1 Introduction

This document provides an assessment of studies conducted within ITU-R Task Group 5/1, specifically those relating to the potential for coexistence between FSS and IMT-2020 applications of the mobile service. Concerns consistently raised by **nbn** throughout the study process relate to the fact that preconditions imposed on TG 5/1 did not allow a representative range of parameters, relating both to the FSS and IMT-2020, to be duly considered in the studies. This document addresses these matters in particular by taking account of the following:

- More representative FSS parameters, particularly as they relate to G/T, off-axis characteristics, and protection requirements
- The possibility – indeed the likelihood or certainty – that actual IMT-2020 deployments will differ from the scenario published by WP 5D in ways which will increase the potential for interference

Appropriate consideration of these factors will allow a more informed interpretation of studies, and will highlight those matters which need to be addressed in any domestic consideration of replanning the Ka-band FSS uplink for terrestrial services.

2 Re-baselining compatibility studies

Before any detailed sensitivity analysis is presented, **nbn** considers it necessary to provide a brief quantitative analysis of the nature of the potential for interference, in particular whether it can be considered ergodic in nature.

Satellite G/T	30 dB/K
I/N	-10.5 dB
Aggregate Interference threshold	-55.5 dBW/Hz
Maximum IMT-2020 EIRP density	BS: -62 (-54)[1] dBW/Hz UE: -69 dBW/Hz
No. stations which exceed interference threshold	BS: 4 (1) UE: 22

Table 1. Interference threshold and number of IMT-2020 stations

Table 1 shows a derivation of the maximum tolerable interference level of a satellite with the characteristics of those operated by **nbn**. It is noteworthy that future satellite architectures with higher figures of merit will not be able to tolerate levels of interference this high and a lower value would need to be specified in this case. Also shown is the very small number of IMT terminals required to exceed this interference threshold under maximum EIRP and worst case pointing assumptions. For an unconstrained IMT deployment in a modestly dense environment, it can be considered a statistical certainty that at least the number of IMT terminals indicated in Table 1 will operate under worst case pointing and power assumptions. This is expected to occur for long term time percentages, and may even be a constant factor in the aggregate interference received by FSS uplinks.

[1] Number in brackets indicates power levels already licensed in Australia

The clear implication of this analysis is that interference into FSS uplinks can, and most likely will be dominated by a very small subset of worst performing IMT stations visible within the satellite footprint, and that interference cannot be considered to be ergodic. It is with these considerations in mind that rebaselining of studies to reflect the Australian interference environment, and a more thorough sensitivity analysis, are conducted.

2.1 Re-baselining

Prior to conducting any sensitivity analyses on IMT-2020 parameters, **nbn** considers it necessary first to establish a new baseline that is relevant to the existing Australian radiocommunications environment. Table 1 summarises how this baseline is determined, with variations explained as follows:

- G/T – one of the most obvious discrepancies in the TG studies is the single satellite scenario in which only a relatively low-gain satellite receiving antenna is assumed. A value 9 dB higher is more representative of current and future VHTS system characteristics
- Interference mechanism – interference is expected to be dominated by emissions arriving at the satellite via the main beam (as was also analysed in TG 5/1-193), whereas TG studies assume as few as zero interferers in the main beam
- I/N – Australia tentatively settled on a long-term, or 20% of time, interference threshold of -10 dB. This translates to -12.2 for 50% of time. This translation is necessary since the simulation deals with averaged values for most parameters.
- Body loss – one of the more speculative parameters in the studies with no clear reason for the value used or its relevance, if any, to Earth-to-space paths – also note that dozens of IMT use cases involve no body and therefore no body loss. Even if a valid parameter, the assumption of globally averaged body losses fits poorly into a non-ergodic interference assessment.
- Polarisation loss – under ideal circumstances 3 dB is valid, but not practically representative of typical or averaged scenarios, especially involving off-axis transmission and reception

With these modifications to the study inputs and assumptions, the effect on the compatibility between FSS and IMT-2020, as shown in Table 1, is a reduced margin of 10 dB. It is noteworthy that this new baseline is established simply by making some realistic assumptions and without applying any sensitivity to the IMT-2020 characteristics.

