Evaluation of the sharing and compatibility of the existing services between the earth stations on board aircraft and ships that communicate with geostationary space stations, and the stations of the fixed satellite services allocated to the frequency band 12.75-13.25 GHz

Hernán Paz[1] , Camilo A. Maldonado[1] and Julián A. Carvajal[1],

[1] University Escuela Colombiana de Ingeniería Julio Garavito
Bogotá, Colombia
hernan.paz@escuelaing.edu.co, {camilo.maldonado-l, julian.carvajal-l}@mail.escuelaing.edu.co

Abstract. There is a great demand for mobility services in the Ku-band uplink; however, only 500 MHz is available for this type of service (14 – 14.5 GHz). With the additional allocation of a spectrum between 12.75 – 13.25 GHz, the satellite industry will be able to meet this need for additional capacity; however, the band must be harmonized because there are already assigned primary services that need to be protected against interference. This article presents the study and evaluation of the spectrum sharing and compatibility of the fixed (primary) satellite services allocated to the frequency band from 12.75 to 13.25 GHz with the mobile (secondary) satellite services to onboard aircraft and vessels (ETEM); Following resolution 172 of the WRC-23 (World Radiocommunication Conference 2023) agenda, both services communicate with GSO (Geostationary Satellite Orbit) space stations through an uplink. The methodology started with the investigation of the technical specifications and characteristics of each service for the case study of Colombia, which is in region 2; then, three interference scenarios between the mentioned satellite services were identified and selected; Subsequently, a study was made of the places (Colombian cities) where cases of interference between these services may occur. Finally, the parameters to evaluate the interference were established, and it was simulated in SEAMCAT® to collect the values of the parameters of interest and make an analysis of the results obtained. These allow concluding coexistence without interference if coordination distances of 50 km, or more are met between ETEM and FSS (Fixed Satellite Service) earth stations in the uplink. Another requirement is that the transmission bandwidths must be a maximum of 7 MHz.

Keywords: Service compatibility, Frequency band sharing, Ku-Band, Fixed Satellite Services, Mobile Services on board ships and aircraft.

1 Introduction

In the WRC held in Egypt in 2019 [1], and more specifically, in item 1.15 of the WRC-23 agenda, it is suggested that to meet the growing need for connectivity and broadband of passengers on board aircraft and vessels ETEM communication with FSS GSO space stations that operate in the frequency band from 12.75 to 13.25 GHz (earth-space) is allowed, through frequency sharing without interference; this implies evaluating the compatibility of the services involved in the same band.

Since there is no methodology on how to protect the GSO space stations of the FSS against ETEMs that communicate simultaneously with the former; nor is there information available on coordination agreements concluded between administrations in relation to the GSO satellite networks of the FSS [2]; The National Spectrum Agency of Colombia (ANE) launched in 2021 a call for research, development and innovation projects that contribute to the development of technical conditions and regulatory provisions on the subject outlined above, which comply with the guidelines proposed by the ITU (International Telecommunication Union) [3]; In this perspective, the research titled Evaluation of the sharing and compatibility between earth stations in aircrafts and vessels that communicate with GSO space stations and current and planned stations of existing services, as well as band services adjacent to those to guarantee the protection and not to impose undue re-strictions on those services and their future development, in the frequency band from 12.75 to 13.25 GHz.

The research is a case study from Colombia focusing on microwave communications in the SHF (super-high-frequency) band, specifically on satellite communications in the Ku-band, sub band of 12.75 -13.25 GHz. This band is currently allocated on a primary basis to the fixed service, mobile service, and FSS (Earth-to-space), and a secondary basis to the space re-search service (deep space) (space-to-Earth) worldwide [4]. Telecommunications services change by geographic region according to the ITU.

In Colombia, the 12.75-13.25 GHz frequency band has been used for tele-vision transmissions intended to feed cable distribution systems, and plans that use a 25 MHz radio channel separation; In addition, some public entities, private companies in the oil, financial, mining and energy sectors take advantage of it; civil government and commerce, for telephony/data trans-missions in radio channels of analog and digital communication systems.

