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Protecting satellite downlink Tracking and Telemetry channels by IMT-2020 5G Base Stations Protection Belts surrounding Satellite TT&C Earth Stations operating in the 40 GHz Band

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Abstract:
Telemetry, tracking & command (TT&C) earth stations (ES) constitute a sensitive part of the communication critical infrastructure in satellite networks, because harmful interference to TT&C channel can cause the total loss of communication with the space station. The ITU WRC 2019[1] identified frequency bands to be shared by 5G (IMT-2020) and satellite systems, including the 40 GHz band, which requires interference mitigation techniques.

This work presents and discusses simulation results to evaluate the effectiveness of characterizing a zone *(Protection Belts)* where *5G base stations* (BSs) could operate under more restrictive configurations to protect from harmful interferences the satellite downlink *TT&C channels* operating at the 40 GHz band. The "protection belt" concept would reduce the need for a wide "silent zone" surrounding the TT&C earth station (ES). The simulations were performed with an open source tool [1][23] that complies with Recommendation ITU-R M.2101 [2]. For more realistic scenarios, our simulation shows the positive effects of reducing the aggregate I/N (interference-to-noise ratio) generated by 5G BSs as a result of more restrictive parameters for the 5G operation deployed nearby the TT&C earth station, avoiding co-channel harmful interference.

Key words: Radio frequency, Spectrum sharing, IMT-2020, Satellite TT&C, Cybersecurity.

[1] Sharm el Sheik, 2019, https://news.itu.int/wrc-19-agrees-to-identify-new-frequency-bands-for-5g/
[2] https://github.com/SIMULATOR-WG/SHARC
[3] https://ieeexplore.ieee.org/document/8121171/

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Background

The main driver for the Economy 4.0 will be the 5G mobile networks, also named by the International Telecommunication Union (ITU) as International Mobile Telecommunications 2020 (IMT-2020) radio interface standard. The IMT-2020 technical requirements place the need for enormous amounts of spectrum resources, meaning a high challenge for Administrations, and demanding new approaches on the spectrum management study field.

The ITU World Radiocommunications Conference 2019 (WRC-19) reviewed the Radio Regulations (RR), an international regulatory spectrum treaty, and identified 17.25 GHz of spectrum in millimeter waves for usage by IMT. The newly identified bands are 24.25-27.5 GHz, 37-43.5 GHz, 45.5-47 GHz, 47.2-48.2 and 66-71 GHz [3]. In the scope of the present work it is highlighted a new footnote (5.550B) to the band 37-43 GHz, in the RR international table of frequency allocations, as highlighted bellow (emphasis added).

"5.550B The <u>frequency band 37-43.5 GHz</u>, or portions thereof, is identified for use by administrations wishing to implement the terrestrial component of International Mobile Telecommunications (IMT). This identification does not preclude the use of this frequency band by any application of the services to which it is allocated and does not establish priority in the Radio Regulations. <u>Because of the potential deployment of FSS earth stations within the frequency range 37.5-42.5 GHz</u> and high-density applications in the fixed-satellite service in the bands 39.5-40 GHz in Region 1, 40-40.5 GHz in all Regions and 40.5-42 GHz in Region 2 (see No. 5.516B), <u>administrations should further take into account potential constraints to IMT in these bands</u>, as appropriate. Resolution 243 (WRC-19) applies. …"

The present paper addresses some of the potential constraint solutions to IMT on the shared use of 37-43.5 GHz frequency band, especially considering its possible use for downlink of Tracking and Telemetry data for TT&C functions in satellite master control centers.

TT&C in the satellite world

In the satellite system, the Tracking, Telemetry and Command (TT&C) subsystem is responsible for the monitoring and controlling functions of the space station during its operational lifecycle. In summary, the tracking (or ranging) function collects information about the angles, distance and velocity to estimate satellite position in its orbit. The telemetry function collects operational status data of the satellite allowing the satellite master control center to continuously monitor its condition. The telecommand subsystem receives all the information, including those received from tracking and telemetry subsystems, and send commands to the space station. The tracking and telemetry are downlink based subsystems and telecommand subsystem is uplink based, as shown in Fig.1 from [4].

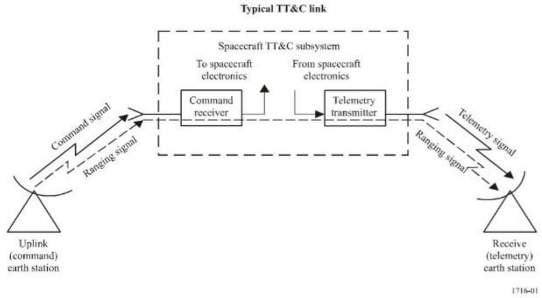

Fig.1. Typical TT&C link (ITU-R S.1716)

In a regulatory level, article 1 of ITU Radio Regulations [5] defines:

"…1.133 space telemetry: The use of telemetry for the transmission from a space station of results of measurements made in a spacecraft, including those relating to the functioning of the spacecraft. …

1.135 space telecommand: The use of radiocommunication for the transmission of signals to a space station to initiate, modify or terminate functions of equipment on an associated space object, including the space station.

