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TECHNICAL REPORT

**System Reference document (SRdoc);
Cognitive radio techniques for
Satellite Communications operating in Ka band**

Reference

RTR/ERM-516

Keywords

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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

As the Internet traffic grows, Broadband satellite systems have to increase their capacity. Beyond space segment performance upgrade, additional spectrum is needed. Ka band is the preferred frequency band for such network. It includes exclusive spectrum allocation to FSS as well as spectrum shared between FSS and other services among which FS or FSS feeder links for BSS.

Until now, the risk associated to the use of these shared bands may have discouraged its full exploitation by satellite systems.

Cognitive radio techniques may help to minimize this risk under appropriate operational and regulatory conditions.

The present document provides an overview of typical Broadband Satellite systems targeting the Ka band shared between FSS and other services, the related market data and spectrum regulation context.

It then analyses the co-existence scenarios of FSS with FS or FSS feeder links for BSS, the enabling Cognitive Radio techniques as well as operational and regulatory conditions for a safer use of the shared spectrum.

Introduction

The present document has been developed to support the co-operation between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

Flexible spectrum utilization is a surging trend for the optimized exploitation of spectrum resources, and the cognitive approach has already demonstrated its potential for terrestrial systems, but not yet in the SatCom domain. However, SatCom are fundamental to achieve the challenging objectives of fast broadband access for everyone by 2020: 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.

The Cognitive Radio (CR) paradigm has been identified as a promising solution to conciliate the existing conflicts between spectrum demand growth and spectrum under utilization, and increase the overall efficiency of spectrum exploitation.

It is worth mentioning the 03-September-2012 Communication (2012) 478 [i.8] from the European Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the promotion of the shared use of radio spectrum resources in the internal market. This communication provides clear guidance on the ways the technology research can help the compliance of the policy objectives.

Furthermore, in 2011, the Radio Spectrum Policy Group (European Commission) issued a *Report on Collective Use of Spectrum* that noted the high demand for shared use [i.1]. The RSPG stated that: "*there is a need to progress further on appropriate regulatory mechanisms in regard to sharing of spectrum*". The key challenge for National Radio Authorities is to find appropriate ways to authorize *shared spectrum access* to a band, i.e. to allow two or more users to use the same frequency range under a defined sharing arrangement.

This justifies the relevance of the present document that analyses the potential of CR concepts in satellite networks context, in order to improve coexistence scenarios in selected spectrum allocated to SatCom services. It has been largely drafted with the support of the EU funded project CoRaSat (see [i.51]).

1 Scope

The present document identifies the potential regulatory impacts associated to the operation of SatCom solutions implementing cognitive radio techniques. In particular it addresses different scenarios in Ka band (17,3 GHz - 20,2 GHz for space to earth and 27,5 GHz - 30,0 GHz for earth to space) where the satellite communication service should not create any harmful interference to another incumbent whether terrestrial or satellite service entitled to use the same spectrum on a primary basis. It includes in particular:

- market information;
- technical information (including expected sharing and compatibility issues);
- regulatory issues.

The present document also identifies the existing related ETSI standards enabling this kind of architecture.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Point Topic: "BB-MED TN3.1, Expected Broadband demand in 'ESA Study Countries' in 2020", March 2012.

[i.2] COM(2010) 245: "A Digital Agenda for Europe, European Communication", Brussels, 19.05.2010.

[i.3] ETSI EN 302 307 (V1.2.1): "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2)".

[i.4] ETSI TS 101 545-1 (V1.1.1): "Digital Video Broadcasting (DVB);Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 1: Overview and System Level specification".

[i.5] ETSI EN 301 545-2 (V1.1.1): "Digital Video Broadcasting (DVB); Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 2: Lower Layers for Satellite standard".

[i.6] ETSI TS 101 545-3 (V1.1.1): "Digital Video Broadcasting (DVB);Second Generation DVB Interactive Satellite System (DVB-RCS2); Part 3: Higher Layers Satellite Specification".

[i.7] BATS Project.

NOTE: Available at: http://www.batsproject.eu/.

[i.8] COM(2012) 478: "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Promoting the shared use of radio spectrum resources in the internal market".

NOTE: Available at: http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/com/com-ssa.pdf.

[i.9] ECC Report 152 (September 2010): "The use of the frequency bands 27.5-30.0 GHz and 17.3-20.2 GHz by satellite networks".

[i.10] Report Recommendation ITU-R SM.2152 (09/2009): "Definition of Software Defined Radio (SDR) and Cognitive Radio Systems (CRS)".

[i.11] ERC Report 099: "The analysis of the coexistence of two FW A cells in the 24.5-26.5 GHz and 27.5 - 29.5 GHz bands".

[i.12] ECC Report 32 (October 2003): "Mechanisms to improve co-existence of Multipoint (MP) systems".

[i.13] CEPT/ERC Report 25: "The European Table of Frequency Allocations and Utilisations Covering the Frequency Range 9 kHz to 275 GHz: Lisboan January 2002 - Dublin 2003 - Turkey 2004".

[i.14] ECC Report 76 (February 2006): "Cross-border coordination of multipoint fixed wireless systems in frequency bands from 3.4 GHz TO 33.4 GHz".

[i.15] Radio Regulations, ITU-Rs incorporated by reference, Edition of 2012.

[i.16] Recommendation ITU-R SF.1719: "Sharing between point-to-point and point-to-multipoint fixed service and transmitting earth stations of GSO and non-GSO FSS systems in the 27.5-29.5 GHz band".

[i.17] ETSI EN 301 459 (V1.3.1): "Satellite Earth Stations and Systems (SES); Harmonized EN for Satellite Interactive Terminals (SIT) and Satellite User Terminals (SUT) transmitting towards satellites in geostationary orbit in the 29,5 GHz to 30,0 GHz frequency bands covering essential requirements under article 3.2 of the R&TTE Directive".

[i.18] Recommendation ITU-R S.580: "Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites".

[i.19] Recommendation ITU-R S.465: "Reference radiation pattern of earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz".

[i.20] Recommendation ITU-R F.758-5: "System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference".

[i.21] ETSI TR 102 243-1: "Fixed Radio Systems; Representative values for transmitter power and antenna gain to support inter- and intra-compatibility and sharing analysis; Part 1: Digital point-to-point systems".

[i.22] Recommendation ITU-R F.699-7: "Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz".

[i.23] ERC/REC(01)03: "European Radiocommunications Committee (ERC) within the European Conference of Postal and Telecommunications Administrations (CEPT); ERC Recommendation (01)03; use of parts of the band 27.5-29.5 GHz for Fixed Wireless Access (FWA)".

[i.24] ETSI EN 302 217-2-2: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 2-2: Digital systems operating in frequency bands where frequency co-ordination is applied; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.25] ETSI EN 303 978: "Satellite Earth Stations and Systems (SES); Harmonized EN for Earth Stations on Mobile Platforms (ESOMP) transmitting towards satellites in geostationary orbit in the 27,5 GHz to 30,0 GHz frequency bands covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.26] ETSI EN 301 360: "Satellite Earth Stations and Systems (SES); Harmonized EN for Satellite Interactive Terminals (SIT) and Satellite User Terminals (SUT) transmitting towards geostationary satellites in the 27,5 GHz to 29,5 GHz frequency bands covering essential requirements under article 3.2 of the R&TTE Directive".

[i.27] ETSI EN 301 359: "Satellite Earth Stations and Systems (SES); Satellite Interactive Terminals (SIT) using satellites in geostationary orbit operating in the 11 GHz to 12 GHz (space-to-earth) and 29,5 GHz to 30,0 GHz (earth-to-space) frequency bands".

[i.28] ETSI EN 301 358: "Satellite Earth Stations and Systems (SES); Satellite User Terminals (SUT) using satellites in geostationary orbit operating in the 19,7 GHz to 20,2 GHz (space-to-earth) and 29,5 GHz to 30 GHz (earth-to-space) frequency bands".

[i.29] ERC/DEC(00)07: "ERC Decision of 19 October 2000 on the shared use of the band 17.7 - 19.7 GHz by the fixed service and Earth stations of the fixed-satellite service (space-to-Earth)".