The harmonization of the frequency band 12.75-13.25 GHz (earth to space) is aimed at minimizing interference. Interference is understood as the effect of unwanted energy due to one or several emissions, radiations, inductions, or their combinations on the reception of the system. This manifests itself as a degradation of the quality of the service, falsification, or loss of information [7]. Several types of interference are distinguished: admissible, that observed or predicted that satisfies the quantitative criteria of interference and sharing given in the ITU regulations [8]; accepted interference, is of a higher level than that defined in permissible interference, which has been agreed between two or more administrations, but without prejudice to other administrations, and lastly, harmful interference, which compromises the operation of a radio navigation service, or which seriously degrades, repeatedly interrupts or prevents the operation of a radiocommunication ser-vice operating under the radiocommunication regulations.

The ITU also defines the concepts of coordination zone and coordination distance that are associated with the sharing and coexistence of services in the same band in the space field. The first determines the need to coordinate the area surrounding an earth station that shares the same frequency band with other terrestrial stations in order not to exceed the admissible interference level; The second is the distance in one azimuth from an earth station sharing the same frequency band with other terrestrial stations, beyond which the permissible level of interference will not be exceeded.

The study on the state of the art of similar proposals in the international and national contexts yielded the following findings: in the international arena, Stankevičius and Oberauskas [5] present the sharing analysis of the 694-790 MHz frequency band for IMT services (International Mobile Communications) and aeronautical radio navigation (ARNS) using the SEAMCAT® software based on the statistical simulation method (Monte-Carlo); analytical calculations show that the required protection distances between ARNS stations and mobile service base stations are 132 km. For the national case, the study on technical parameters to evaluate interference in microwave links was found [6]; This was developed by the Francisco José de Caldas District University of Bogotá in 2017, and its objective was to define the thresholds of the C/I and T/I technical parameters in microwave links, for which they used the ICS TELECOM® software.

2 Methodology

Initially, three scenarios corresponding to the sharing and compatibility of secondary services were identified: ETEM (ETA and ETB) and the primary ones, allocated to the Ku-band from 12.75 to 13.25 GHz (ETSE). These are specified in Fig. 1.

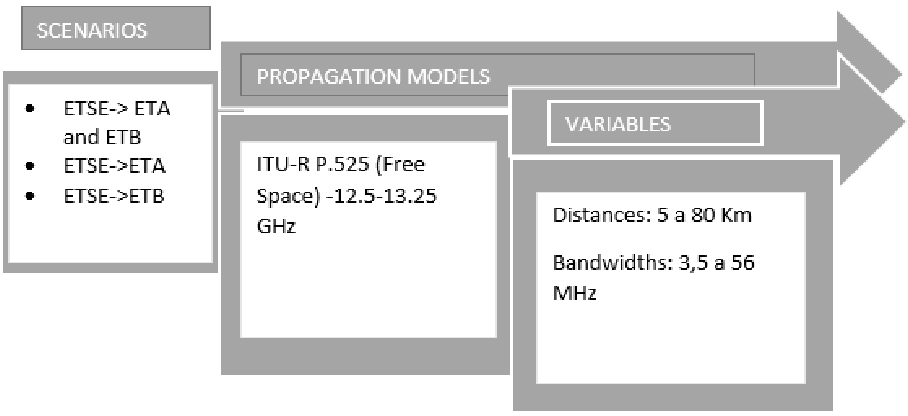

Fig. 1. Tree model of simulations and parameters to vary.

For scenario 1 in Fig. 2, the aircraft and ship mobile earth stations (ETA and ETB) and the FSS earth station (ETSE) communicate simultaneously with the GSO via an uplink. The interference is produced by the ETA and ETB mobile services.