1.136 space tracking: Determination of the orbit, velocity or instantaneous position of an object in space by means of radiodetermination, excluding primary radar, for the purpose of following the movement of the object. …"

The TT&C systems are different subsystems jointly working, integrated, so the perfect functioning of satellite command and control processes rely on their total availability.Their earth stations are considered a crucial part of satellite communication critical infrastructures. Harmful interferences to tracking and telemetry downlink channels can cause the total loss of contact with the space station, affecting services rendered to millions of users. In this regard, it is clear the high criticity of such communication systems and the need to ensure their protection from radio interferences.

The increasing relevance of studies about interference prevention on TT&C ES relies on the fact that there are around 200 geostationary satellite network filings under coordination process in ITU which have specific TT&C payloads in Q/V bands. Their orbital positions in the geostationary arc are distributed around all the globe, as shown in Fig.2. These filings reflect satellite projects to be launched and be brought into use in less than 7 years from now.

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Fig.2. Satellite Network Filings for Q/V TT&C payload per orbital position (Source: the authors)

Previous cases of frequency sharing between TT&C and terrestrial systems

It is not a new debate and references can be found dealing with approaches for spectrum sharing between different TT&C systems and other radio communication system in several frequency bands. TT&C channels are used by highly critical applications, in that sense new approaches should be explored for preserving the security of such sensitive systems while a more efficient usage of spectrum is also promoted. In this context, the Aeronautical Mobile Telemetry (AMT) topic was addressed in the European Test and Telemetry Conference - ETTC 2018 [6], where the spectrum environmental congestion challenges led to new ideas on better tools and methodologies to accommodate the telemetry operations in this new densely occupied spectrum scenario with IMT.

Although it is well understood that the TT&C industry must also evolve by promoting researches into new technologies and concepts to operate in a shared spectral environment, there are also opportunities to study ways to protect the TT&C operations by the adoption of technical variations in the co-shared system, which means the IMT-2020 in this case. In this scenario, taking the perspectives from directional beams domains, advancements in smart phased array antenna field, especially in terms of beamforming techniques and sidelobe cancelling, can help the co-channel interference over TT&C stations to be removed. The concept herein discussed is clearly one of the new tools, as pointed out in [6], to be developed to establish the necessary RF "fortress" for protecting TT&C critical applications in a congested spectrum environment.

In 2018, the national regulatory authority of Hong Kong issued a decision [7] on the change of primary allocation of 3.4 to 3.7 GHz frequency band from Fixed Satellite Service to Mobile Service. Given the fact that existing TT&C earth stations of satellites in Hong Kong´s territory operate in this band and noting that they are important for the operation of licensed satellites currently in orbit, the decision also issued that TT&C will be protected from radio interference of public mobile services. In this regard, an exception was created, allowing TT&C earth stations as having a sort of "primary status" in two restriction zones (in Tai Po and Stanley in Fig. 3) where these TT&C Stations are located. In those regions, geographical polygons are delineated to constrain the deployment of mobile base stations (BSs) of public mobile services operating in the 3.4–3.6 GHz band.

As stated in the decision about the "restriction zones", the authority stated that the necessary spatial separations between TT&C Stations and mobile BSs in different directions are devised to prevent desensitization of satellite receivers caused by in-band signals of the public mobile services in the 3.4–3.6 GHz band, taking into account the actual terrain, clutters, buildings in the surrounding areas and deployment of BSs over the years, among others.

It can be understood that this specific condition of confining the TT&C in only two sites was necessary due to C band propagation characteristics, and because it will be mostly used for 5G macro cells, making restriction zones extremely extensive as seen in Fig. 3 [7].

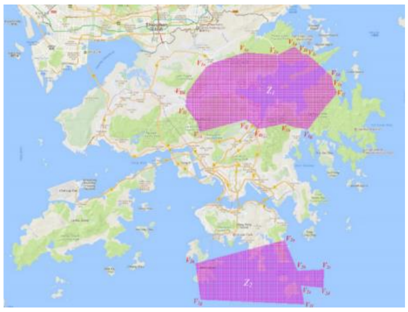

Fig.3. Restriction zones for protection of C Band TT&C earth stations in Hong Kong [7]

Considerations for sharing Q/V bands between IMT and satellite TT&C ES

The use of Q/V band (40/50 GHz) for TT&C will, by nature, face additional challenges due to propagations characteristics, including high levels of attenuation caused by dry air and water vapor (see Fig. 4) from [8]. On the other hand, satellite TT&C links in Q/V will benefit from high building entry losses (see Fig. 5) getting additional protection from terrestrial emissions.

In this regard, the deployment of concrete made structures surrounding the TT&C earth station may be a way to impose at least 20dB or more protection due to attenuation from terrestrial interference signals received by the antenna sidelobes in 40 GHz band, as it may be seen in Fig. 5 [9].

