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Service and Market Requirements

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Table of Contents

1 EXECUTIVE SUMMARY

This document summarizes the outcomes of Task 2.1 of Work Package 2 (WP2) of the CoRaSat project. The aim is to define and analyse the commercial, market, and service requirements framework for the CoRaSat project. This document is to be read specifically on the potential business impact of Cognitive Radios for each scenario on the basis of the defined use cases from the SatCom business and market points of view.

In Chapters 3 to 5, the scenarios defined in the CoRaSat Description of Work (DoW) are reviewed and the commercial, market, and service requirements assessment for Cognitive Radios have been benchmarked against Satellite Operator requirements and are subsequently categorized in three major key aspect areas: interference mitigation, Cognitive Radios in secondary spectrum allocations, and Cognitive Radios in primary spectrum allocations.

Specifically, in Chapter 5, the different requirements for applying Cognitive Radio techniques to the considered frequency bands and scenarios are classified applying the feedback gathered on some example markets. Thereafter, possible gaps to the existing market offerings as of today are identified and further analysed, classified, and prioritized based on business impact criteria, reflecting as close as possible the market demand and the potential impact of Cognitive Radios in Satellite Communications globally. The highest demand and the most promising applications for Cognitive Radios in Satellite Communications have been stated for the Ka-band related scenarios.

To determine all aspects of the business impact, in Chapter 6, various past, current, and future forecasted market evolutions, interference (RFI) cases and statistics related to Cognitive Radios have been considered. For each scenario a specific metric for the most appropriate Cognitive Radio application has been developed to determine the potential business impact on Satellite Communications. In line with the demand expressed in Chapter 5, the highest business impact was identified and detailed for the Ka-band scenarios, where cognition would significantly increase the amount of supported subscribers in a Ka-band multi-beam scenario, depending on the chosen gateway locations.

Finally, in Chapter 7, qualitative conclusions are given to prioritise the scenarios from the satellite market & business point of view, in order to provide the subsequent CoRaSat WPs and Tasks (WP2 and beyond) the required information to select the most promising scenario. Consolidating the results of the previous chapters, the document recommends investigating especially the Ka-band related scenarios in the subsequent work packages, as these provide the highest potential from the satellite market & business perspective.

2 Scope and Structure of the Document

The scope of this document is to analyse the commercial and business frameworks of the scenarios defined within the CoRaSat project.

Market and service requirements in the Cognitive Radio (CR) context are identified for each of the defined CoRaSat scenarios. A gap analysis report is also presented, which summarizes the potential commercial benefits and risks of CRs in the satellite domain, and the possible required additional information to define CR applications.

The remainder of this document is organised as follows:

Chapter 3 provides the definition of the considered CoRaSat Baseline Scenarios.

Chapter 4 provides the major business drivers and market challenges for CRs in Satellite Communications (SatCom).

Chapter 5 provides the market and service requirements for each CoRaSat scenario, identified following a wide range of SES internal interviews and complemented with other relevant inputs available.

Chapter 6 provides the business impact assessment for each CoRaSat scenario, taking into account practical assumptions for the associated frequency bands and system scenarios, as well as their relevant impact on Satellite Communications business.

Chapter 7 contains the conclusions for this document.

Chapter 8 lists all the references employed in this document.

Chapter 9 contains a table with acronyms, definitions, and abbreviations used in this document.

Chapter 10 provides the document history.

Chapter 11 provides as Annex I the SES company background to help the understanding of SES internal interviews structure in association with Chapter 5.

3 Baseline CoRaSat Scenarios Definition

Table 1 summarizes the main scenarios of interest for CoRaSat, which are described in more detail hereinafter.

Table 1: Cognitive Radio SatCom Scenarios

Scenario	Frequency Band	Spectrum Range	Satellite Orbit	Link Direction
A	Ka	17.3-17.7 GHz	GSO	DL
B	Ka	17.7-19.7 GHz	GSO	DL
C	Ka	27.5-29.5 GHz	GSO	UL
D	Ku	10.7-12.75 GHz 12.75-13.25 GHz 13.75-14.5GHz	GSO	DL UL UL
E	C	3.4-3.8 GHz 5.85–6.725 GHz	GSO	DL UL
F	S	1980-2010 MHz 2170-2200 MHz	GSO	UL DL
G	Ka	17.8-20.2 GHz 27.5-30 GHz	NGSO	DL UL

(GSO: Geostationary Satellite Orbit, NGSO: Non- Geostationary Satellite Orbit, DL: Downlink, UL: Uplink)

As it can be seen in Table 1, various frequency bands are evaluated, such as Ka-band, Ku-band, C-band, and S-band. Note also that the scenarios are related to specific frequency ranges within the given frequency bands, to which different regulatory conditions apply. Also, both downlink and uplink satellite link directions, as well as both Geostationary Satellite Orbit (GSO) and Non-Geostationary Satellite Orbit (NGSO), are considered. Moreover, both fixed and mobile satellite terminals are taken into account.

The outline of the scenarios considered is summarized in the following, along the line of the defined scenarios in references [2] and [3] as well.

3.1 Description of Scenario A

Cognitive Radio Satellite downlink in Ka-band [17.3 – 17.7 GHz]. CEPT has adopted a Decision, ECC/DEC/(05)08, which gives guidance on the use of this band by High Density applications in the Fixed-Satellite Service (HDFSS). The Decision stipulates that the designation of the band 17.3 – 17.7 GHz is without prejudice to the use of this band by BSS feeder uplinks and that it is not allocated to any terrestrial service on a primary basis (except in some countries). The deployment of uncoordinated FSS Earth stations is also authorized in these bands. FSS stations will be able to maximize frequency exploitation by flexible usage of the spectrum portion through the adoption of Cognitive Radio techniques. In WP2 the following aspects of the scenario are investigated:

a) FSS cognitive satellite terminals reusing frequency bands of other BSS Geo feeder link systems also operating in this band
b) Support of satellite terminals on mobile platforms

3.2 Description of Scenario B

Cognitive Radio Satellite downlink in Ka-band [17.7 – 19.7 GHz]. CEPT has adopted a Decision, ECC/DEC/(00)07, which gives guidance on the use of this band by Fixed Satellite Service and Fixed Services. The Decision stipulates that stations of the FSS can be deployed anywhere, but without right of protection from interference generated by Fixed Service radio stations. CoRaSat will demonstrate that Cognitive Radio techniques significantly increase the spectrum usage allocated to FSS by enabling access to frequency spectrum in the vicinity of terrestrial transmitters. Cognitive techniques will act as a dynamic and flexible protection of FSS downlink from Fixed Services interference. This scenario can be seen as an extension of the FSS exclusive frequency band 19.7 – 20.2 GHz by adding significant user capacity in the 17.7 – 19.7 GHz bandwidth. In WP2 the following aspects of the scenario are investigated:

a. FSS cognitive satellite terminal reusing frequency bands of FS links with priority protection
b. FSS cognitive satellite terminals reusing frequency bands of FS bands and other GSO/NGSO systems also operating in this band
c. Support of satellite terminals on mobile platforms

3.3 Description of Scenario C

Cognitive Radio Satellite uplink in Ka-band [27.5 – 29.5 GHz]. CEPT Decision ECC/DEC/(05)01 provides a segmentation between FS and FSS stations in this band. FS segment is lightly used through Europe. FSS stations will be able to maximize frequency exploitation by flexibly usage of the FS segment through the adoption of Cognitive Radio techniques in the satellite uplink able to dynamic control the interference generated on the FS station. In WP2 the following aspects of the scenario are investigated:

a. FSS cognitive satellite terminal reusing frequency bands of FS links with priority protection
b. FSS cognitive satellite terminals reusing frequency bands of FS bands and other Geo feeder link systems also operating in this band
c. Support of satellite terminals on mobile platforms

3.4 Description of Scenario D

Cognitive Radio Satellite uplink/downlink in Ku-band [10.7 – 12.75 GHz, 12.75 – 13.25 GHz, and 13.75 – 14.5 GHz]. This portion of the spectrum is used on a primary basis by satellite systems. A secondary satellite system using terminals with non-directive antennas, *e.g.*, mobile devices, and CoRaSat techniques on both the uplink and downlink can exploit this frequency by dynamically adapting to the evolving interference environment. In WP2 the following aspects of the scenario are investigated:

a. BSS/FSS cognitive satellite terminal reusing frequency in D1/D2
b. Support of satellite terminals on mobile platforms in D1/D2

where

- D1: Ku-band downlink in the 10.7 GHz to 12.75 GHz band
- D2: Ku-band uplink in the 12.75 – 13.25 GHz and 13.75 GHz to 14.5 GHz band

3.5 Description of Scenario E

Cognitive Radio Satellite uplink/downlink in C-band [3.4 – 3.8 GHz and 5.85 – 6.725 GHz]. This portion of C-band spectrum is currently shared (for what concerns the satellite uplink bands) and co-allocated (for what concerns the satellite downlink bands) between terrestrial and satellite services and the primary system can be either satellite or terrestrial. In this context, CoRaSat will consider a secondary satellite system dynamically adapting its frequencies usage, in both the uplink and downlink, according to the interference environment generated by the primary system. In WP2 the following aspects of the scenario are investigated:

a. FS cognitive terrestrial terminals using frequency bands of FSS satellite links in E1/E2
b. Support of satellite terminals on mobile platforms in E1/E2

where

- E1: C-band downlink band 3.4 – 3.8 GHz
- E2: C-band uplink band 5.85 – 6.725 GHz

3.6 Description of Scenario F

Cognitive Radio Satellite uplink/downlink in S-band [1980 – 2010 MHz and 2170 – 2200 MHz]. In this portion of the spectrum, hybrid satellite terrestrial networks with mobile end user terminals are deployed utilizing potentially different broadcast and interactive technologies in the space and terrestrial segment. The primary part of the integrated network can either be the satellite or the complementary terrestrial network. The [complementary terrestrial] mobile secondary CoRaSat link will dynamically adapt its forward and return link to the changing interference scenario. In WP2 the following aspects of the scenario are investigated:

a. Cognitive hybrid broadcast terminals using frequency bands of F1/F2
b. Cognitive terrestrial terminals using frequency bands of F1/F2

where

- F1: S-band uplink 1980 – 2010 MHz, [complementary terrestrial] use of entire exclusive band in secondary hybrid Sat/Terr system
- F2: S-band downlink 2170 – 2200 MHz, [complementary terrestrial] use of entire exclusive band in secondary hybrid Sat/Terr system

3.7 Description of Scenario G

Cognitive Radio Satellite NGSO FSS downlink/uplink in Ka-band [17.8 – 20.2 and 27.5 – 30 GHz]. ITU RR No 5.523A provides a specific regulatory framework for NGSO FSS systems with regard to GSO systems in the bands 18.8 – 19.3 GHz and 28.6 – 29.1 GHz. NGSO FSS systems can also use the bands 17.8 – 18.6 GHz, 19.7 – 20.2 GHz, 27.5 – 28.6 GHz, and 29.5 – 30 GHz but have to comply with the EPFD limits contained in RR No 22.5C in order to protect GSO systems. NGSO and GSO FSS stations will be able to maximize further frequency exploitation by flexibly usage of the respectively allocated frequency segments (temporal and spatial domain) through the adoption of Cognitive Radio techniques in the satellite downlink and uplink and to be able to dynamic control the interference generated on the fixed/mobile FSS or FS station. In WP2 the following aspects of the scenario are investigated:

- G1: LEO/MEO context downlink in the 17.7 GHz to 19.7 GHz bands reusing shared frequencies
- G2: LEO/MEO context uplink in the 27.5 – 29.5 GHz bands reusing shared frequencies
- G3: LEO/MEO cognitive satellite terminal reusing frequency bands of FS links with priority protection

The defined scenarios are reviewed for the following aspects within Task 2.1:

a) Market and Service Requirements for the usage of the frequency rights as the primary user and requirements related to a possible secondary usage;

b) Business Impact Assessment for the usage of the frequency rights as the primary user and related to a possible secondary user.

4 Major Business Drivers for Cognitive Radios in Satellite Communications

Satellite Communications are considered a key element in achieving the challenging Digital Agenda objective of high-speed broadband access for everyone by 2020 [5]. Their inherent large coverage footprint makes them the most suitable access scheme to reach those areas where deployment of wired and wireless networks is not economically viable.

Satellite systems and networks require hundreds of millions of Euros of investment, and years of advance in planning and construction prior to deployment. Investment decisions related to the development of networks are made based on the business case and require market access on reasonable terms to the countries in the footprint. Once a satellite is operational, commercial viability depends on the availability of spectrum and the applicable regulatory regimes that the satellite network will be serving.

The business challenges related to the proposed CRs development in Satellite Communications lie in the efficient exploitation of currently unused or underused frequency bands by non-coordinated end user equipment. Specifically, the business case needs to be built around the costs and complexity of the added CR technology and its operation against the advantages from additional spectrum usage, capacity increase and potential reduction in service costs. The development of such new techniques, equipment, and infrastructures represents an investment in addition to conventional approaches in other exclusive frequency bands that do not require coordination and cooperation techniques. For actual deployments, this implies that the end-user equipment needs to be made available at a reasonable cost. In fact, part of the end-user equipment and associated infrastructure need a new development that requires a justified business case to pursue this development. This is mainly based on the exploitation of the currently underused spectral resources that could be made available with the introduction of CR techniques. Flexible spectrum utilization could be a cornerstone for more efficient exploitation of spectrum resources, and CR approaches have already demonstrated their potential towards this aim in terrestrial communication systems. The CoRaSat project is thus focusing on specific use cases where satellite services are provided on a secondary basis, where the primary service can be either terrestrial or satellite. The scope of this study is to commercially justify the additional costs by the benefits of the additional spectral resources made available through these techniques. Secondary access to temporarily available frequencies would allow the Satellite Communications operators and service providers to exploit unused resources, thus increasing the market opportunities and the commercial incomes as well.

Another important commercial driver, especially for satellite operators, is interference mitigation. Interference is a major issue for every satellite operator as it is affecting the core business of everyone providing business in this domain. Interference has a multi-fold impact to the revenues of a satellite operator. Temporal and/or spatial interference can be analysed, localized, and mitigated typically with dedicated efforts with only short-term impact on the revenues. As such, the value of CR solutions can be made measurable with the ratio of their mitigated interferences. Moreover, long-term and persistent interferences from terrestrial or other satellite systems provide a major challenge to satellite operators as the interfered spectrum is having a substantially lower revenue potential, thus reducing the value of solutions including these frequencies as of today. CR based solutions could thus provide relief and provide measurable usage and revenue increases.

5 Market And Service Requirements

5.1 Scope

In this Chapter, the Market and Service requirements are defined for the usage of the frequency rights as the primary user as well as for a possible secondary usage.

To define the relevant market and service requirements for each defined CoRaSat scenario, the results of a wide range of interviews conducted within SES are largely taken into account. These are further complemented by other relevant inputs available, such as from Web search analysis and project results, representing so a more general view of satellite operators in the context of CRs, to the extent possible.

5.2 Interview Strategy

5.2.1 Satellite operator interviews

In order to define the CoRaSat market and service requirements, a wide range of interviews have been conducted in SES as the participating satellite operator to promote the project and to gather the necessary information to subsequently structure and setup most appropriately this document.

After careful assessment, the following departments within SES (see Annex I for SES company structure) have been involved:

A. SES Corporate Development
    - 2 interviews to gather input on strategic aspects for Cognitive Radios and Satellite Communications.

B. SES Business Development
    - 3 interviews to gather input on the business requirements for the specific geographic markets in each of the ITU regions, for each of the SES business segments.

C. SES Spectrum Management
    - 3 interviews to gather input on the requirements of the spectrum management team for the specific geographic markets in each of the ITU regions.

D. SES Sales
    - 2 interviews to gather input on the experiences of the sales and sales engineering teams and their actual requirements for Cognitive Radio solutions in the major geographic markets in each of the ITU regions.

E. SES Technology
    - 1 interview to gather understanding on the impact of Cognitive Radio spacecraft and earth station requirements.

F. SBBS (SES Broadband Services)

- 1 interview to understand the market and service requirements of Cognitive Radios for a consumer satellite broadband solution in different markets.

G. SES GI (Government Solutions)

- 1 interview to understand the market and service requirements of Cognitive Radios specifically oriented towards institutional and governmental bodies in different markets.

5.2.2 Satellite Operator interviews – applied methodology

The interviews in SES have been held either face-to-face or via telephone conferences, based on individual availability and/or travel schedule.

The interviews have been structured in two parts, first the introduction of the main principles, benefits, and potential risks of Cognitive Radios, followed by a questionnaire to be answered live or in subsequent days and supported with additional material and references deemed useful for the CoRaSat project.

In the following, an extract of the introduction material presented and discussed during the interview sessions is provided:

Cognitive Radio

▲ Motivation
  - Increasing Spectrum demand and efficiency needs
  - Satellite Spectrum Scarcity and Fragmentation
  - Temporal and spatial variations
  - Interference and Jamming concerns
  - Better operational efficiency

▲ Current Status
  - Spectrum segmentation and more static frequency allocation & coexistence
  - Future Solution:
    - Dynamic Spectrum Access
    - Primary/secondary cognition

▲ Cognitive Radio Techniques
  - Spectrum Sensing, Underlay, Overlay, Database
  - Applied Spectrum dimensions:
    - Frequency, power levels, time, area, satellite orbit segments, polarization, angles

Examples of Cognitive Radio Requirements

Satellite Domain

- ▲ Coexistence between FSS and FS terrestrial link in Ka-band
- ▲ C-band Satellite Communications and, *e.g.*, WiMAX networks
    - Other applications: Cellular Networks (WiMAX backhaul), Smart Grid Networks, Public Safety Networks, Wireless Medical Networks
- ▲ VSAT Networks and Terrestrial microwave
- ▲ Coexistence between GEO satellites
- ▲ Coexistence between GEO and Non-GEO satellites
- ▲ Enhanced Interference and Jamming mitigation

Terrestrial Domain

- ▲ Coexistence between Macrocells and Femtocells
- ▲ TV whitespaces and different terrestrial services
    - Opportunities for TV whitespaces: wireless distribution networks, licensed-exempt mobile broadband, last mile wireless broadband, mobile TV, cognitive Femtocells

In the following, an extract of the questionnaire developed to best discuss Cognitive Radio aspects for Satellite Communications in SES for CoRaSat is provided:

- ▲ *Based on your experience, what would you see as the main typical use cases or applications where Cognitive Radios could be beneficial for a satellite operator, separated in*
    - *In Ka-band (DL and UL)*
    - *In Ku-band (DL and UL)*
    - *In C-band (DL)*
    - *Other (S-band, O3b, etc.)*
- ▲ *What would you see as the main Pros & Cons for Cognitive Radios, or risks and benefits in different dimensions (as technologically, regulatory, and commercially)?*
    - *In Ka-band (DL and UL)*
    - *In Ku-band (DL and UL)*
    - *In C-band (DL)*
    - *Other (S-band, O3b, etc.)*
- ▲ *Would you have market or service requirements you would see as beneficial to be addressed in the CoRaSat project?*

- ▲ *Would you have applicable material (documents / references) which could be useful for the CoRaSat project?*
- ▲ *Which other colleague in a satellite operator you see as worthwhile to be contacted for a similar questionnaire?*

5.2.3 Satellite Operator interviews – applied methodology to structure the feedback

During the interviews there has been an enormous amount of feedback received which, due to the different background of the interviewed persons, was having a widely diverging level of depth, and having different directions as well.

