WHITE PAPER

SATELLITE SOLUTIONS IN C-BAND

A value-generating ecosystem

OVERVIEW

C-band is a critical radio spectrum for satellite communications

3.4–4.2 GHz in the downlink and 5.925–7.025 GHz in the uplink

The wide area coverage provided by C-band satellites simplifies the ground infrastructure required to provide connectivity between remote points and contributes to lower the total cost of ownership of a telecommunications solution, compared to an equal-reach terrestrial microwave network.

C-band frequencies provide unmatched capabilities to service providers as a result of two unique physical characteristics—wide reach and resistance to rain fade. C-band satellites implement hemispherical and global coverage beams (not generally available in typical Ku- or Ka-band payloads for commercial use), which are critical to support cross-continent (or global) service delivery. The wide area coverage simplifies the ground infrastructure required to provide connectivity between remote points and contributes to lower the total cost of ownership of a telecommunications solution, compared to an equal-reach terrestrial microwave network.

As described in more detail below, satellite operators use the C-band to provide aircraft navigation, data connectivity for governments and enterprises, mobile communications for ships, and television distribution around the world. The satellite industry continues to invest in payloads with C-Band capacity, with a considerable number of satellites with a C-band payload expected to be launched between 2022 and 2026.

The C-band uplink and downlink frequencies are now under consideration for reallocation to terrestrial services in many countries around the world. If a national regulator is considering such a reallocation, it must take into consideration the full communications ecosystem of its country, and to do so, service providers and their customers relying on C-band must speak so that the regulator understands how important the C-band is to their country.

ENABLING BOTH CRITICAL SERVICES AND VALUE ADD FOR AN ECONOMY

Spectrum in the C-band is a key component of satellite service delivery all over the world

Regional branches of multinational entities in Africa or Latin America are a single hop away from their main offices.

Video services are a natural beneficiary of the wide coverage beams and the resilience provided by the C-band: using hemispherical and global beams it is easy to reach millions of viewers from one satellite with low risk for disruption. This unique combination of wide coverage and high resilience to rain is needed for the broadcasting services (hundreds of TV channels) that cover Latin America, Africa, South-East Asia, or any region with a tropical climate and cannot be achieved with higher frequencies.

Furthermore, other sectors such as enterprise, government and defence also benefit. Regional branches of multinational entities in Africa or Latin America are a single hop away from their main offices. Embassies, consulates, and other governmental sites abroad can be linked via a single hop to their main centres in their native countries.

Below are some examples of how service providers use C-band satellite services to support a variety of communications solutions:

BROADCASTING

C-band is used in broadcast distribution to deliver high quality content to millions of end-users globally. C band distribution services include direct-to-home (DTH) distribution, and delivery to content aggregation earth-stations for delivery to other platforms, including online, cable, Ku-band DTH, terrestrial television and radio distribution points.

1,900

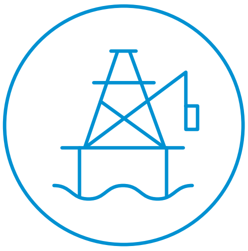
head-ends in Latin America with 250 in Brazil

12M+

receive-only C-band antennas for direct distibution in Brazil

- According to SES's estimates, there are approximately 1,900 head-ends in Latin America (with 250 in Brazil). There are over 12 professional C-band antennas in each of the bigger head-ends sites, fewer than 8 in each of the small ones (around 1,470 head-ends). There are over 12 million receive-only C-band antennas (TVROs) for direct distribution to consumers in Brazil alone. Even considering the initiatives to migrate direct video distribution in Brazil to other bands, given the number of unregistered TVRO stations and the magnitude of the migration task, SES expects the C-band to continue to have an important role DTH distribution in Brazil for the foreseeable future.

- European Broadcasting Union members such as the BBC, RFI Eurovision and RTPI rely on C-Band for the delivery of premium news, sports, and music events outside of Europe, with extensive use of C-band in the Americas, Asia and Africa, using over 340 MHz of leased transponder capacity on different satellites (Asiasat, Apstar, Intelsat, SES) for contribution links and major worldwide sport events (such as the Olympics Games, FIFA World Cup, UEFA Champions' League and UEFA European Championship, Grand Slam Tennis, NBA, Formula 1).



OIL AND GAS

C-band supports mission-critical operations in Africa and the North and Baltic seas. Drilling operations are normally interrupted if connectivity and monitoring on the site are not available.

HUMANITARIAN PROGRAMMES, IGOs, NGOs, RESEARCH

C-band offers connectivity for NGO and IGO field offices, supporting missions and disaster management in remote areas.

- UN agencies rely on C-band global coverage to support their operations,[1] connecting theatre of operations back to their European hubs. UNHCR continues to use nearly 300Mbps of space segment, primarily C-band.

- SES provides connectivity to Belgian Antarctica research via C-band capacity on SES-5, SES-4, NSS-9, NSS-12.[2]

EMERGENCY RESPONSE

Global coverage via satellite remains the best solution for rapid deployment of communications, tele-medicine, and it is unfortunately expected to be of increasing importance in the presence of more intense and frequent extreme weather events all over the globe.

Emergency.lu:

- SES has supported emergency.lu since 2012 with permanent global and wide area C-band capacity on three satellites, which is increased during emergency events as needed.

- Emergency.lu has supported 27 missions since its inception, with 69 deployments in the Caribbean, Asia, Europe, Africa and the Middle East.[3]

- Amongst the most recent missions, emergency.lu was deployed in Syria and Venezuela in support of UNHR/UNICEF, to provide broadband service for community-based projects in the areas of health, education, protection, water, and sanitation.

1 https://www.itu.int/en/ITU-D/Emergency-Telecommunications/Documents/events/2020/03_NETP/ESOA%20presentation.pdf
2 https://www.speedcast.com/newsroom/press-releases/2017/speedcast-secures-multi-year-contract-to-provide-mission-critical-remote-communication-services/
3 http://www.emergency.lu/missions/

TELE-MEDICINE

C-band supports the remote delivery of healthcare services, reaching otherwise underserved rural populations.