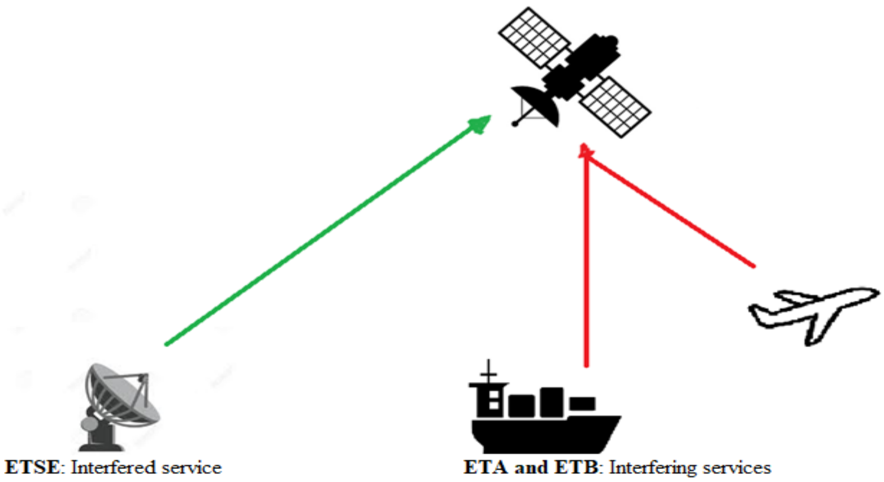

Fig. 2. Scenario 1 with FSS as a victim and ETEMs as interferers.

For scenario 2 in Fig. 3, aircraft mobile earth stations (ETA) and FSS earth stations (ETSE) transmit simultaneously to the GSO. The interference is produced by the ETA mobile service.

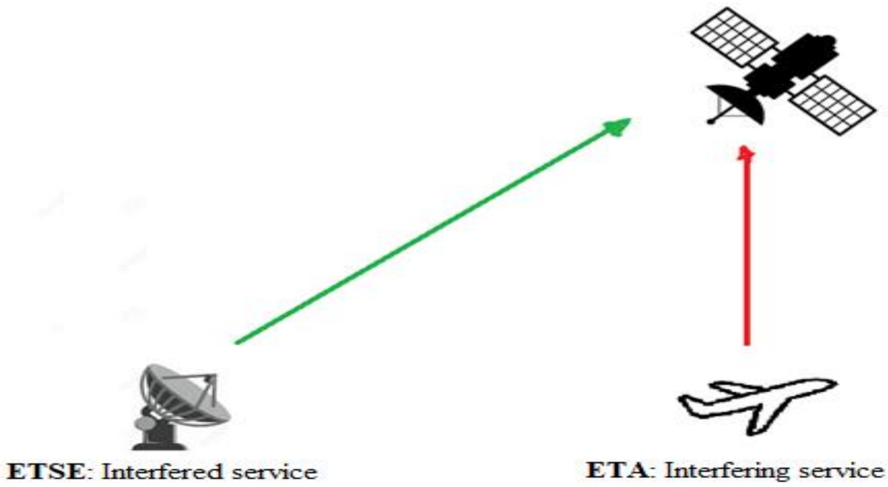

Fig. 3. Scenario 2 with FSS as victim and aircraft services as an interferer.

In scenario 3 of Fig. 4, the mobile earth stations of ships (ETB) and the earth stations FSS (ETSE) communicate simultaneously with the GSO. The interference is produced by ETB mobile services.

