Coexistence Analysis Between IMT-2020 and AES operating in L Band on a Final Approach

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***Abstract*– This paper is regarding the statistical coexistence analysis between a cluster of International Mobile Telecommunication 2020 (IMT-2020) Base Stations and an Aircraft Earth Station (AES) operating during flight time in the L Band on a final approach. We assess the cumulative distribution function (CDF) of interference-over-noise ratio (INR) considering the fuselage attenuation contribution and compare it with the AES protection criteria. Our coexistence analysis approach considers the use of a high gain AES commercial antenna model, for an aircraft at two different altitudes, 187 m and 83 m, for 3600 m and 1600 m of horizontal distance from the runway threshold, respectively. Therefore, considering the IMT-2020 suburban scenario near the airport, simulation results presented an INR that met the protection criteria for 100% and 99.95% of the time for the distances of 3600 m and 1600 m from the runway, respectively, making the spectrum sharing feasible between systems. To the best of our knowledge, this is the first time in the literature that fuselage attenuation considering part of the plane, in the L-band is presented in a statistical coexistence analysis.**

***Index Terms*–** 5G, AES, coexistence, IMT and spectrum sharing. .

I. INTRODUCTION

The spectrum demand for wireless communications has been increasing in the last years and many services already in operation should be protected against possible harmful interferences from new systems operating in co-channel or in adjacent channel scenarios. According to International Telecommunication Union (ITU) Radio Regulations (RR), No. 1.84, defines an Aircraft Earth Station (AES) as a mobile earth station in the aeronautical Mobile-Satellite Service (MSS) located onboard an aircraft [1]. The AES service uses a geostationary satellite in which provides voice, data, and location services for the aircraft during the flight. The spectrum band from 1518 MHz to 1525 MHz was specified for MSS use at World Radiocommunication Conference 2003 (WRC- 03). Additionally, there are different types of MSS terminal types that operate in this frequency band, including land, maritime and aeronautical. In this same L-band, the frequency range 1427 - 1518 MHz was identified for International Mobile Telecommunication (IMT) in WRC 2015 (WRC-15) and frequency arrangements in Recommendation ITU-R M.1036-6 [2], and it is expected to be used by fourth or five generation of mobile communication (4G or 5G) technologies.

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Furthermore, there are researchers and study groups around the world which are involved in coexistence studies among IMT-2020 (5G) and other communications systems trying to provide a harmonized affordable spectrum for terrestrial and space systems [3]–[6]. Our research group investigated the 5G coexistence with Fixed Satellite Services - Earth Station (FSS-ES) in C-Band providing the technological solution to be employed in Low Noise Block Feeder (LNBF) to have a peaceful coexistence [7], whereas in [8] we investigated the 5G New Radio coexistence with Narrow-band Internet-of-Things (NB-IoT) and IMT-Advanced (4G) in an indoor scenario. As a result, were presented techniques to share the 10 MHz spectrum in the 700 MHz Band among three technologies. In addition, is presented in [9] the coexistence between High Altitude Platform Stations as IMT Base Stations (HIBS) and Fixed Services to support World Radiocommunication Conference 2023 decisions. In [10] authors investigate the coexistence between IMT-2020 and Earth Exploration Satellite Services in 26 GHz Band comparing different element spacing in Advanced Antenna Systems (AAS). Our previous contribution [11] investigated the coexistence between an IMT Base Station and an AES, in which was assessed the minimum coupling loss value to ensure the coexistence between systems.

In this context, this work presents a contribution to the coexistence analysis between AES located in the aircraft and IMT-2020 Base Stations (BS) in the ground operating in adjacent bands in the L-band, by means of reporting computed fuselage loss and the statistical assessments of interference-over-noise (INR) ratio received by the aircraft receiver flying in two altitudes from the runway airport in a final approach. This article is organized as follows. Section II presents the simulation results of aircraft fuselage attenuation. The coexistence analysis results are presented in section III. Finally, Section IV outlines the conclusion and future works.