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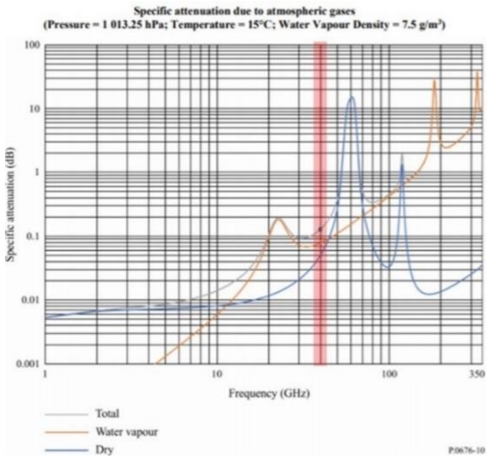

Fig.4. Atmospheric attenuation from 1GHz to 350 GHz in dB/km (Rec. ITU-R P.676-12)

This behavior is particularly important in millimeter waves, and definitively a positive factor for better protection from IMT-2020, mainly in urban, or suburban environments.

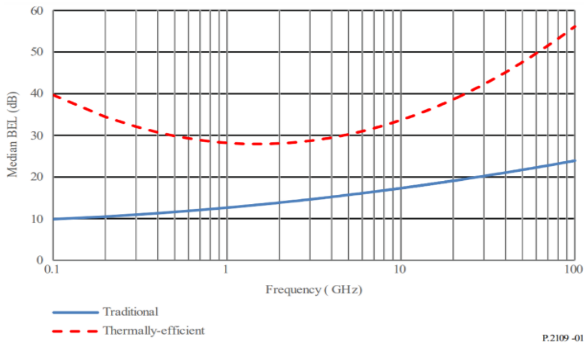

Fig.5. Building Entry Loss (Rec. ITU-R P.2109)

TT&C Protection Belt concept

In a traditional coordination between IMT BS and TT&C in co-channel operation, the solution would be to establish a very wide separation distance surrounding the TT&C ES, acting as a sort of "silent zone" where no IMT operation is allowed in the same frequency band. The proposed approach is to study ways to protect a TT&C ES in a more spectrally efficient way, by adopting restrictions to IMT BS operating in these areas surrounding the TT&C ES, allowing reduced "silent zones".

Fig.6 illustrates a general idea of "protection belt" concept, which benefits from the possibilities of antenna beamforming techniques and flexible adjustments in some RF parameters.

Although this study will focus on the application of only one "protection belt" zone near the TT&C ES, this idea could evolve in the future towards a set of several concentric protection belt layers centered in the TT&C ES position, with different radius and widths, each one providing a different level of protection, depending on the proximity to the TT&C earth station and the QoS required for IMT.

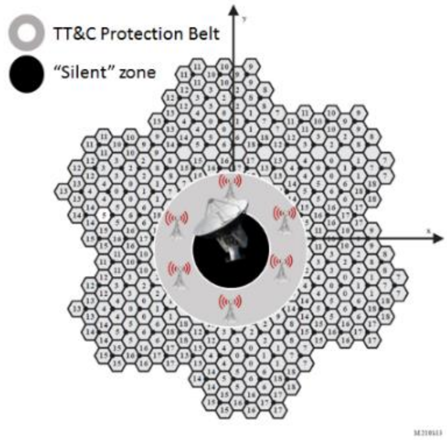

Fig.6. TT&C Protection Belt concept

Spectrum sharing methodology and simulation tool (SHARC)

In order to evaluate the frequency sharing scenario between TT&C ES and IMT, this study made use of an open source collaborative simulation tool developed under leadership of Spectrum, Orbit and Broadcasting Division of the Brazilian National Telecommunication Agency (ANATEL), called SHARC (simulator for SHARing and Compatibility studies) [1]. The tool follows the harmonized methodology defined by ITU [2], which was applied by several sharing and compatibility studies performed in preparation to ITU WRC-19 discussions and regulatory decisions for the identification of new frequency bands for IMT-2020 (5G) such as [10]*.

The ITU-R M.2101 recommendation [2] specifies, among other, how simulations should address the possible deployment scenarios of BSs in the IMT-2020 network (i.e. Indoor, Micro and Micro Suburban and Urban), power control, advanced antenna, antenna height, density distribution, propagation models, network topology, modelling of IMT network for interference calculation, simulation algorithm defining calculation steps, antenna beamforming implementation, determination of aggregate interference and demonstration of results.

Summary of simulation and calculations

The focus on the present study is on co-channel interference emissions from downlink of IMT-2020 BSs into the reception of downlink TT&C ES channel, since it will be responsible for the major impact in the unavailability of satellite TT&C channel caused by interference as illustrated by Fig 7.

*Reference documents may be provided upon motivated request.