The following section provides a structure, based on the major applications defined suitable for Cognitive Radios in Satellite Communications, to split and frame the gathered information into three sub-sections, thus enabling an easy to follow information and requirements set. That is:

- Key Aspect I: Cognitive Radio based Interference Mitigation
- Key Aspect II: Cognitive Radios for Satellite Communications operating in secondary spectrum allocations
- Key Aspect III: Cognitive Radios for Satellite Communications operating in primary spectrum allocations

Note that the following interview feedback has been further consolidated with other relevant inputs available, such as from Web search analysis and project results (*e.g.*, [6],[7]), thus representing a more general view of satellite operators in the context of CRs, to the extent possible.

5.3 Interview Feedback

5.3.1 Key Aspect I: Cognitive Radio based Interference Mitigation

Description

Interference is a major issue for every Satellite Operator as it is affecting the core business of everyone providing business in this domain.

Interference can be separated into

<u>Source/Victim</u>

- from or to terrestrial fixed or mobile services
- from or to other geo-stationary satellites
- from or to other satellites or satellite constellations in non-geostationary orbits

<u>Geographic Location (ITU Region)</u>

- Europe / Russia

- Africa
- Americas
- Asia
- Australia

Business Impact

- Type of Service affected (DTH / VSAT / etc.)
- Frequency Band affected

SES is targeting intentional and un-intentional interference issues with substantial resources as typically it is directly impacting the business being conducted. One recent initiative together with various other satellite operators and the suppliers in the market is Carrier-ID in services with MPEG transport streams, being a universally agreed-upon approach to address the interference problem, predominantly for DTH services.

Interference is distributed not very evenly across the globe, and differently in each area and frequency band. In general, interference is low in DTH markets in developed countries and higher for VSAT oriented markets, and currently low in Ka-band and high in C- and Ku-band.

The type of interference of these is concentrating on the following major areas:

- Cross Pol (Xpol) Interference
- Adjacent Satellite Interference (ASI)
- Terrestrial Interference – FS to FSS
- Deliberate Interference (Jamming)

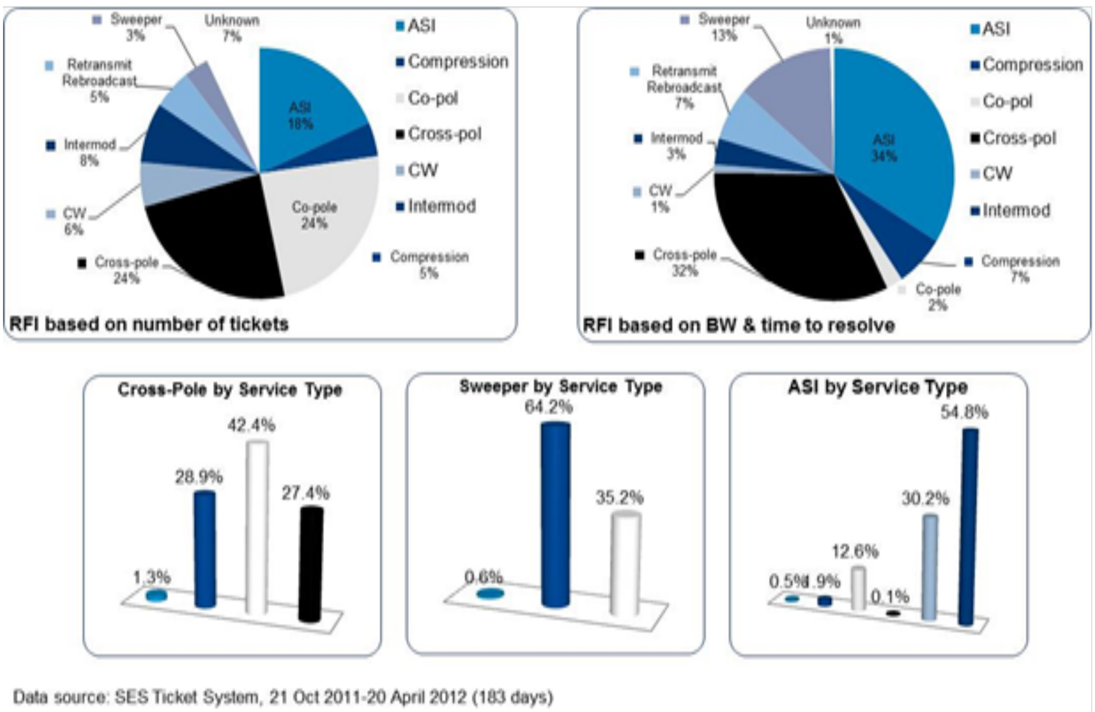


Figure 1: RFI Statistics directly impacting satellite transmission (Source: SES)

Cross Pol (Xpol) Interference

This type of interference is usually caused by: i) incompatible modulation types transmitted in the opposite polarization field to digital services on the cross-pol; ii) poorly aligned antennas; and iii) lack of training/experience of the uplink operators. It is extremely time consuming and labor intensive in both equipment and training. Due to its nature it is expected that Cognitive Radios will provide here only limited benefits.

ASI – Adjacent Satellite Interference

This type of interference is generally accidental, due to operator error, or poor inter-system coordination. Frequently, this can be resolved between the satellite operators. Unfortunately, this type of interference is becoming more prevalent as two degree spacing between satellites in the geostationary arc becomes more common. One main action to minimize it is the provision of substantial training session of the installers and the operators. Separately, the impacted satellites operators have to validate their EIRP settings to adhere to the specific allowed maximum levels. As another main action, the provision of additional options to access further spectrum provided by future Cognitive Radios is understood to be a basis of substantial additional value.

Terrestrial Interference – FS to FSS

This type of interference, often caused by terrestrial services to the fixed satellite services, is different for the frequency bands, the interference type, and highly dependent on the geographic region and the applicable regulatory framework being enforced.

It is seen as a very important application for Cognitive Radio solutions, with their potential application of dynamic adaptation measures to enhance the availability of satellite transmissions.

Deliberate Interference

This sporadic type of interference is usually geopolitically motivated. It is, generally, relatively easy to locate, but almost impossible to remove without political intervention, which can prove difficult.

Figure 2 presents cost savings and revenues that could be protected from jamming in the 2010-2015 (6 years) period, illustrating the financial need for protection of satellite capacity against jamming [8].

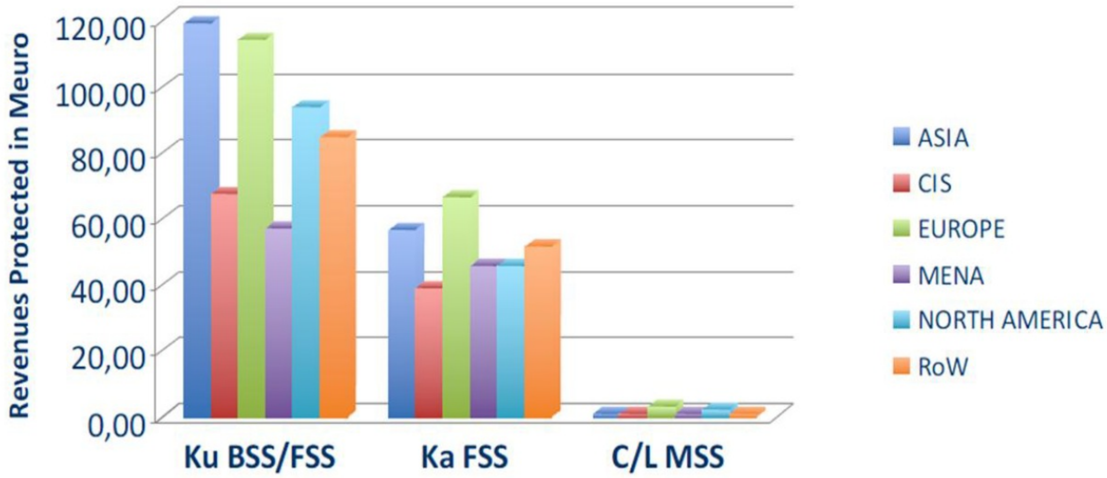


Figure 2: Cost savings and revenues that could be protected from jamming in 2010-2015 (Source: ESA [8])

Moreover, the following table provides a summary of the various types of deliberate interference and their effects on current satellite networks.

Table 2: Nature of jamming and its effect on current satellite networks (Source: ESA [8])

Analitical Parameters		Piracy	Tone Jamming (CW)		Multi-Tone Jamming	Sweep Jamming		Deceptive Jamming
High Level	Detail Level	FSS/BSS (Ku-Band)	FSS/BSS (Ku-Band)	FSS (Ka-Band)	FSS/BSS (Ku-Band)	FSS/BSS (Ku-Band)	MSS (C-L Band)	FSS/BSS (Ku-Band)
Physical Layer	C/N+I Reduction	No loss	18,08 dB	18,08 dB	18,08 dB	18,08 dB	0,48 dB	23,61 dB
Signalling Level	Loss of access due to loss of signalling	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA
	Time to Resolve after end of interference	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA	No Signalling due to FDMA
Network Level	Time To Re-Sync	Not applicable	Up to 20 sec	Up to 20 sec	Up to 20 sec	Up to 20 sec	NDA	Up to 20 sec
	Time to Resolve after interference ends	Not applicable	Up to 20 sec	Up to 20 sec	Up to 20 sec	Up to 20 sec	NDA	Up to 20 sec
Capacity Level	Generation of Capacity Loss	No	Often due to CW signal high power level	Often due to CW signal high power level	Often due to CW signal high power level	Often due to Sweeping signal high power level	NDA	Yes
	Amount of Capacity Loss	No	Total loss of Capacity	Total loss of Capacity	Total loss of Capacity	Total loss of Capacity	NDA	Total loss of Capacity
Availability Level	Generation of Availability Loss	If TPX is 100% loaded and in saturation	Often due to CW signal high power level	Often due to CW signal high power level	Often due to CW signal high power level	Often due to CW signal high power level	NDA	Often due to CW signal high power level
	Amount of Availability Loss	Even drop to 0	Total outage	Total outage	Total outage	Total outage	NDA	Total outage
Other Effects	Indirect Additional effects	No	No	No	No	No	NDA	No

Commercial Impact of Interference

Interference has a multifold impact to the revenues of a Satellite Operator.

First temporal and/or spatial interferences can be analyzed, localized and mitigated typically with dedicated efforts with only short-term impact on the revenues. As such the value of CR solutions can be made measurable with the ratio of their mitigated interferences.

Long-term and persistent interference from terrestrial systems provide a major challenge to the Satellite Operators, as the interfered spectrum is having a substantially lower revenue potential, thus reducing the value of solutions including these frequencies as of today. Cognitive Radio based solutions could provide relief and provide measurable usage and revenue increases.

Moreover, deliberate jamming affects the satellite broadcasting business and innovative solutions are currently sought by the EU satellite industry. Recent examples of TV channel interference in the Middle East and in East Asia have featured satellite channels and service providers well equipped to curb passive jamming. However, intentional jamming has affected Middle East operators, increasingly and significantly, since 2009 when political unrest broke out in Iran, exacerbated in subsequent-year Arab spring breakouts. Deliberate jamming prevents satellite reception, creates collateral damage for other broadcasters, and is contrary to international conventions for the use of satellites. Efforts to combat it are a priority issue for several satellite operators because modern broadcasting satellites aggregate broadcast channels in a “multiplex,” meaning hostile jamming of one channel could quickly affect other channels. Recent sharp rise in deliberate broadcast satellite interference has given greater urgency to the search for solutions. For example, not only SES is impacted, but as well Eutelsat reported 340 cases in the first 10 months of 2012, an overall threefold increase since 2009 [9]. Of these incidents, the satellite operator traced 90% of hostile signals to Iran and Syria. Possible anti-jamming solutions that are currently being looked at by European satellite operators to address such issues can be found in [8].

5.3.2 Key Aspect II: Cognitive Radios in Secondary Spectrum Allocations

Scope

In Ka-band downlink

- There are only 500 MHz of exclusive primary spectrum available in all ITU Regions.
- Thus access to 2.0 GHz secondary spectrum desired for Satellite Operators to meet demand for feeder links and user links subsequently, constraints exists today with Teledesic band – 18.8 – 19.3 GHz DL and 28.6 – 29.1 GHZ UL.
- US most advanced with adopted band segmentation plan from 18.3 – 18.8 GHz. Smaller countries lacking definitions and apply first come, first serve principles so far, hindering adequate service developments.
- High Throughput Satellites suffering today from spectrum scarcity in Ka-band to deliver meaningful performance with appropriate frequency reuse schemes. Downlink spectrum availability is major difficulty.

- Some restrictions exist between GSO and NGSO satellite systems. Impact depending on frequency band (former Teledesic bands or not), geographic location, and orbit of NGSO systems.
- Some countries and satellite systems utilize secondary allocation (US & Viasat, Brazil, etc.) for satellite feeder and user links today based on national agreements and granted landing rights. Extension sought to allow global definitions.
- EIRP levels might differ substantially between different service offers; at least a minimum range of 10 dB shall be supported.
- Complex inconsistent national regulations – EU and worldwide - and use by FS operators, provide significant overhead to be considered.
- Additionally the terminals supporting Cognitive Radio functions should support automated configuration, provide qualified installation procedures and built-in monitoring functions to enable remote monitoring by the hub (as proposed by the Global VSAT Forum [18]).

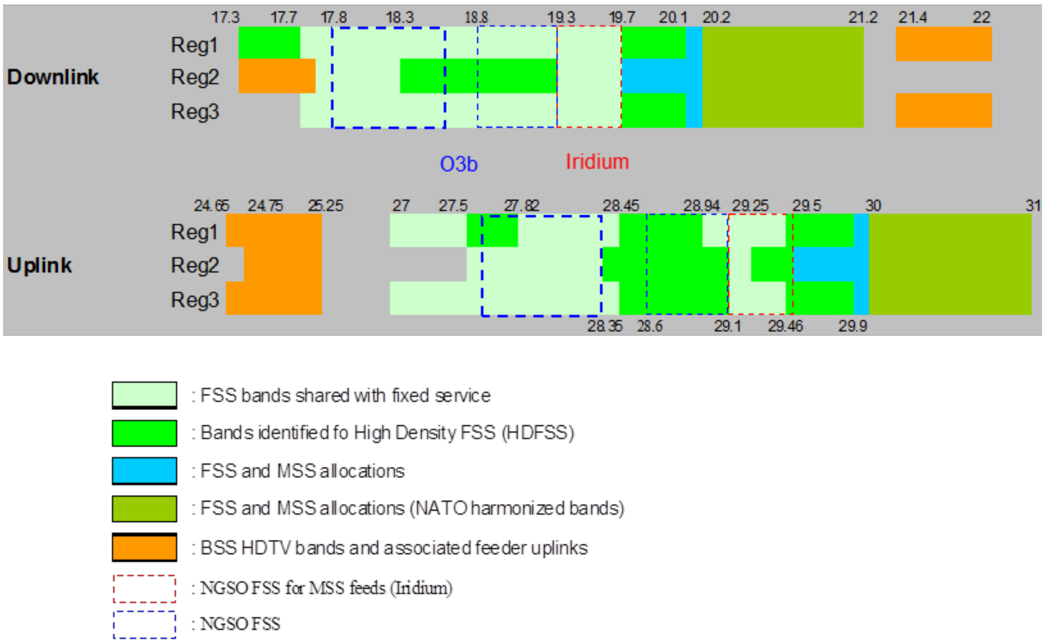


Figure 3: Ka-band Frequency allocations

In Ka-band uplink

- The situation is not as critical, with substantially less FS service deployments globally.
- The traffic profile is asymmetric less throughput required compared towards the downlink spectrum.
- Specific allocations (HDFSS) treated differently by regulatory bodies, thus providing additional efforts for coordination.
- There is no information, no study nor concern today about aggregated terrestrial interference to the GSO and NGSO satellites.

For MEO/LEO satellite constellations

The ITU has designated part of the spectrum, as shown in Figure 3: Ka-band Frequency allocations, as being in priority reserved for non-geostationary satellite communications (NGSO – former Teledesic band). In the remainder of the spectrum, geostationary satellite communications (GSO) have priority, see regulatory part of CoRaSat.
Given the difference in orbital distance, interference can occur between MEO and GEO communications only in a relatively small band around the equator, as shown below.