II. Aircraft Fuselage Attenuation Simulation

The objective of this section is to present the evaluation of the fuselage attenuation in compatibility studies between an IMT BS located in the ground and the AES antenna located on top of the aircraft body during flight time. We used the High-Frequency Simulation Software (HFSS) from Ansys and modeled a part of Boeing 737 internal dimensions [12], [13]. To reduce the computational time, we considered the external dimensional parameters as presented in Fig. 1. In the HFSS simulation environment, we set a plane wave source centered in 1518 MHz and we variate vertical θ angle from 90 to 0 degrees, simulating the IMT signal arriving in whole aircraft structure from different elevations. The electric field was measured at the point of AES antenna placement, on top, and in the center of the structure. Furthermore, current density and electric field distribution on aircraft fuselage for plane wave located at 90 degree from AES antenna are presented in Fig. 1.

We assess the electric field loss with and without fuselage to consider only the influences of the aircraft body in our coexistence analysis [14]–[16]. For this assessment we used the HFSS Integral Equation (IE) solver, once it is effective for radiation and scattering studies of large and mostly conducting structures. The simulation results of the fuselage attenuation are presented in Fig. 2. As shown in Fig. 2, the fuselage loss varied from 43.58 to 2.98 dB when the fuselage edge is closed and varied from 29 to 2 dB when the fuselage edge is open, depending on the incidence elevation angle (θ) of the interfering signal arriving at the victim system. In a coexistence analysis, it is important to consider these attenuation's of the fuselage to not overestimate interference of IMT BS in AES System and turn the compatibility assessment in a situation closer to the real scenario of operation.

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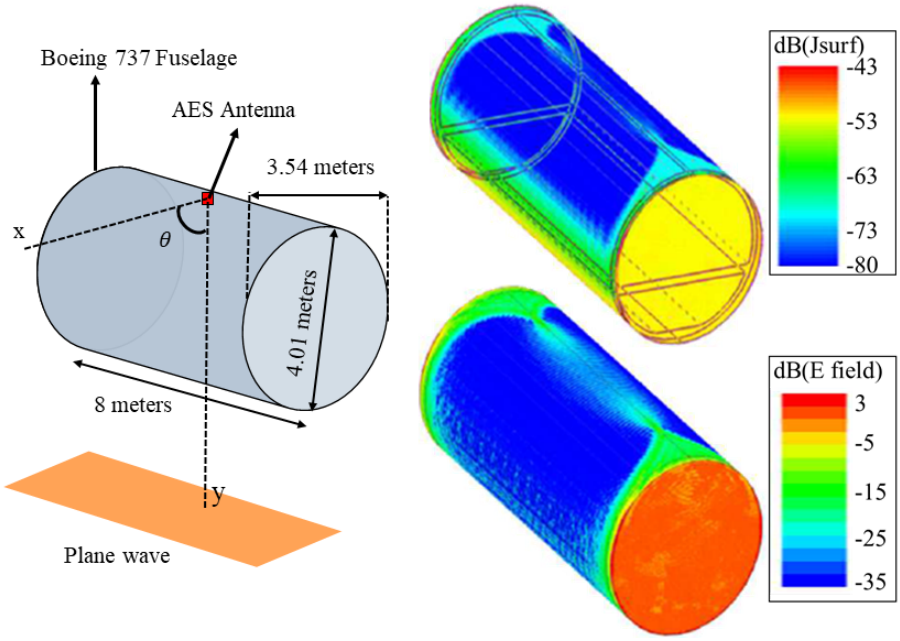


Fig. 1. Aircraft fuselage electromagnetic numerical current density and electric field.