[i.30] ECC/DEC/(05)01: "The use of the band 27.5-29.5 GHz by the Fixed Service and uncoordinated Earth stations of the Fixed-Satellite Service (Earth-to-space)".

[i.31] ECC/DEC/(05)08: "The availability of frequency bands for high density applications in the Fixed-Satellite Service (space-to-Earth and Earth-to-space)".

[i.32] ECC Report 184: "The Use of Earth Stations on Mobile Platforms Operating with GSO Satellite Networks in the Frequency Range 17.3-20.2 GHz and 27.5-30.0 GHz".

[i.33] ERC Recommendation T/R 13-02: "Preferred channel arrangements for fixed service systems in the frequency range 22.0 - 29.5 GHz".

[i.34] ECC Report 198 (May 2013): "Adaptive modulation and ATPC operations in fixed point-to-point systems - Guideline on coordination procedures".

[i.35] ECC FM(13)126 (6 August 2013): "Summary of the WGFM Questionnaire on the 17.7-19.7 GHz Fixed Service".

[i.36] ECC Report 211: "Technical assessment of the possible use of asymmetrical point-to-point links".

[i.37] ECC Report 173 (04/04/2012): "Fixed Service in Europe".

[i.38] Recommendation ITU-R F.1245-2: "Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz".

[i.39] "Demography report 2010", March 2011, Eurostat, ©European Union.

[i.40] CEPT, FM44: "Responses of FS use of 28 GHz".

NOTE: Available at: Responses of FS use of 28 GHz.

[i.41] "Spectrum awareness and exploitation for cognitive radio satellite communications", A. Guidotti, V. Icolari, D. Tarchi, A. Vanelli-Coralli, EUCNC 2015 (www.eucnc.com).

[i.42] Recommendation ITU-R P.452-15: "Prediction procedure for the evaluation of interference between stations on the surface of the earth at frequencies above about 0.1 GHz", 2013.

[i.43] S. Cioni, G. Corazza, and M. Bousquet: "An analytical characterization of maximum likelihood signal-to-noise ratio estimation", Wireless Communication Systems, 2005. 2nd International Symposium on, pp. 827830, Sept. 2005.

[i.44] EU FP7 Project CoRaSat, Deliverable 3.3: "Adaptation and design of cognitive techniques for satellite communications", 2014.

NOTE: Available at: http://www.ict-corasat.eu/documents/deliverables.

[i.45] "Methods for the determination of the coordination area around an earth station in frequency bands between 100 MHz and 105 GHz", ITU Radio Regulation Appendix 7, International Telecommunication Union, Tech. Rep., 2012.

[i.46] P.Thompson and B.Evans: "A data base approach to extending the usable Ka band spectrum for FSS satellite systems", SPACCOMM conference, Barcelona May 2015.

[i.47] Recommendation ITU-R S.580: "Radiation diagrams for use as design objectives for antennas of earth stations operating with geostationary satellites", International Telecommunication Union, Tech. Rep., 2004.

[i.48] ITU-R Terrestrial BRIFIC.

NOTE: Available at: http://www.itu.int/en/ITU-R/terrestrial/brific/Pages/default.aspx.

[i.49] A. Vanelli-Coralli, A. Guidotti, D. Tarchi, S. Chatzinotas, S. K. Sharma, D. Kapetanovic, B. Evans, M. Lopez-Benitez, W. Tang, K. Liolis, J. Grotz, N. Chuberre, T. Gallet: "Cognitive Radio Scenarios for Satellite Communications: The CoRaSat Project," in "Co-operative and Cognitive Satellite Systems", Eds. S. Chatzinotas, B. Ottersten and R. de Gaudenzi, Elsevier, ISBN:9780127999487.

[i.50] Maleki S., Chatzinotas S., Evans B., Liolis K., Grotz J., Vanelli-Coralli A., Chuberre N.: "Cognitive Spectrum Utilization in Ka Band Multibeam Satellite Communications", IEEE Wireless Communication Magazine, vol.53, no.3, pp.24-29, 2015.

[i.51] CoRaSat Project.

NOTE: Available at: http://www.ict-corasat.eu/.

[i.52] Lagunas E., Sharma S.K., Maleki S., Chatzinotas S., Grotz J., Krause J., Ottersten B.: "Resource Allocation for Cognitive Satellite Uplink and Fixed-Service Terrestrial Coexistence in Ka-band", International Conference on Cognitive Radio Oriented Wireless Networks, CROWNCOM 2015, Doha, Qatar, April 2015.

[i.53] Sharma S.K., Lagunas E., Maleki S., Chatzinotas S., Grotz J., Krause J., Ottersten B.: "Resource Allocation for Cognitive Satellite Communications in Ka-band (17.7-19.7 GHz)", International Conference on Communications, ICC 2015, London, UK, June 2015.

[i.54] Sharma S.K., Maleki S., Chatzinotas S., Grotz J., Krause J., Ottersten B.: "Joint Carrier Allocation and Beamforming for Cognitive SatComs in Ka-band (17.3-18.1 GHz)", International Conference on Communications, ICC 2015, London, UK, June 2015.

[i.55] Digital Agenda for Europe.

NOTE: Available at: http://ec.europa.eu/digital-agenda/en.

[i.56] ETSI EN 301 751: "Fixed Radio Systems; Point-to-Point equipments and antennas; Generic harmonized standard for Point-to-Point digital fixed radio systems and antennas covering the essential requirements under article 3.2 of the 1999/5/EC Directive".

[i.57] ETSI EN 300 430: "Fixed Radio Systems; Point-to-point equipment; Parameters for radio systems for the transmission of STM-1 digital signals operating in the 18 GHz frequency band with channel spacing of 55 MHz and 27,5 MHz".

[i.58] ETSI EN 300 431: "Fixed Radio Systems; Point-to-point equipment; Parameters for radio system for the transmission of digital signals operating in the frequency range 24,50 GHz to 29,50 GHz".

[i.59] ECC Report 232: "Compatibility between Fixed Satellite Service uncoordinated receive Earth Stations and the Fixed Service in the band 17.7-19.7 GHz".

[i.60] ECC Report 241: "Enhanced access to spectrum for FSS uncoordinated earth stations in the 17.7-19.7 GHz band".

[i.61] Decision D-OCG 21/3.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

NOTE: Where possible, definitions from the ITU Radio Regulations [i.15] should be used. If there is not a definition in the ITU Radio Regulations [i.15], wherever possible, existing definitions in the ETSI TEDDI should be used rather than creating new ones (see Decision D-OCG 21/3 [i.61]).

centralized reference database: structured set of records which describe the RF transmitters characteristics of the incumbent and the cognitive radio systems

EXAMPLE: Geographical location, frequency band, EIRP, bandwidth, azimuth/elevation of the main lobe.

Cognitive Radio System (CRS): employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained in Report Recommendation ITU-R SM.2152 [i.10]

frequency sharing: sharing of a frequency band between incumbent and cognitive systems

incumbent system: system already deployed and operating in a given frequency band

spectrum sensing: mechanism which characterizes the usage of a frequency band by incumbent systems