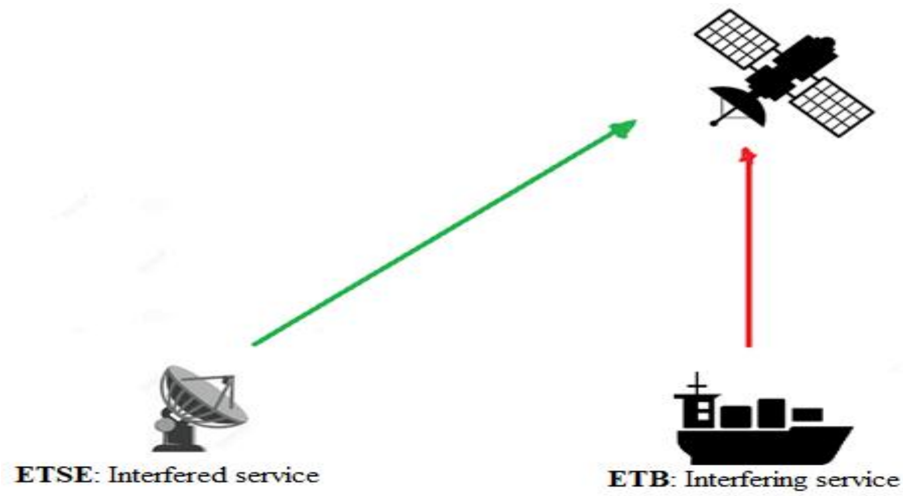

Fig. 4. Scenario 3 with FSS as the victim and communications on board ships as the interferer.

For the characterization of the scenarios, the main port and airport areas of Colombia were located; likewise, the maritime and fluvial naval bases of the national navy, and the military bases of the Colombian air force FAC. The FSS earth stations were also located in the Ku-band, for which it was necessary to identify the Ku-band satellite operators in Colombia; Subsequently, with the help of the CLARO® coverage tool, the ground stations near the previously identified ports and airports were located.

The cities of San Andrés and Cartagena were selected to carry out the simulations for this study, because they have a port, airport, and the presence of ground station, and because they are the most sensitive in Colombian territory. Table 1 shows the distances between the airports and ports of the two mentioned cities.

Table 1. Port-airport distance for Cartagena and San Andrés.

City	Airport (Latitude, longitude)	Port (Latitude, longitude)	Distance (km)
Cartagena	10.446093421302567, -75.5164754605313	10.406332236365493, -75.5284170427762	4.62
San Andrés	12.585812731420924, -81.7021899893457	12.551142085867491, -81.7012263910467	3.91

Table 2 shows the distances between the airports and the FSS earth stations of the two mentioned cities.

Table 2. Distance airport – earth station for Cartagena and San Andrés.

City	Airport (Latitude, longitude)	Port (Latitude, longitude)	Distance (km)

Cartagena	10.446093421302567, -75.5164754605313	10.3878131096099, -5.44500430689193	10,06
San Andrés	12.585812731420924, -81.7021899893457	12.575646, -81.704765	1,20

Table 3 shows the distances between the FSS earth stations and the ports of the two mentioned cities.

Table 3. Port-airport distance for Cartagena and San Andrés.

City	Airport (Latitude, longitude)	Port (Latitude, longitude)	Distance (km)
Cartagena	10.446093421302567, -75.5164754605313	10.406332236365493, -75.5284170427762	4.62
San Andrés	12.585812731420924, -81.7021899893457	12.551142085867491, -81.7012263910467	3.91

Parameters to assess interference (column 1) and their threshold values were also selected. The classification criteria for the type of interference are shown in columns 2 to 4. The bibliographical reference for the parameter selection is specified in column five of Table 4.

Table 4. Evaluation Parameter Thresholds for Simulations.

Parameter	Harmful	Accepted Threshold	Admissible	Reference
TD	TD>1	0<TD<1	TD=0z	Agreement HCM Annexed #9
C/I	C/I < 17dB	17 dB < C/I < 20 dB	20 dB < C/I	Rec ITU-R S.1432 (ITU,2006) ITU-R S.1328-4 (ITU-R, 2002)
C/N+I	C/N+I < 5 dB	5 dB < C/N+I < 12 dB	12 dB < C/N+I	ITU-R S.1328-4 (ITU-R, 2002)
I/N	I/N > -6.5 dB	-12.2 dB < I/N < -6.5 dB	I/N < -12.2dB	Rec ITU-R S.1432 (ITU, 2006)

The relationships specified in Table 4 involve the following variables: I is the interfering power level at the receiver; N is the noise power level in the receiver bandwidth, and C is the received power level.

The TD (Threshold Degradation) parameter is defined as the minimum desired signal level at the receiver for a good received signal quality. In the presence of an interfering signal the level of this parameter increases. The allowed TD must not exceed 1 dB; for values between 0 and 1 it is considered an accepted type of interference, and for values greater than 1 harmful interference occurs [9].