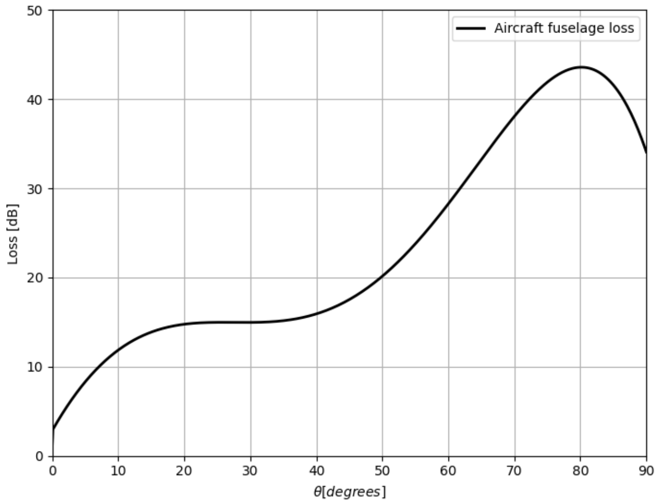


Fig. 2. Aircraft fuselage loss.

III. Coexistence Analysis

European Conference of Postal and Telecommunications Administrations – Electronic Communications Committee (CEPT-ECC) developed an adjacent compatibility study between AES and IMT operating in L-Band. The authors presented the minimum coupling loss between IMT BS and AES taking into account the discrimination of both antennas, and the frequency separation [16]. Our last work improved the CEPT study considering the fuselage attenuation [11]. Therefore, our new approach and contribution are to perform and present for the first time in the literature the coexistence analysis between IMT-2020 and AES system in a land procedure approach based on Monte Carlo simulations, which uses the open-source simulator SHARC (SHARing and Compatibility studies for radiocommunications systems) [17], supported by Brazilian Telecommunications Regulatory Agency (ANATEL) in cooperation with partners of the industry and academia. This Monte Carlo simulator is based on the framework proposed by Recommendation ITU-R M.2101. It has the main features required for a common system-level simulator, such as antenna beamforming, power control, and resource blocks allocation, among others. At each simulation snapshot, the user equipment (UE) is randomly generated in a uniform distribution located within a cell cluster. The coupling loss is calculated between the UE and their nearest IMT BS. The simulation then performs resource scheduling and power control, enabling the interference calculation between systems. Finally, system performance indicators are collected, and this procedure is repeated for a fixed number of snapshots.

In addition, there are two interference mechanisms that could impact in AES receiver operation, overload and unwanted emissions. Our approach evaluated the impact of unwanted IMT BS emission on the AES receiver. This harmful interference effect start to appear with smaller levels than compared to receiver blocking [11]. Fig. 3. presents our simulation scenario in which a IMT suburban topology following Recommendation ITU-R M.2101 with 57 macrocells is deployed nearby the airport. The suburban scenario is the most common scenario among the main cities in Brazil, but there are specific cases in which the airport can be located in dense urban scenarios which we will try to assess in future works. Each macro cell has 3 UE's distributed within each sector.