EXAMPLE: Time slot, geographical area, frequency carrier, RF power, channel bandwidth, etc.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

f	Frequency
P	Power
R	Distance
t	Time

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACM	Adaptive Coding and Modulation
ACP	Adjacent Channel Power
ASI	Adjacent Satellite Interference
BATS	Broadband Access via integrated Terrestrial & Satellite systems
BB-MED	BroadBand Mediterranean Development
BFWA	Broadband Fixed Wireless Access
BR IFIC	BR International Frequency Information Circular
BR	Bureau des Radio-communications
BRIFIC	BR International Frequency Information Circular
BSS	Broadcast Satellite Service
CA	Channel Allocation
CDF	Cumulative Distribution Function
CEPT	Conférence Européenne des administrations des Postes et Télécommunications
CR	Cognitive Radio

dB	deciBel
dBi	decibel relative to an isotropic radiator
DVB-RCS2	Digital Video Broadcasting - Return Channel via Satellite - 2nd Generation
DVB-S	Digital Video Broadcasting - Satellite
DVB-S2	Digital Video Broadcasting - Satellite - Second Generation
DVB-S2X	Digital Video Broadcasting - Satellite - Second Generation Extension
EC	European Community
ECC	Electronic Communications Committee
ECO	European Communications Office
EFIS	ECO Frequency Information System (European Spectrum Information Portal)
EG	ETSI Guide
EIRP	Effective Isotropic Radiated Power
ERC	European Radiocommunications Committee
ESOMP	Earth Station On Mobile Platform
EU	European Union
FM	Frequency Management
FS	Fixed Service
FSS	Fixed Satellite Service
FWA	Fixed Wireless Access
GSO	GeoSynchronous Orbit
GW	GateWay
HD	High Definition
HDFSS	High Density Fixed Satellite Service
HEST	High EIRP Satellite Terminals
HPA	High Power Amplifier
HTS	High Throughout Satellite
IC	Interference Cartography
IFIC	International Frequency Information Circular
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union - Radio Sector
KPI	Key Performance Indicator
LEST	Low EIRP Satellite Terminals
LNB	Low Noise Block
LOS	Line Of Sight
MF-TDMA	Multi-Frequency - Time Division Multiple Access
MPEG	Moving Picture Experts Group
MS	Mobile Service
MSS	Mobile Satellite Service
MWS	Multimedia Wireless Systems
NCC	Network Control Centre
OFCOM	The Federal Office of Communications
P2M	Point-to-Multipoint
P2P	Point To Point
PC	Power Control
PSD	Power Spectral Density
PT	Project Team
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RA	Resource Allocation
RF	Radio Frequency
RR	Radio Regulation
RSPG	Radio Spectrum Policy Group
SCC	Satellite Control Centre
SD	Standard Definition
SINR	Signal to Interference and Noise Ratio
SIT	Satellite Interactive Terminal
SME	Small Medium Enterprise
SNORE	Signal–to–NOise Ratio Estimator
SPD	Spectral Power Density
SRR	Short Range Radar
SS	Spectrum Sensing
STM	Synchronous Transport Module

SUT	Satellite User Terminal
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TM	Transmission Mask
TTC	Telemetry, Tracking & Control
TVWS	TV White Space
UK	United Kingdom
UT	User Terminal
VSAT	Very Small Aperture Terminal
WGFM	Working Group Frequency Management
WRC	World Radio-communication Conference

4 Comments on the System Reference document

4.1 Statements by ETSI Members

No ETSI members raised any comments.

This version is preliminary. ETSI seeks guidance/feedbacks from CEPT on its content.

5 Presentation of the system or technology

This clause entails high level information such as system description, applications, new technology (if any).

The system scenario refers to the deployment of FSS earth stations in non-exclusive Ka frequency band.

It implies the coexistence of a cognitive FSS system together with incumbent systems among which FS or BSS.

The FSS system is assumed to be a geo-satellite system offering broad or multi-spot beam coverage with a frequency re-use scheme. The FSS system is described further in subsequent clause.

6 Market information

The following is extracted from the D2.2 "Broadband Technologies, Capabilities & Challenges" produced by the BATS project [i.7].

"*Point Topic produced, within the framework of the European Space Agency's project "BB-MED TN3.1, Expected Broadband demand in 'ESA Study Countries' in 2020", the broadband demand is forecast per country by 2020. Note that this study focused on commercial deployment of broadband; public support was considered separately. One of the key results of this study is that over a 20 % of premises in the current EU27 will either not be covered by or will not take-up a superfast broadband connection (i.e. > 30 Mbps) by 2020.*"

Figure 1 illustrates the superfast broadband gaps in the EU27 countries by 2020 considering both, the unavailability and the lack of take-up. Note that in many European regions more than the 50 % of households will not subscribe to or lack availability to superfast broadband.

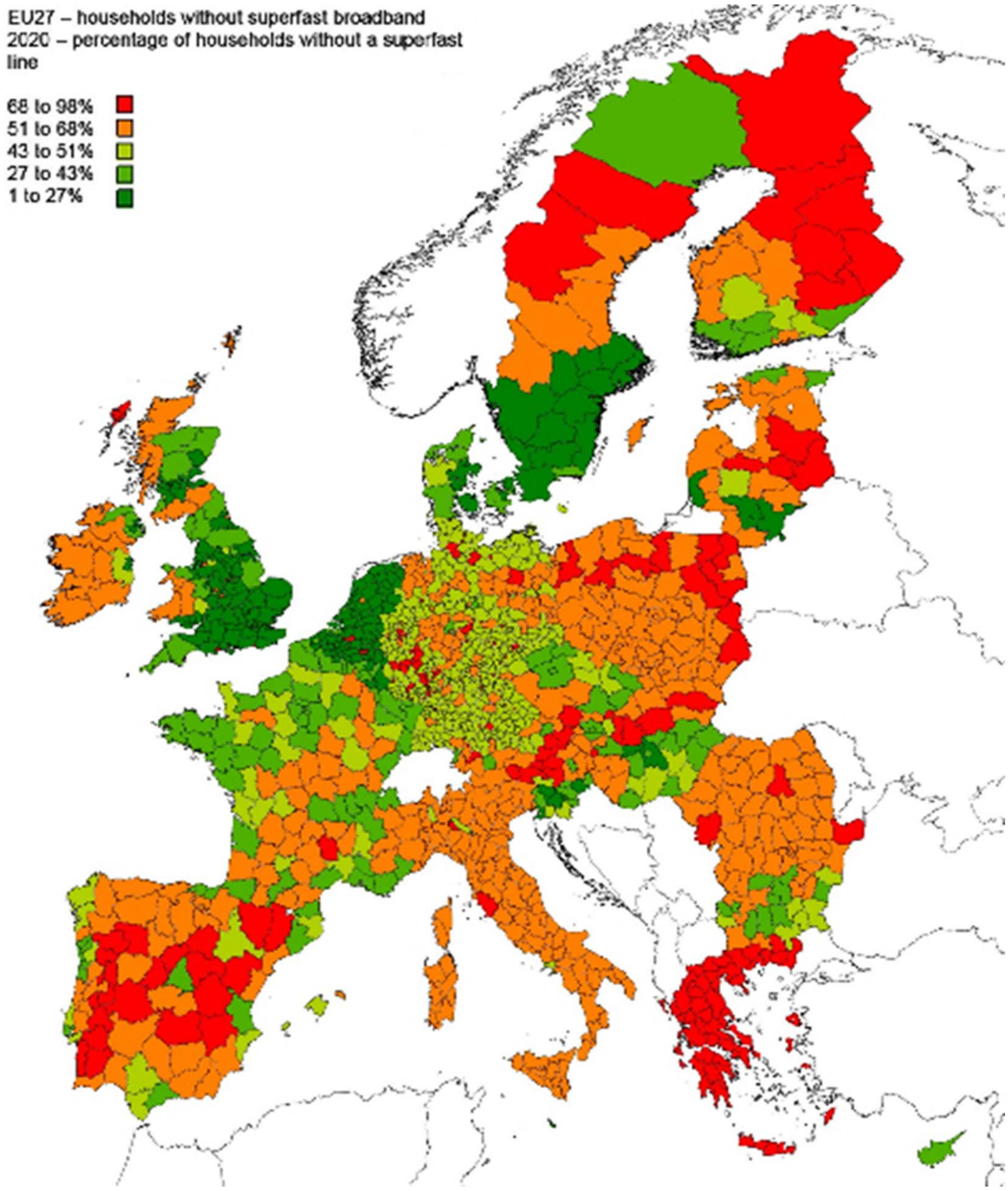


Figure 1: Superfast broadband gaps predicted for 2020 in EU27 countries [i.1]

Figure 2 shows the percentage of households in the EU27 countries and Turkey which are predicted to have access to broadband speeds above 30 Mbps by 2020. Densely populated countries like Belgium, Malta, the Netherlands, Sweden and the United Kingdom will be leading in terms of superfast broadband availability. On the other hand, the study suggests that countries especially in Eastern Europe and the Mediterranean will still be far from achieving the objectives of the Digital Agenda without public intervention [i.55]. Very few countries will exceed 90 % availability.