Sensitivity parameter	TG studies	TG studies re-baselined
Satellite G/T	20.6 dB/K	30 dB/K
Interferer locations	Visible Earth	Satellite main beam
I/N	-10 dB	-12.2 dB
Body loss	4 dB	0 dB
Polarisation isolation	3 dB	1.5 dB
IMT-2020 – FSS interference margin	**32 dB**	**10 dB**

Table 1. Re-baselining of the FSS-IMT2020 compatibility studies

3 Sensitivity of IMT-2020 characteristics

With a new baseline established for a realistic satellite sharing scenario relevant to the Australian context, it is now possible to determine the effect of the variability of IMT-2020 parameters on the compatibility with the FSS.

Parameters considered suitable for assessment as part of a sensitivity analysis, and the reasoning behind selection of these parameters and their associated values, are as follows:

- UE array size: it appears from a review of IMT-2020 standardisation activities 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. Although it will be possible to design UE antennas with more elements, these are expected to be used as multiple 4-element radiators
- BS array size: from available literature it seems reasonable to assume that 8 x 8 element arrays will be used at the IMT-2020 BS, however these can and most likely will often be used as multiple smaller sized arrays transmitting simultaneously
- IMT station density: research conducted by the small cell forum indicates that many operators will aim for BS densities of 100 to 350 per square kilometre. Furthermore UE densities are essentially uncontrollable and unpredictable. Therefore modest increases to IMT-2020 station densities appear reasonable to assume
- IMT base station height: BS height will be dictated by infrastructure height, and is expected to range from ground level to building tops. The standard 30-metre height of many communications infrastructure platforms appears a reasonable assumption to make for the purpose of conducting sensitivity analyses
- BS transmit power: a modest increase in IMT-2020 BS power is assumed to align more closely with the standards under development and systems already trialed and licensed in Australia
- TDD and activity factors: it is considered reasonable to assume some variation in these parameters, e.g. it is difficult to imagine that, at all times, no more than 20% of cells will be active, or that upload-intensive applications will not exist

Sensitivity parameter	TG studies re-baselined	Sensitivity analysis	Effect on compatibility
UE antenna dimensions	4 x 4	2 x 2	5 dB
IMT deployment density	BS: 30/km^2 UE: 100/km^2	BS: 100/km^2 UE: 400/km^2	5 dB
BS antenna height	6 m	30 m	3 dB
BS segmentation	8 x 8	4 x 4	2 dB
TDD downlink factor	80%	60%	3 dB
BS/UE activity factor	20%	50%	4 dB
BS transmit power	2 dBm/MHz	10 dBm/MHz	2 dB
IMT-2020 – FSS interference margin	**10 dB**	**-11 dB**	**21 dB**

Table 2. FSS-IMT2020 compatibility studies – sensitivity analyses

The results of the consideration of these sensitivity parameters are shown in Table 2, and compared alongside the new baseline established above. These results show the individual effect of each variation, and that the cumulative effect gives a deficit of 11 dB.

3.1 Expected IMT-2020 deployment scenarios

Appendix A provides illustrations of expected IMT-2020 deployment scenario and network parameter deviations from the ones assumed in the TG 5/1 technical studies. This information is drawn entirely from documents describing the mobile industry's efforts to standardise the use of bands above 24.25 GHz for wireless access.

Appendix A

3GPP is now in the process of developing a standard for New Radio (NR) the 3GPP term for IMT-2020, as well as associated specifications and requirements for below 6 GHz (FR1) and mm wave bands (FR2) to facilitate interoperability testing and deployment of networks with common characteristics and capability to facilitate seamless interworking ability including global roaming.

An appreciation and understanding of the IMT-2020 network deployment scenarios and emission parameters now under development by industry and that are critical for the assessment of potential interference can arguably only be gained by resorting to 3GPP documentation related to NR/FR2. The contributions to 3GPP RAN#4 from mobile operators and equipment manufacturers together with the results of the latest academic research on mm wave 5G are particularly pertinent.

While some elements of anticipated mm wave network deployment scenarios and related emission parameters have been carried over into the work of the ITU-R notably WP5D and subsequently TG 5/1, this information constitutes just one example of a network configuration that is likely to be of interest to operators. However a review of 3GPP RAN#4 documents provides a clear indication that there are a number of other deployment scenarios with characteristics that arguably have a greater potential to adversely impact on the feasibility of co-existence with other services notably the FSS.