Then it was simulated in Seamcat®, for which a simulation protocol was developed. The distance between earth stations and transmission bandwidths varied according to scenarios. Subsequently, an analysis of interference and acceptable, admissible, and detrimental compatibility between the services and for the three scenarios specified above was made. The technical specifications used in the simulation are shown in Table 5.

Table 5. Technical Specifications of the Uplink for Simulations.

Parameter	Uplink Fixed satellite service	Aircraft upload link	Boats upload link
Distance from earth to geostationary orbit.	36000 km		
Frequency band.	12,75-13,25 GHz (bandwidth per transponder from 26 to 72 MHz)		
Uplink frequency.	13,25 GHz	13,25 GHz	13,25 GHz
Propagation model.	ITU-R P.525-4	ITU-R P.525-4	ITU-R P.525-4
EIRP (Effective Isotropic Radiated Power), uplink.	13 a 20,8 dBW	46 a 49 dBW	24-36 dBW
Antenna height.	0.6m	Immersed in the fuselage	0.6m
Inclination angle.	25°	25°	25°
Noise figure.	5 dB	5 dB	5 dB
Modulation.	MF/TV	QPSK	QPSK
Bandwidth.	25 MHz	18 MHz	18 MHz
Time delay.	250 ms		
Availability Percentage.	100%		
Sensitivity for BER 10^{-3}.	-80 dBm		

3 Results and Discussion of Results

The results of the simulations show that scenario 1, both in Cartagena and San Andrés, is the one that shows the presence of the highest aver-age percentage of data in the harmful threshold (70%) and acceptable (20%) for the TD parameters. , I/N, C/I and C/N+I, so it is concluded that it is the least suitable scenario for spectrum sharing in the study band; while scenario 2 is the most promising for spectrum sharing without service interference because it shows a higher average per-centage of data in the admissible (40%) and acceptable (40%) thresh-old for the mentioned parameters. In scenario 3, there is evidence of the behavior of the results with a bias towards the acceptable threshold (50) and harmful threshold (30), which marks it as a scenario with un-certainty.

Taking the analysis expressed in the previous paragraph as a reference, the results presented below correspond to scenario 2. Tables 6 and 7 present the results of the TD parameter in dB for scenario 2, in the cities of San Andrés and Cartagena respectively.

Table 6 shows that there is no interference for any distance when 3.5 MHz bandwidths are transmitted; it is acceptable for 7 and 14 MHz bandwidths and is detrimental for bandwidths greater than or equal to 28 MHz.

Table 6. Results of the TD Parameter (dB) for scenario 2 in San Andrés.

BW MHz	Distance (Km)								
	5	10	20	30	40	50	60	70	80
3,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
7	0,03	0,03	0,03	0,03	0,03	0,02	0,02	0,02	0,02
14	0,37	0,36	0,35	0,33	0,32	0,30	0,29	0,27	0,26
28	1,16	1,15	1,12	1,10	1,08	1,06	1,03	1,01	0,98
56	2,02	2,01	2,00	1,98	1,96	1,95	1,93	1,91	1,88

Table 7 shows that as the bandwidth increases, the value of TD in-creases, in such a way that the results are located at the admissible threshold for all distances when transmitting with a bandwidth of 3.5 MHz, pass the acceptable threshold with the 7 and 14 MHz bandwidths and end up being detrimental for frequencies greater than or equal to 28 MHz.

Table 7. Results of the TD Parameter (dB) for scenario 2 in Cartagena.

BW MHz	Distance (Km)								
	5	10	20	30	40	50	60	70	80
3,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
7	0,04	0,03	0,04	0,03	0,03	0,03	0,03	0,02	0,02
14	0,38	0,39	0,38	0,35	0,34	0,32	0,31	0,29	0,27
28	1,17	1,17	1,15	1,10	1,08	1,06	1,04	1,01	0,98
56	2,04	2,05	2,05	2,01	2,00	1,98	1,96	1,94	1,92

Figure 5 shows the data of the C/I parameter as a function of the distance for the fixed 3.5 MHz bandwidth, which was obtained in Seam-cat® for scenario 2. Their behavior shows a greater C/I ratio for Cartagena than those obtained for San Andrés, although for both cities they are within the admissible threshold.