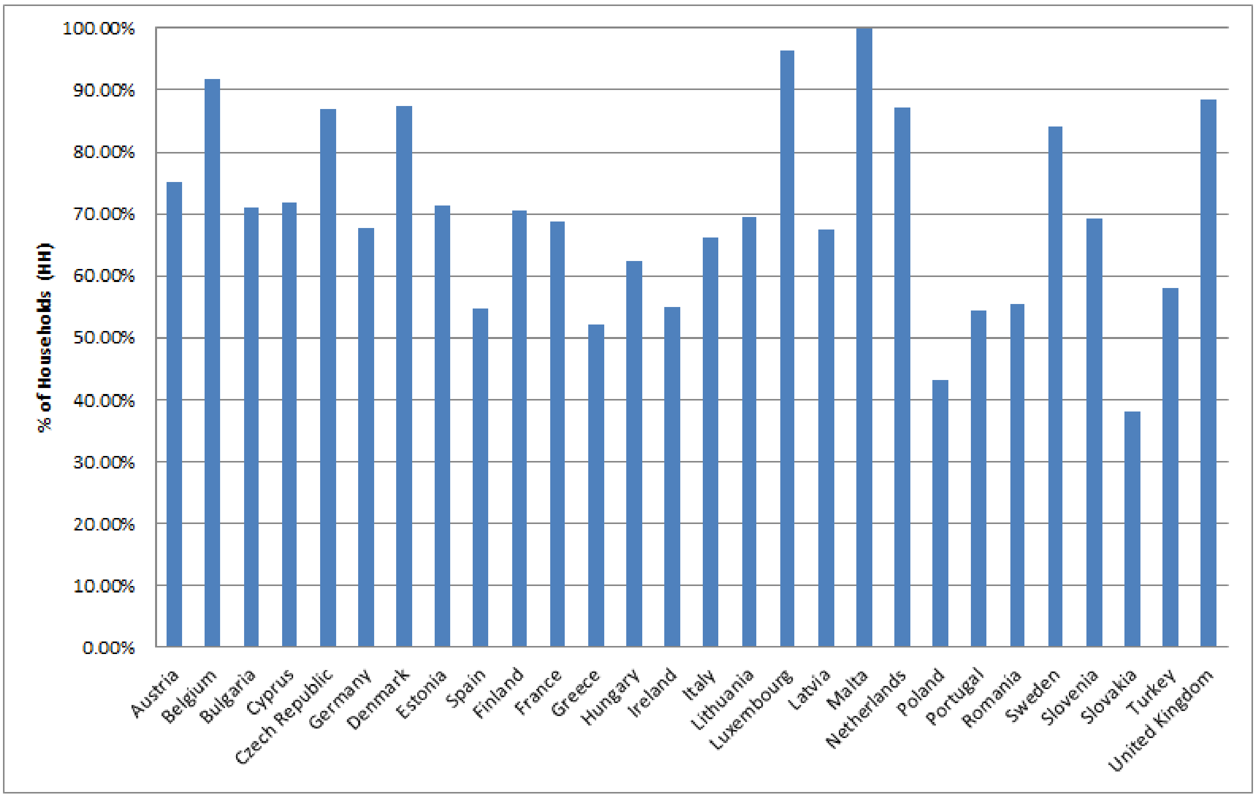


Figure 2: Superfast Broadband Availability by 2020 [i.1]

Figure 3 illustrates the take-up of superfast broadband in the same subset of countries. In other words, it illustrates the percentage of the total number of households in each country which will subscribe to superfast broadband by 2020. From the study data, one can establish that on average superfast broadband will be available to 67,8 % of households but only 53,8 % will take up the service.

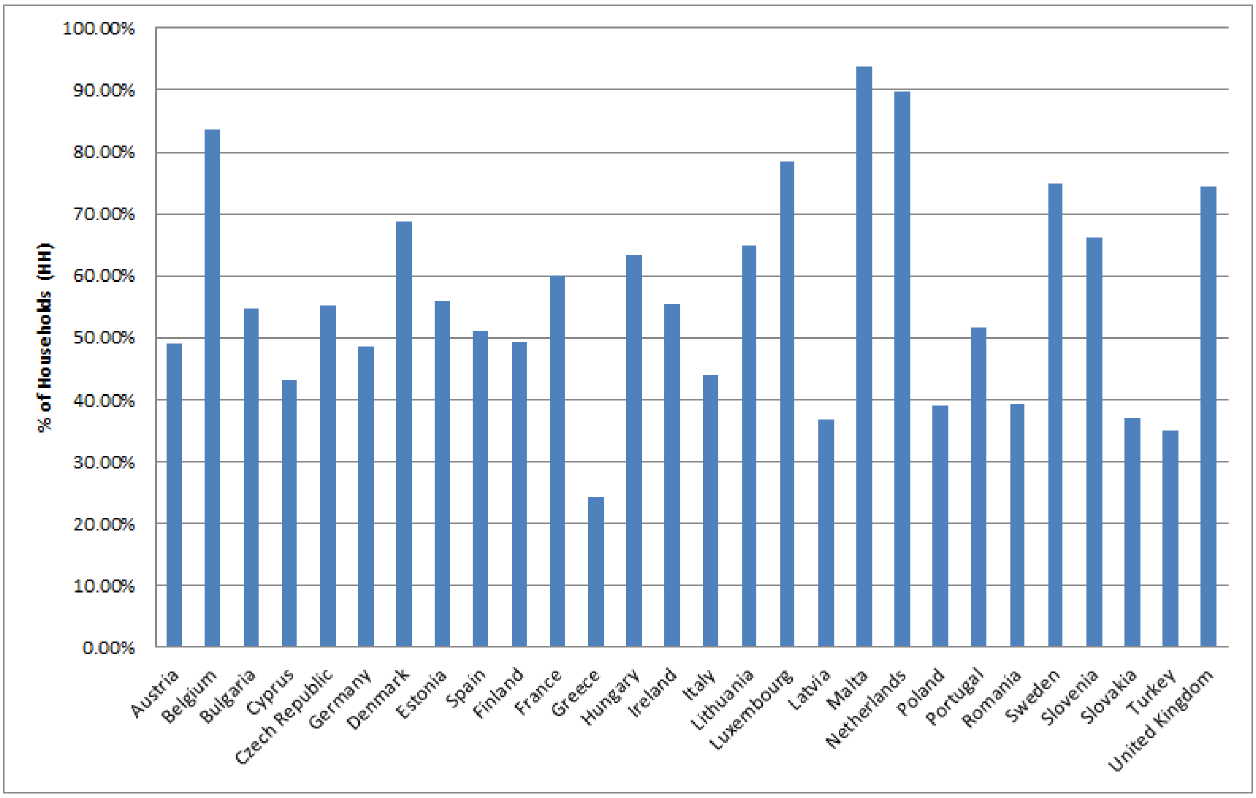


Figure 3: Superfast Broadband Take-up Penetration by 2020 [i.1]

Looking in more detail to satellite broadband service provision, figure 4 shows its addressable market (blue bars) and take-up percentage (red bars) by 2020 as established in [i.1]. In other words, it shows the percentage of households covered by satellite outside fixed and LTE intersection, and the percentage of premises which will subscribe to satellite broadband services. The study states that, on average, 14,4 % of households in E27 and Turkey will have satellite as the only available technology for contracting broadband services. However, the average percentage of total households which will take up a satellite broadband connection is 3,72 %, which are mostly located in remote areas.

Assuming 500 M of inhabitants in the Europe Union and an average of 2,4 inhabitants per households [i.39], the satellite broadband market potential corresponds to up to ~7,7 M households in Europe and Turkey in un served areas and partly in underserved areas.

Assuming an average number of 1 Million subscribers served per high throughput satellite operating in Ka band and delivering broadband access, the market represents in Europe a potential of several satellites to meet the Digital Agenda policy objective [i.2] that seeks to ensure that, by 2020, all Europeans have access to higher internet speeds of above 30 Mbps (peak rates).