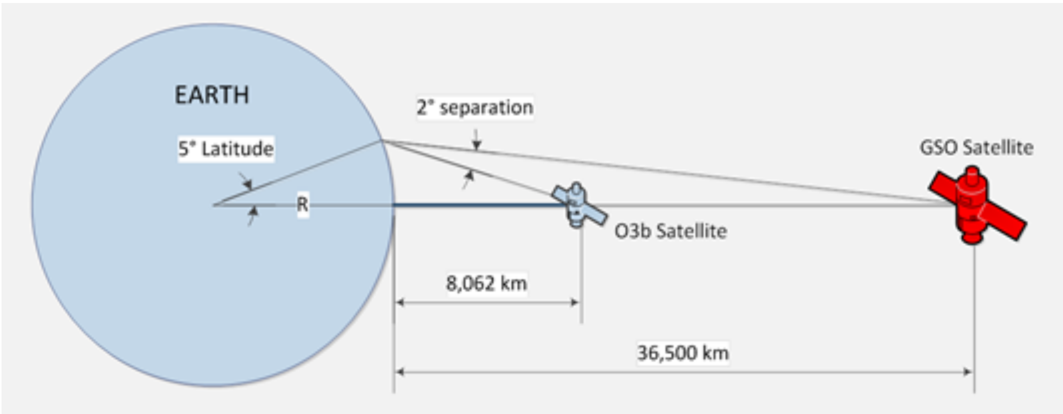


Figure 4: O3b angular separation to GSO

In that region, O3b communications are planned only in the Non-GSO part of the spectrum. This is because the O3b satellites orbit the earth so that each one returns to the same point above the equator every four hours. With an initial constellation of eight satellites this means that every forty-five minutes the earth station must perform a handover from the setting satellite to the newly rising satellite. During the forty-five minutes of tracking a satellite, the transmission follows an arc across the sky, so for a terminal situated close to the equator, there is the potential for interference with GSO satellites across that segment of the geostationary arc.
It is the intention of O3b to launch additional spacecraft so as to increase the number of satellites in the constellation. This would mean that more than one satellite would be easily visible at a given time to any earth station. At that point one could consider switching communications to alternative satellites during the pass overhead in order to mitigate interference with GSO satellites. This might allow use of the GSO spectrum, which would significantly extend the available capacity of the system at low latitudes.

However the above procedures are predictable with knowledge of the longitudes of Ka-band satellites on the geostationary arc, and thus would require neither extensive spectral monitoring nor dynamic response. Requirements for this more evolved behavior are more likely to arise from interference within the MEO system, or with other, yet-to-be developed MEO or LEO systems, or with terrestrial services in the same frequency band.

The current status – Existing Ka-band High Throughput Satellites

One may broadly categorize existing Ka-band high-throughput satellites (HTS) as those with small, regional coverage, and as those with continental coverage. The tables below show the characteristics of these systems. It shall be kept in mind that all these satellites have not exactly the same mission (mobile vs. fixed, civil vs. military, etc.).

The regional satellites (see Table 3) generally do not have many Ka-band transponders, the coverage generally consists in disconnected "spots of opportunity" and, except for HYLAS 2, all have different missions besides Ka-band broadband. These non-Ka-band broadband missions complicate the economic evaluation of these systems, as they may either subsidize the high-capacity broadband payload, or *vice versa*, be subsidized by the high-capacity payload.

Table 3: Regional Ka-band Broadband Satellites (Source : SES [7])

Service – Operator	**Avanti**		**Nilesat**	**Spacecom**	**Hispasat**
Satellite	***HYLAS 1 (33.5W)***	***HYLAS 2 (31.0E)***	***Nilesat 201 (7W)***	***Amos 3 (4W)***	***HAG1 (30.0W)***
Service Coverage	West and Central Europe	East Europe, North Africa, Middle East	North Africa, Middle East	E. EU, E. USA, Middle East	Iberian Peninsula, South America
Ka-band solid angle (deg^2)	3	8	3	2	2
Band	Ka/Ku band	Ka-band	Ka/Ku band	Ka/Ku band	Ku/Ka band
Launch Date	26-Nov-10	02-Aug-12	04-Aug-10	28-Apr-08	2013-4
Number of spots	8 user beams – 2 feeder beams	24 user beams – 6 feeder beams	-	2 Ka / 4 Ku	Ku: Regional Ka: 3 spots?
Payload Manufacturer	Astrium	Orbital	TAS	TAS	TAS
Satellite Platform	ISRO I-2K, 2.2 tons (dry), 2.5KW (2.2KW P/L)	OSC Star-2.4 Bus, 3.1 tons (launch), 5KW	TAS Spacebus, 3.2 tons (launch)	IAI Amos Bus, 1.2 tons (launch), 2.8KW	OHB Luxor bus, ≥2.5 tons (launch), >3KW
Area-Filling Spot Pattern?	No	Partially	No	No	Unlikely
Number of transponders (devoted to the service)	8 Ka Fwd 1 Ka Rtn 2Ku	24 Fwd 6 Rtn	4 Ka 24 Ku	2 Ka 12 Ku	20:24 Ku 3:5 Ka
Ground Segment Vendor	Hughes	Hughes	N/A	N/A	N/A
User Terminal	74 cm / 2W, FWD:DVB-S2, RTN:IpoS	74 cm / 2W, FWD:DVB-S2, RTN:IpoS	50 to 75cm	80 to 110cm	No specific information available

Service – Operator	Avanti		Nilesat	Spacecom	Hispasat
Satellite	*HYLAS 1 (33.5W)*	*HYLAS 2 (31.0E)*	*Nilesat 201 (7W)*	*Amos 3 (4W)*	*HAG1 (30.0W)*
System Capacity (Forward and Return)	3 Gbps	≥ 9 Gbps	< 200 Mbps Ka	< 400 Mbps Ka	TBD

Table 4: Continental Ka-band Broadband Satellites (Source : SES [7])

Satellite	**Spaceway 3 (95W)**	**Jupiter 1 (107.1W)**	**Ka Sat (9 E)**	**Wild Blue (111.1W)**	**Viasat 1 (115.1W)**	**Yahsat 1B (47.5E)**	**Ekxpress AM-5, -6 & -X (53E, 140E)**	**Inmarsat 5s**
Service Coverage	USA	USA	Europe	USA	USA	Europe	Central USSR	Global
Broadband Solid angle (deg^2)	24	15	18	15	24	11	30	154
Band	Ka band	Ka band	Ka band	Ka band	Ka band	Ka band	Ka band	Ka band
Launch Date	14-Aug-07	05-Jul-12	26-Dec-10	08-Dec-06	20-Oct-11	24-Apr-12	2012-13	2013-4
Number of spots	OBP-ctrl'd rptr sweeps across 112 uplink spots, each with 7 cells down	60 user 15 GW	82 user 10 GW	35 user 6 GW	63 user 17 GW	56 user 7? GW	35 user 6 GW	89 user+ 6 Steerable
Payload Mfr	Boeing	SSL	Astrium	SSL	SSL	TAS	TAS	Boeing
Satellite Platform	Boeing BS-702HP, 6075 kg (launch), 12 kW PL	Loral LS-1300, 6.5 tons (launch), 14kW 11kW P/L	EADS Astrium Eurostar E3000, 6.1 tons (launch), 14kW 11kW P/L	Loral LS-1300, 4735 kg (launch), 4.1 KW P/L	Loral LS-1300, 6.5 tons (launch), 10.3 kW P/L	EADS Astrium Eurostar E3000, 6 tons (launch), 10 KW P/L	Reshetnev	Boeing BS-702HP, ~6 tons (launch), ~15 kW PL
Number of physical xpdrs	1500 Tx array elements	170 Fwd 15 Rtn	48?	41	80	48	41?	144
Ground Segment Vendor	Hughes	Hughes	Viasat	Viasat	Viasat	Hughes	TBD	Hughes?
User Terminal	68 cm	68 cm	70 cm	65 cm	70 cm	68 cm	60 cm	60 cm
Service	FWD: 5Mbps RTN: 0.5Mbps	FWD: 25Mbps RTN: 4Mbps	FWD: 30Mbps RTN: 5Mbps	FWD: 1.5Mbps RTN: 0.25Mbps	FWD: 50Mbps RTN: 5Mbps	FWD: 121Mbps RTN: 3.2Mbps	FWD: 1Mbps RTN: 0.5 Mbps	FWD: 50Mbps RTN: 5Mbps
Max sys capacity	10	100	70	6	130	15	6	12

Satellite	Spaceway 3 (95W)	Jupiter 1 (107.1W)	Ka Sat (9 E)	Wild Blue (111.1W)	Viasat 1 (115.1W)	Yahsat 1B (47.5E)	Ekxpress AM-5, -6 & -X (53E, 140E)	Inmarsat 5s
Service Coverage	USA	USA	Europe	USA	USA	Europe	Central USSR	Global
(fwd + rtn) (Gbps)								

Table 4 summarizes existing and near-term continental HTS. Two pioneering systems which are not on this table are IpStar, which is in Ku-band, and Anik F2. Neither IpStar nor Anik F2 had broadband occupying the entire payload. Key themes of the Continental broadband payload designs are contiguous coverage area and high maximum throughput rates, typically between 70 and 100 Gbps. Such satellites correspond to the state-of-the-art with more than 14 kW power and 6 tons launched mass. For all these systems, the feeder and the user links use Ka-band.

The above provided data clearly indicates the use of Ka-band by SatComs, which in turn shows that there actually is a business case for satellite operators. Further info in this regard can be found in [7]).

Furthermore, Q/V bands are interesting candidates for future feeder links (gateway-to-satellite) [7]. In these frequency ranges, there are no exclusive satellite bands so CRs may also be essential.

EchoStar® XVII satellite with JUPITER High-Throughput Technology

The EchoStar® XVII satellite with JUPITER High-Throughput Technology, built by Space Systems/Loral, was successfully launched on July 5, 2012 by Arianespace and is now placed in its permanent geosynchronous orbital slot of 107.1° West longitude, setting the stage for the new HughesNet® Gen4 satellite Internet services offering, with dramatically increased performance and capacity [10].

Employing a multi-spot beam, bent-pipe architecture, this next-generation, Ka-band, high-throughput satellite will provide significant additional capacity—over 100 Gbps—to further fuel the rapidly growing HughesNet® service business in North America. It will build on the success of the award-winning SPACEWAY 3 satellite system, which serves over 500,000 HughesNet consumer and small business subscribers in North America, delivering high-speed satellite Internet offerings in the market, from 1 to 5 Mbps downloads.

The new ECHOSTAR XVII satellite employs an enhanced version of the IPoS/DVB-S2 standard, the world's leading broadband satellite standard approved by ETSI, TIA, and ITU. Space Systems/Loral was selected to manufacture the satellite based on its SSL 1300 platform, which has the proven flexibility for a broad range of applications and is expected to provide service for 15 years or more.

The unique mix of the world's first switch-in-the-sky, SPACEWAY 3, which enables single-hop, site-to-site connectivity, and ECHOSTAR XVII's enormous capacity—100 times that of conventional Ku-band satellites—will ensure continued leadership by Hughes as provider of satellite broadband services and solutions.

Interestingly, to achieve the overall high throughput rates, ECHOSTAR XVII uses both the NGSO and GSO bands and has detection on board the satellite to switch back to only GSO if it detects NGSO interference. Thus, a sort if CR technique is already employed in that sense.

The current status – Terrestrial deployments in Ka-band

Europe:

Characteristic cases of FS links deployment in Ka-band over various European countries and regions are provided below. Such data is particularly useful to carry out interference assessment in CoRaSat Ka-band scenarios.

In particular, Table 5 below shows the current number of FS links in different European countries in the 18 GHz frequency band. This data has been collected from the Regulatory Authorities of each country.

Table 5: Examples of FS links density in some areas in Europe

Country/City	FS links	Frequency range
Barcelona (Spain) within 200 Km circle	208	18.3-18.8 GHz
Madrid (Spain), within 200 Km circle	190	18.3-18.8 GHz
France	4268	17.7-19.7 GHz
Slovenia	197	18.3-18.8 GHz
Hungary	1378	18.3-18.8 GHz

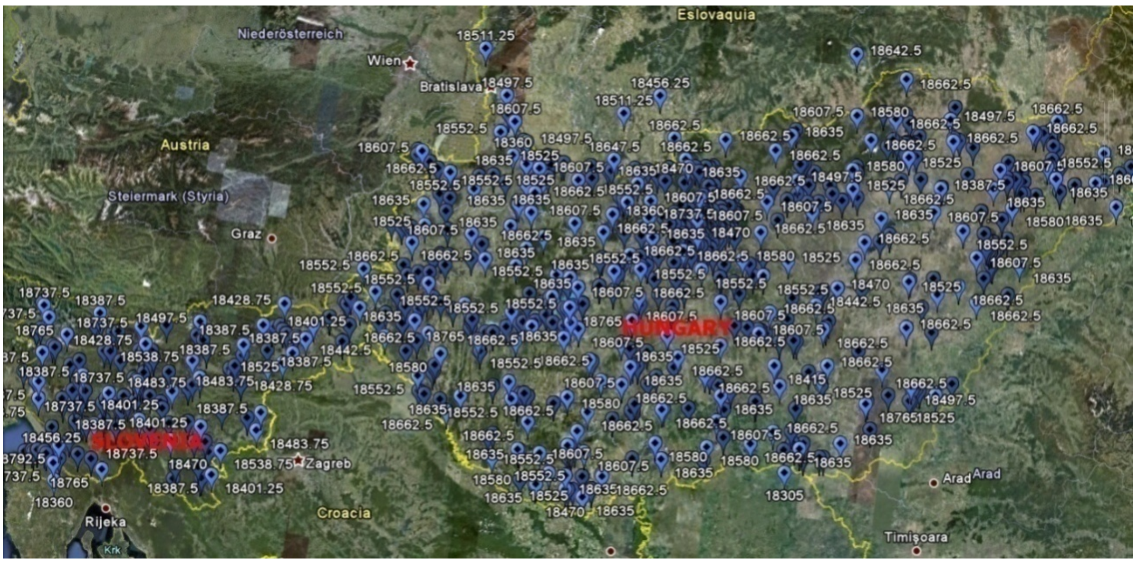


Figure 5: Example of FS deployment case. Location of FS transmitters in the range of 18.3 – 18.8 GHz in Slovenia and Hungary.

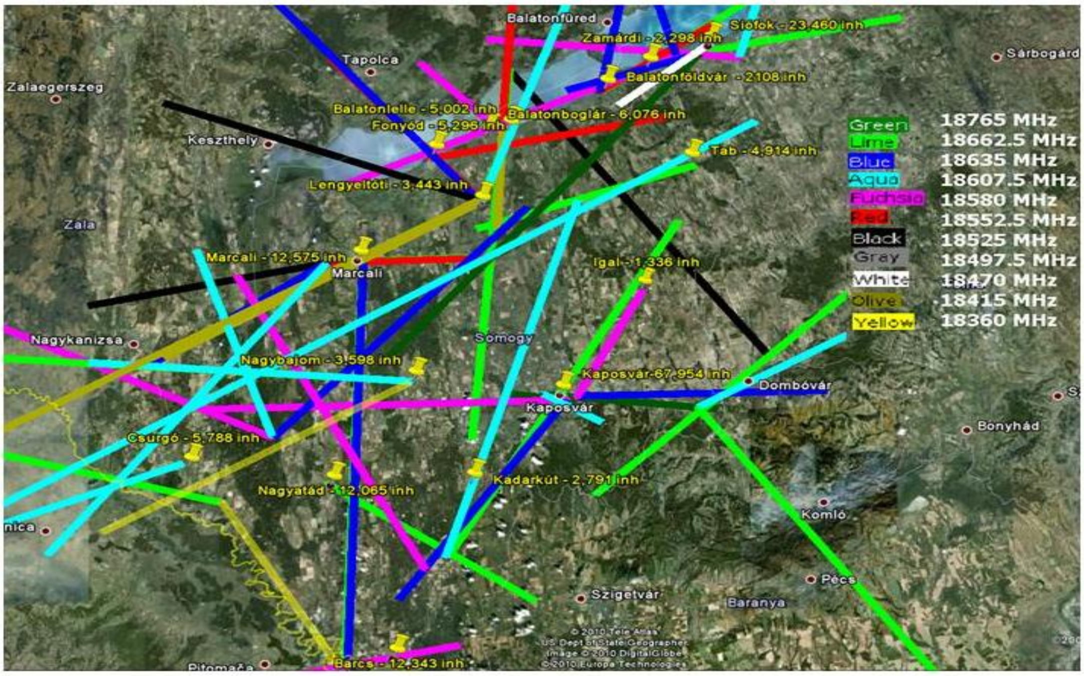
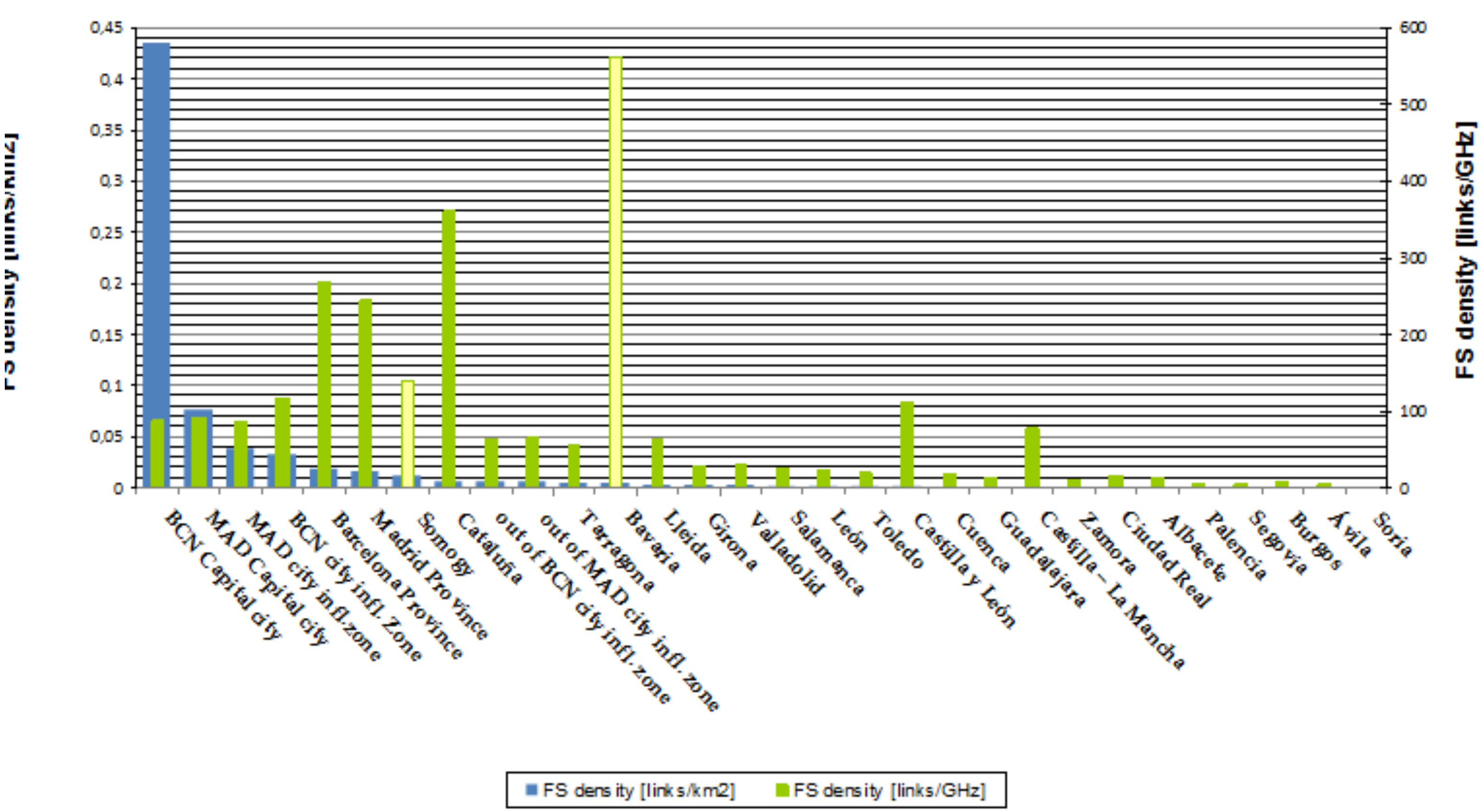


Figure 6: FS transmitter deployment exclusion zones colored by frequency. Location of FS transmitters in the range of 18.3 – 18.8 GHz in Slovenia and Hungary.