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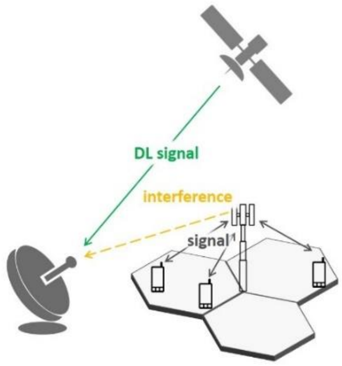

Fig.7. TT&C ES Downlink Interference scenario

The interference scenario to be discussed is the one where the interferer and interfered-with systems operate on the same frequency (co-channel), which is the dominant type of interference. A summary of simulation steps and relevant calculations performed for this specific scenario:

1.Generation of IMT BS locations in hotspot topology

2.Generation of IMT user equipment

3.Apply load BS activity factor probability

4.Connect UEs to BSs and calculate path coupling loss

5.Apply “Power control” / “scheduler”

6.Calculate interference to interfered-with system

7.Calculate interfered-with system performance degradation (I/N) and CDF

Following the same approach of previous studies for this frequency band [11], the simulation considers Recommendation ITU-R P.452-16 [12] model for propagation between IMT and the TT&C earth station and Clutter loss according to Recommendation ITU-R P.2108-0 [13]. As for the channel model within the IMT system, it is considered the (UMi) Urban Micro from 3GPP.

The aggregate external-system interference from IMT-2020 BS towards the TT&C earth station, as indicated in step 6, is performed following [2], according to (1).

$$I_{External} = \sum_{j} \sum_{k} I_{External}(TX_{BS_j}^{UE_k}, RX^{victim})$$

(1) Where:

$I_{External}(TX_{BS_j}^{UE_k}, RX^{victim})$ (2) Inter-system interference from base station BS_j (when its k-th UE is served) to the interfered receiver (RX^{victim}).

$I_{External}$: Aggregate external system interference towards the interfered-with system.

One of the most important components for the computation of inter-system interference is the gain from BSs antenna towards the TT&C ES, which is directly affected by IMT BS antenna pattern resulting from the IMT antenna beamforming expressions from [2].

After computing $I_{External}$, and in conjunction with the value of the receiving TT&C ES noise power, finally the main output performance indicator, Interference-to-Noise Ratio (I/N), is obtained by means of a CDF (Cumulative Distribution Function) of I/N over all snapshots samples.

Simulation of interference from IMT base stations into TT&C ES in 40GHz

The sharing study to evaluate the interference from IMT-2020 BSs into a TT&C ES in 40 GHz band is performed by simulating the aggregate interference generated by all the IMT BSs into the victim system (TT&C ES). The aggregate interference is translated into a I/N value, which is compared to protection criteria. When the I/N exceeds the protection criteria, the protection is assumed as not achieved, and harmful interference may occur, otherwise the victim system is not likely to be interfered.

The TT&C earth station and IMT-2020 BS reference parameters used as input data in the simulation tool [1] are presented in Tabs. 1 and 2.

Tab. 1: TT&C Earth Station (ES) reference setup for downlink channel of a geostationary satellite

Parameters – TT&C Earth Station (ES)	
Centre Frequency	40.750 GHz
Channel Bandwidth	1 MHz
Antenna height	6 m
Antenna diameter	6.1 m
Antenna Gain (peak)	66.1 dBi
Antenna pattern	ITU-R S.580 [14]
Antenna elevation	50 degrees
Noise temperature	250 K
Max *I/N* protection criteria	-12.2 dB

The input parameters of satellite TT&C earth station, of “victim system” are collected from ITU from previous studies and information provided by ITU concerned groups [10] [11] [15].

Regarding the protection criteria, there are different approaches on requirements of Fixed Satellite Services, including long and short-term values. The most relevant [17] is based on percentages of time, probability or location for which the *I/N* value could be exceeded, and establishes

+8dB (0.02%), -6dB (1%) and -10.5dB (20% or I/N average). Since we are dealing with a critical application (TT&C), and in order to promote a higher protection, a more conservative criteria of -12.2dB I/N was considered as a basis for the assessments of this study. However, it is recognized that this subject deserves further discussions.

For the IMT-2000 system, acting as “interferer” in the simulations, a “reference setup” represents an assumed regular IMT operation, with no additional restrictions to protect TT&C ES from co-channel interference. The set of IMT system parameters and propagation models adopted are based on those recommended for sharing and compatibility studies [11], and further related studies. In order to allow comparability, some values adopted as input parameter are similar to previous studies [10] performed with the same simulation tool [1]. Tab. 2 presents a summary of main parameters used for the reference setup.

Tab. 2: IMT-2020 link reference setup for downlink channel

Parameters – IMT-2020	
Base station (BS) transmitter	
Centre Frequency	40.750 GHz
Duplex method	TDD
Channel bandwidth	200 MHz
Signal bandwidth	>90% of channel
Antenna pattern	ITU-R M.2101 [2]
Antenna array	8×16 elements
Element gain	5 dBi
BS front to back ratio of single element	30 dB
BS horizontal and vertical 3dB beamwidth of single element	65 degrees
Conducted power per antenna element	8 dBm/200 MHz
Deployment (outdoor urban hotspot)	
Hotspots density	30 BSs/km^2
Antenna height	6m
Network loading factor	50%
UEs/cell	3
User Equipment characteristics	
Antenna Pattern	ITU-R M.2101 [2]
Antenna array	4×4 elements

Parameters – IMT-2020	
Element gain	5 dBi
Noise figure	12 dB

In order to measure the positive effects in terms of I/N, some of the IMT RF parameters of the reference scenario are isolated, varied and simulations are repeated in order to assess the interference reduction from IMT into TT&C ES from the new scenario. Each simulation performs 5.000 snapshots, and the % CDF I/N output curves quantifies the probability that, for one snapshot, the defined protection criteria is exceeded, and in those cases it is considered that the TT&C ES may be harmfully interfered. The IMT hotspot topology in Fig.7 from [10] is the most likely for the IMT-2020 BSs in this frequency band. The position of IMT BSs and user equipment in the simulation follows random distribution at each simulation snapshot, as recommended by [2].