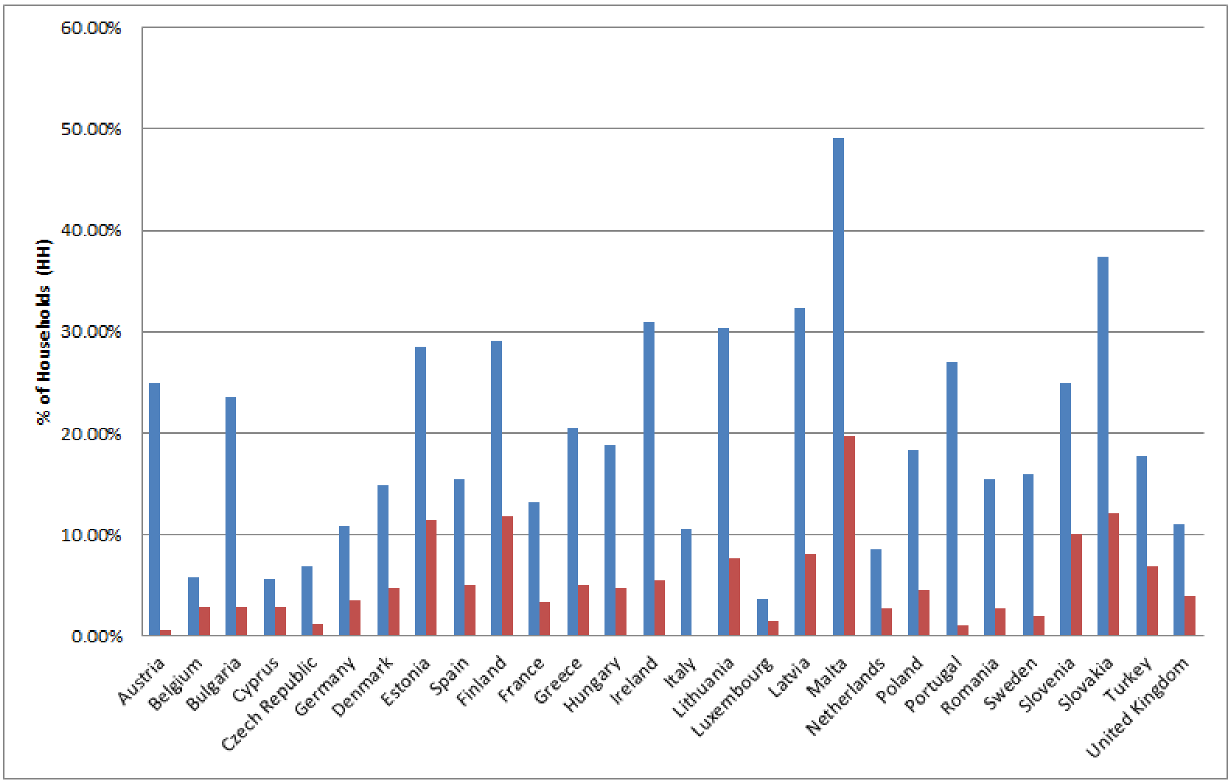


Figure 4: Satellite broadband addressable market (blue) and take-up penetration (red) by 2020

In view of this above market potential and considering the increasing bandwidth demand, there is strong interest to access extra spectrum including the chunks shared with other services. This justifies the need to explore Cognitive radio techniques in SatCom context to allow the exploitation of these shared frequency band with minimum risk of interference.

Furthermore, cognitive radio techniques are expected to have a high potential market since they can be used to alleviate some of the interferences experienced in exclusive FSS allocation:

- Cross Pol (Xpol) Interference.
- Adjacent Satellite Interference (ASI).
- Terrestrial Interference - FS to FSS.
- Earth station interference - Uplink feeder link to FSS.
- Interference to incumber users 1. - FSS to FS.
- Interference to incumber users 2. - FSS to BSS feeder link stations.

- Deliberate Interference (Jamming).

Cross Pol (Xpol) Interference: This type of interference is usually caused by incompatible modulation types transmitted in the orthogonal polarization field; poorly aligned antennas; and 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 Radio 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 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 max. levels. As another main action, the provision of additional options to access further spectrum provided by future Cognitive Radio 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 its potential application of dynamic adaptation measures to enhance the availability of satellite transmissions.

Earth station interference - Uplink feeder link to FSS: The feeder link uplink Earth stations (incumbent users) may cause harmful interference to cognitive FSS users in the shared frequency bands.

Interference to incumber users 1. - FSS to FS: The cognitive FSS users may cause harmful interference to FS services in the shared frequency bands. The FS receiver towers (terrestrial link stations) may receive the FSS signal using the same frequency band and under the usage of the shared common bands.

Interference to incumber users 2. - FSS to BSS feeder link stations: The cognitive FSS users may cause harmful interference to incumbent users of the bands used by BSS feeder link stations, received by the satellite on this incumbent network and be received as harmful interference by the users of the BSS feeder link network on the downlink.

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.

7 Technical information

7.1 Detailed technical description

7.1.1 System architecture overview

The example system analysed in this clause refers to a satellite network operating in the Ka band and providing broadband access to user terminals. It supports a wide range of services among which Internet services (email, file sharing, P2P, P2M, voice and video-conferencing, video download or streaming in SD, HD or 3D format), backhaul services as well as telehealth, elearning and ecommerce and remote monitoring services.

Such network is typically addressing user terminals:

- fixed terminals on the roof of a residential home or a SME premises in rural or remote areas;
- mobile terminals on a mobile platforms such as trains, vessels or aircrafts (ESOMPS).

The satellite network provides connectivity between the user terminals and anchor gateways, which are also connected to the Public Internet. An anchor gateway can typically serve up to ten thousands of user terminals (professional market) or up to hundred thousand of terminals (consumer market) in a star topology. The system's geostationary satellite also named "high throughput satellite" typically generates between several tens and several hundred beams to achieve high transmission and reception gains towards the user terminals distributed across its service area. Multi beam coverage allows to implement a frequency re-use scheme which allocate a given frequency band and polarization to a "group" of non-adjacent beams. Typically a frequency re-use factor of 4 is adopted in such multi beam satellite network.

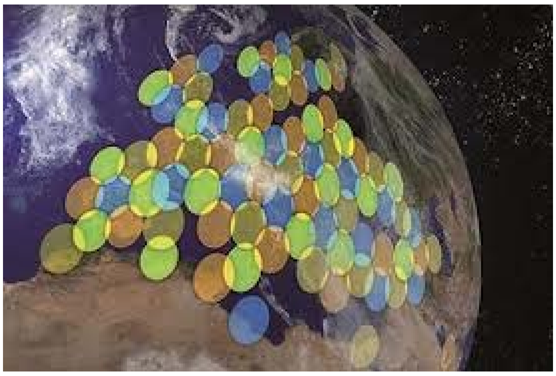


Figure 5: Illustration of a frequency re-use pattern in a multi beam satellite (reuse factor 4)

In order to accompany the ever increasing demand for bandwidth and cost per Mbps reduction, the satellite throughput has to be maximized. This can be achieved by:

- Reduction of the beam width, typically below 0,4°.
- Increase of the frequency band allocated per beam, by using for example non-exclusive FSS frequency bands that are shared between FSS and other services (e.g. FS or BSS in this system scenario).
- Efficient waveforms robust towards signal degradation thanks to interference mitigation techniques including ground-based signal processing.

In the present document, it can be assumed that the satellite network is based on state of the art radio interfaces, such as:

- Forward link: TDM based DVB-S2 [i.3] and its upcoming evolution DVB-Sx.
- Return link: MF-TDMA based DVB-RCS2 [i.4], [i.5] and [i.6].

(or similar radio interfaces, which operate in a comparable manner and have similar functionality but could use proprietary air interface technologies.)