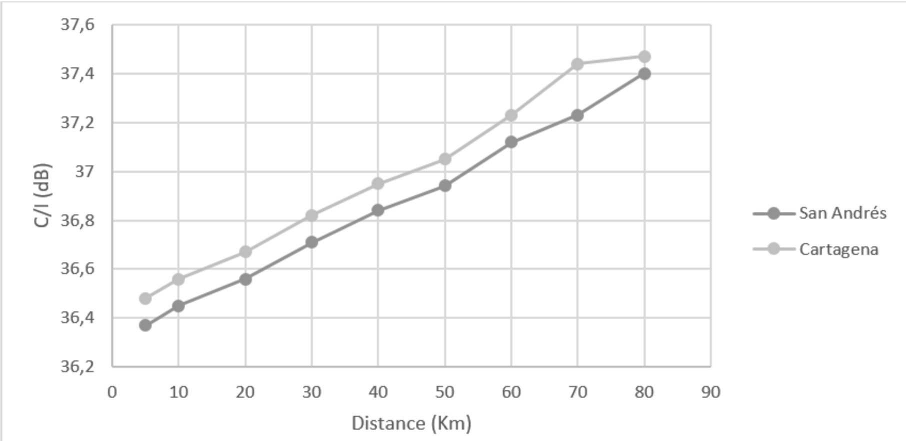

Fig. 5. C/I behavior versus distance for scenario 2 with 3.5 MHz bandwidth.

If the same parameter is simulated in scenario 2 for a 7 MHz bandwidth, lower values are obtained concerning those shown in Fig. 5, although they remain within the admissible threshold; It is also noted that the results of the simulation for San Andrés and Cartagena are closer to us. If you continue successively with bandwidths of 14, 28, and 56 MHz, the values decrease, and pass to the acceptable threshold at 14 MHz, and harmful from 28 MHz, for distances less than 60 km.

It is concluded that the 3.5 and 7 MHz bandwidths do not condition the distances between ETEM and FSS ground stations so that they can operate their services without interference.

Fig. 6 shows the data for the C/N+I parameter as a function of distance for the 3.5 MHz fixed bandwidth, which was obtained in Seamcat® for scenario 2. Their behavior shows a greater C/N+I ratio for San Andrés than those obtained for Cartagena for distances less than 20 km. The C/N+I data for both places are within the admissible threshold.

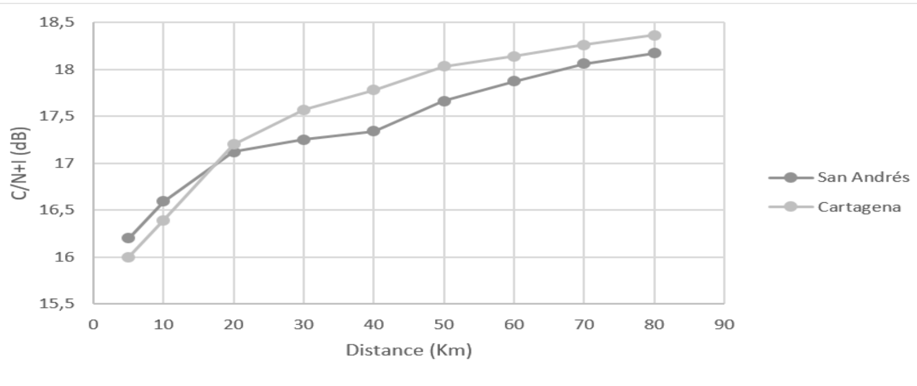

Fig. 6. Behavior of C/N+I versus distance for scenario 2 with 3.5 MHz bandwidth.