Figure 7 illustrates example of FS deployment, having selected the Hungarian Region of Somogy (full genuine FS deployment data is available) as an example case in terms of FS links, for comparative assessment, provided that:

- All the Spanish regions, both predominantly urban and intermediate rural ones, feature much less FS density comparing to that of Somogy. The FS density of Somogy is only surpassed by the predominantly urban provinces or regions of Spain, including Madrid and Barcelona capital cities, their influence zones (*i.e.*, metropolitan areas or conurbations excluding the capital city) and their respective Autonomous Communities.
- In terms of FS links and thus FS links per GHz, it can be seen that Somogy features a significantly higher number when compared to similar extension Spanish territories and becomes close to the value given by the urban territories governed by a capital city. Note that Somogy has more FS links than the capital cities and its corresponding regions of influence (excl. the capital city).

FS density for all the territories considered



A corresponding illustrative map of the FS deployment in France in the 17.7 – 19.7 GHz band is provided below (source: ARCEP 2012 public consultation on fixed service, www.arcep.fr).

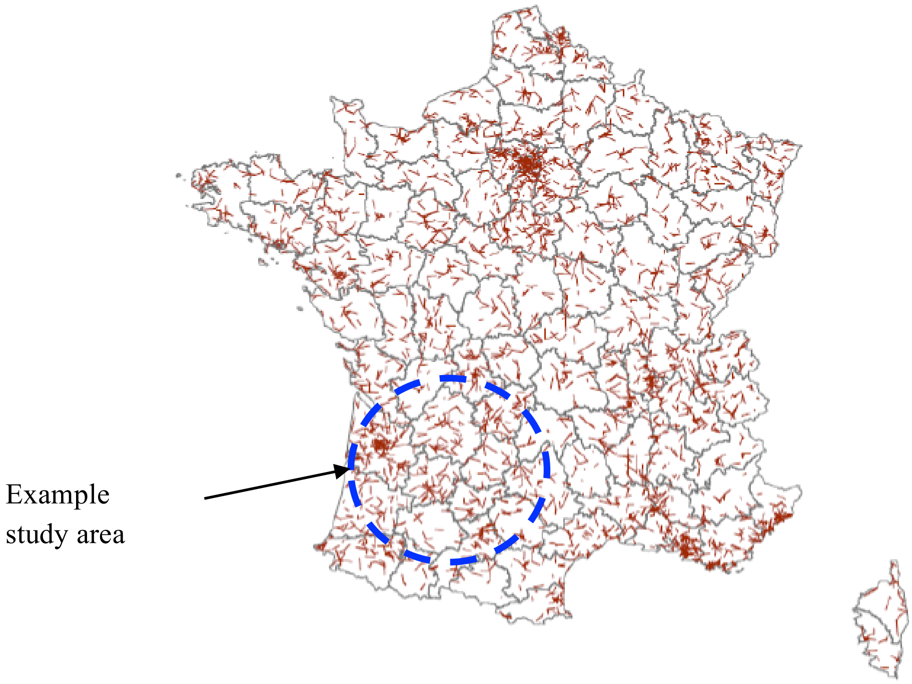


Figure 8: FS deployment in France in the 17.7-19.7 GHz band (Source: ARCEP)

US:

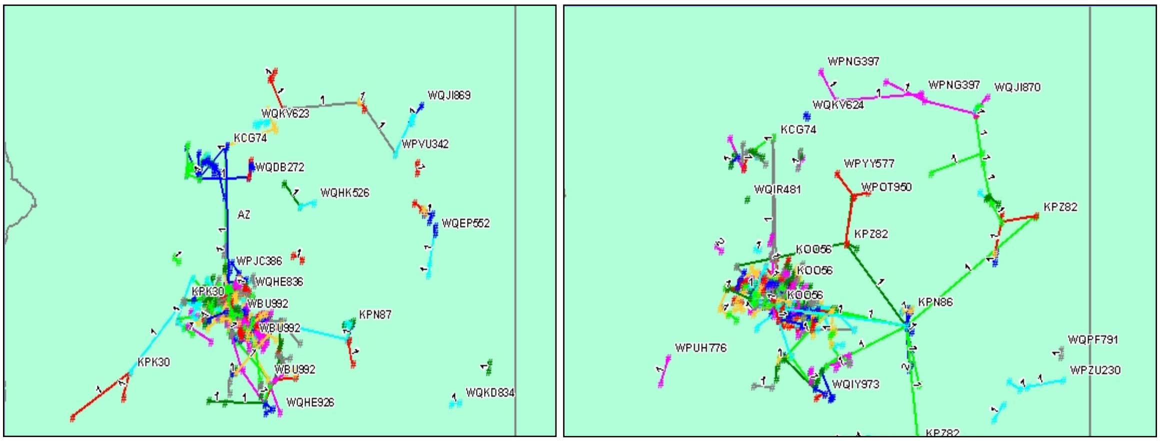
In the US, the 17.7 – 19.7 GHz band plan is defined and stable, clearly separating between FS and FSS services. The frequency band is widely used, requiring substantial local efforts to validate availability to deploy earth stations on a case-by-case basis with a guard area with radius of 300 km to be considered.

Actual plots can be acquired at http://www.comsearch.com/ for any location in the US.

As an illustration, Table 6 and Figure 9 present an example of study in the US, resulting in a high number of links in more rural environments. In urban areas, it is considerably more complex to find suitable locations for Earth Stations.

Table 6: Study in US, rural environment with objective to find possible Earth Station.

Radius	Location 1 300 km	Location 2 300 km
17.8-18.05 GHz	311	122
18.05-18.3 GHz	98	61
19.3-19.55 GHz	349	117
19.45-19.7 GHz	252	96



17.8 – 18.05 GHz 19.3 – 19.55 GHz

Figure 9: Study in US, rural environment with objective to find possible Earth Station.

<u>Brazil</u>

As a further example of potential sources of interference in Ka-band, the map of Brazil below shows the location of terrestrial radio sources in this region of the spectrum.

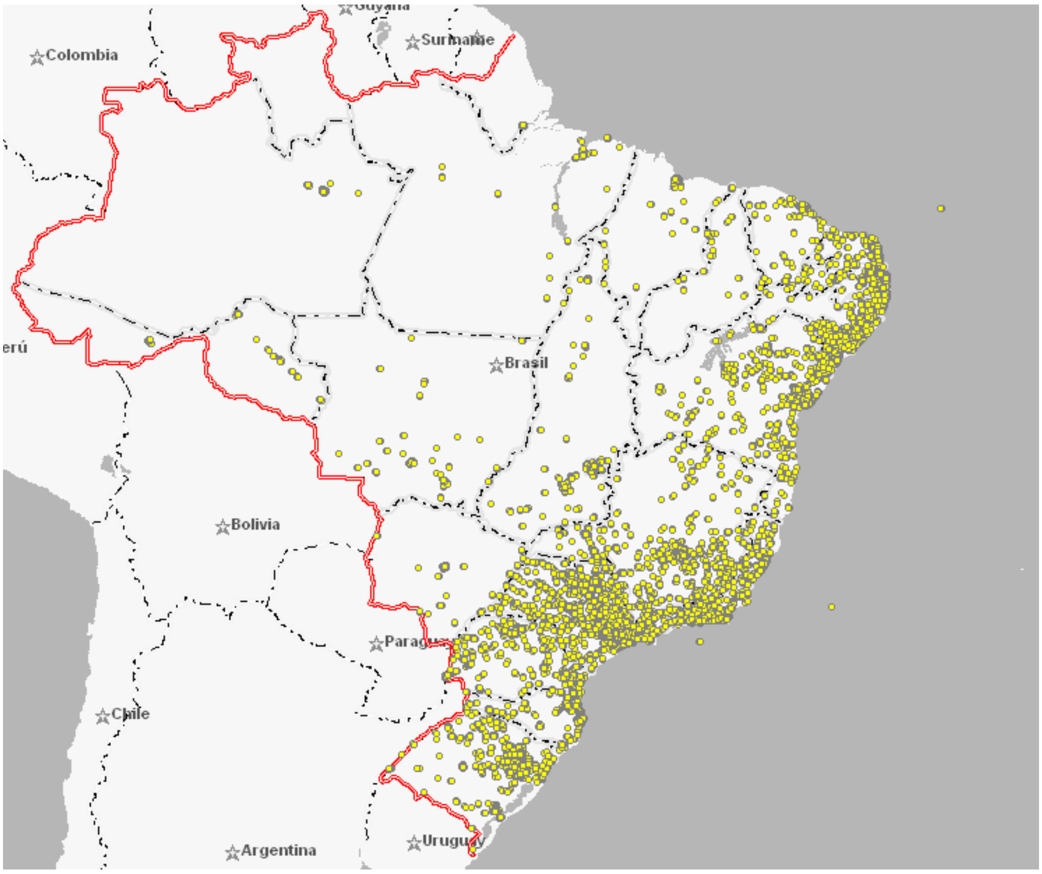


Figure 10: Ka-band Terrestrial Deployments in Brazil

Table 7: Brazil the number of MHz segment, graphically 11: FS Brazil.

Number of Terrestrial Stations in Brazil			
Downlink (GHz)		Uplink (GHz)	
17.8 – 18.6	11571	27.5 – 28.4	0
18.8 – 19.3	8326	28.6 – 29.1	0
19.7 – 20.2	0	29.5 - 30	0

FS Link gives sites per 100 and is shown in Figure Distribution in

Table 7: Brazil FS Link

Frequency, GHz	Sites in 100MHz band
17.8	5202
17.9	3009
18	2287
18.1	846
18.2	0
18.3	0
18.4	0
18.5	642
18.6	3071
18.7	1307
18.8	80
18.9	2363
19	2377
19.1	355
19.2	3503
19.3	6141
19.4	3939
19.5	2861
19.6	1956
19.7	0
19.8	0
19.9	0
20	0
20.1	0

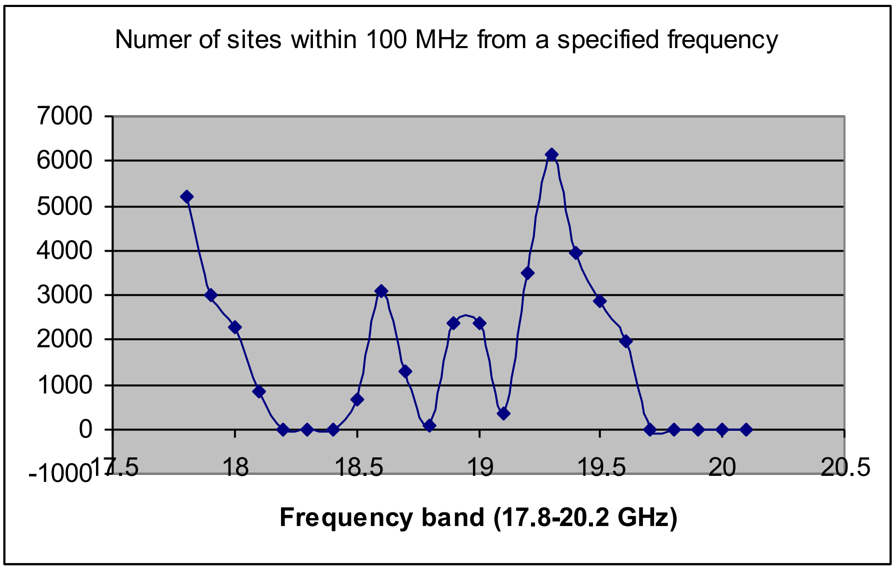


Figure 11: FS Distribution in Brazil

Where these are highly collimated LOS transmitters, there is only a certain likelihood that there will be significant interference with satellite earth stations. However until measurements are taken on site, the extent of interference remains uncertain.

5.3.3 Key Aspect III: Cognitive Radios in Primary Spectrum Allocations

Scope

The C-band is perceived to be a very good example to validate whether Cognitive Radios can be applied adequately for Satellite Communications in primary spectrum allocations or not.

Using satellite spectrum for other technologies decreases the signal quality for satellites and negatively affects the quality of service. Better ground and space technology cannot completely mitigate such interference, especially when it comes to higher data rates. In order to provide stable and predictable quality of service, Satellite Communications rely on the protection of spectrum allocations.

The increasing demand for terrestrial use of spectrum therefore threatens the service quality via satellite. Due to the larger coverage zone of the satellites, the requirements and regulation of spectrum in one region also have high impacts on neighboring areas. For example, the C-band is heavily used in Africa, Asia, and South America, but less used for consumers in Europe. Nevertheless there are numerous links from Africa and South America to Europe providing contribution links to large hub stations for re-transmission to the origin countries via another satellite or frequency bands, thus any disruption or interference would have a wide impact. As well, it is difficult to judge the number of unregistered earth stations used as cable head-ends or directly by consumers.

Allowing the usage of these frequencies in Europe for terrestrial systems would not only impact users in Europe or North America, but as well the users in the developing countries.

The extended C-band from 3.4 – 3.6 GHz is allocated to IMT-2000 globally (cellular services) based on specific clauses as defined in WRC decisions. In Europe CEPT went further to allocate 3.6 to 3.8 GHz as primary to IMT-2000 without protection to Satellite Communications and first implementations options of LTE are now being analyzed by some MNOs, providing substantial interference concerns to satellite communications for transmissions into low elevation angles.

In Ku-band, downlink typical use cases for Cognitive Radios are encompassing the support of non- or less preforming directional antennas as used for aeronautical or maritime applications. The level of frequency coordination requirements and regulations is substantial.

For the Ku-band, typical use cases for Cognitive Radios cover in the up-link the possibility for certain countries not to only operate coordinated earth stations with antenna sizes > 1.2 m in frequencies between 13.75 – 14.00 GHz, due to restrictions originating from Military Radar stations. However, it is possible to have small un-coordinated terminals suitable in the neighborhood of the radar installations, irrespectively mounted stationary, terrestrial or in maritime context as well. In the rest of the Ku-band, the compatibility is with Fixed Services (FS) depending on the specific sub-band and country where the lower uplink band 12.75 – 13.25 GHz is heavily utilized by FS, thus requiring often re-planning of satellite uplink sites, incurring additional costs.

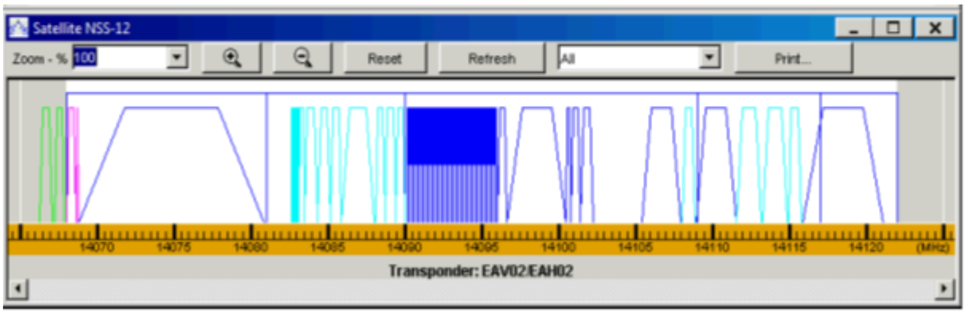


Figure 12: Ku-band - Fragmented Spectrum Use

Within heavily used primary spectrum allocations there is the additional aspect of optimized usage of the spectrum, especially considering fragmented usage due to interference or other reasons (see image Figure 12: Ku-band - Fragmented Spectrum Use). The possible applications of Cognitive Radios are seen to provide substantial benefits within the primary spectrum allocations. With high use, there is a high number of operational activities to activate, deactivate or relocate carriers resulting in often undesired fragmentation and un-utilized spectrum blocks as visible in diagram Figure 12: Ku-band - Fragmented Spectrum Use.

In S-band, due to its favorable frequency band, the operation of an Hybrid Network consisting of the Satellite Segment and the Complementary Ground Segment (CGC) has advantages exploited also by existing mobile network operators such as small antenna and small form factor handsets, good indoor penetration, good atmospheric propagation, good performance at high speed, low power transmission, and low noise floor in relatively interference free and unencumbered spectrum. In addition, S-band enables very wide area coverage from satellite creating a hybrid network topology and two times 15 MHz + 15 MHz of harmonized availability across the 27 EU member states. The 2 GHz S-band frequency spectrum sits alongside the UMTS standard already used across Europe for 3G terrestrial services. As such considerable attention must be given to in-band interferences between the satellite space segment transmission and the terrestrial CGC ground segment potentially utilizing different technologies. As well, due to the adjacent allocation of UMTS services, the out-of-band interference to/from these Node-Bs by the S-band transmissions needs to be considered.