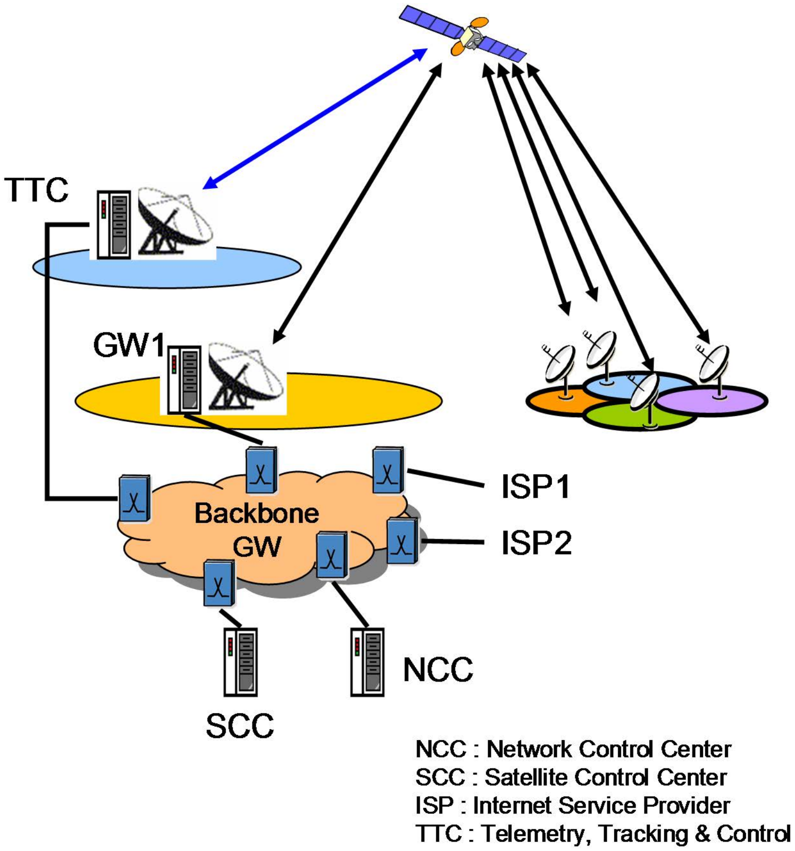


Figure 6: Overall satellite network architecture

As depicted above, the system encompasses:

- A space segment composed by at least one geostationary satellite. Each satellite allows to establish bi-directional links between a set of gateways (GW) and the user terminals, thanks to a set of feeder and user beams.
- A ground segment which includes:
  - A set of anchor gateways which are in charge of transmitting and receiving data, control and management traffic to or from the user terminals.
  - A Telemetry Tracking and Control (TTC) station to transmit and receive information to or from the space segment.
  - A Satellite Control Centre (SCC) which aims at monitoring and controlling the space segment.
  - A Network Control Centre (NCC) in charge of managing the set of gateways.
- A user segment which is composed of a set of user terminals. The user terminal is connected to a local area network in order to deliver the useful traffic to the end user. Each terminal includes a reception and a transmission RF chains. The size of the terminal dish is typically 75 cm, while its power ranges between 2 and 4 W.

The network connecting the anchor GWs and the user terminals follows a star topology. A backbone network, which is not part of the access network, is in charge of interconnecting the SCC, the NCC, the GWs, the TTC and the Internet Service Providers (ISPs), namely to convey management and control traffics.

A forward (respectively return) link is divided into a feeder (respectively a user) uplink and a user (respectively a feeder) downlink.

It is considered 2 possible frequency plans based on a 4 color scheme.

A nominal frequency plan is illustrated in figure 7:

- The **user downlink** is assigned the exclusive FSS band (namely [19,7 - 20,2] GHz) and a portion of the Ka-band spectrum primarily shared with BSS (namely [17,3 - 17,7] GHz) and FS (namely [17,7 - 19,7] GHz). Thus the frequency plan assigned to the user downlink features 2,9 GHz of spectrum on two orthogonal circular polarization. This corresponds to a 1,4 GHz spectrum allocation per beam, according to a regular four-color scheme (including a frequency guard band between 18,7 GHz and 18,8 GHz). This enables an "increase" of the useful spectrum by 5,6 (= 1,4 / 0,25 GHz) with respect to systems operating in the exclusive FSS band only.

- Regarding the **user uplink**, the system uses the exclusive FSS band (namely [29,5 - 30] GHz) as well as the band [27,5 - 29,5] GHz shared with FS. Thus the frequency plan assigned to the user downlink features 2,5 GHz of spectrum on two orthogonal circular polarization. This corresponds to a 1,25 GHz spectrum allocation per beam, according to a regular four-color scheme. This enables an "increase" of the useful spectrum by 5 (= 1,25 / 0,25 GHz) with respect to systems operating in the exclusive FSS band only.

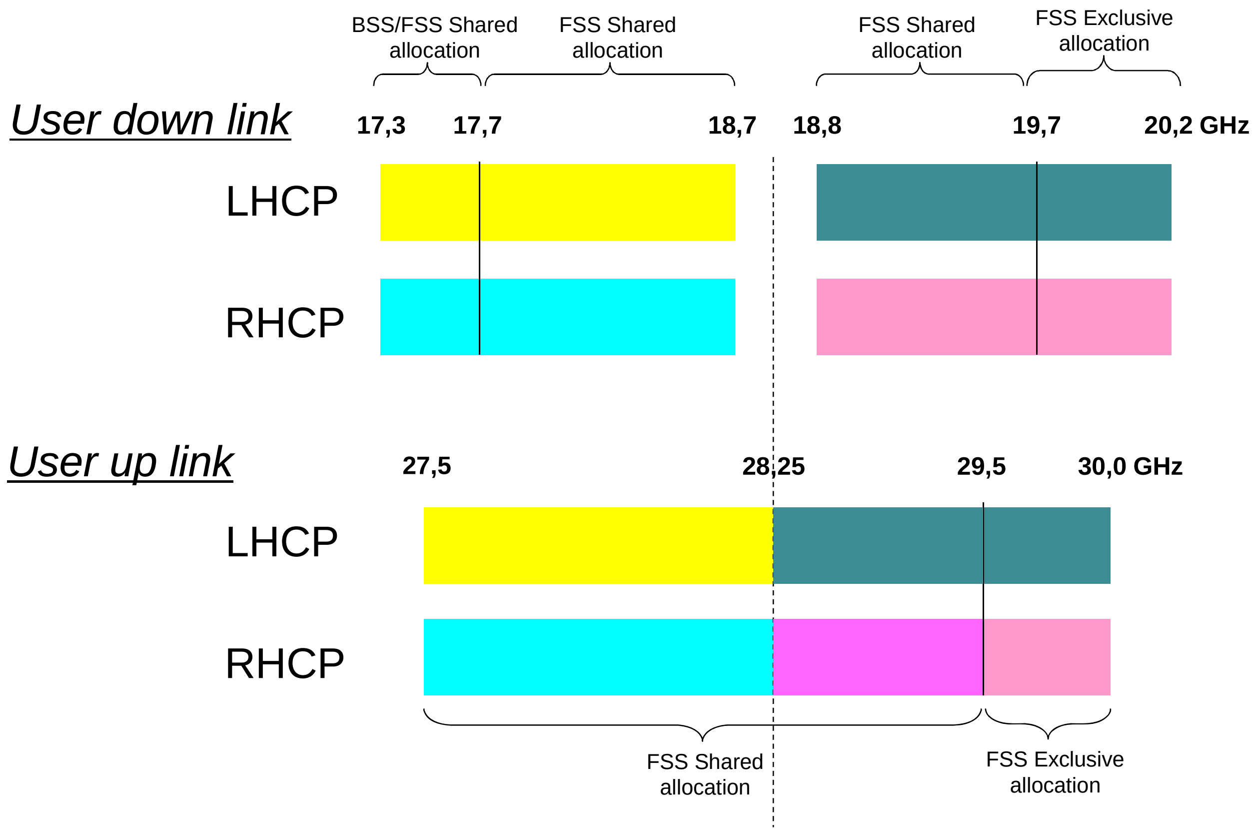


Figure 7: Nominal frequency plan for the FSS satellite system

An alternative frequency plan illustrated in figure 8:

- The **user downlink** is assigned the exclusive FSS band (namely [19,7 - 20,2] GHz) but also a portion of the Ka-band spectrum primarily shared with BSS (namely [17,3 - 17,7] GHz) and FS (namely [17,7 - 19,7] GHz). Thus the frequency plan assigned to the user downlink features 2,9 GHz of spectrum on two orthogonal circular polarization. This corresponds to a 1,4 GHz spectrum allocation per beam, according to a regular four-color scheme (including a frequency guard band between 18,7 GHz and 18,8 GHz). This enables an "increase" of the useful spectrum by 5,6 (= 1,4/0,25 GHz) with respect to systems operating in the exclusive FSS band only.