By continuing the simulations of the mentioned parameter with the increase in bandwidth at 7, 14, 28, and 56 MHz, the data pass to the acceptable threshold at 14, 28, and 56 MHz, and end with values at the detrimental threshold at 56 MHz for distances less than or equal to 40 km. The results of the simulation of the C/N+I parameter for scenario 2, allow us to infer compatibility between services for bandwidths be-tween 3.5 and 7 MHz; the 14 MHz bandwidth can also be used, but for distances greater than 40 km. Fig. 7 shows the data for the I/N parameter as a function of distance for the fixed 3.5 MHz bandwidth, which is obtained in Seamcat® for scenario 2. Their behavior shows slightly higher values in San Andrés than those obtained for Cartagena; In addition, it is observed that the data group for all distances is in the allowable interference threshold.

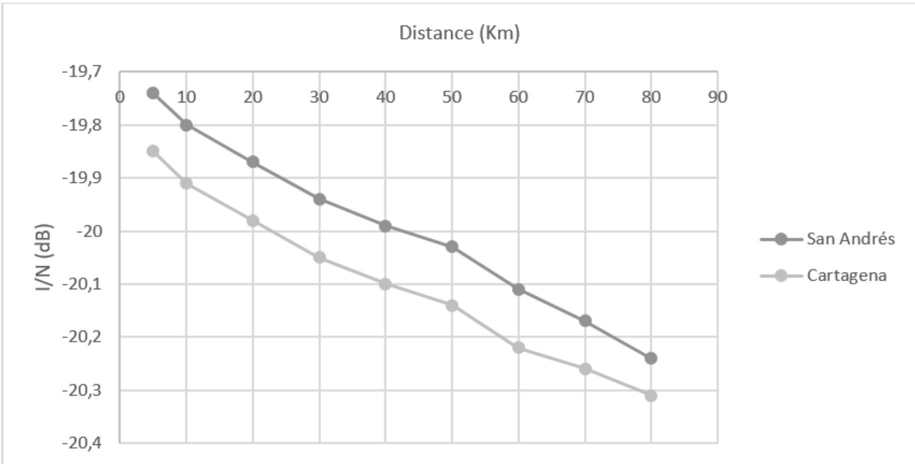

Fig. 7. I/N Behavior vs. Distance for Scenario 2 with 3.5 MHz Bandwidth.

When simulating I/N in scenario 2 for 7, 14, 28, and 56 MHz bandwidths, the same downward behavior is observed with lower values that move the allowable interference region to the acceptable interference threshold. This happens with the 7 MHz bandwidth and from distances of 5 km; it remains at that threshold for the 14-bandwidth and passes to the harmful interference threshold for the 28-MHz bandwidth with distances greater than 10 km.

From the results it can be concluded that the FSS services can share their spectrum in the Ku-band from 12.75 to 13.25 GHz with the ser-vices on board ships without interference for communications with bandwidths of 3.5 and 7 MHz, without any specification as to the protection distance; and that for the 14 and 28 MHz bandwidths, distances must be considered to achieve spectrum sharing with acceptable levels of interference.

It is expected that the number of licenses in the 12.7-13.25 GHz band will begin to decline rapidly as the cable television industry shifts from microwave television programming distribution to fiber distribution systems. optics: In this perspective, there could be less demand for FSS service bandwidth, which would give rise to more spectrum to be used by ETEM.

Ku-band tends to have noticeable degradation due to problems caused by and proportional to the amount of rain (commonly known as “rain fading”) where its signals can be affected by rain absorption. In the case of television reception, only heavy rain (greater than 100 mm/h) will have effects that the user can notice. Therefore, it is not recommended for areas with a lot of precipitation. However, this problem can be mitigated by deploying an appropriate link budget strategy when designing the satellite network and allocating higher power consumption to compensate for rain fade loss.

In the present investigation, the evaluation of sharing and compatibility of fixed satellite services and mobile earth stations, on board ships and aircraft in the 12.75-13.25 GHz band for the Colombian territory yielded the following conclusions:

In the first instance, it could be concluded that since the uplink distances between ETEM and FSS transmitters are long, the use of the ITU-R P.525-4 free space propagation model is recommended for simulations; In addition, this model covers frequencies up to 30 GHz.