In modelling of previous studies from [10], the interference generated into a victim system (e.g. Fixed Satellite ES) was assessed by calculating the aggregate interference generated by hotspots deployed inside an IMT cluster with 57 cells concentrated in an area of 1.9km^2. The hotspots are uniformly distributed, one per cell, and randomly located. Macro cells are not considered because they operate in lower frequencies. The Users Equipment are distributed within the hotspot coverage area, with a Rayleigh distribution with scale parameter σ_d = 32 m for the distance between UE and BS hotspot, and a normal distribution for the azimuth between them, truncated at the ±60º range, with mean μ_a = 0º and standard deviation σ_a = 30º.

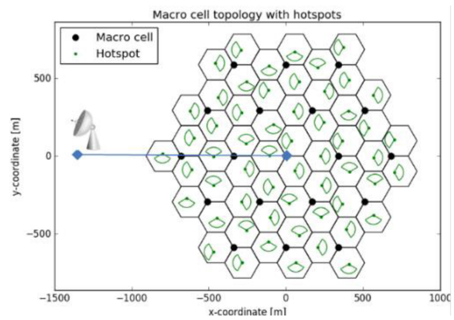

Fig.8. Hotspots in the Macro cell topology and TT&C Earth Station separation distances

In the present study, in order to estimate the aggregate interference generated by hotspots deployed inside a specific area surrounding the TT&C ES, in the format of a “belt”, the model was adapted to meet a geometrical modelling of a circular crown.

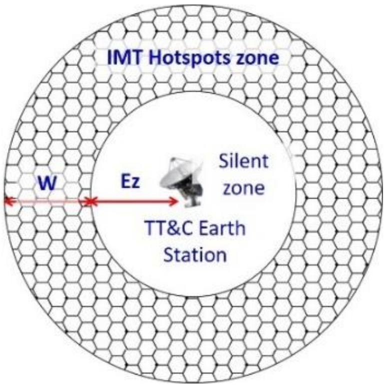

Fig.9. IMT Hotspots zone in the "protection belt"

A segment factor concept from [18][*] is applied in order to adapt the cluster topology and allows estimating the aggregate interference from IMT hotspots in the protection belt (hotspot zone). The separation distance "Ez" also named as "silent zone radius", of 150m between the TT&C ES and the inner border of the protection belt represents the radius of a "silent zone", where no IMT hotspot is deployed in the same frequency of the TT&C ES. A hotspot zone width (w) of 1.7km in the protection belt is defined, as shown in Fig. 9.

Variation of IMT base station parameters

The study was focused only in the IMT BS downlink parameters because its output power is higher than the user terminal, being more harmful for co-channel interference. Also, it is much more complex to customize and promote modifications in billions of user terminals, which involves many factors including increased costs for manufacture and consumer, and a need for industry scale to be effective.

Besides variating the distance between the TT&C ES to the inner border of the protection belt (Ez), the following IMT BS parameters were focused:

- Number of elements of IMT BS antenna array (line and column)
- Conducted power per antenna array element
- Downtilt angle of IMT BS antenna

<u>Separation distance (Ez) between the TT&C ES and the inner border of TT&C ES Protection Belt</u>

The initial simulations, made for reference purposes, adopted input parameters from Tab. 1 and 2, and considered 0m,150m, 300m and 500m separation distances "Ez" between the TT&C ES and the inner border of the protection belt.

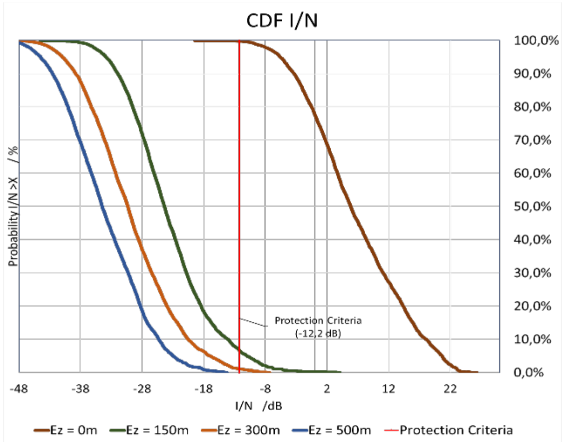

Fig.10. CDF of I/N (0m, 150m, 300m and 500m).

The results, as shown in Fig.10, indicated exceedance of the protection criteria (I/N) on 99.76% of snapshots for 0m, and 6.7% for 150m, considering the aggregate interference from the same total number of IMT BSs. Simulations with 300m and 500m indicated 1% and 0% exceedance of protection criteria, respectively, which confirms that when higher separation distances are applied, the I/N protection criterion is easily achieved. However, this leads to a more inefficient use of spectrum because IMT could not operate in a larger "silent zone'.