- SES supports SATMED, the medical arm of the emergency.lu service, which supplies services such as interactive tele-radiology sessions, remote consultation, health information management (data collection and analysis), conferencing and remote learning.

BROADBAND ACCESS/IP PIPE

C-band IP trunking solutions provide exceptionally reliable internet access services to wireless distribution points.

- SES supports OptimERA's services in Alaska with an IP trunking service of 280 Mbps to their central location in Unalaska, enabling them to provide broadband internet access through their wireless network.[4]

BANKING/FINANCIAL

C-band is crucial to providing continental connectivity for services that require high reliability, such as banking transactions.

- The African Development Bank (AFDB) relies on C-band capacity for the interconnection of their locations in Africa.

GOVERNMENT

E-government solutions facilitate efficient delivery of government services to underserved areas in the world.

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- Nunavut is the largest and northernmost territory in Canada (over 1.8 million squared kilometers), and it is the fifth-largest country subdivision in the world. The Kativik Region is Québec's far north, covering 500,164 km[5] of territory beyond the 55th parallel.

- SES supports the Nunavut[5] and Kativik Regional Governments in Canada using C-band capacity on its satellite fleet to deliver e-government services including broadband, disaster recovery, first responders, and tele-medicine.

- SES supports the Galileo Data Dissemination Network (GDDN) interconnecting all the remote sensor and uplink stations to the control centres in Europe. Through the network we support the entire family of products and services offered by the Galileo constellation.

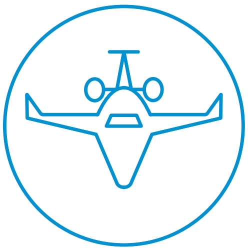
4 https://www.ses.com/press-release/ses-networks-and-optimera-scale-capacity-rural-alaska-city-under-stay-home-rule#:~:text=OptimERA%20started%20working%20with%20SES%20Networks%20in%202017,is%20800%20miles%20from%20the%20nearest%20fibre-based%20network

5 SSi Canada Partners with SES Networks to Deliver New Satellite Capacity into Northern Canada. https://www.ses.com/press-release/ssi-canada-partners-ses-networks-deliver-new-satellite-capacity-northern-canada

MARITIME

Global coverage is crucial for vessels operating beyond the reach of terrestrial networks, moreover C-band is considered of increasing importance for large vessels.

- SES managed services provide reliable IP connectivity to our customers for crew welfare and entertainment as well as for fleet management.



AIR TRAFFIC MANAGEMENT, METEOROLOGICAL DATA DISSEMINATION AND NAVIGATION SERVICES

C-band is used for ATM networks which require deterministic behavior, wide coverage and high reliability.

- According to ICAO,[6] out of the 4.3 billion passengers carried or scheduled in 2018, 2.1% are in Africa and 5.3% in Latin America. These regional networks[7] use C-band capacity to support ATM networks and air navigation services. For example, Aeronautical Civil in Colombia uses C-band to support their communications network across 28 airports.[8]

- Satellite solutions in C-band support AFTN,[9] AMHS,[10] meteorological forecasts and advisory delivery (ICAO Meteorological Information Exchange Model, IWXXM), voice services (Air to ground A/G or GROUND-TO-GROUND G/G), video services (Remote/Digital Tower), and radar data exchange.

- SES supports the C-band uplink of signals for the European Geostationary Navigation Overlay Service (EGNOS) and the US Wide Area Augmentation Service (WAAS).

MOBILE BACKHAUL & DIGITAL DIVIDE

C-band offers reliable backhaul connectivity solutions for mobile networks in remote areas and provides capacity for large regions. Various operators in Asia and Afric[11] rely on C-band solutions for cellular backhaul.

- In the Pacific Islands of French Polynesia, Tonga and Papua New Guinea, C-band connectivity is at the core of the inter-island communication service. Given the meteorological conditions experienced in the Pacific Islands, the government mandate to provide services in the area, and knowing that the large distances in between islands render other connectivity options too expensive, satellite services are paramount to the network infrastructure. Specifically, C-band satellite services enable high reliability connectivity solutions and ensure that critical services are maintained when other satellite bands are too heavily attenuated due to rain.

- SES has partnered with Tele-Post (TP) Greenland to supply over 1 Gbps of Internet access to power 4G deployment in Greenland,[12] and provides capacity for cellular backhaul to customers in Myanmar and French Polynesia.

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6 https://www.icao.int/annual-report-2018/Pages/the-world-of-air-transport-in-2018.aspx
7 Aeronautical Navigation Service Providers (ANSP) in Latin America use REDDIG II and in Africa AFISNET
8 https://www.developingtelecoms.com/telecom-technology/satellite-communications-networks/9191-satcoms-support-for-colombian-airports.html?utm_source=related_articles&utm_medium=website&utm_campaign=related_articles_click
9 Aeronautical Fixed Telecommunication Network. a worldwide system of aeronautical fixed circuits for the exchange of messages and/or digital data between aeronautical fixed stations.
10 Aeronautical Messaging Handling System, a standard for aeronautical ground-ground communications (e.g. for the transmission of NOTAM, Flight Plans or Meteorological Data)
11 https://www.itu.int/en/ITU-D/Regional-Presence/Europe/Documents/Events/2020/5G_EUR_CIS/Session%204_Alexander%20Geurtz%20SES%20-%2020201023%20ITU%20Reg%20Forum%20Europe%20-%20SES%20%28final%29.pdf
12 Tusass | SES Case Study. https://www.ses.com/case-study/tusass

ENGAGEMENT WITH REGULATORS IS NECESSARY TO PROTECT C-BAND SERVICES

Despite all of the services C-band satellite enables, it is often invisible to the service users

When new services and applications seek access to spectrum, regulators aim to balance the demand from the new services with that of the existing services, with an approach that is technology-neutral, considering the technological ecosystem in operation, and with a view towards maximizing the benefit for its administration and the services at play.