When analyzing the Colombian environment for the problem pro-posed in this research, three possible interference scenarios were pro-posed for the seven main cities of the country; Two critical cities were selected from these: Cartagena and San Andrés, considering the conditions of proximity between ground stations, air, and sea traffic. Subsequently, the three scenarios for the two critical cities were simulated with the Seamcat software.

From the results of the simulations, it was possible to infer that the bandwidth and the distances between the fixed satellite services and the interfering services depend on the parameter used to analyze the interference. The results showed acceptable interference and no interference for the TD parameter with bandwidths of 7 and 14 MHz. On the other hand, the results of the I/N and C/I parameters present simi-lar results for bandwidths of 3 .5 and 7 MHz.

It was possible to conclude that the scenario most affected by interference is number one in San Andrés, where fixed satellite services and communications on board ships and aircraft coexist, and where 70% of the values were identified. belonging to the harmful interference threshold, therefore spectrum sharing is not recommended under this scenario in said city.

It is also concluded that the scenario with the best performance in compatibility and service sharing is number two in San Andrés, since harmful interference occurs in 20%, and evidence 40% of the results in the permissible interference threshold.

Finally, this work leaves open possible future research on channeling strategies, modulation, and guard distances to improve the conditions of coexistence and sharing between the services present in the scenarios in which the interference was acceptable or harmful [10].

4 Conclusions

The use of the frequency band 12.75-13.25 GHz for ground-space links of ETEM earth stations that work with GSO networks of the FSS will constitute an additional use of the spectrum and will improve the mobile broadband communications of the passengers on board aircraft/vessels, and that band will not be used in the safety of life applications.

A globally harmonized framework would allow maritime and aviation services, which are global in nature, to take advantage of economies of scale to allow operators to offer connectivity to customers/passengers in national and international airspace and waterways, independent of -mind your location. A harmonized approach at the regional level would be beneficial for both regional administrations and industries.

Administrations wishing to operate ETEM earth stations in the Appendix 30B frequency bands shall submit to the ITU the commitment to conform to the envelope to protect Appendix 30B assignments; similarly, eliminate any unacceptable interference or reduce it to an acceptable level in case such interference is caused to terrestrial services. Under this scenario, technological advances in new monitoring techniques for ETEM services will allow ground stations on board aircraft and vessels to use them to function following the characteristics of FSS fixed ground stations, favoring spectrum sharing without interference. Another possible mitigation technique could be antenna pat-tern correction.

The recommendation to the ANE is that the earth stations on board aircraft and vessels (ETEM) with the current and planned stations for the frequency band 12.75-13.25 GHz (Earth-Space) can simultaneously transmit their data, without interference, for 3.5 and 7 MHz bandwidths, with maximum coordination distances of 50 km in Colombia.

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Bibliography

Hernán Paz Penagos, PhD.
hernan.paz@escuelaing.edu.co
ORCID: http://orcid.org/0000-0002-2692-1989

Received his Ph.D. degree from the National Pedagogical University of Colombia in 2012. He graduated in electronic engineering from the District University Francisco José de Caldas and received his master from the same university. He currently works at Escuela Colombiana de Ingeniería JULIO GARAVITO. During the past 20 years, his research has been centered on various topics of digital communications, antennas, including analysis, design, development, measurement, and propagation and radiation aspects of terrestrial and space-based communication, wireless, mobile, satellite, and telecommunications. As a professor and researcher, he has directed several research projects and published more than 30 scientific papers and five research books on communications systems. In addition, he has researched in teaching methods and pedagogic theory., ID Scopus: 55344136500 and Google Scholar: https://scholar.google.com/citations?user=8YmHJ6EAAAAJ&hl=en.

Camilo A. Maldonado
University Escuela Colombiana de Ingeniería Julio Garavito, Bogotá, Colombia, camilo.maldonado-l@mail.escuelaing.edu.co
Julián A. Carvajal
University Escuela Colombiana de Ingeniería Julio Garavito, Bogotá, Colombia, julian.carvajal-l@mail.escuelaing.edu.co