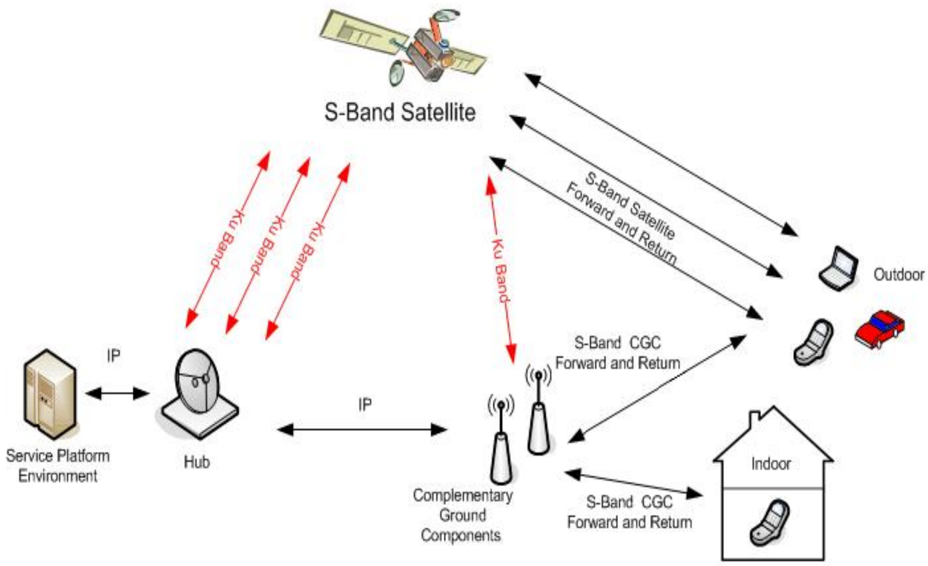


Figure 13: S-band Architecture

It is understood that the problems derived from the operation of the hybrid satellite-terrestrial scenario can allow deployment of mitigation techniques managed under an intra-system environment, consisting of several shaped beams in the forward direction and multiple beams in the return direction, supported by a terrestrial CGC in urban and suburban areas, with either low tower or high tower architectures.

Therefore, technical solutions and network management techniques should be developed to make the most efficient use of the combined satellite and terrestrial components, which are managed by the same operator.

For most efficient utilization from commercial and operational perspectives it is proposed that the S-band spectrum is split into separate 5 MHz carriers as shown in Figure 14: Example S-band frequency plan. These carriers will have to support designated applications utilizing a three-color frequency re-use pattern, supported by respective change of polarization in each beam. Terrestrially there shall be minimal interference from the other beams, or from intersystem (3G/4G) be allowed.

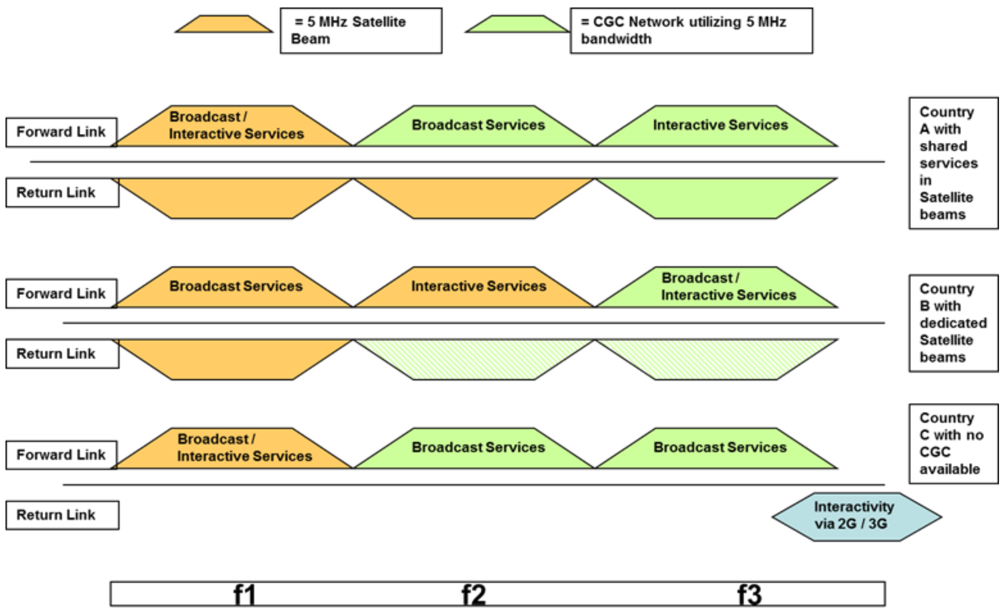


Figure 14: Example S-band frequency plan

To illustrate the complexity of network planning already applicable for a broadcast network, the following paragraphs demonstrate the considerations required and the complex interference aspects to be taken into account. Cognitive Radios may provide interesting performance improvements.

Principles of a DVB-SH broadcast network:

With the intended use of an SFN between the satellite component and the terrestrial component, all the transport streams, whether transmitted via satellite or via terrestrial repeaters, correspond to the same network.

Independently of the use of SFN, a DVB-SH network may be divided into "regions", within each a different terrestrial frequency plan is used. A simple example of the partitioning of an SH-network into regions as depicted below.

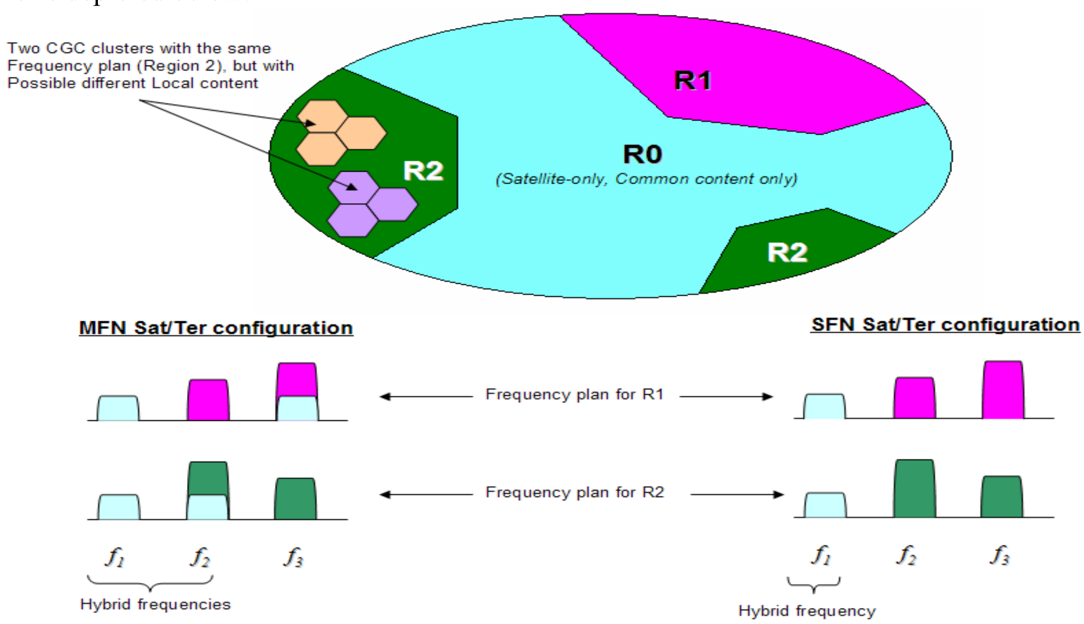


Figure 15: Regional concept of a network based on DVB-SH (Source [15])

With reference to Figure 15 and as described herewith, a region should <u>not</u> be interpreted as a contiguous area, or as a cluster of terrestrial component - CGC coverage in SFN mode. For example, in example region R2, the figure shows two disjoint clusters of CGC coverage in SFN mode. The local content in these two clusters may be different while their frequency plan is identical, by definition of the term "Region". When the satellite component and the terrestrial component operate in MFN for the common content, the frequency of the terrestrial retransmission (the "hybrid frequency") may be different between regions, as depicted in the left part of the examples. When satellite component and the terrestrial component operate in SFN for the common content, the physical parameters chosen for the two "terrestrial-only" frequencies may differ between regions, as shown in the right part of the examples. This may be imposed by interference constraints at the border of the satellite beam. This is illustrated in the Figure by indicating that frequency f3 has more terrestrial capacity than frequency f2 in Region R1 (and vice versa for Region R2).

Comparing to the EU, the S-band situation is more active in Asia where China, Korea, and Japan have a coordination problem and the Regulations are different for FS and FSS. As a consequence, interference mitigation has been taken into account in these areas and there has been already some work done.

The current status – Satellite Networks in C-band

Based on public research information and studies, the C-band demand and supply is increasing as shown below. Due to favorable propagation conditions, the C-band plays an important role to enable communication with very high availabilities and very wide coverage, spanning, *e.g.*, entire Continents.

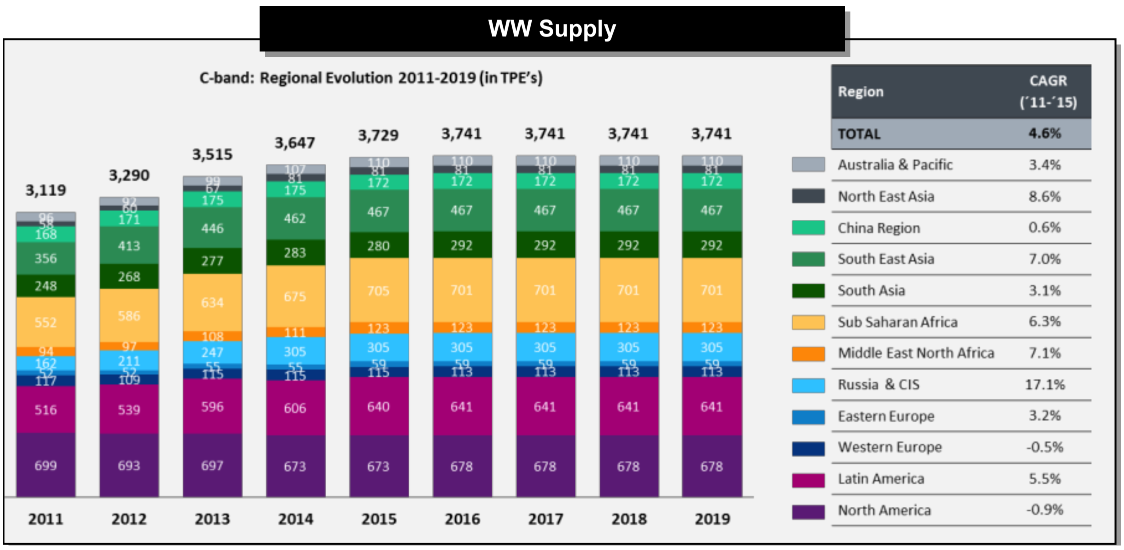


Figure 16: C-band WW Supply (Source: NSR [17])

- Global C-band supply will increase by 4.6% p.a. by 2015, while assuming that post 2015 replacement satellites carry an identical payload
- Increase in C-band supply is mainly taking place in Russia, Sub-Saharan Africa, and South East Asia

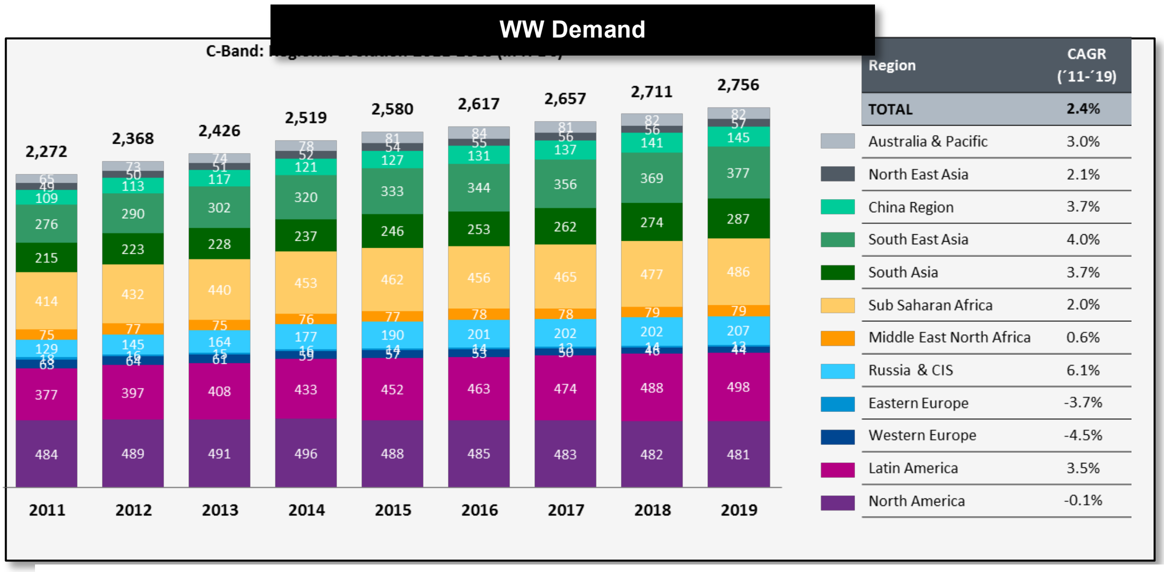


Figure 17: C-band WW Demand (Source: NSR [17])

- C-band worldwide demand is expected to grow at a CAGR of 2.4% over 2011-2019
- Growth in markets such as Latin America, South Asia, and Russia are driven by video distribution and GSM Backhaul needs

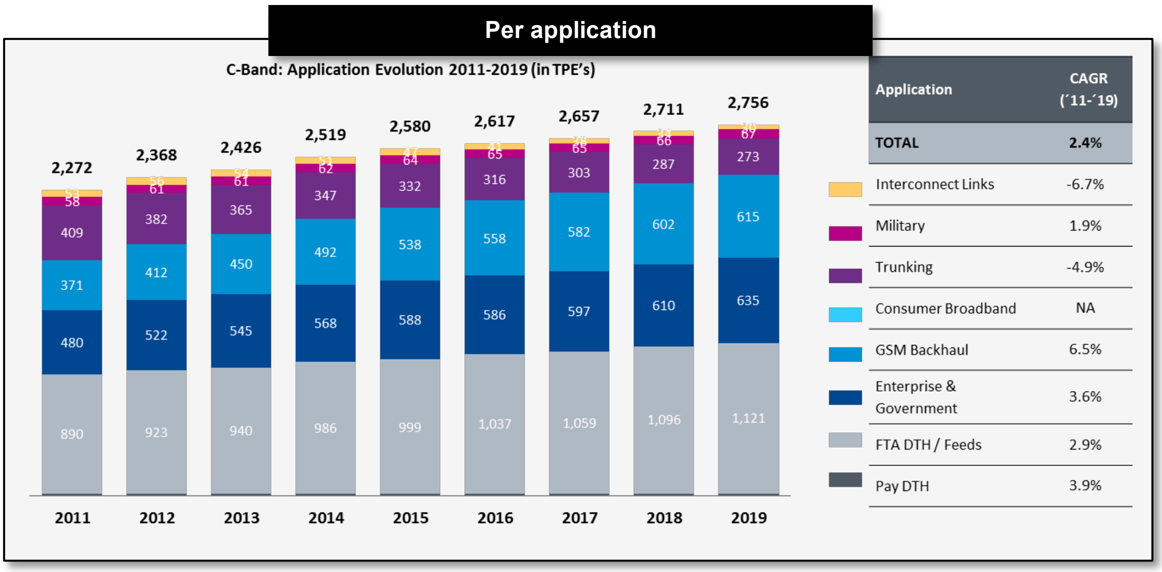


Figure 18: C-band Applications band (Source: NSR [17])

- Substitution risk is mainly taken into account for international telephony trunking (due to transcontinental fiber)
- No consideration of any similar substitution risk on distribution (be it to terrestrial and to other satellite bands – Ku or Ka); and predict growth based on new 3D, HD, 4K formats
- Global fill rate around 80% driven by Asia & LATAM

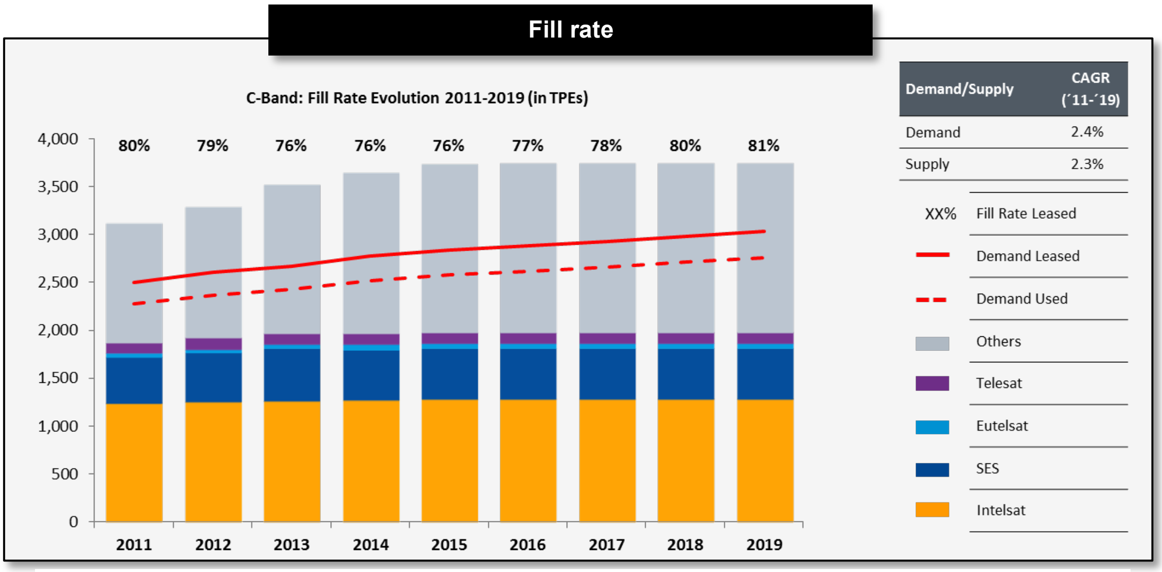


Figure 19: C-band Fill Rates (Source: NSR [17])

The current status – Terrestrial deployments in C-band

Based on public research information and studies, the regulatory and operational situation of terrestrial deployments in C-band are briefly addressed below.