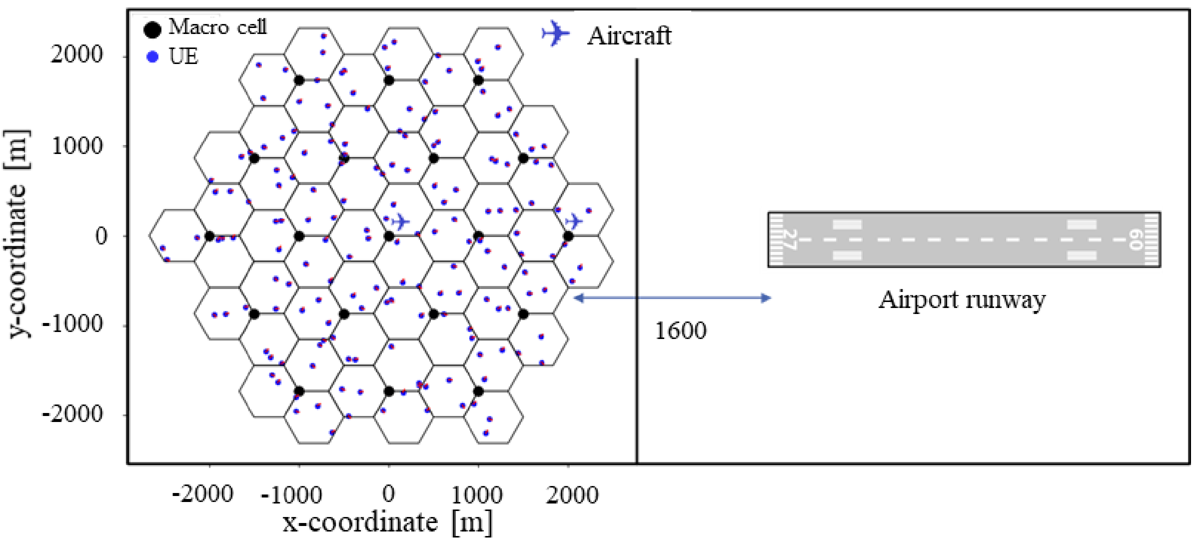
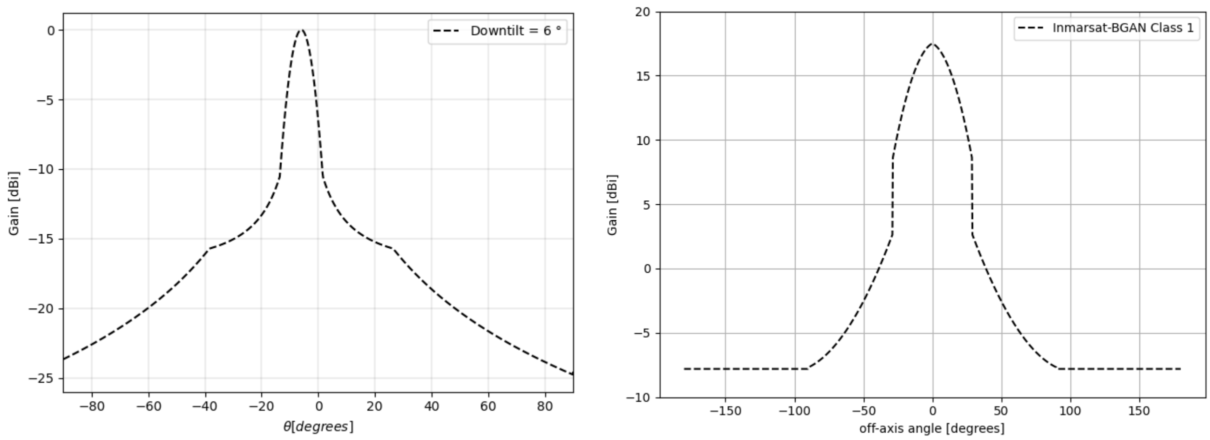


Fig. 3. Simulation scenario between IMT-2020 Base Stations and AES.

At each simulation snapshot, the UE's are randomly generated and uniformly distributed in a cell. The coupling loss is calculated between UE and BS, considering the limit angles in serving BS. In addition, the simulation performs the resource scheduling, and power control, enabling the interference calculation between the IMT-2020 system and AES receiver. We assess the interference in an aircraft landing procedure approach, in which the aircraft is positioned at an altitude of 187 and 83 meters at a distance from 3600 and 1600 meters of the airport runway threshold, respectively. In this scenario, the aircraft is located in the center and above the last base station of the IMT topology. The nearest BS position is set at the minimum distance within the International Civil Aviation Organization (ICAO) limit of obstruction height for the height of the BS. For the macro suburban case this is 1600 m from the touchdown point. An aircraft on approach is set to a 3-degree glideslope, with a 2-degree pitch, as per the Australian Communications and Media Authority (ACMA) study [18]. The aircraft altitude difference and position is explained by the final approach and descending procedure, and this interference assessment are important to check the possibility of interference when many IMT BS is around the airport. The simulations were done with 10 000 snapshots.