Therefore, the satellite industry must make regulators and the public aware of the fundamental role satellite solutions play in the economy, both directly (such as enterprise data networks) and indirectly (such as satellite solutions that provide backhaul for terrestrial services). These efforts include regular conversations with regulatory bodies at the national and regional levels. In the case of the C-band spectrum, regulators must consider not only the importance of the communications solutions provided with the support of satellite systems, but also the harmful impact of interference originating from existing or potential new services sharing the band in a co-frequency or adjacent band scenario. The impact of potential interference is a particularly important aspect when considering C-band spectrum reallocation to high-powered terrestrial services.

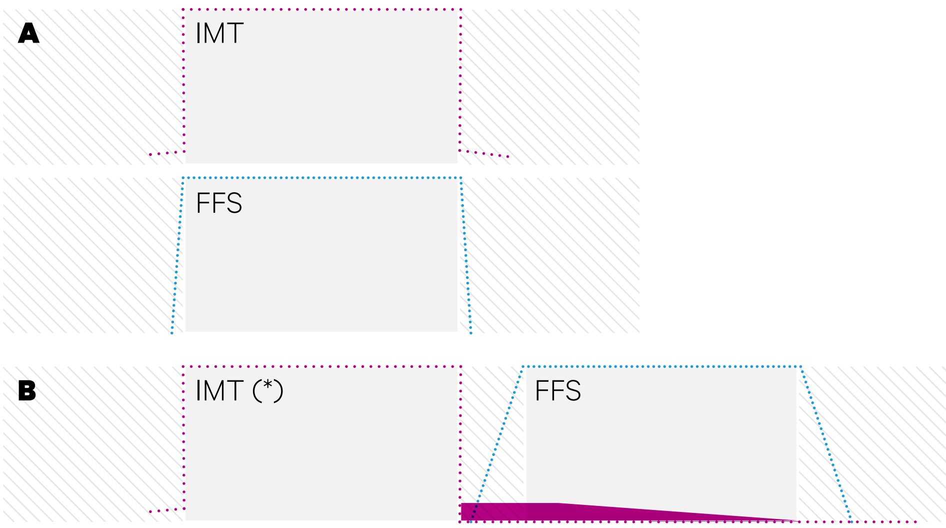


Fig 1
Illustration of two cases of spectrum use
A: co-frequency deployments, B: Adjacent band deployment

Terrestrial services should use the spectrum that has already been identified for such services to the fullest extent before additional spectrum is reallocated, potentially putting critical satellite services at risk.

The mid-band frequencies already identified for terrestrial wireless services should be exploited before new identifications are pursued

When evaluating the need to reallocate C-band spectrum to terrestrial wireless services, such as mobile 5G services, regulators should consider first whether additional spectrum is needed to achieve the goals set for their country. The mobile industry has made increasing demands for spectrum in the C-band range with the stated goal of supporting additional capacity for 5G mainly in urban areas.[13] However, at the International level (as recorded in the Radio Regulations), a total of 19 GHz of spectrum has been identified for 5G services, with nearly 1 GHz in the mid-band range.[14] Worldwide, the following footnotes identify spectrum for 5G in the 2 and 3 GHz range:

- **Footnote 5.384A**, providing a global identification in the range 1710-1885, 2300-2400, and 2500-2690 MHz ranges, for a total of 465MHz, and
- **Footnote 5.388**, providing another global identification in the 1885-2025 MHz and 2 110-2200 MHz for IMT use, aggregating to 695 MHz.

In Region 2, up to 400 additional MHz are identified as Administrations can, in addition, adhere to:

- **Footnote 5.429D**, in the 3300–3400 MHz range,
- **Footnote 5.431B**, identifying the 3400–3600 MHz range for IMT,
- **Footnote 5.434**, identifying the 3600–3700 MH range for IMT, and
- **Footnote 5.441A**, identifying the 4800–4900 MHz range.

13 https://venturebeat.com/2019/12/10/the-definitive-guide-to 5g-low-mid-and-high-band-speeds/
14 https://www.itu.int/en/ITU-R/Documents/ITU-R-FAQ-IMT.pdf

Register receive-only earth stations in the C-Band, even if the process is not mandatory in your country, to inform regulators of the number of stations in service and where those stations are deployed.

Regulators can understand the scope of C-band use through earth station registration

As noted in the previous section, C-Band spectrum is currently used to offer a variety of services. Some of these services are bidirectional, and in most cases, a transmit earth station needs to be registered with satellite operators to obtain service and national regulators to either obtain or comply with a license.

Having a registry of earth stations at a national level is useful from a regulator's perspective when assessing the usage levels of a spectrum segment. It helps regulators to understand the type of services provided and the amount of spectrum used, enabling them to better evaluate the impact that introducing another service in, or adjacent to, the spectrum (under any category, co-primary, secondary, or other) may have on existing services.

However, receive-only earth stations such as those used in some data dissemination services and in the broadcasting services, are exempt from many national registration requirements. This means that the regulator has no means to derive spectrum usage or activity information from this large segment of users. It is beneficial and recommended to register C-band receive-only earth stations in any available national register even if not mandatory, to inform regulators of the number of stations in service and where those stations are deployed.[15]

Furthermore, informing regulators of the location and characteristics of the receive-only stations can also encourage regulators to grant protected status to the earth stations. See for example the process followed in the United States to identify and grant protection from interference coming from new 5G systems operating in the 3.7-3.98 GHz band.