Below are examples of just three areas where there is anticipated to be significant deviation from the assumptions used in the TG 5/1 studies.

A – Deviation from M.2101 assumption of beam forming antenna pattern.

B – Deviations from "hot-spot" deployment scenario and minimum/maximum BS and UE channel powers.

C - Assumptions related to handheld UE antenna array configurations

It should be noted that many uncertainties regarding deployment scenarios that have the potential to impact on coexistence with the FSS are still to be addressed. For example –

- The network and user device densities assumed in the TG 5/1 studies may turn out to be pessimistic, in which case the interference levels will rise accordingly.
- Surveillance networks that may require communication to aerial vehicles such as drones. Such types of links would pose a significant risk to satellite receivers even if operated intermittently and in small numbers.
- Autonomous vehicle communication. Future autonomous vehicle links are anticipated to require very high data rates and be active for extended periods. The prospect of such a deployment type would open the potential for significant impact on the FSS given the number of vehicles that may be operated in autonomous or assisted modes in the future.

Finally, many questions have been raised concerning the validity of a statistical (Monte-Carlo) averaging model for the purpose of determining aggregate interference, Such a 50% of time 50% of location approach would appear to represent a valid representation of aggregate interference when applied to a "homogeneous" network comprising very large numbers of similar sectors and user devices but such a methodology masks outlier conditions and parameter distributions that may be representative of certain types of deployments. Hence the results obtained with an "averaging" model should be treated with considerable caution.

A – Deviation from M.2101 assumption of beam forming antenna pattern.

Recommendation M.2101 contains the formulas to be used to mathematically model a beam-forming antenna and hence is critical for the calculation of the antenna side-lobe gain towards satellite obits. To date no information has been provided to the ITU-R concerning measured antenna patterns for beam-forming antennas, and therefore it has not been possible to validate interference calculations using measured antenna data. This is a cause for concern particularly when in the draft release 15 of the 3GPP NR standard we have the following note of caution in section 9.9.1 of TR 38.817-2-100.

9.9 Transmitter spatial emissions

9.9.1 General

Traditional antenna data sheets provide information on not only the antenna gain in the intended direction but also the gain in unwanted directions. Traditional metrics are:

- Front to back ration (FBR) – which captured the ratio of emissions behind the antenna compared to those in the forward direction.
- Side Lode Ratio (SLR) – ratio of the side lobe antenna gain to the main lobe antenna gain.

For an AAS it is clear that these traditional metrics of antenna gain are not directly applicable, as an AAS has the ability to manipulate the shape of the spatial emissions to maintain optimum network throughput it is unlikely that the spatial pattern of the emissions will relate to a specific beam pattern with identifiable side and back lobes. An example of a realistic AAS beam pattern in an operational environment is shown in Figure 9.9.1-1.

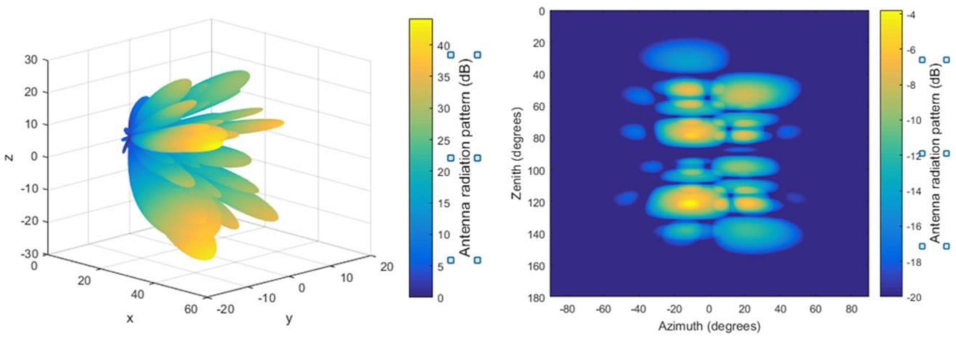

Figure 9.9.1-1: Example of a realistic AAS beam pattern in an operational environment (with DFT subband precoding)

The influence that the shape of the antenna pattern (and wanted and unwanted cell emission) has depends on the number of simultaneously operating beams, which could be depend on the operational state of the beamforming algorithm and operator configurations. The wanted and in the same time the unwanted spatial emissions strongly depends on the number of simultaneously beams and their shapes and directions.