Our coexistence analysis considered only the downlink contribution of IMT BS suburban scenario around the airport, which is close to the reality of many cities in Brazil. Fig. 4a presents the IMT antenna pattern modeled based on Rec. ITU-R F.1336, whereas the AES antenna model used in this work, are approximated antenna pattern of the commercial AES system [13]. Fig. 4b shows the Inmarsat AES high gain Broadband Global Area Network (BGAN) Class 1 antenna pattern with a peak gain of 17.5 dBi. It´s important to highlight that AES antenna has a mechanical elevation of 30° in relation to the aircraft's horizontal axis.



(a) (b)

Fig. 4. Antenna models used in the simulation. (a) IMT Suburban Base Station (normalized), (b) Inmarsat-BGAN Class 1.

The cumulative distribution function of interference over noise ratio (INR) was calculated considering the protection criteria of interference over noise ratio (I/N) < - 10 dB [16]. A 3dB polarization loss applies due to no domination of interfering power level for one or a limited number of the BS with the same sense of rotation or the same tilt angle of the polarization vector. In this context, we performed our coexistence analysis by calculating the aggregated INR according to (1), and we assess the possible interference in the aircraft at two distances in a final approach procedure.

$$\left(\frac{I}{N}\right)_{total} = \sum_{1}^{n}((EIRP_n)_{\Theta,\Phi} - Pathloss + G_{AES(\Theta,\Phi)} - Fuselage_{loss(\Theta,\Phi)} - L_{pol} - N_{AES}) \quad (1)$$

Where, $EIRP_{\Theta,\Phi}$ is the equivalent isotropic radiated power of each activated base station considering the respective azimuth and elevation toward the interfered system, the path loss is calculated using Rec. ITU-R P.525, the $G_{AES(\Theta,\Phi)}$ is the AES antenna gain considering the gain in azimuth and elevation towards the IMT BS, depolarization loss L_{pol} and N_{AES} is the AES receiver thermal noise. The interference assessment is based on technical parameters presented in Tables I and II, for IMT and AES respectively. Therefore, the out-of-band effective isotropic radiated power (OOB_{eirp}) is -17 dBm/MHz [19], [20].

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TABLE I. IMT BASE STATION CHARACTERISTICS

Parameter	Unit	Value
Downlink center frequency	MHz	1512
Bandwidth	MHz	10
Deployment	-	Macro (suburban)
Maximum transmitter power	dBm	46
Maximum antenna gain	dBi	16
Antenna height	m	30
Feeder loss	dB	3
Sectorization	sectors	3
Downtilt	degrees	6
Polarization	-	Linear
Antenna pattern	-	Recommendation ITU-R F.1336-4 (recommends 3.1) k_a=0.7 k_p=0.7 k_n=0.7 k_h=0.7 k_v=0.3
Out-of-band emission limit	dBm/MHz	-30
Macro cell radius	-	1 km

TABLE II. AES TERMINAL CHARACTERISTICS

Parameter	Unit	Value
Receiver frequency	MHz	1525
Reference bandwidth	KHz	200
Receiver Noise temperature	K	316
Receiver thermal noise level	dBW	-150.6
Receiver thermal noise level for 200 KHz ref.BW	dBm/200KHz	-120.6
Receiver thermal noise level for 1 MHz ref.BW	dBm/MHz	-113.6
ACS (1st adjacent channel)	dBc	30
ACS (2nd adjacent channel and up to 2 MHz)	dBc	37
ACS above 2MHz	dBc	87
Antenna gain	dBi	17.5
Polarization	-	circular
Receiver blocking	dBm	-60 dBm (<2 MHz separation) -52 dBm (>2 MHz and <5 MHz separation) -40 dBm (>5 MHz separation)
Aeronautical station antenna height	m	187 and 83

Fig.5 presents the Cumulative Distribution Function (CDF) results of INR received by the AES receiver. The fuselage loss ($Fuselage_{loss(\Theta,\Phi)}$) contribution depends on the angle of arrival of the interferer signal of each IMT BS in the topology. As a result, the achieved aggregated INR level for an aircraft positioned from 3600 m to the runway threshold are -15.47 dB, - 17.43 dB for 0.01 and 0.1% of the cases whereas for the aircraft positioned from 1600 m to the runway threshold the INR are -9.82 dB, and -11.44 dB for the same probabilities presented before. Table III summarize the main results for each scenario simulated.