15 Registration of earth stations usually carries some associated administrative cost.

SATELLITE AND MS OR 5G SERVICES: SPECTRUM SHARING

Many regulators suggest that spectrum, such as the C-band, can be shared with other services. On paper, this sounds like an ideal solution that allows citizens to benefit from new services while continuing to use existing ones. But sharing, in the C-band in particular, is not always possible and attempts to share spectrum often lead to the loss of existing services or holes in the deployment of new services.

Why is the satellite industry concerned with sharing the C-band with mobile services?

The rapid growth of mobile technologies and emerging 5G network deployments have led the mobile industry to demand access to spectrum in the C-band range.

As an industry, satellite operators recognise that sharing may be possible, but we emphasize that sharing situations are specific in nature, and studies from one region cannot automatically be transposed to another. The main concern of the satellite industry is the inevitable interference that will result from 5G base stations and, to a lesser extent, the mobile terminals which could be deployed in the frequency range 3400–4200 MHz.

An overview of technical aspects associated to sharing in the 3400–4200 MHz band

The receive chain of a satellite earth station is designed to be sensitive, as the power levels of the signals coming from the geostationary orbit (at an altitude of 36,000 km) will be extremely weak once they reach the earth station. Amplifiers on earth stations are sensitive and wideband: they are designed to operate across the 3400–4200 MHz range with gains exceeding 60 dB in most cases. As a result, the system can be quickly overloaded in the presence of powerful signals such as those coming from a number of 5G base stations.

Regulators evaluating coexistence of mobile terrestrial services and satellite services in the band must consider the following interference scenarios and ensure they will not harm existing satellite services:

- In situations where the services operate either in co-frequency or in adjacent bands, the emissions generated by 5G devices will be received by the satellite earth stations inside the operating band of the low noise block downconverters (LNBs) and will cause interference.

- In situations where the services operate adjacent to each other, emissions generated by 5G devices out of their intended band of operation (OOBE) will fall fully inside the operating band of the satellite service causing interference and degrading the carrier-to-noise ratio of existing and future satellite services.

Together, these two classes of interfering scenarios (In-Band and OOBE) generate two problems for the satellite earth stations.

Blocking of the satellite earth station LNB

LNBs that amplify the signal received by the satellite earth station operate in the full 3400-4200 MHz band and with a relatively flat gain response across it. The receivers in the satellite service have no built-in radio frequency (RF) filtering and all selectivity is limited to the intermediate-frequency (IF) devices in the chain.

The LNBs are designed to receive and amplify very low power signals received from satellites. The addition of a high-power signal at the LNB input will drive it into an unwanted region of operation, resulting in degradation of the device performance and ultimately the inability to deliver a useable signal. This is known as LNB Blocking. Moreover, although the blocking effect completely prevents the receive chain of an satellite earth station from operating, degradation of the signals delivered by the LNB to receivers can be experienced with power levels below the blocking threshold and satellite services will experience increased levels of interference potentially resulting in loss of service as the Carrier-to-noise and interference ratio falls below the minimum value required for operations.

Increased noise and interference ratio within the pass band of the satellite service

Signals originating from services in the adjacent band and falling within the pass band of the filters installed to protect the satellite service, will not be rejected by the filter. Thus, controlling the OOBE profile of the 5G service is necessary to minimize the impact on the satellite service. When defining the technical conditions that will apply to 5G emissions, regulators should consider limits to emissions in the spurious and OOB domains that take into account the conditions for coexistence of the services.

Figure 2 summarizes the impact that 5G emissions have on satellite earth stations sharing the same frequency band, and the mitigating actions that could be pursued to minimize the impact.

To compound the problem, there is a large population of operational receive-only earth stations, used for video services, for which the precise location is not known. Identifying them in order to avoid placing mobile base stations in their vicinity would be very difficult.

Protect C-band satellite earth stations receiving in 3625–4200 MHz

- Register earth stations with national regulatory authorities. In some instances, this may grant additional interference protection.
- Impose an out-of-band emission limit on 5G emitters operating below 3625 MHz to protect satellite operations in 3625-4200 MHz (e.g., in the form of a maximum PFD limit at the earth station antenna).
- Establish a guard band between 5G operations below 3625 MHz and satellite operations in 3625-4200 MHz (e.g. US: 20 MHz, Singapore: 50 MHz, Hong Kong: 100 MHz).
- Implement a minimum separation distance between 5G operations below 3625 MHz and satellite operations in 3625-4200 MHz.
- Earth station operators may need to implement appropriate filters or other equipment changes to better resist blocking or overload.

Fig 2
Overview of the impact of IMT/5G emissions on satellite services and potential mitigation techniques.

Emissions inside the band identified for IMT	**Emissions within the guard band**	**Emissions falling inside the FSS allocation**
Effect upon FSS E/S	Effect upon FSS E/S	Effect upon FSS E/S
LNB blocking and non-linear behaviour	LNB blocking and non-linear behaviour	No effect on the RF chain of the E/S
Impact on services	**Impact on services**	**Impact on services**
Outages (due to LNB blocking and interference)	Outages (due to LNB blocking and interference)	Increase interference > reduction in link margin, reduced availability > increased outage times, increased outage intensity
Increase of BER	Increase of BER	
Degradation in video signal quality	Degradation in video signal quality	
Mitigation technique	**Mitigation technique**	**Mitigation technique**
Protection/exclusion zones	RF filtering is limited (transitioning to pass-band)	Controlling 5G OOB and spurious emissions control (emission masks)
Addition of RF filtering: Adj. band scenario	Emission masks: keep OOB and spurious emissions LOW within the guardband	
Side-effects of the mitigation technique (RF filtering)	**Side-effects of the mitigation technique (RF filtering)**	**Side-effects of the mitigation technique (OOB masks)**
Reduction in E/S G/T, increase in outage time, reduction in link margin and throughput	Increased interference > reduction in link margin, reduced availability > increased outage times, increased outage intensity	OOBE masks have no side effects on the FSS earth station or service

3300 MHz | 3xxx MHz | 3x00 MHz | 4200 MHz

The optimum width of the guard band is a complex trade-off including the 5G BEM (emission profile), the acceptable interference from the 5G service into the satellite service, and the required specifications of the RF filters to be installed on the satellite earth stations.