Based on that, the present work focused on a smaller separation distance of 150 meters, in which 7% of the snapshots still exceed the I/N protection criteria. This can be considered insufficient for protection of such a critical service as TT&C. In this context, it is assumed that most of the problem is concentrated around this % of cases with higher I/N, and where opportunities for a layer of protection belt can be investigated.

<u>IMT BS antenna array size (number of elements in rows and columns)</u>

The simulations resulted in different curves of % of cases where I/N values are exceeded for each antenna array sizes simulated (8x8, 8x16,16x32, 32x64 and 64x128) as presented in Fig. 11. For better visualization, the plot was focused on the behavior over the 20% of samples with most degraded I/N values. Tab.3 indicates the % of cases where I/N exceeds the protection criteria per BS antenna array size.

[*]Reference documents may be provided upon motivated request.

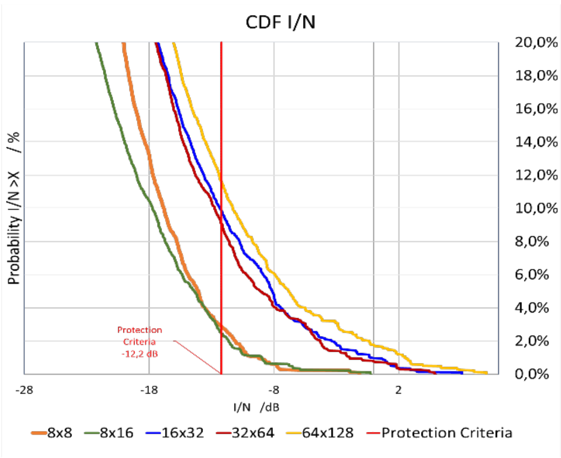

Fig. 11. I/N CDF curves for different antenna array sizes

Tab. 3 % of cases where protection criteria is exceeded for different antenna array sizes

Array Size	% of cases I/N exceeds protection criteria
8x8	2,86%
8x16	6,72%
16x32	9,84%
32x64	9,04%
64x128	11,62%

It is important to have in mind that a higher number of elements in the IMT BS antenna array will increase the array gain, and will also increase the RF power delivered to the array, leading to a higher EIRP (effective isotropic radiated power), which helps increasing the % of I/N exceedance.

In situations of “in line” events, when the main lobe of the IMT BS antenna beamforming points towards the direction of TT&C ES, the interference will be higher than what would happen with a smaller array. However, the different shapes of antenna patterns will also influence on the interference behavior and may compensate (in some measure) the negative effects of EIRP increase. For better clarification on the effects of different array sizes, Figures 12 and 13 present the CDF curves of antenna gain towards the TT&C ES and antenna array patterns for different array sizes, respectively. It is concluded that, once different array configurations are adopted, careful adjustments in other parameters may also be necessary depending on the aimed objective.

<u>Conducted Power per element of IMT BS antenna array</u>

A reduction of 3dB at the conducted power per antenna element resulted in 3,46% reduction in cases where the protection criterion is exceeded in relation to the reference scenario (8x16 array), as shown in Fig. 14.