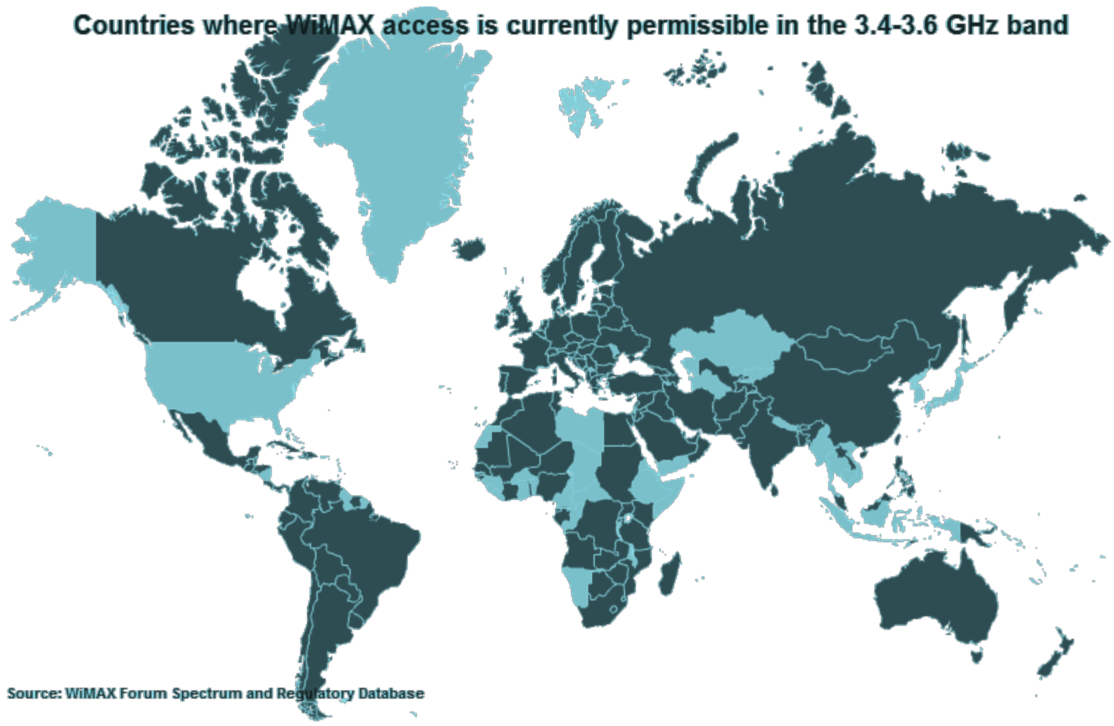


Figure 20: The regulatory situation of terrestrial deployments in C-band (Source WIMAX Forum)

Figure 21: The operational situation of terrestrial deployments in C-band (Source: GVF [18])

As an illustration, with regard to C-band terrestrial networks deployment, the following aspects can be highlighted:

- 308 WiMAX networks in the 3.5 GHz band worldwide…
- … But supporting less than 10 Mio subs all together
- April 2012, 1st commercial LTE 3.5 GHz service launched by UK Broadband (PCCW), several other deployments and tests ongoing, relating to future potential interference areas towards low elevation C-band feeder links to Asia
- Especially in the UK, cellular operators intend to use LTE in C-bands, which will cause interference into low elevation - circa 5 deg (Indian Ocean) - GEO satellite links. This really means that there is a problem with coexistence with LTE roll out in these bands, which is starting in London
- Since WRC12, ZTE and Huawei very actively promote 3.5 GHz "Chinese" TD LTE

Mitigation

Regulatory Challenges

Despite the rising demand in various parts of the world, in the view of the satellite operator, the pressure on the C-band primary allocation for satellite communications is rising as visible in an agenda item for WRC15.

Technical Challenges caused by interference

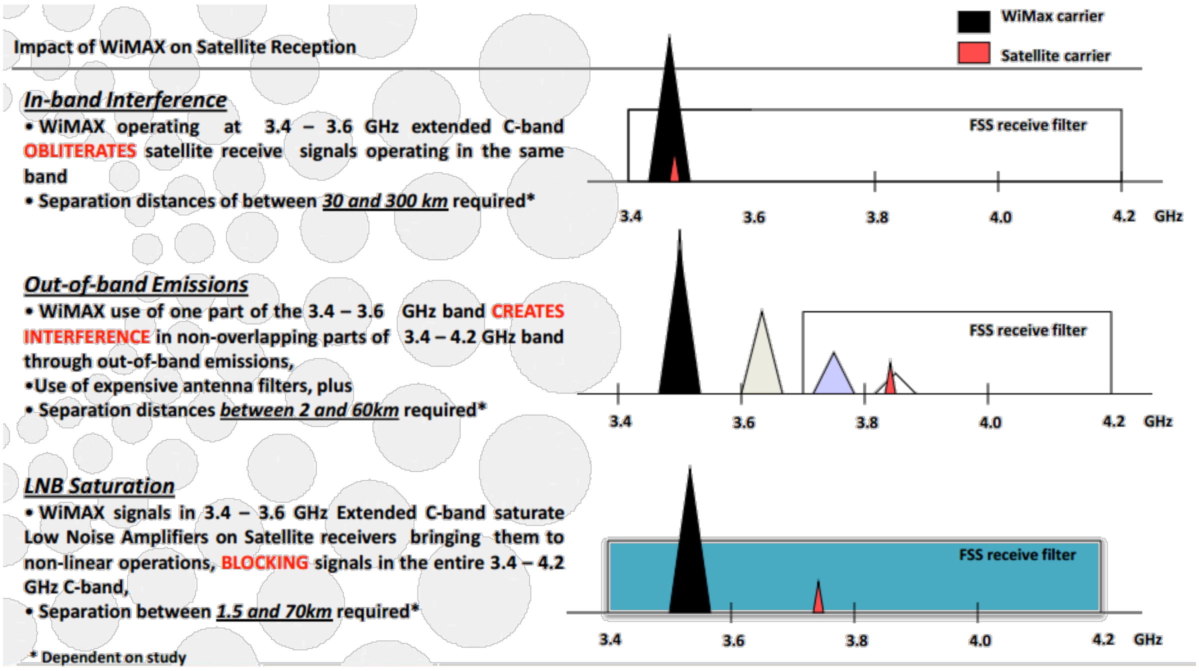
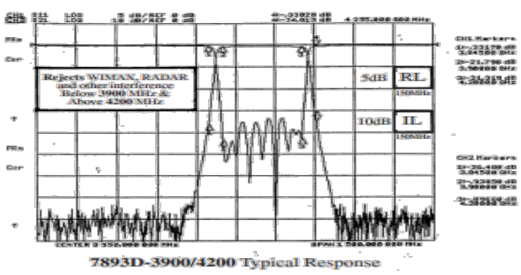


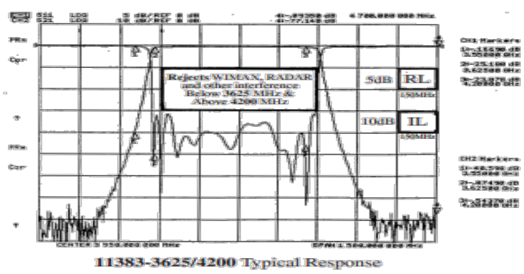
Figure 22: WiMAX Interference - Source GVF

WiMAX signal has an approximately 40 dB higher power than satellite signal.

Even where 3.5 GHz terrestrial usage is constrained to cities and sat sites are protected, interferences are observed. Costs involved with subsequently identifying and resolving the problem are on the satellite operators

- ITU M.2109 & CEPT surveys
- SES survey
- CASBAA survey





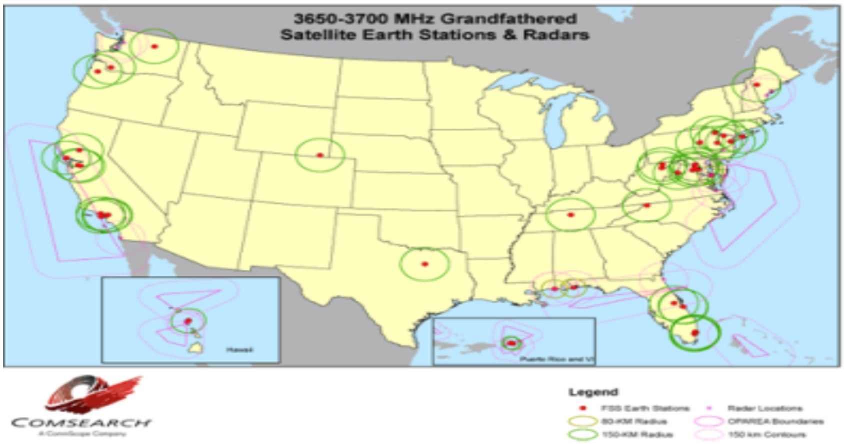


Figure 23: C-band SES & Radars (Source Comsearch)

<u>Impact on satellite operator and its customers</u>:

- Potential sterilization or requirement of price reductions for specific C-band transponders
- Some customers had to deploy new filters
- Larger dishes are to be recommended
- Re-farming was required in exceptional cases
- Larger separation distance required

Main observed impact is in Asia and Africa

- Incidents (mainly TV reception) led some Asian countries to withdraw or refuse WiMAX extended C-band licenses (Philippines, Indonesia, Malaysia, Viet-Nam)
- Contagion effect was observed in Africa and some Asian countries

5.4 Summary List of Market and Service Requirements

The aggregated service and market requirements as described above are provided in the form of a summary list below for each identified scenario (A-G).

5.4.1 Scenario A – Satellite Downlink in Ka-band (17.3 – 17.7 GHz)

1. The solution shall provide access to the complete 17.3 – 17.7 GHz secondary allocation in addition to other secondary and primary allocations.
2. The solution shall support the operation of FSS GSO satellite services in presence of BSS GSO satellite services without causing harmful interference to the primary system.
3. The solution shall support the operation of FSS GSO satellite services on ESOMP (Earth Stations on Mobile Platforms as aeronautical or maritime platforms) in presence of other GSO satellite services without causing harmful interference to the primary service.

4. The solution shall incorporate an agreed migration path to a future standard compliant version, as DVB and ETSI standards (*e.g.*, evolutions of EN 302 307 V1.3.1).
5. The solution shall support justified evolutions of the DVB standard family.
6. The solution shall be able to mitigate all in-band interference types as stated in chapter 5, avoid out of band emissions as defined in [59] and LNB saturation.
7. The solution shall have at least comparable system performances to current satellite COTS equipment (*e.g.*, NEWTEC MDM 6000 and MDM 31000).
8. The solution shall support point-to-point, point-to-multipoint and broadcast topologies.
9. The solution shall at least support two of the four Cognitive Radio categories as stated in DoW [1] (Spectrum Sensing, Underlay, Overlay, Database).
10. The solution shall support GSO EIRP level variations of > 10 dB.
11. The solution shall support automated terminal configuration, provide qualified installation procedures and built-in monitoring functions to enable remote configuration and maintenance operations.
12. The solution shall enable cost efficient deployment and operation of Cognitive Radio based systems.

5.4.2 Scenario B – Satellite Downlink in Ka-band (17.7 – 19.7 GHz)

The solution shall support all requirements as listed in 5.4.1, with exception to the following requirements:

1. The solution shall provide access to the complete 17.7 – 17.9 GHz in addition to other secondary and primary allocations in this frequency band.
2. The solution shall support the operation of FSS GSO satellite services in presence of terrestrial services or other FSS GSO / MEO / LEO satellite services without causing harmful interference to the primary system.
3. The solution shall support the operation of FSS satellite terminals in non-primary Ka-band spectrum allocations in and switch back to primary Ka-band operation when interference from primary users is detected or announced from external systems.
4. The solution shall support effective measures against LNB saturation, avoidance of non-linear operation

5.4.3 Scenario C – Satellite Uplink in Ka-Band (27.5 – 29.5 GHz)

The solution shall support requirements 4-12 as listed in 5.4.1, with exception to the following requirements:

1. The solution shall support the complete 27.5 – 29.5 GHz in addition to other secondary and primary allocations in this frequency band.
2. The solution shall support remote power-off of BUC.

3. The solution shall support the operation of FSS GSO satellite services in presence of terrestrial services or other FSS GSO / MEO / LEO satellite services without causing harmful interference to the primary system.

5.4.4 Scenario D – Satellite Downlink/Uplink in Ku-band (10.7 – 12.75, 12.75 – 13.25, 13.75 – 14.5 GHz)

The solution shall support requirements 4-12 as listed in 5.4.1, with exception to the following requirements:

1. The solution shall support the complete Ku-downlink band 10.7 – 12.75 GHz for primary and secondary allocations in this frequency band.
2. The solution shall support the complete Ku-uplink band 12.75 – 13.25 and 13.75 – 14.5 GHz for primary and secondary allocations in this frequency band.
3. The solution shall support terminals with antenna sizes > 1.2 m in Ku-uplink band allowing un-coordinated installation and operation without causing harmful interference to the primary Military Radar system, as required in specific sub-band and countries.

5.4.5 Scenario E – Satellite Downlink in C-band (3.4 – 3.8 GHz)

The solution shall support requirements 4-12 as listed in 5.4.1, with exception to the following requirements:

1. The solution shall support the complete C-Band downlink 3.4 – 3.8 GHz for primary and secondary allocations in this frequency band.

5.4.6 Scenario F – Satellite Uplink/Downlink in S-band (1980 – 2010 and 2170 – 2200 MHz)

1. The solution shall provide access to the complete MSS allocation from 1980 – 2010 MHz in Uplink and 2170 – 2200 MHz in Downlink.
2. The solution shall be compliant to the most recent DVB and ETSI standards (*e.g.*, TS 102 721 V1.3.1, EN 302 550 V1.3.1, EN 302 574 V1.1.1, TR 102 601 V1.1.1) including for terminals and earth stations the support of the
    2.1.) wideband option;
    2.2.) narrowband option.
3. The solution shall apply as appropriate the OoB limits and protection masks as defined in 3GPP 36.101ff for intersystem considerations.
4. Based on [15] the solution shall support typical G/T values for different terminal types are: i) vehicular/specific/fixed: -21 dB/K; ii) emergency: -21 dB/K (-21 dB/K is stated for vehicular terminals, whereas -25 dB/K is stated for portable terminals); and iii) portable/handheld (with two antennas on the terminal): -29 dB/K.
5. The solution shall support the performance characteristics referenced in DVB-SH Implementation guideline [15]

5.4.7 Scenario G - Satellite NGSO FSS Downlink/Uplink in Ka-band (17.8 – 20.2 and 27.5 – 30 GHz)

1. The solution shall support requirements 4-12 as listed in 5.4.1
2. The solution shall support the NGSO systems considering these preliminary requirements:

2.1. MEO/LEO orbit specifics, angular separation, etc.

2.2. Reduced path loss

2.3. Reduced power requirements (based on reduced path loss)

2.4. Reduced latency

2.5. Tracking Earth Stations

2.6. NGSO frequency allocations and required coordination

2.7. Applicable EPFD limits towards other GSO/NGSO systems

Further requirements are under discussion.

6 BUSINESS IMPACT ANALYSIS

This Chapter deals with the Business Impact Assessment for the usage in all defined scenarios, *i.e.*, scenarios A-G.

6.1 Applied Principles for Business Impact Assessment

The CoRaSat assessment described below is understood to be built around the costs and complexity of the added Cognitive Radio technology and its operation as against the advantages from additional/more efficient spectrum usage, capacity increase and potential reduction in service costs. The development of such new techniques, equipment and infrastructures represents an investment in addition to conventional approaches in other exclusive frequency bands that do not require coordination and cooperation techniques.

During the market and service assessments the following use cases have been considered as defined in CoRaSat DoW [1] along with some further amendments in the course of the project.

Table 7: Brazil FS Link gives the number of sites per 100 MHz segment, and is graphically shown in Figure 11: FS Distribution in Brazil.

Use case\scenario	**Scenario A**	**Scenario B**	**Scenario C**	**Scenario D**	**Scenario E**	**Scenario F**	**Scenario G**
Broadband SatCom							
Fixed	FL	FL	RL	FL/RL	FL/RL	FL/RL	FL/RL
Nomadic	FL	FL	RL	FL/RL	FL/RL	FL/RL	FL/RL
Vehicular			RL	FL/RL	FL/RL	FL/RL	
Maritime	FL	FL	RL	FL/RL			FL/RL
Aeronautical	FL	FL	RL	FL/RL			
Narrowband SatCom							
Handheld						FL/RL	FL/RL
Vehicular						FL/RL	FL/RL
Sensor networks			RL			FL/RL	FL/RL
Interactive TV			RL				

6.2 Scenario A – Satellite Downlink in Ka-band (17.3 – 17.7 GHz)

Considered use cases: Broadband Fixed, Nomadic, Maritime, and Aeronautical Satellite Communications.

Detailed Use Case Description:

Broadband Satellite Communication is a significant driver for the exploitation of this scenario A.

In ITU Region 1 this frequency allocation is assigned on a primary basis to the BSS service to uplink from a specific lower number of sites spread across EU to various GSO satellites in suitable orbital slots. As the uplink environment is rather easy to control, it is possible to utilize the Ka-band spectrum as outlined as an extension to the Scenario B.

With this approach the overall spectrum available would increase on the downlink by 400 MHz, opening up various possibilities to utilize it for broadband satellite communications. As no corresponding suitable uplink spectrum is available two main use cases are discussed supporting broadband satellite communications:

1. Extension of overall Ka-band DL spectrum to accommodate better the UL/DL traffic disparities typical in today's internet broadband access networks.
2. Frequency separation of gateway links to the user links, reducing substantially the deployment complexity and costs of multi beam satellite networks and increasing the user link performance by extending their available allocated spectrum.

Based on Scenario B, extended spectrum to cover Ka-band 17.3 to 20.2 GHz for user and gateway links (reserving 500 MHz for terrestrial and/or NGSO services – 2 GHz available) with gateway links outside main coverage

CoRaSat GW Outside	4 x 1GHz	User	DL
	1 x 4 GHz	GW	UL
	4 x 1GHz	User	UL
	1 x 4 GHz	GW	DL
			4 beams per gateway

2 GHz per beam resulting in 6 dB lower margin with reduction of bitrate efficiency from 3 bits/Hz to 1.5 bits/Hz

Applied ModCod: QPSK ¾ with efficiency of 1.5 bit/Hz

Aggregated User Throughput (Beam):1500 MBit

Total aggregated satellite user throughput: 72 GBit

Max total aggregated number of customer supported in a beam 50000

Expected benefits: Cognitive Radios for Scenario A will provide additional DL throughput when offered thus increasing the number of supported customers per beam, suitable for broadband services, especially when highly asymmetric DL/UL traffic patterns exists.

6.3 Scenario B – Satellite Downlink in Ka-band (17.7 – 19.7 GHz)

Considered use cases: Fixed, Nomadic, Maritime, Aeronautical Broadband Satellite Communications leveraging symmetric UL/DL access to secondary spectrum to be utilized in downlink in conjunction with existing primary spectrum Ka-band FSS spectrum allocation

Detailed Use Case Description:

All broadband satellite communication applications are often being realized with the support of a multi beam satellite concept in the Downlink to achieve the desired throughput for the envisaged high number of users.