The importance of establishing an inter-service guard band of adequate width

An inter-service guard band ("guard band") is the frequency separation between the nominal edges of band of one service and the nominal start of band of the service in the immediately adjacent spectrum allocation. This dedicated portion of the spectrum acts as a "buffer" between two adjacent services.

In the specific case of 5G deployments, the guard band should be designed to guarantee that the OOBE from the 5G service reach a level sufficiently low to ensure interference in the adjacent band does not exceed the value defined as protection criterion for the satellite service.

Figure 3 below illustrates the typical shape of an 5G block-edge emission profile, overlaid with a filter frequency response.

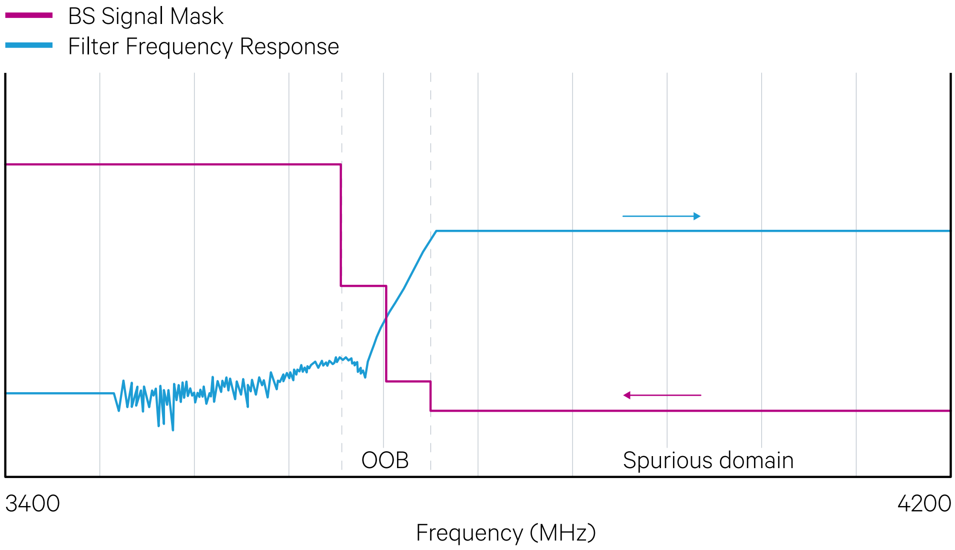


Fig 3
Illustration of the relationship between a 5G emission profile (BEM), and an RF filter response.

Referring to the elements in Figure 3, the definition of a guard band separating the operation of 5G and satellite services has two objectives:

I. On the one hand, it ensures that the emissions of 5G stations reach the lowest levels of unwanted emissions (spurious levels) in the band assigned to the satellite. An inspection of the 5G emission profile in the figure reveals the need to establish a guard band between services to prevent the emissions of the 5G service overlapping with those of the satellite service. The size of the guard band will then correspond to the characteristics of the emission profile of the adjacent band 5G stations. Emissions from 5G base stations reach the spurious levels after a frequency separation of about 40 MHz, but national regulators could prescribe specific conditions to further restrict the exact spurious level and/or frequency offset associated with the applicability of this spurious level.

II. On the other hand, when RF filters are installed on satellite earth stations, the guard band is a necessary element to ensure that emissions falling in the filter transition region continuously decrease with increasing frequency. Otherwise, the RF filter will not be effective in its main task of mitigating interference. Without the definition of a suitable guard band, coupled with an adequate separation between 5G base stations and satellite earth stations, the high-power levels of IMT signals will result in the complete loss of the satellite service even in the presence of RF filters

The filter insertion loss introduces a degradation in the earth station figure of merit (G/T) which needs to be considered.

Additionally, and to establish an adequate size of the guard band, it is important to consider the characteristics of the frequency response of the bandpass filters that are required to ensure that the LNB on the satellite earth stations does not operate in a non-linear region.

Transition regions are those regions of the filter response located between the pass band and the rejection bands in which the response of the filter decreases in attenuation from the rejection levels (high attenuation) to the pass-band levels (low attenuation). Within this region, the filter's response does not meet either the rejection or the pass band criteria.

One of the fundamental trade-offs performed in RF filter design is that of balancing the width of a transition region with the acceptable insertion loss within the filter pass band.

Designing a filter for narrow transition regions to accommodate a narrow guard band will result in high insertion loss within the pass band, which will cause a degradation in performance of any signal present within the bandwidth where the loss is appreciable. In the specific case of satellite services, such loss in the pass band will cause:

a. additional attenuation within the spectrum allocated to the satellite service, and
b. an increase in the noise temperature of the satellite earth stations.

Combined, these two effects result in a degradation of the earth station figure of merit (G/T) which in turn impacts link carrier-to-noise ratio, margin, and achievable throughput.

Therefore, narrow guard bands could lead to a degradation of signal in satellite links and a negative impact on the associated satellite service.

Engage with local regulators to emphasize the importance of clearly defining the emission profile associated with 5G systems.

5G system operational limits must be clearly defined by local regulators to ensure mitigations can be effectively applied

The installation of RF filters is a necessary step to prevent earth station amplifiers from suffering signal blocking. The required filter response specification and filter rejection depend on factors such as the emission profile of the 5G systems, the dimension of the guard band between services and the geometry of the path between the IMT base stations and the earth stations, which determines the antenna gain towards the 5G base stations. It is therefore important to understand the characteristics of the 5G emissions to develop specifications for filters. This makes the issue local: as countries develop their own regulations for 5G use, filters could become country-specific, affecting economies of scale.