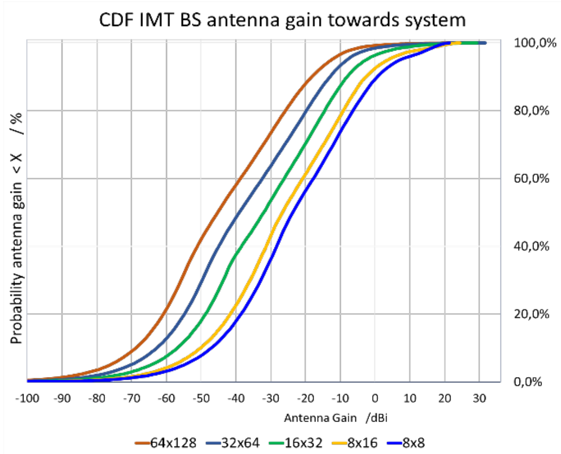

Fig.12.CDF of antenna gain towards TT&C ES

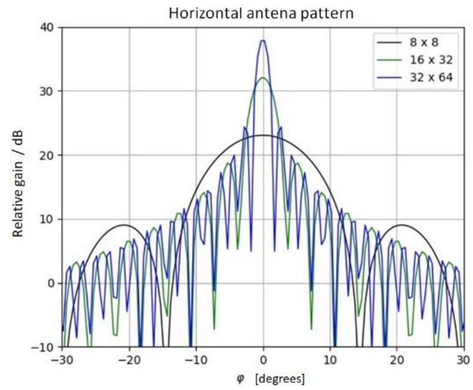

Fig.13. BS antenna patterns for different arrays

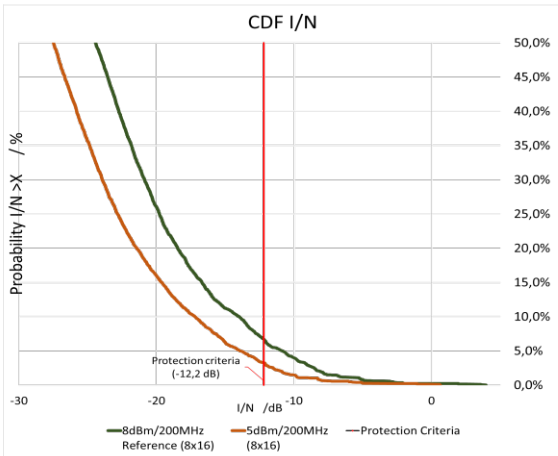

Fig. 14. I/N CDF curve for – 3dB power/element

Tab 4 shows that the different antenna array sizes will have different responses due to different composite antenna pattern, gain characteristics and output EIRP.

Tab. 4: % reduction in the cases of protection criteria exceedance (-3dB power per element)

Size	Reduction % I/N exceedance
4x8	0,14%

8x16	3,12%
16x32	3,54%
32x64	3,92%

Downtilt angle of IMT BS antenna

The reference scenario was simulated with a downtilt angle of 10 degrees for the hotspot antennas. Further simulation applying 20 degrees to the same reference setup indicated additional reduction of around 1% in cases where I/N is exceeded, as shown in Fig. 15.

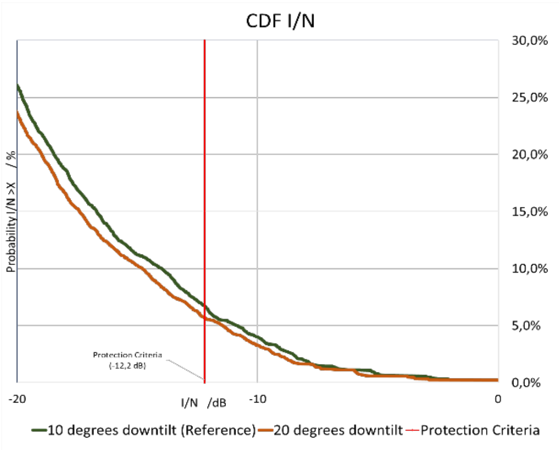

Fig. 15 I/N CDF curves for 10 and 20 degrees IMT BS antenna downtilt angles

From Tab. 5 it can be concluded that the improvement on the I/N curve for 10 degrees higher downtilt angle has also an intimate relation with the IMT BS antenna array sizes, as a result from additional simulation scenarios. In this case, 8x16 array had a better result.

Tab. 5: % reduction in the cases of protection criteria exceedance (+10 degrees in IMT BS downtilt angle)

Size	Reduction % I/N exceedance
8x8	0,56%
8x16	1,16%
16x32	0,78%
32x64	0,36%

A last simulation scenario was tested in which variations of the different parameters were combined. In this scenario the following parameters of the IMT BS antenna array were adjusted. An array size 8x8, 5 dBm/200 MHz in the conducted power per element, and 20 degrees downtilt were adopted. This resulted in only 0,22% of cases where the I/N exceeded the protection criteria.

Conclusions for TT&C ES Protection Belts in Q/V bands

This study concludes that there are possible alternatives for the effectiveness of implementing a geographical layer ("Protection Belts") where the deployment of IMT BSs could operate with a more restrictive configuration in order to prevent co-channel interference to TT&C ES in 40 GHz band.

Simulations performed with higher separation distances between the TT&C ES and inner border of the IMT hotspots zone (500m and 300m) confirmed that the most effective way to prevent interference into a TT&C ES from IMT in co-channel operation is by increasing this distancing. However, it leads to a wider "silent zone". In order to promote a more efficient use of spectrum in 40 GHz, it is possible to reduce this distance by promoting a "fine tuning" on the parameters of IMT BS deployed in an area surrounding the TT&C ("protection belt"), with good results up to a reduced separation distance of 150m.

This can be achieved by combining the adjustments of IMT BSs antenna parameters such as alternate array sizes, reduction on the conducted power per array element and increasing downtilt angle. When adopted, it could additionally prevent up to 10% of cases where I/N exceeds protection criteria. If the adjustments were not adopted, a wider "silent zone" would be needed.

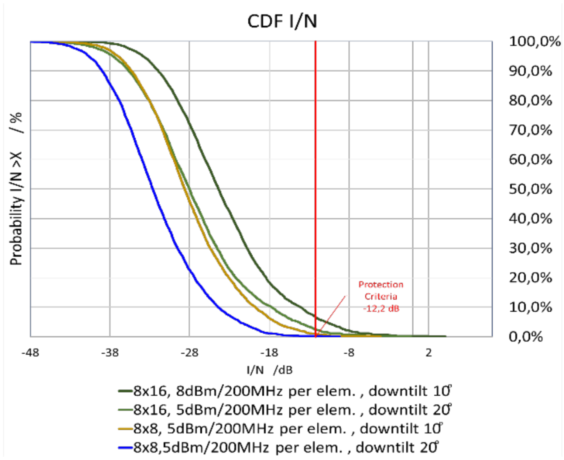

Fig.16. CDF of I/N with % cases exceeding protection criteria

Fig. 16 presents simulation results for more restrictive configurations of IMT that could be applied in a protection belt concept in order to reduce % I/N exceeding the protection criteria.