A frequency re-use color scheme (often a factor of 4) needs to be applied in order to support the required throughput with the high number of beam with a relative small beam diameter. Though any frequency re-use limits the available spectrum on ground out of the total available spectrum. As such it is beneficial for broadband applications to utilize wider bandwidth to increase the offered bandwidth in certain beams, thus enabling a system engineered for maximized throughput per Watt, instead of throughput per Hz, and thus providing the optimized cost per bit.

It is recognized that the frequency band identified in scenario B is in some parts of the world used intensively by terrestrial fixed services (FS) to backhaul via microwave fixed and wireless traffic between fixed locations and expected to grow substantially more, thus changing the current limited interference situation on a worldwide basis.

To compensate the rising interference constraints caused by local clusters of terrestrial deployments, it is assumed that a spectrum block of 500 MHz is occupied by the primary FS user in any beam in any geographic location in the footprint of a theoretical Ka-band multi beam satellite.

With Cognitive Radio functionalities applied it is anticipated that the overall spectrum available would increase on the downlink by 2 GHz, opening up various possibilities to utilize it for broadband satellite communications, thus four times the spectrum available in the primary FSS allocation. As such the following use cases are being discussed:

1. Extension of overall Ka-band DL spectrum to accommodate better the UL/DL traffic disparities typical in today's internet broadband access networks.
2. Frequency separation of gateway links to the user links, reducing substantially the deployment complexity and costs of multi beam satellite networks and increasing the user link performance by extending their available allocated spectrum.

The same extension of the usable spectrum for the terrestrial fixed satellite broadband is as well applicable to the aeronautical and maritime broadband use cases, providing the same expected system gains, complemented with the additional benefit of the non-existence of interference of the terrestrial primary users in this FS allocation.

Expected benefits: Cognitive Radios for Scenario B will provide access to potential substantial additional DL throughput of the satellite, whilst providing mitigation to local interference conditions more and more likely, thus an increase of the number of supported customers across the beam footprints. This would be suitable for, *e.g.*, broadband services, especially in combination to Scenario

C providing the corresponding uplink capacity. As well there will be increase of operational efficiency, and a reduction of cost per bit.

6.4 Scenario C – Satellite Uplink in Ka-band (27.5 – 29.5 GHz)

Considered use cases: Fixed, Nomadic, Maritime, Aeronautical Broadband Satellite Communications leveraging symmetric UL/DL access to secondary spectrum to be utilized in uplink in conjunction with existing primary spectrum Ka-band FSS spectrum allocation

Detailed Use Case Description:

Similar to the challenges and benefits in [13] for all broadband satellite communication applications are often being realized with the support of a multi beam satellite concept in the Uplink to achieve the desired throughput for the envisaged high number of users.

A frequency re-use color scheme (often a factor of 4) needs to be applied in order to support the required throughput with the high number of beam with a relative small beam diameter. Though any frequency re-use limits the available spectrum on ground out of the total available spectrum. As such it is beneficial for broadband applications to utilize wider bandwidth to increase the offered bandwidth in certain beams, thus enabling a system engineered for maximized throughput per Watt, instead of throughput per Hz, and thus providing the optimized cost per bit.

It is recognized that the frequency band identified in scenario B is in some parts of the world used intensively by terrestrial fixed services (FS) to backhaul via microwave fixed and wireless traffic between fixed locations and expected to grow substantially more, thus changing the current limited interference situation on a worldwide basis.

To compensate the rising interference constraints caused by local clusters of terrestrial deployments, it is assumed in this exercise that 500 MHz of contiguous/non-contiguous spectrum is occupied by the primary FS user in any beam in any geographic location in the footprint of a theoretical Ka-band multi beam satellite. This number shall be seen in the context of this chapter to ease calculations and does not reflect necessarily any current actual allocation.

With Cognitive Radio functionalities applied it is anticipated that the overall spectrum available would increase on the downlink by 2 GHz, opening up various possibilities to utilize it for broadband satellite communications, thus four times the spectrum available in the primary FSS allocation. As such the following use cases are being discussed:

1. Extension of overall Ka-band UL spectrum to accommodate better the UL/DL traffic disparities typical in today's internet broadband access networks.
2. Frequency separation of gateway links to the user links, reducing substantially the deployment complexity and costs of multi beam satellite networks and increasing the user link performance by extending their available allocated spectrum.

The same extension of the usable spectrum for the terrestrial fixed satellite broadband is as well applicable to the aeronautical and maritime broadband use cases, providing the same expected system gains, complemented with the additional benefit of the non-existence of interference of the terrestrial primary users in this FS allocation.

Considered common parameters in analysis:

Disclaimer: The utilized architecture and system parameters show below are for an artificial satellite system and chosen to help the case studies listed below and do not necessarily reflect current or future system aspects.

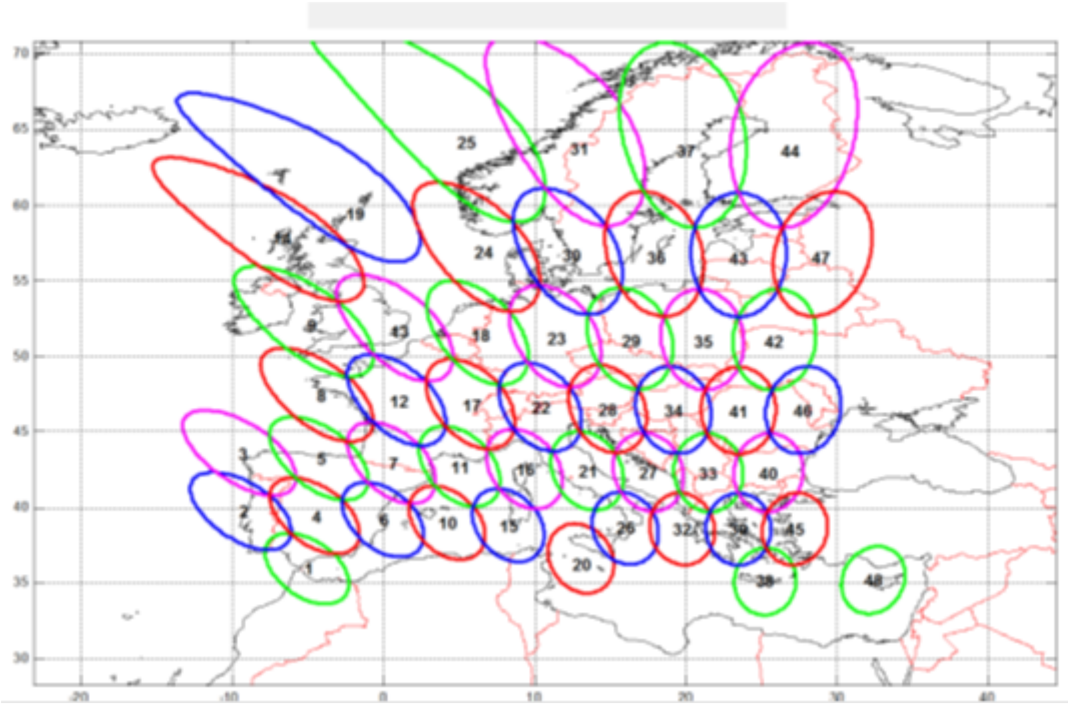


Figure 24: Ka-band multi-beam satellite scenario

- *Multibeam Satellite (Ka-band) covering EU 27: 48 beams.*
- *Frequency Reuse Factor: 4.*
- *Rain Fade Margin: 10 dB for 500 MHz scenario.*
- *FL / RL ratio: 3/2, conservative. No consideration of traffic shaper and Contention Ratio.*
- *No change for Satellite DC Payload power in all scenarios.*
- *Overall lower QoS provided due to reduced availability in some scenarios, partially to be compensated by new developments as DVB-S2 follow-up.*
- *No consideration for one-off costs associated to terminals and satellite being specification items for new contracts.*
- *Service: Consumer Broadband.*
- *Average throughput per customer (guidance see [13]) 30 kbps.*

Baseline Scenario

Ka Band 19.7 to 20.2 GHz with gateway inside EU and main coverage

Baseline GW Inside	4 x 150 MHz	User	DL
	1 x 600 MHz	GW	UL

	4 x100 MHz	User	UL
	1 x 400 MHz	GW	DL
			4 beams per gateway

- *250 MHz per beam split in 150 MHz Forward and 100 MHz Return Capacity*
- *Applied ModCod: 8PSK ¾ with efficiency of 2.25 bit/Hz*
- *Aggregated User Throughput (Beam): 337.5 MBit*
- *Max total aggregated satellite user throughput: 16.2 GBit*
- *Max total aggregated number of customer supported in a beam* ***11250***

CoRaSat Scenario

Ka-band 17.7 to 20.2 GHz (reserving 500 MHz for terrestrial and/or NGSO services – 2 GHz available) with gateway inside EU and main coverage

CoRaSat GW Inside	4 x 650 MHz	User	DL
	2.6 GHz	GW	UL
	4 x 350 MHz	User	UL
	1.4 GHz	GW	DL
			4 beams per gateway

2 GHz per beam resulting in 6 dB lower margin with reduction of bitrate efficiency from 3 bits/hz to 1.5 bits/hz

- *Applied ModCod: QPSK ¾ with efficiency of 1.5 bit/Hz*
- *Aggregated User Throughput (Beam):975 MBit*
- *Total aggregated satellite user throughput: 46.8 GBit*
- *Max total aggregated number of customer supported in a beam* ***32500***

Extended Baseline Scenario

Ka-band 19.7 to 20.2 GHz for user links (FSS) and 17.7 to 20.2 GHz (reserving 500 MHz for terrestrial and/or NGSO services – 2 GHz available) for gateway links required to be outside main coverage

Baseline GW Outside	4 x 250 MHZ	User	DL FSS
	2 GHz	GW	UL FSS + NE
	4 x 250MHz	User	UL FSS
	2 GHz	GW	DL FSS + NE

			16 beams per gateway

- *250MHz per beam split in 150 MHz Forward and 100 MHz Return Capacity*
- *Applied ModCod: 8PSK ¾ with efficiency of 2.25 bit/Hz*
- *Aggregated User Throughput (Beam): 337.5 MBit*
- *Total aggregated satellite user throughput: 16.2 GBit*
- *Max total aggregated number of customer supported in a beam* ***11250***

Extended CoRaSat Scenario:

Ka-band 17.7 to 20.2 GHz for user and gateway links (reserving 500 MHz for terrestrial and/or NGSO services – 2 GHz available) with gateway links outside main coverage

CoRaSat GW Outside	4 x 1GHz	User	DL
	1 x 4 GHz	GW	UL
	4 x 1GHz	User	UL
	1 x 4 GHz	GW	DL
			4 beams per gateway

- *2 GHz per beam resulting in 6 dB lower margin with reduction of bitrate efficiency from 3 bits/hz to 1.5 bits/hz*
- *Applied ModCod: QPSK ¾ with efficiency of 1.5 bit/Hz*
- *Aggregated User Throughput (Beam):1500 MBit*
- *Total aggregated satellite user throughput: 72 GBit*
- *Max total aggregated number of customer supported in a beam* ***50000***

Summary Throughput Table for all four discussed Scenario B concepts

Baseline GW Inside	4 x 150 MHz	User	DL
	1 x 600 MHz	GW	UL
	4 x100 MHz	User	UL
	1 x 400 MHz	GW	DL
			4 beams per gateway
CoRaSat GW Inside	4 x 650 MHz	User	DL

	2.6 GHz	GW	UL
	4 x 350 MHz	User	UL
	1.4 GHz	GW	DL
			4 beams per gateway
CoRaSat GW Outside	4 x 1GHz	User	DL
	1 x 4 GHz	GW	UL
	4 x 1GHz	User	UL
	1 x 4 GHz	GW	DL
			4 beams per gateway
Baseline GW Outside	4 x 250 MHZ	User	DL FSS
	2 GHz	GW	UL FSS + NE
	4 x 250MHz	User	UL FSS
	2 GHz	GW	DL FSS + NE
			16 beams per gateway

Cognitive Radios for Scenario C will provide access to potential substantial additional UL throughput of the satellite, whilst providing mitigation to local interference conditions, thus an increase of the number of supported customers across the beam footprints. This would be suitable for e.g. broadband services, especially in combination to Scenario B providing the corresponding downlink capacity. As well there will be increase of operational efficiency, and a reduction of cost per bit.

6.5 Scenario D – Satellite Downlink/Uplink in Ku-band (10.7 – 12.75, 12.75 – 13.25, and 13.75 – 14.5 GHz)

Considered use case: Fixed, Nomadic, Vehicular, Maritime, Aeronautical Broadband Satellite Communications experiencing in developing countries high interference levels from terrestrial and satellite sources, intentionally or un-intentionally, in Ku-band.

Detailed Use Case Description:

Significant parts of satellite communication applications in Ku-band are often experiencing interference from terrestrial sources more and more being deployed, providing either microwave based backhaul services or broadband wireless access (BWA) type of applications based on various technologies.

As described in section 5.3.3, Cognitive Radio functionalities would be most efficiently be suited and applied to combat efficiently these interference types. This would significantly increase the availability of Ku-band spectrum to be used, and thus enhance the possibilities to protect fixed and nomadic broadband services to be delivered with high availabilities via satellite.

Considered common parameters in analysis:

- Target region: Africa.
- Transponders in typically interfered Ku-band areas have lower market prices.
- Transponders defined as 36 MHz equivalents
- Service: Consumer Broadband with 30 kbp/s average consumption, Traffic Shaper and Contention Ratio not considered.
- Only a subset of transponders with impairments suitable to Cognitive Radio improvement.
- Transponder considered with impairments of some level as part of contracted capacity, not equal to total unusable capacity.
- Influences from high EIRP and/or G/T (specific implementations) are not considered.

Target region: Sub Saharan Africa		
Total satellite supply Ku-band transponders:	390[1]	
Estimated total satellite industry transponders with impairments:	12	2-3%
Estimated share of transponders suitable to benefit from Cognitive Radios:	0.2	
Estimated total number of transponders suitable to benefit from Cognitive Radio:	2.4	36 MHz Transponder Equivalent
Total Mbit/s enabled by CRs	130 Mbit/s	QPSK ¾ with 1.5 bps/hz
Total additional Broadband Subscribers	4333	

Averaged across services as defined in [17].

Expected benefits: Cognitive Radios for Scenario D will predominantly enhanced interference mitigation in mostly primary spectrum allocations, which will enable access to otherwise unusable transponders resulting either in higher throughput or support of additional customers, prevailing the benefits of access in secondary spectrum allocations.

[1] *Ref: [17]: NSR Report Global Assessment of Satellite Supply & Demand 9th Edition, 2012.*

6.6 Scenario E – Satellite Downlink in C-band (3.4 – 3.8 GHz)

Considered use case: Fixed, Nomadic, Vehicular, and Aeronautical Broadband Satellite Communications experiencing high interference levels from terrestrial and satellite sources, intentionally or un-intentionally in extended C-band.

Detailed Use Case Description:

Significant parts of satellite communication applications in C-band are often experiencing interference from terrestrial sources more and more being deployed to provide either backhaul services or broadband wireless access (BWA) type of applications based on WIMAX or other technologies.

Cognitive Radio functionalities to mitigate efficiently these interference types would significantly increase the availability of C-band spectrum to be used, and thus enhance the possibilities to protect fixed and nomadic broadband services to be delivered with high availabilities via satellite in regions with high rain rates.

Considered common parameters in analysis:

- Target region: Sub Sahara Africa.
- Transponders in lower extended C-band have lower market prices.
- Transponders in lower extended C-band are more likely to be subject of terrestrial interference.
- Transponders defined as 36 MHz equivalents
- Only a subset of transponders with impairments suitable to Cognitive Radio improvement.
- Transponder considered with impairments of some level as part of contracted capacity, not equal to total unusable capacity.
- Service: Enterprise/SME Broadband with 60 kbp/s average consumption, Traffic Shaper and Contention Ratio not considered.
- Influences from high EIRP and/or G/T (specific implementations) are not considered.

Target region: Sub Saharan Africa		
Total satellite supply C-band transponders:	337[1]	
Total satellite industry interfered transponders:	10	2-3%
Share of transponders suitable to benefit from Cognitive Radios:	0.30	
Total number of transponders suitable to benefit from Cognitive Radios:	6	36 MHz Transponder Equivalent
Total Mbit/s enabled by CRs	324 Mbit/s	QPSK ¾ with 1.5 bps/hz
Total additional Broadband Subscribers	5400	

Averaged across service defined in [17].

Expected benefits: Cognitive Radios for Scenario E will predominantly enhanced interference mitigation in primary and secondary spectrum allocations as present in the extended C-band specific to sub-bands and specific countries. It will enable access to otherwise unusable transponders resulting either in higher throughput or support of additional customers.

6.7 Scenario F – Satellite in Uplink/Downlink in S-band (1980 – 2010 and 2170 – 2200 MHz)

Considered use case: Handheld & Vehicular Narrowband Satellite Communications, Nomadic Broadband Satellite Communications subject to intra-system interference between the space segment and the complementary ground components (CGC) segments, at the edge of the beams, at the system inherent exclusion zones and inter-system interferences from UMTS/3G deployments in adjacent spectrum allocation.

Detailed Use Case Description:

Hybrid Satellite/Terrestrial services in the S-band utilize the MSS frequencies from 1980 – 2010 MHz in the uplink and 2170 – 2200 MHz in the downlink.

In 2008 the European Commission awarded 2x15 MHz to Inmarsat and Solaris Mobile each to launch services in these designated spectrum allocations. Major part of the services in scope has been the broadcast of multimedia services like satellite radio (SDARS [16]) to terminals with small form factors (handsets/dongles, vehicular receivers, etc.) utilizing standards as DVB-SH[14][15]. Typical hybrid network architectures applied consist of:

a.) The space segment providing with typically either spot-beam or regional beams coverage across a specific wider region as, *e.g.*, Europe.

b.) The terrestrial segment providing with a high tower/high power or a low tower/low-medium power complementary coverage in areas with difficult reception conditions in S-band.

c.) Handheld, mobile or vehicular terminals with the ability to receive the space and terrestrial segments in complementary manners, e.g. as defined in DVB-SH (A or B variant).

In DVB-SH networks, Single Frequency Networks (SFN) are being utilized, either satellite in combination with terrestrial networks (DVB-SH A) or terrestrial only (DVB-SH B) in conjunction with the satellite segment operating in another MSS frequency allocation (Multi Frequency Network – MFN).