- Regarding the **user uplink**, the system uses the exclusive FSS band (namely [29,5 - 30] GHz) as well as the band [28,4465 - 28,9465] GHz shared with FS, plus the band [27,5 - 27,8285] GHz. Thus the frequency plan assigned to the user downlink features 1,3 GHz of spectrum on two orthogonal circular polarization. This corresponds to a 500 MHz spectrum allocation per beam, according to a regular four-color scheme. This enables an "increase" of the useful spectrum by 2,6 (= 1,3 / 0,5 GHz) with respect to systems operating in the exclusive FSS band only.

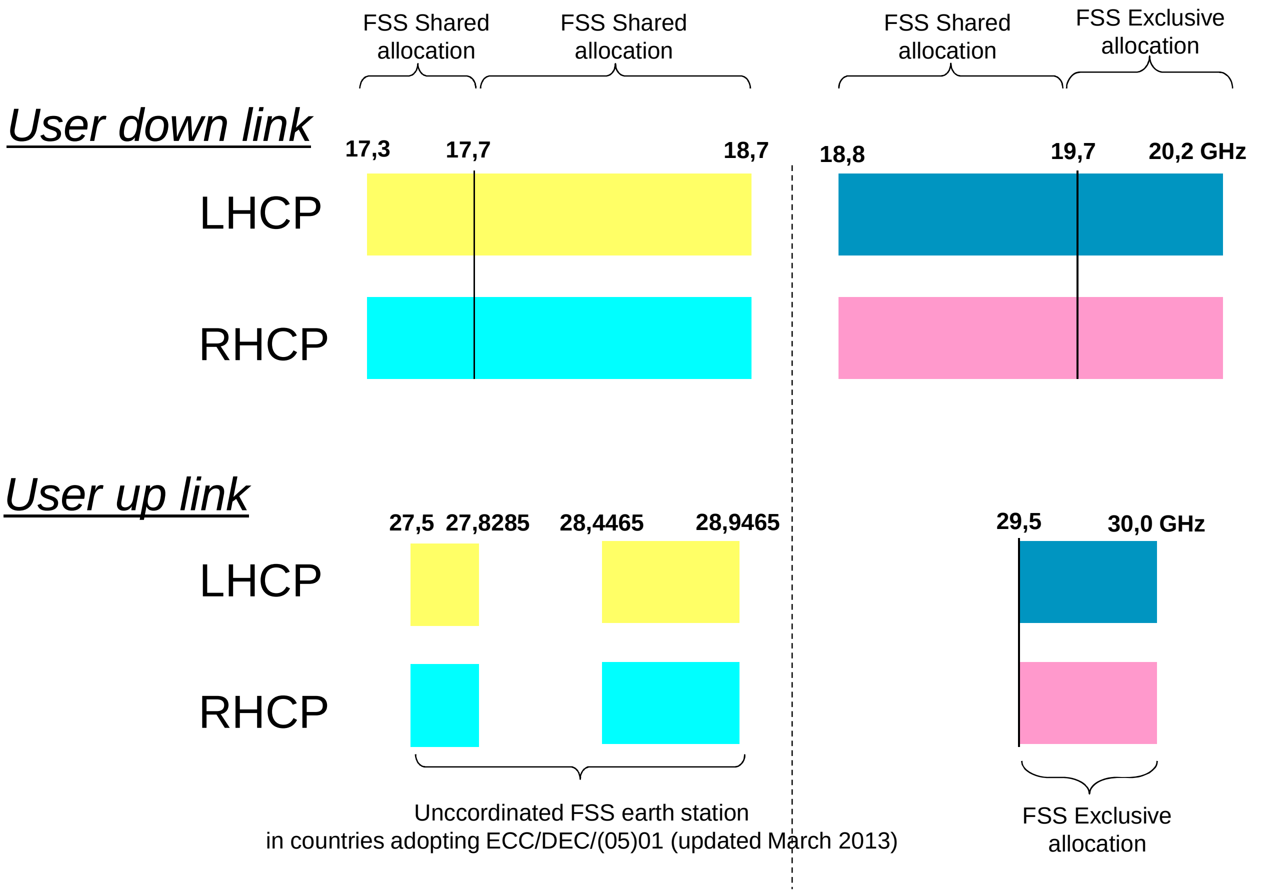


Figure 8: Alternative frequency plan for the FSS satellite system

In both cases, it is assumed that the feeder link uses spectrum at Q (downlink) and V (uplink) bands. Portions of Ka-band that are not used on the user uplink, could also be used so as to maximize the forward capacity per gateway, and thus reduce the number of gateways. The satellite model chosen is considered to be representative of future Ka band HTS system for EU coverage. Although the capacity calculations are dependent on the model chosen the techniques employed herein are considered to be widely applicable to all such satellites.

The use of cognitive radio techniques in the network is expected to allow the use of frequency bands shared with FS and BSS in order to increase the overall system throughput at comparable QoS than a satellite network operating in exclusive FSS bands only.

7.1.2 Frequency band scenarios

From the above frequency plans, different interference scenarios are defined as indicated below [i.49] and [i.50].

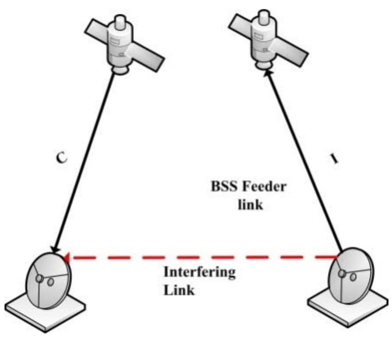


Figure 9: Scenario A

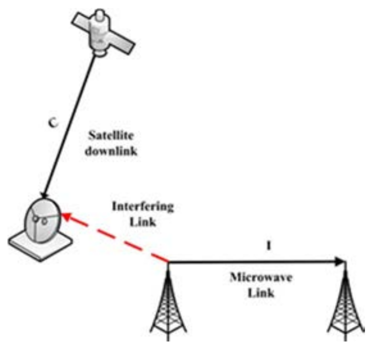


Figure 10: Scenario B

In Scenario A (coexistence of FSS downlink with BSS feeder links in 17,3 GHz - 17,7 GHz), the main issue is the coordination of cognitive FSS terminals with the incumbent BSS uplinks. Since the number of BSS feeder link sites is small, for example 8 in UK, accurate information about the BSS feeder links can be easily acquired. In this scenario, dynamic sharing techniques may be redundant. A simple coordination mechanism based on the protection areas can be implemented in order to provide cognitive access to the FSS terminals Furthermore, existing ITU models or their modified versions can be investigated in order to design protection zones around the existing BSS feeder stations.

In Scenario B (coexistence of FSS downlink with the FS links in 17,7 GHz - 19,7 GHz), FS databases can be a very useful step in order to reduce or even eliminate the complexity of wideband sensing across large geographical areas. To establish such a database, a number of parameters of the FS links should be taken into account. These parameters can be used to verify locations at which FSS reception is not going to be interfered by the FS. The FS database information is in this case used to verify whether the FSS location is in a cognitive zone where interference from the FS links may exceed a given threshold and therefore the FSS terminal may be subject to unacceptable levels of interference. Since the number of FS links is larger (estimated over 300 000 FS links in Europe in 2012, according to ECC Report 173 [i.37], and subject to changes over time) in comparison to the BSS feeder links in Scenario A, the feasibility and practical arrangements of obtaining the FS database accurately for the purpose described above needs to be investigated further. The FS station information itself may not be necessary to be released to the FSS user/operator by the administration and a database user interface may provide the necessary information for a dedicated FSS earth station location in question, thus avoiding data protection and non-public information issues. If there exist clear gaps in the terrestrial channel occupancy, then it would be possible to straightforwardly apply the database approach. In this context, another promising technique for avoiding harmful interference is sensing the FS transmission. For this purpose, the knowledge on the characteristics of FS links such as power, directivity and bandwidth is important in order to determine the correct sensing threshold. If prior information about the FS link parameters is not available, one needs to explore blind sensing and avoiding schemes. When a FSS terminal detects interference from the FS transmitters, the FSS system need to apply some cognitive actions such as switching to exclusive bands, resource/carrier allocation techniques or beamforming in order to achieve the desired QoS of the cognitive FSS link. The aforementioned cognitive actions can be selected depending on the allowable complexity level of implementation and desired performance level.