Therefore, engage with local regulators to emphasize the importance of clearly defining the emission profile associated to 5G systems.

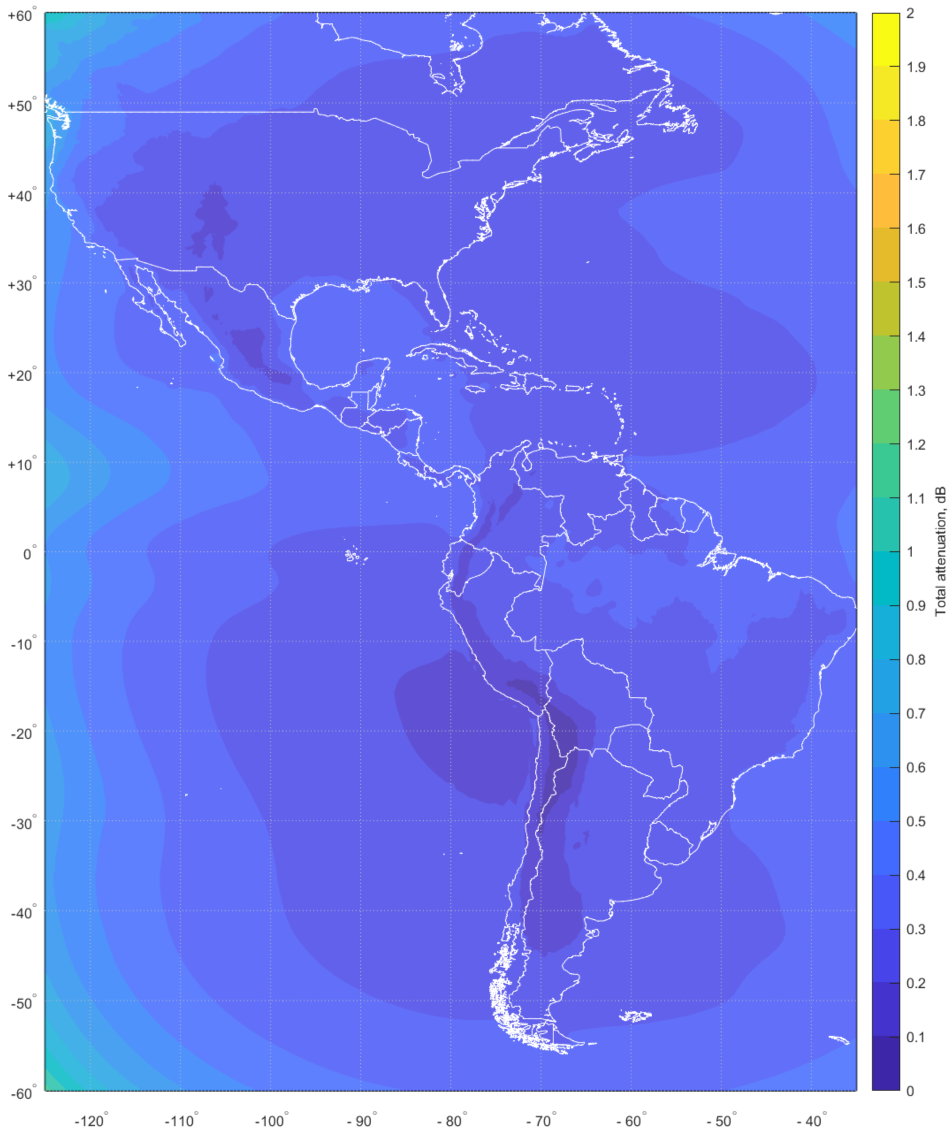
APPENDIX A

Technical characteristics of C-band satellite services

The unparalleled coverage and robust capabilities offered by the C-Band frequency range makes it fundamental for supporting high-reliability services with constant throughput requirements,[16] especially in equatorial and tropical regions.

A comparison of the magnitude of outages at two frequencies helps illustrate the robust nature of the C-band. Figures A1-1 and A1-2 below show the magnitude of signal loss due to rain over the Americas, for two frequencies: C-band (4 GHz) and Ku band (12 GHz), for a given service availability or uptime (in percentage of time of a year). Lighter colours correspond to higher levels of loss. The resistance of C-band to heavy rain is evident: over the same region, for example north-east Brazil or most of Colombia, the impact of rain on a Ku-band frequency is over four times higher than the impact on the C-Band frequency.

Fig A1-1
A map illustrating the magnitude of margin required to achieve 99.95% availability on a downlink path (4GHz) in the Americas. The values required over tropical regions is around 1 dB.



16 Although adaptive solutions for rain fade mitigation (such as Adaptive Coding and Modulation ACM) are frequently used in Ku- and Ka-bands, the applications must be able to support the variations in available throughput caused by changes in modulation. Not all services are able to work under adaptive bitrate conditions.

Fig A1-2
A map illustrating the magnitude of margin required to achieve 99.95% availability on a downlink path in Ku band (12GHz) in the Americas. The values required over tropical regions are between 10 and 12 dB.