Applied Cognitive Radio functionalities are expected to increase system throughput and/or to mitigate efficiently intra-system interference between the space and the terrestrial segments and/or between different terrestrial segments (either in SFN or MFN mode). Additionally it is expected that they would provide a higher system availability and performance due to higher antenna system gains and SNR values, thus enabling higher number of supported channels in a beam or on local level.

Theoretical examples based on a broadcast service, to be proven by field trials under realistic conditions:

Satellite Modcod w/o CR – averaged: OFDM 5 MHz, QPSK 1/3, GI ¼, 2.2 Mbit/s

Satellite Modcod with CR- averaged: : OFDM 5 MHz, QPSK 1/2, GI ¼,3.35 Mbit/s

Terrestrial Modcod w/o CR- averaged: OFDM 5 MHz, 16QAM 1/3, GI ¼, 4.4 Mbit/s

Terrestrial Modcod with CR- averaged: OFDM 5 MHz, 16QAM 1/2, GI ¼, 6.7 Mbit/s

One Audio channel: HE-AACv2 with 64 kbit/s

Two channels minimum reserved for signaling, EPG and CAS overhead

Target region: Europe		
Number of audio channels (beam) w/o CR	32	2.2 Mbit/s beam
Number of audio channels (beam) with CR	50	3.35 Mbit/s beam
Number of audio channels (local) w/o CR	64	4.4 Mbit/s beam
Number of audio channels (local) with CR	100	6.7 Mbit/s beam
Number of beams (EU27)	6	

Accordingly, as provided for a broadcast only service scenario, CR methods could increase in satellite only coverage the offered number of broadcasted satellite radio channels **from 32 to 50 – 18 channels** and would support the equivalent **of 36 additional local radio channels** broadcasted terrestrially. Due to the favorable propagation characteristics the same improvements could be anticipated for two-way voice/data services.

Expected benefits: Cognitive Radio measures will enable higher baseline system throughput, the offering of additional offerings or an increase of supported customers for bi-directional services.

6.8 Scenario G - Satellite NGSO FSS Downlink/Uplink in Ka-band (17.8 – 20.2 and 27.5 – 30 GHz)

Considered use case: Fixed, Nomadic, Maritime Broadband Satellite Communications experiencing in countries +/- 45 degrees northern or southern Latitude, subject to potential interference levels from terrestrial and Non-GSO satellite sources in Ka-band.

Detailed Use Case Description:

Satellite communications in LEO or MEO orbits differs significantly from the principles existing in the traditional methods applied for satellites in GEO orbits.

For the satellites in NGSO orbits one or several antennas are required to track and to follow the satellites. Interference between the GSO and the NGSO satellites can only occur in a relatively small belt around the equator (+/-5 degree N/S). In these zones only the primary NGSO allocations can be used without interferences, thus limiting the available bandwidth for NGSO systems by half. Still these occurrences between GSO and NGSO system are predictable due to the known orbits and thus can be mitigated with adequate planning and system layout.

Far more substantial threat to the NGSO systems operating in this frequency band would be interferences from terrestrial sources, more and more being deployed, providing either microwave based backhaul services or broadband wireless access (BWA) type of applications based on various technologies. Based on the current and planned further build out of these microwave links more and more problems for NGSO terminals are expected. Detailed impacts need to be proven by extensive trial campaigns.

As described in section 5.3.3, Cognitive Radio functionalities would be most efficiently be suited and applied to combat efficiently these interference types. This would significantly increase the availability of Ka-band terminals used, and thus enhance the possibilities to enable fixed and nomadic broadband services to be delivered with high availabilities via NGSO satellites.

Considered common parameters in analysis:

- Target region: countries +/- 45 degrees northern or southern Latitude.
- Business impact of NGSO throughput limitation +/- 5 degrees northern or southern Latitude.

Target region: See above		
Not possible to assess business impact of Ka-band Interference as O3b Networks is not yet operational.	N/A in H1/2013	Business impact is real mid-to long term for O3b Networks

Expected benefits: Cognitive Radio measures will enable for NGSO systems predominantly the interference mitigation outside scheduled perturbations due to common GSO/NGSO propagation paths. Still as with scenario B and C the use of the secondary spectrum with available Cognitive Radio measures to prevent interferences to/from FS system is seen as the main benefit.

7 Results Consolidation and Conclusions

Result consolidation

This document provided a thorough and in-depth qualitative and quantitative assessments of the applicability of Cognitive Radios in Satellite Communications for each CoRaSat scenario (see Table 8) from a satellite commercial, market, service, and business perspective.

Table 8: Recollection of investigated Cognitive Radio SatCom Scenarios

Scenario	Frequency Band	Spectrum Range	Satellite Orbit	Link Direction
A	Ka	17.3-17.7 GHz	GSO	DL
B	Ka	17.7-19.7 GHz	GSO	DL
C	Ka	27.5-29.5 GHz	GSO	UL
D	Ku	10.7-12.75 GHz 12.75-13.25 GHz 13.75-14.5GHz	GSO	DL UL
E	C	3.4-3.8 GHz 5.85–6.725GHz	GSO	DL UL
F	S	1980-2010 MHz 2170-2200 MHz	GSO	UL DL
G	Ka	17.8-20.2 GHz 27.5-30 GHz	NGSO	DL UL

(GSO: Geostationary Satellite Orbit, NGSO: Non- Geostationary Satellite Orbit, DL: Downlink, UL: Uplink)

In Table 9 all of the aspects described in chapters 5 and 6 are consolidated providing a high level summary to be considered in subsequent project documents and work-packages as a starting base for scenario selection.

Table 9: Consolidation of CoRaSat Scenario and business impact estimate

Scenario[2]	CR Main Aspects (see footnote[3] for explanations)	CR Business Impact Estimate
Scenario A	• Highest probability of CR techniques applied for findings outlined for key aspect II • Medium benefits as the potential CR measures would enable additional DL throughput for Ka-Band multibeam satellite.	+++
Scenario B	• Highest probability of CR techniques applied for findings outlined for key aspect II • High benefits for satellite footprint of Ka-band Multi-Beam system, as potential CR measures would enable substantial additional DL throughput (symmetric in combination with Scenario C).	++++
Scenario C	• Highest probability of CR techniques applied for findings outlined for key aspect II • High benefits for satellite footprint of Ka-band Multi-Beam system, as potential CR measures would enable substantial additional UL throughput (symmetric in combination with Scenario B).	++++
Scenario D	• Highest probability of CR techniques applied for findings outlined for key aspect I • Medium benefits as potential enhanced interference mitigation in Ku-band provided by CR techniques would increase SatCom resilience, overall business impact expected to be less compared to Ka-band benefits.	++

[2] Recall Table 1: Cognitive Radio SatCom Scenarios, see Chapter 3

[3] Key aspect I – Interference Mitigation, see Chapter 5.3

Key aspect II – Cognitive Radios in secondary allocation, see Chapter 5.3

Key aspect III – Cognitive Radios in primary allocation, see Chapter 5.3

Scenario E	• Highest probability of CR techniques applied for findings outlined for key aspect I • Medium benefits as potential enhanced interference mitigation in C-band provided by CR techniques would increase SatCom resilience, though overall business impact expected to be less compared to Ka-band benefits.	++
Scenario F	• Highest probability of CR techniques applied for findings outlined for key aspect III • Medium benefits, the potential business impact of CR measures would enhance performance and throughput for S-band services.	++
Scenario G	• Highest probability of CR techniques applied for findings outlined for key aspect I • Medium benefits, the potential business impact of CR measures would help to increase system throughput in problematic areas and would help to mitigate interference to/from FS for upcoming NGSO systems.	+++

Conclusions

For Scenarios A, B, C, and G, it is anticipated that future Cognitive Radio functionalities would show for Satellite Communications the highest benefits, based on the quantitative and qualitative assessments as described in chapters 5 and 6. Scenarios D, E, and F would still provide potential considerable tangible benefits for Satellite Communications too, but the overall business impact is expected to be lower compared to the previous.

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9 DEFINITION, SYMBOLS AND ABBREVIATIONS

2G/3G/4G	Second/Third/Fourth Generation Mobile Communication
3GPP	Third Generation Partnership Project
ARCEP	French Regulatory Authority
ASI	Adjacent Satellite Interference
BSM	Broadband Satellite Multimedia
BSS	Broadcast Satellite System
BWA	Broadband Wireless Access
CBw	Channel BandWidth
CENELEC	Centre for Electro Technical Standards
CEPT	European Conference on Posts and Telecommunications
CGC	Complementary Ground Component
CR	Cognitive Radio
CRS	Cognitive Radio System
DARPA	Defense Advanced Research Projects Agency
DBS	Direct Broadcast Satellite
DCA	Dynamic Channel Assignment
DEC	CEPT Decision
DL	Downlink
DTH	Direct-To-Home
DVB	Digital Video Broadcasting
DVB-H	Digital Video Broadcasting - Handheld
DVB-RCS	Digital Video Broadcasting with Return Channel via Satellite
DVB-S	Digital Video Broadcasting via Satellite
DVB-S2	DVB via Satellite version 2
DVB-T2	DVB Terrestrial version 2
EBU	European Broadcasting Union
EC	European Commission
ECC	European Communications Committee
ECO	European Communications Office
EIRP	Equivalent Isotropically Radiated Power
EMEA	Europe, the Middle East, and Africa
ERO	European Radiocommunications Office
ETSI	European Telecommunications Standards Institute
EU	European Union
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network (a.k.a LTE)
FCC	Federal Communications Commission
FL	Forward Link
FM	Frequency Management
FS	Fixed Service
FSS	Fixed Satellite Service
FWA	Fixed Wireless Access
GI	Guard Interval
GPRS	General Packet Radio Service
GEO	Geostationary Earth Orbit
GSO	Geostationary Orbit

GVF	Global VSAT Forum
HDFS	High Density Fixed Service
HDFSS	High Density Fixed Satellite Service
HTS	High Throughput Satellite
IMT	International Mobile Telecommunications
ITU	International Telecommunications Union
ITU-R	Radio communications Sector of the ITU
LAN	Local Area Network
LEO	Low Earth Orbit
LMDS	Local Multipoint Distribution Service
LSA	Licensed Shared Access
LTE	Long Term Evolution
LTE-A	LTE Advanced
MAC	Medium Access Control
MEO	Medium Earth Orbit
MSS	Mobile Satellite Service
NCC	Network Control Centre
NCF	Network Control Facility
NGSO	Non Geostationary Orbit
NRA	National Regulatory Authority
NSR	Northern Sky Research
O3b	Other 3 billion (people)
OBP	On-Board Processing
OFCOM	UK regulator for communications
PFD	Power Flux Density
P-MP	Point to Multipoint
P-P	Point to Point
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RCST	RCS Terminal
RFI	Radio Frequency Interference
RL	Return Link
RLC	Radio Link Control
RR	Radio Regulations
RSPG	Radio Spectrum Policy Group
SES	Société Européenne des Satellites
SBBS	SES Broadband Services
SGS	SES Government Solutions
SIN	Satellite Interactive Network
SFCG	Space Frequency Coordination Group
SRD	Short Range Device
TDD	Time Division Duplex
VSAT	Very Small Aperture Terminal

UMTS	Universal Mobile Telecommunication System
UL	Uplink
UTRAN	UMTS Terrestrial Radio Access Network
WG	Working Group
WP	Work Package
Xpol	Cross Polarization

10 Document History

Rel.	version	Date	Change Status	Author
0	0	09/11/2012	Document Setup	SES
0	1	14/12/2012	Amendments/Update	SES
0	2	17/01/2013	Amendment with business impact structure	SES
0	3	11/03/2013	Amendments/Update taking into account comments from internal SES, UNIS, UL and UNIBO	SES
0	4	18/03/2013	Updated integrated version	SES
0	5	28/03/2013	Updated pre-final integrated version taking into account final review comments from TAS, NTC, UNIS and UL	SES
1	0	09/04/2013	Final Version for Delivery to EC	SES

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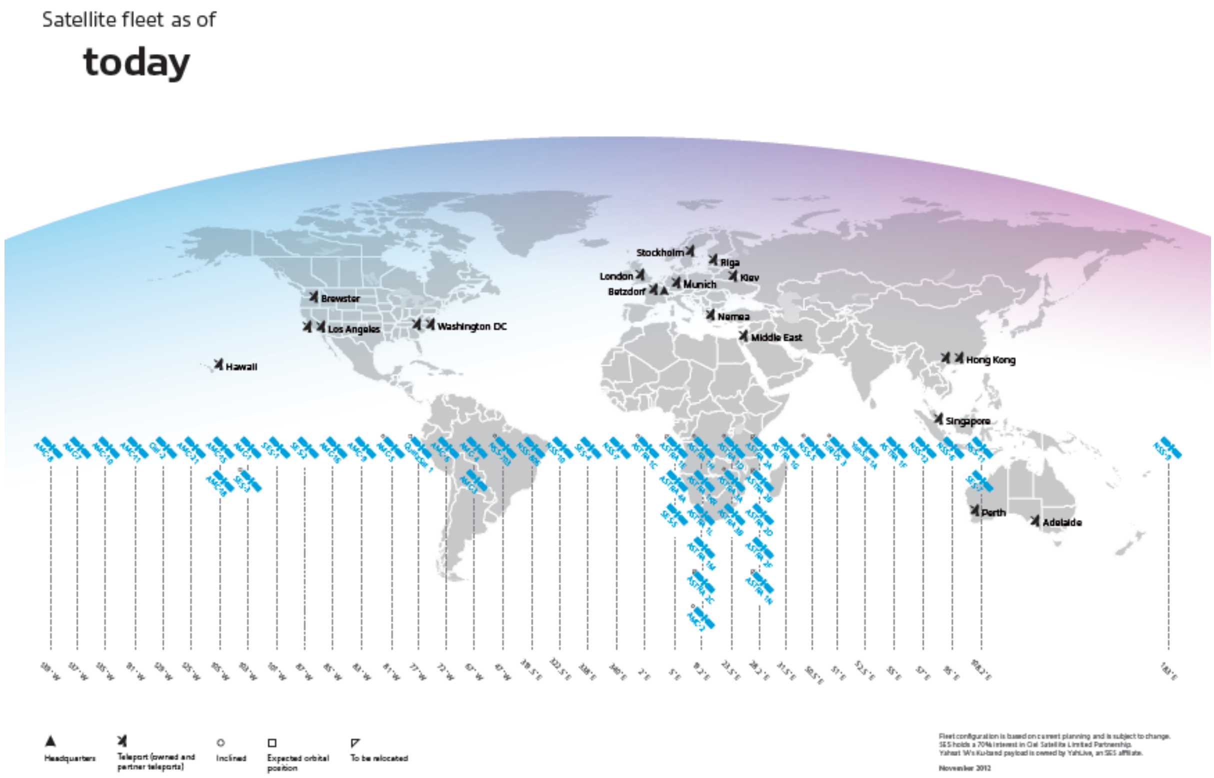
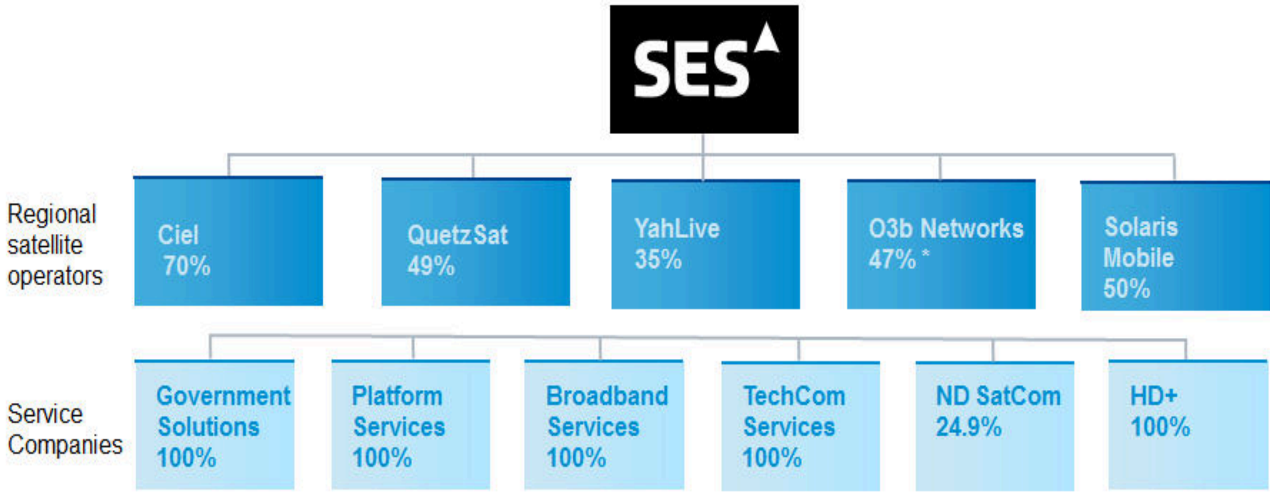
11 ANNEX I: SES COMPANY BACKGROUND

SES is one of the world's leading global satellite operators. Our satellites cover 99 % of the world's population to enable our customers to provide services to every part of the world. SES owns and operate over 50 geostationary satellites that are complemented by a network of teleports located around the globe. Each day, the world's leading broadcasters use SES satellites to deliver thousands of hours of TV programming to provide information and entertainment to hundreds of millions around the globe. SES coverage allows SES enterprise customers to provide high-speed broadband access that bridges the digital divide. Governments rely on SES connectivity to establish secure communications links to support their vital missions.



SES is headquartered in Betzdorf, Luxembourg and operate worldwide through dedicated regional teams, in 18 offices worldwide and present in all ITU regions, providing customized technical and marketing support for our customers around the world.

SES is organized in the following structure:



* on a fully diluted basis, pro forma post issuance of shares for in-kind services provided by SES

SES conducts business on a global basis, organized in three main business segments:

- Media and Broadcasters
  - Direct-to-home
  - Cable distribution (DTC)
  - Digital terrestrial TV
  - Full-time contribution
  - Occasional use / Satellite news gathering
  - Content management services
  - Internet TV services
  - Broadcast services
  - Play-out services
  - Encryption services

- Telcos and Enterprise
  - Broadband access
  - Trunking
  - Mobile backhaul
  - VSAT networks
  - Occasional use

- Government and Institutions
  - Full-time contribution
  - Occasional use
  - Bi-directional broadband access
  - Satellite programs
  - Hosted payloads
  - US Government Solutions
  - Tailored engineering services