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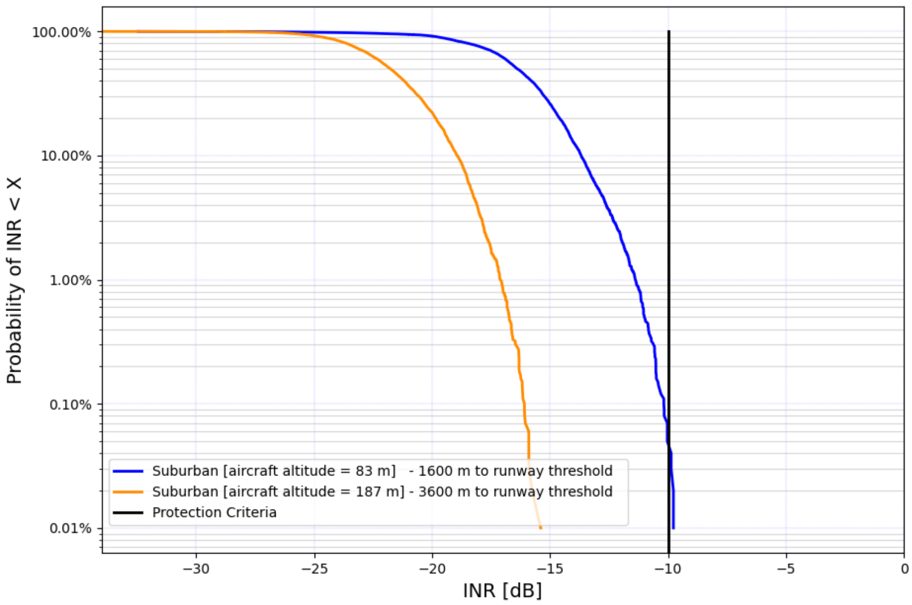

Fig. 5. CDF of interference over noise ratio (INR) received from IMT-2020 (10000 snapshots).

TABLE III. INTERFERENCE OVER NOISE RESULTS

Probability (%)	INR (AES - 1600m)	INR (AES - 3600m)
50	-16.43 dB	-21.77 dB
10	-13.69 dB	-19.90 dB
1	-11.38 dB	-17.10 dB
0.1	-10.15 dB	-16.09 dB
0.01	-9.82 dB	-15.39 dB

It´s important to note that the protection criteria is not met in the last case in less than 0.05% of the cases and about 0.18 dB to reach the protection criteria. Nevertheless, this small probability of interference is unlikely and represents a conservative scenario, due to the IMT antenna model and parameters used in coexistence studies being conservative in order to maintain a secure margin of protection between systems. Additionally, it´s important to stress that INR < -10 dB implies in a link budget degradation of less than 0.5 dB, and does not mean that system will not operate. The worst result complies with INR = -6 dB, that would impact in 1 dB the link budget.

IV. CONCLUSIONS

This paper presents an important contribution to the coexistence analysis between IMT Base Stations and AES located onboard an aircraft in L-Band on a final approach using Monte Carlo simulations. Our contribution complements a previous CEPT-ECC work that was taken into account for the European decisions about the usage of L-band and also our previous study that included the fuselage loss in the analysis based on the European study.

As a result, we presented the statistical CDF of the INR metric for an airplane on a landing approach procedure positioned above a cluster of IMT Base Stations in a suburban scenario at two distances from the runway threshold. For the first distance (1600 m), the protection criteria (INR < -10 dB) is met more than 99.9% of the cases. Regarding the 3600 m distance, the simulation results indicate that protection criteria is met in all cases with a minimum margin of 5.39 dB. In addition, the INR < -6 dB, is not reached. Finally, the results demonstrate the feasibility of spectrum sharing between systems. As future works, we envisage using a statistical compatibility analysis between these systems in an urban scenario.

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