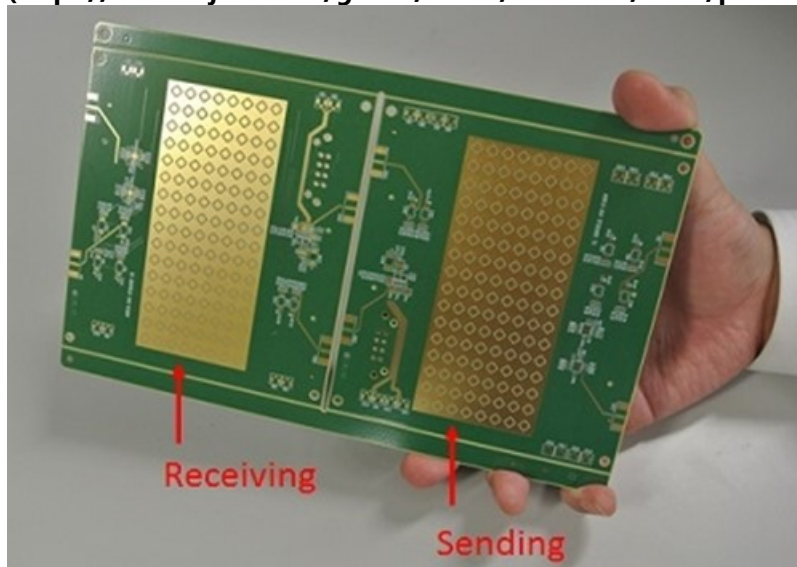
Note ():** In the case of 16TRX, columns can have analogue phase shifters for electrical down-tilt.⁴⁰

⁴⁰ Source: 5G Americas White Paper: Advanced Antenna Systems for 5G—2019

NBN raised concerns about the potential impact of grating lobes. These will apply in the horizontal plane for sub-urban and rural areas and the vertical and horizontal plane for urban areas. It is important to consider the actual deployment geometry and the relationship between the main beam and the grating lobes. In the case of a grating lobe pointing towards the satellite (at 40 degrees elevation) it is necessary for the BS to be pointing at 20 degrees above the horizon assuming a 10 degree downtilt of the BS antenna. For the UE grating lobe to be at 40 degrees generally the UE will be very close to the base station and the transmitter power reduced considerably.

The probability of the grating lobe contributing to interference is an important consideration and depends on practical deployments. It is likely that base stations will see a reduction in the grating lobe as for hot spots the base station will be often deployed with a structure behind (120 degree coverage span) which will reduce the signal level.

Figure E.2: 8 x 16 antenna arrays for 28 GHz base station. Source: Fujitsu
(<https://www.fujitsu.com/global/about/resources/news/press-releases/2018/1129-01.html>)



Appendix F—Glossary

AR	Augmented Reality
BS	Base Station
EESS	The 'Earth Exploration Satellite Service' (Earth sensors for land-use, climate, oceanography, etc)
FSS	The 'Fixed Satellite Service', i.e. systems such as Sky Muster
GSO	Geostationary orbit
G/T	A 'figure of merit' for a radio receiver, given as a ratio of antenna gain to system noise
IMT-2020	The formal ITU term for 5G technologies and system
I/N	Interference to noise ratio
TG 5/1	An ITU-R Task Group constituted to study sharing issues relating to IMT-2020 prior to the World Radio Conference in 2019
TRP	Total radiated Power
UE	User equipment. Typically a handheld device, but may include fixed wireless access terminals, vehicle terminals, etc
VR	Virtual reality
WP	Working Party (with an ITU-R Study Group)
WRC-19	The ITU-R World Radio Conference to be held in October 2019, where spectrum regulation rules are agreed internationally

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