Further studies

It is important to highlight new opportunities for innovative spectrum coordination approaches in Q/V band. Due to its physical characteristics, and depending on the services involved, lower protection efforts will be necessary to promote its shared use, than what happens in lower bands. Interesting solutions are expected and, in a more refined spectrum coordination scenario, some of the parameters for IMT operating inner a “Protection Belt” zone could be subject to coordination agreements jointly developed between the 5G and satellite operators. Although it has not been subject to simulations performed in this study, it can be understood from [9] that, due to particularly high Building Entry Losses in the 40GHz band, new opportunities are in place to combine building infrastructure concrete wall as a shielding implementation in the satellite operator side, in order to improve even more the protection of TT&C ES.

In addition, further work should be done for evaluating the results of simulating the impact of wider, or several layers of IMT protection belts, representing larger urban and suburban areas. Studies should also be done on further mitigation techniques for reducing the aggregate impact on TT&C earth stations connecting to NGSO, with other elevation angles, the impact of unwanted emissions from IMT in adjacent bands and new techniques for avoidance angles to reduce in line events between IMT BS and TT&C ES and antenna sidelobe cancelling techniques.

This is a study with academic purposes, based on simulated scenarios. For real deployments, other factors may fluctuate the results, and field test approaches are also recommended.

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References

[1] An Open Source Implementation of Recommendation ITU-R M.2101 – https://www.itu.int/oth/R0A0600007A/en

[2] ITU-R Recommendation M.2101: Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies – https://www.itu.int/rec/R-REC-M.2101/en

[3] ITU World Radiocommunication Conference 2019 (WRC-19), Sharm el Sheik. Final Acts - https://www.itu.int/dms_pub/itu-r/opb/act/R-ACT-WRC.14-2019-PDF-E.pdf

[4] ITU-R Recommendation S.1716 Performance and availability objectives for fixed-satellite service telemetry, tracking and command systems - https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.1716-0-200502-I!!PDF-E.pdf

[5] ITU Radio Regulations 2016, Volume 1 - https://www.itu.int/pub/R-REG-RR-2016

[6] Ninja Telemetry AMT Survival in a Congested Spectral Environment – https://www.ama-science.org/proceedings/details/2811

[7] Statement of the Communications Authority, Change in the Allocation of the 3.4 – 3.7 GHz Band from Fixed Satellite Service to Mobile Service, 28 march 2018. https://www.coms-auth.hk/filemanager/statement/en/upload/441/ca_statements20180328_en.pdf

[8] ITU-R Recommendation P.676-12 Attenuation by atmospheric gases and related effects. Aug 2019 - https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.676-12-201908-I!!PDF-E.pdf

[9] ITU-R Recommendation P.2109-0 Prediction of building entry loss. Jun2017 -https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2109-0-201706-I!!PDF-E.pdf

[10] ITU-R – Brazil - TG5/1 Doc. 5-1/436-E Update on sharing and compatibility study between IMT systems and fixed-satellite service (Space-to-Earth) in the 37-42.5 GHz frequency band –https://www.itu.int/md/R15-TG5.1-C-0436/en

[11] ITU-R – TG 5/1 Doc. 5-1/478-E Annex 1 to Task Group 5/1 Chairman’s Report System parameters and propagation models to be used in sharing and compatibility studies - https://www.itu.int/md/R15-TG5.1-C-0478/en

[12] ITU-R Recommendation P.452-16 Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz -https://www.itu.int/rec/R-REC-P.452/en

[13] ITU-R Recommendation P.2108-0 – Prediction of Clutter Loss - https://www.itu.int/rec/R-REC-P.2108/en

[14] ITU-R Recommendation S.580-6 – Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites – https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.580-6-200401-I!!PDF-E.pdf

[15] ITU-R Working Party 4A – TG 5/1 Doc. 5-1/183 - Liaison Statement to Task Group 5/1 FSS/BSS Technical parameters for sharing studies under WRC-19 Agenda item 1.13 -https://www.itu.int/md/R15-TG5.1-C-0183/en

[16] ITU-R Working Party 5D – TG 5/1 [36] attachment 2 - Liaison statement to Task Group 5/1 – Spectrum needs and characteristics for the terrestrial component of IMT in the frequency range between 24.25 GHz and 86 GHz -https://www.itu.int/md/R15-TG5.1-C-0036/en

[17] ITU-R - Working Party 4A – TG 5/1 Doc. 5-1/411 - Reply to Liaison Statement to task group 5/1 -E https://www.itu.int/md/R15-TG5.1-C-0411/en

[18] ITU-R - Brazil - TG5-1 Doc. 5-1/435-EUpdate on the Sharing and compatibility study between RAS in the 42.5-43.5 GHz frequency band and IMT systems operating in the 37-43.5 GHz frequency band https://www.itu.int/md/meetingdoc.asp?lang=en&parent=R15-TG5.1-C-0435