The antenna pattern also depends on beamforming architectures and algorithms, amplitude tapering level, antenna structure, etc. and is affected by realistic propagation channel as described below in example.

The fact is that the capability to excite beam-forming arrays to facilitate the transmission of multiple simultaneous beams will undoubtedly be exploited to enhance commercial viability of mm wave networks[2]. Taken together it seems clear that M.2101 assumptions concerning the level of sidelobe energy that will be directed as satellites based on theoretical mathematical antenna models alone must be treated with great caution and that almost certainly the sidelobe energy has been significantly underestimated in the TG 5/1 studies.

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[2] See, for example, "*Massive MIMO 5G Cellular Networks: mm-Wave vs. μ-Wave Frequencies*" by Stefano Buzzi and Carmen D'Andrea, reported in *ZTE Communications* Vol 15 No S1 (June 2017) page 41*ff*, for further insight into this aspect.

B – Deviations from "hot-spot" deployment scenario and minimum/maximum BS and UE channel powers.

The TG 5/1 studies have been performed on the basis that the dominant mm wave deployment scenario is related to urban and to a lesser extent suburban "hotspots" comprising single sector low power base stations mounted below roof height (6 ~ 15 meters) with the main beam pointing well below the horizon. 3GPP documentation[3] casts considerable doubt on the assumption as can be seen from the following

The rated carrier output power of the BS type 1-C shall be as specified in table 6.2.2.1-1.

Table 6.2.1-1: BS type 1-C rated output power limits for BS classes

NR BS class	$P_{rated,c,AC}$
Wide Area BS	(Note)
Medium Range BS	≤ + 38 dBm
Local Area BS	≤ + 24 dBm
NOTE: There is no upper limit for the $P_{rated,c,AC}$ rated output power of the Wide Area Base Station.	

The rated carrier output power of the BS type 1-H shall be as specified in table 6.2.2.1-2.

Table 6.2.1-2: BS type 1-H rated output power limits for BS classes

AAS BS class	$P_{rated,c,sys}$	$P_{rated,c,TABC}$
Wide Area BS	(Note)	(Note)
Medium Range BS	≤ 38 dBm +10log($N_{TXU,counted}$)	≤ 38dBm
Local Area BS	≤ 24 dBm +10log($N_{TXU,counted}$)	≤ 24dBm
NOTE: There is no upper limit for the $P_{Rated,c,sys}$ or $P_{Rated,c,TABC}$ of the Wide Area Base Station.		

Table 1: NR FR2 UE Type summary [1]

#	Min Peak EIRP (dBm)	Spherical coverage	Maximum allowed EIRP (dBm)	Maximum allowed TRP (dBm)	Comments*
1	[22.0-22.4]	Full sphere	43	23	Handheld UE
2	[26-30]	Half sphere	43	23	Vehicle mounted UE (fixed on moving platform)
3	[~35]	Full sphere	43	23	Higher power mobile UE
4	[30-40]	Half sphere or further limited sphere	55	35	FWA on fixed platform

***Note: these notes are meant to illustrate examples that have the requirements listed, other examples are not precluded**

The above demonstrates that 3GPP is now considering deployment scenarios that range from micro cell "hot-spots" with handheld UEs as envisaged in the TG 5/1 studies but also higher power terminal devices including CPEs (FWA) and vehicle mounted ones to be used in larger cells as indicated in the tables above. In the case of the lowest "Local Area" type has a "minimum" rating equivalent to the highest hotspot channel power used in the TG studies and maximum is not defined as it is left to local regulators. base station EIRPs.

C - Assumptions related to handheld UE antenna array configurations

Ensuring "spherical coverage" is a vital aspect of UE design and this is the focus of much attention in 3GPP. Following are extracts from Documents, R4-1801594 (Feb 2018) and two from R4-1807490 (May 2018)[4]

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[3] See 3GPP TSG-RAN WG4 Meeting #85 27 November – 1 December 2017 R4-1712641; and Meeting #87 21 - 25 May 2018 R4-1807849

[4] See 3GPP TSG-RAN WG4 Meeting #86 26 February – 2 March 2018, R4-1801594; Meeting #87 21 – 25 May 2018, R4-1807490

It Has now been explicitly assumed in 3GPP that the standard array in handheld UEs will comprise 2x2 element patches and that a number of such patches will be mounted in different places depending on the form factor to ensure "spherical" coverage irrespective of the orientation of the device.