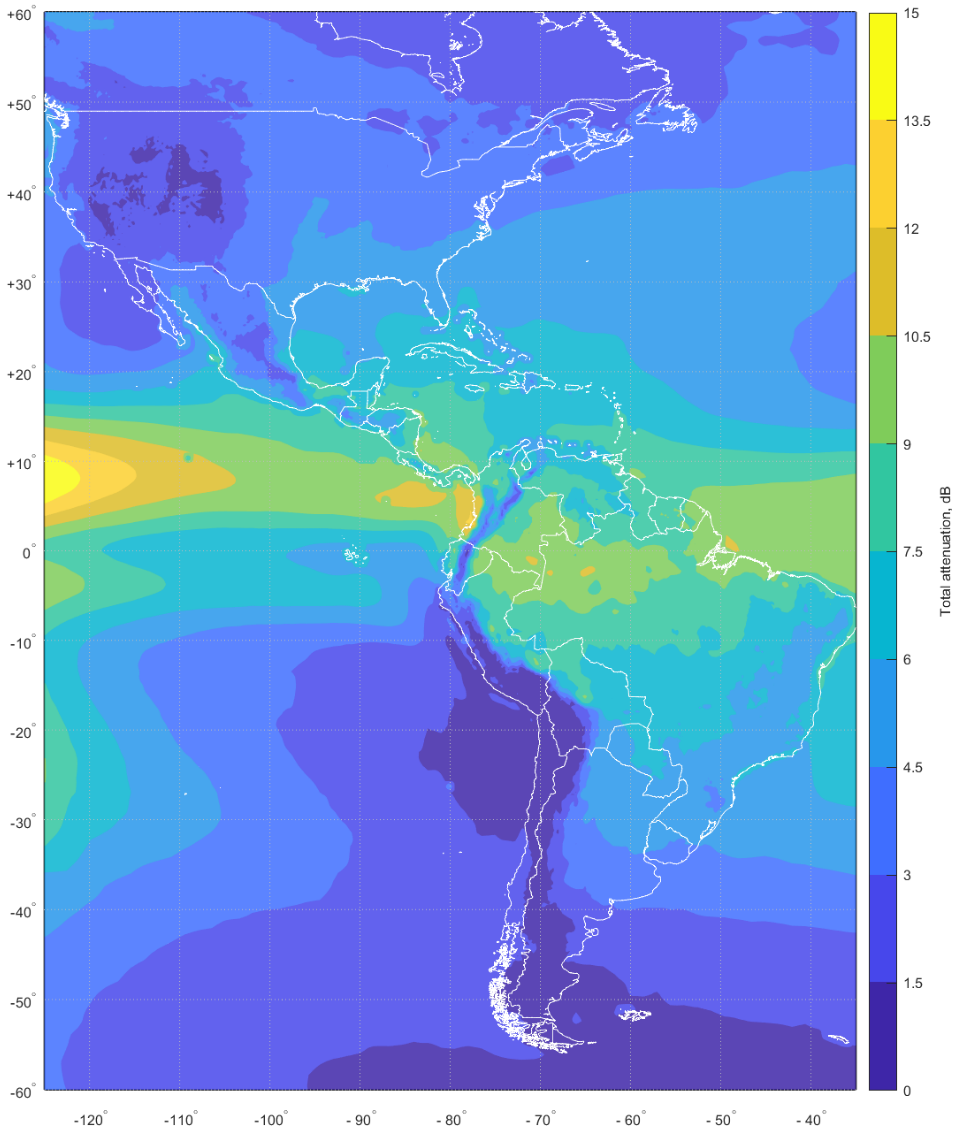
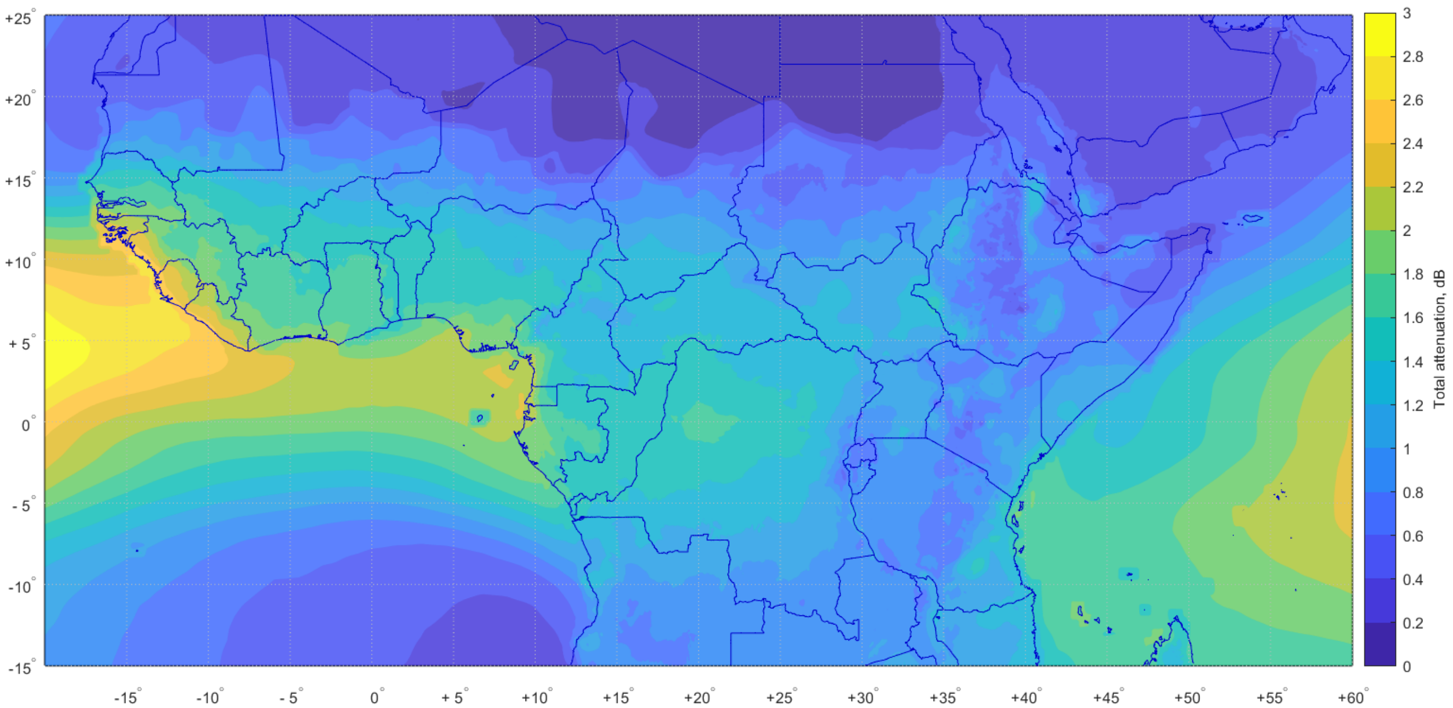


Fig A1-3
Map illustrating the required link margin (6.8GHz) to reach 99.95% availability. The value required is around 2 to 2.5 dB.