Preliminary information from handheld device manufacturers such as Intel, Qualcomm, Samsung and others confirm this trend but also indicate that other 4 element configurations such a 1x4 and even 1x8 are being evaluated as they may provide better performance noting that the objective is to maximise gain in the azimuth direction for improved intra-system interference suppression. Irrespective of whether it is 2x2 or 1x4, the consequence is significantly increased interference to the satellite orbits compared to what has been calculated using the TG 5/1 parameter assumptions.

1 Introduction

According to WF on EIRP CDF topic for spherical coverage [1-2], we would like to present more simulation results.

2 Discussion

In this paper, we still classify the assumptions as two groups. Group 1 has full screen display and metal bezel characteristics; Group 2 has partial screen display and plastic bezel characteristics. Please find Table 1 for detailed information of Group 1 assumptions and Table 2 for Group 2 assumptions. Noted that, all results here are nominal values.

	Full Screen Display & Metal Bezel (Nominal Value)		
	1 Antenna Array	**2 Antenna Arrays**	**3 Antenna Arrays**
Frequency range	n257	n257	n257
# of antenna in an antenna module/set	4 Patches 4 Dipoles	4 Patches 4 Dipoles	4 Patches 4 Dipoles
# of antenna module/set in total	1	2	3
Finite UV test points	9999	9999	9999
Beam phase shifter controller (degree)	45	45	45
Antenna type (patch, dipole, or both)	Both	Both	Both
Antenna module/set location	Back_Top_Right	Back_Top_Right Back_Bottom_Left	Back_Top_Right Back_Bottom_Left Back_Middle
Front cover	Glass	Glass	Glass
Back cover	Glass	Glass	Glass
Side cover / Frame	Metal	Metal	Metal
Device size (WxHxD in cm)	14.3x7.1x0.77	14.3x7.1x0.77	14.3x7.1x0.77
Display panel (Y/N)	Y (Full Screen Display)	Y (Full Screen Display)	Y (Full Screen Display)
Bezel margin (mm)	1.5	1.5	1.5

Table 1. Group 1 Assumptions Details

2 Measurement set-up

The measurement is done on an evaluation prototype in a smartphone UE size (slightly larger than 3GPP simulation assumption) with partial display (i.e. front side antenna is behind glass cover) and plastic back cover. A schematic outline is shown in Figure 1. Measurement is done with a CW signal and therefore only relative gain is reported. Antenna modules consists of patch elements in 2x2 matrices. A far field test method is used. Measurements are reported for front side antenna only (glass cover), backside antenna only (plastic cover) and combined performance (best beam chosen). Each antenna panel has 5 discrete beams.

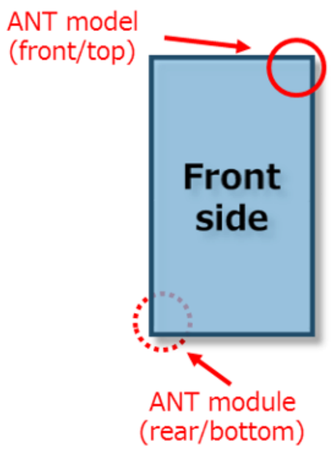

Figure 1. Schematic outline of measurement prototype.

Assumption	-	**2-modules**	**Back-side only**	**Front-side only**
Display	Partial / Full	Partial		
No antenna arrays	Back side	1	1	N/A
	Front side	1	N/A	1
Side cover (cover material near antennas)	Metal / Plastic	Plastic	Plastic	Plastic
Back cover	Glass / Plastic	Plastic	Plastic	N/A
Front cover	Glass / Plastic	Glass	N/A	Glass
EIRP @ 100%%-tile point	dBm	**22.4dBm (agreement in #86bis [4])**		
Δ EIRP @ 50%	dB	**9.1**	**12.5**	**13.1**
Δ EIRP @ 40%	dB	**10.1**	**14.2**	**14.7**
Δ EIRP @ 30%	dB	**11.1**	**16.2**	**17.9**
Δ EIRP @ 20%	dB	**12**	**19.1**	**21**

Table 1. Summary of measured CDF spherical performance