A similar problem exists in the uplink frequency band. Figure A1-3 and A1-4 focus over equatorial Africa and for frequencies associated to the uplink spectrum allocation (6.425–7.025 GHz).



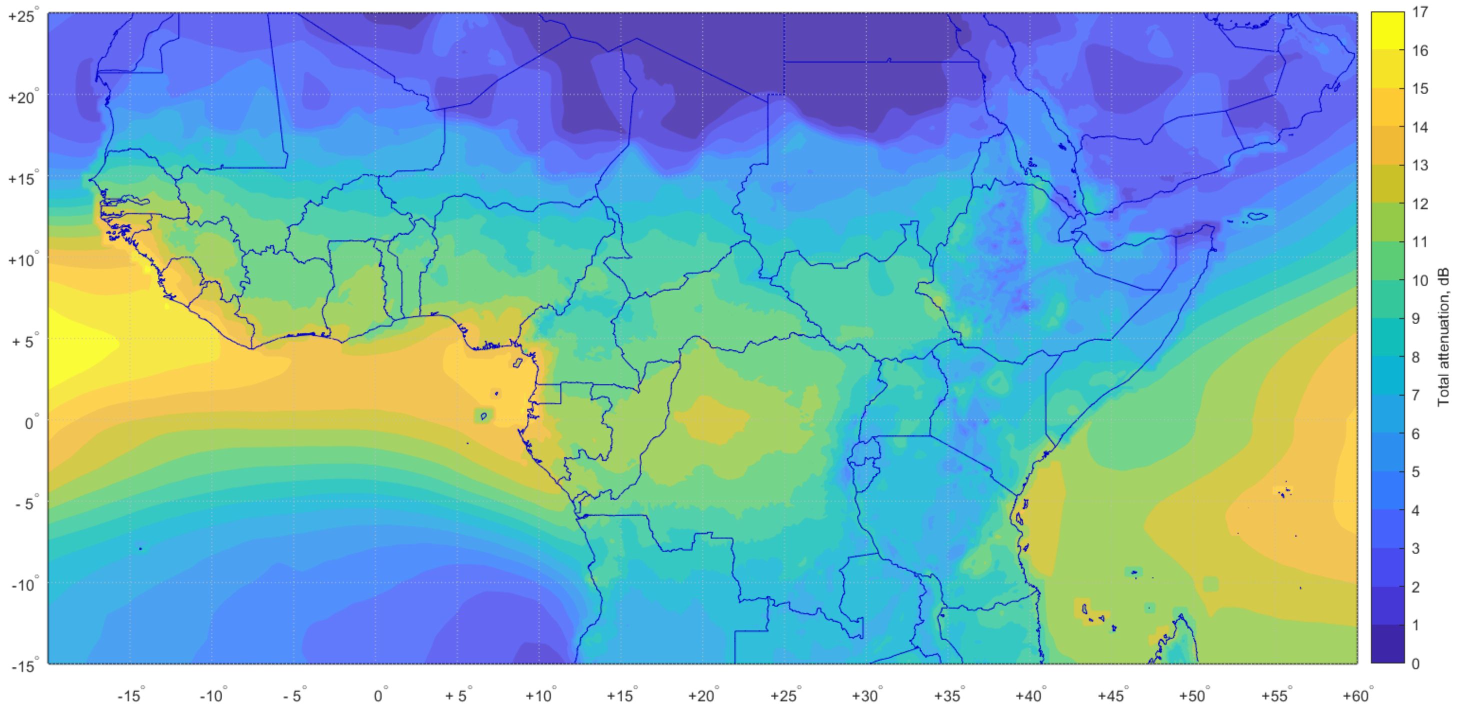


Fig A1- 4
A map for frequencies in the Ku band (14GHz).
The value required to reach 99.95% availability in tropical regions is between 10 and 14 dB.

Table A1-1
Magnitude of aggregate outage time in Lagos, Nigeria, for various frequencies. Fixed margin of 6 dB.

Aggregate outage time in hours with a fixed margin of 6 dB

6 GHz C-band	14 GHz Ku-band	29.7 GHz Ka-band
< 1 hr. (>99.99% aggregate availability).	22 hr. (~99.75% aggregate availability).	438 hr. (95% aggregate availability)

Table A1-1 provides a slightly different perspective. In this case, we provide a comparison of aggregate outage times for a reference link with a fixed 6 dB of margin, at three different frequencies corresponding to the C-, Ku- and Ka-bands. The values have been prepared considering conditions in Lagos, Nigeria, as an illustration.

The results in Table A1-1 exemplify the resilience of C-Band solutions during intense rain events—this makes C-band the band of choice for high reliability and mission critical services such as aeronautical communication networks, emergency response services, or breaking news video contributions. The importance of C-band for aeronautical communications is confirmed by ICAO's position on Agenda Item 9.1 Issue 3 of WRC-2019.[17]

Although C-band was among the first frequency bands to be used effectively for worldwide communications, it continues to be a vital component of the strategy of satellite service providers. C-band will be used to support gateway stations for High-Throughput Satellites (HTS) via high capability spot beams coupled to switched or processed payloads, and as part of multi-band ground stations for maritime solutions, capable of transitioning seamlessly between frequency bands depending on location and service characteristics.

17 https://www.icao.int/safety/FSMP/Documents/ITU-WRC19/049english.pdf, page 31.

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