In Scenario C (coexistence of FSS uplinks with FS links in 27,5 GHz - 29,5 GHz), the main issue is the protection of FS receivers from the FSS uplink transmission. Within Europe the band is segmented between FS and HDFSS usage and for most systems the use of the HDFSS plus the exclusive band should provide adequate up link capacity but the HDFSS band should be protected for satellite use. For Ka band gateways operating in this band, the coordination process is simpler since they are a few in numbers. Should there be a future demand for additional up link capacity from a large number of FSS user terminals similar techniques to those adopted for scenario's A and B can be adopted. In these cases the interference maps will be from the FSS into the FS receivers which have to be protected. Consequently, based on the interference maps or available databases plus a resource allocation scheme the EIRP of the FSS can be controlled to ensure protection to the FS. Furthermore, in the regions where FS deployment is sparse, pre-coordinated areas can be investigated in order to deploy the FSS terminals.

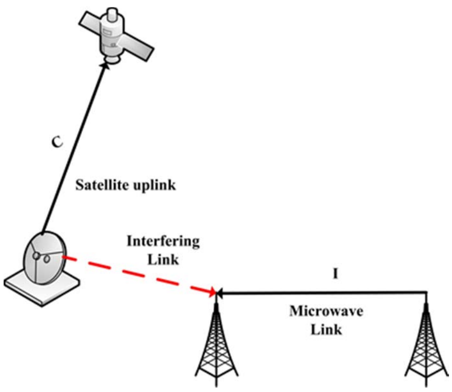


Figure 11: Scenario C

7.1.3 Principles of cognitive radio techniques for SatCom operating in Ka band

In the Ka band, the following three different Cognitive Radio principles can be used for allowing the spectral coexistence of the cognitive FSS system with the incumbent FS/BSS systems:

(i) **Pre-coordinated areas:** The coexistence mechanism based on pre-coordinated areas is simple and can be applied simply using the prior knowledge about the locations of incumbent terminals, hence no need of creating a database. For example, in rural areas, FS deployment is sparse while the FSS services are more likely to be used in these areas. In this case, one can design simple pre-coordinated areas around the existing FS links beyond which uncoordinated FSS earth stations can be deployed.

(ii) **FS databases/Exclusion Zones:** Database coexistence mechanisms require prior information about the incumbent terminals' locations, directivity, power levels, activity levels, etc. Some of this information can be obtained from regulators/operators and some information may need to be obtained with the help of spectrum sensing. In this context, the database approach could also be used as a preliminary step in order to avoid wideband sensing across large areas. Exclusion Zones can be considered as a simpler method related to the database which only needs to design spatial spectral gaps based on the geographical region. In this approach, optimized FSS channel assignment can be employed based on the accurate calculation of interference based on geographical and spectral distribution i.e. creating an interference cartography (IC) map.

(iii) **Dynamic Frequency Sharing:** It can be applied by putting intelligence into the FSS terminals in such a way that they can sense interference and adapt transceiver parameters in order to avoid the interference. Dynamic access by the cognitive system can be implemented by continuously monitoring the vacant bands through periodic sensing and adaptation.

7.1.4 Cognitive radio solutions

7.1.4.1 Solution types

Cognitive Radio (CR) solution is an adaptive, intelligent radio and network technology aware of its environment that can automatically detect available channels in a wireless spectrum and change transmission parameters enabling more communications to run concurrently and also improve radio operating behavior.

In general the cognitive radio solution may be expected to use parameters such as channel occupancy, free channels, the type of data to be transmitted and the modulation types that may be used. It should also take into account the regulatory constraints, and in some cases the geographical constraints.

In establishing appropriate Cognitive Radio Solutions the Cognitive Radio Principles outlined in clause 7.1.2 are implemented namely:

1) Pre-coordinated areas

2) FS Databases/Exclusion Zones

3) Dynamic Frequency Sharing including features such as Sensing and Beamforming

These principles do not independently map into solutions and consequently the solutions detailed below incorporate a mix of the principles. There are three main types of cognitive radio solutions considered appropriate for satellite systems, [i.41]:

1) **Spectrum Awareness**, which aims at identifying bands that can be accessed on a shared basis and the related interference levels, which are needed to define the achievable Quality of Service (QoS).

2) **Spectrum Exploitation**, which defines advanced cognitive techniques to exploit the bands identified by spectrum awareness algorithms.

3) **Advanced Interference mitigation** techniques, to increase further the level of protection of cognitive FSS terminals from incumbent terminal transmission or vice versa.

7.1.4.2 Spectrum awareness

Spectrum awareness solutions aim at identifying bands that are available for cognitive transmissions, and provide information on the interference level on these bands so as to define the achievable QoS. Spectrum databases and interference estimation are discussed and assessed in the following. These solutions implement the principles of "Pre-coordinated areas", "FS Databases/Exclusion Zones" as well as Dynamic Frequency Sharing through sensing techniques.

Data base Approach

A spectrum database includes operational characteristics and locations of the potential interferers. In particular, a database related to satellite terminals also needs to store information on the azimuth and elevation angles. This information can be exploited by means of accurate propagation and equipment models, as well as propagation path characteristics, and provide an assessment of the interference levels at a given location (at the FSS terminal, specifically). Information on operational parameters and locations of BSS and FS systems are held by national administrations and are needed so as to implement a spectrum database in the proposed scenarios.

When such information is available, it can be processed by an interference modelling engine that provides the interference levels at each given location. In a particular interference modelling, the Recommendation ITU-R P.452-15 modelling procedure can be used, which describes how to evaluate the path loss between stations, also exploiting terrain databases [i.42]. This Recommendation includes all of the propagation effects present between 0,1 and 50 GHz, earth surface effects, terrain height, bandwidth overlapping, etc. For the specific implementation adopted herein the interference level that is provided as output of the proposed engine represents the long-term interference, i.e. the interference that is 10 dB under the noise floor for at least 20 % of the average year. Note that short term additional interference can be handled by ACM technique.

The output interference level is then compared to the long term interference threshold for FSS reception defined by ITU-R in Appendix 7 of the Radio Regulations [i.15], which is -154 dBW/MHz. This procedure is performed on a carrier-by-carrier basis for each location of the considered area. Once the interference is determined, the cognitive gateway can decide to assign a new carrier either in another part of the shared band or in the exclusive band.

Spectrum Sensing - Signal to interference and noise measurement

A database approach, although very efficient, requires knowledge on incumbent stations, which might be confidential for some countries. Moreover, even in countries where such information is available, the database approach does not allow to adapt to short-term variations in spectrum occupancy. To cope with this, a Signal-to-Interference plus Noise Ratio (SINR) estimation algorithm can be implemented. The Data Aided SNORE (DA-SNORE) algorithm is a possible interference estimator [i.43]. It requires that the cognitive earth terminal is equipped with a receiving chain able to scan all frequencies of interest with a sensing sub-band equal to 36 MHz, which is the typical bandwidth of DVB-S2 and DVB-S2x standards [i.3], used by the cognitive satellite system. A possible algorithm, is described in [i.44]. It is based on the knowledge of the pilot blocks of the DVB-S2 standard. Measures need to be taken to ensure that the SINR reflects the presence of FS interference only by excluding rain fades and any self-interference within the satellite system itself (from adjacent beams and carriers).

7.1.4.3 Spectrum exploitation

Spectrum Exploitation solutions aims at allocating to cognitive FSS terminals, the usable radio resources identified by spectrum awareness. These solutions implement the principles of Dynamic Frequency Sharing.

It refers for example, to agile frequency Channel Allocation (CA) based upon interference at the user terminals.

Channel allocation

The CA module assigns carriers to each user based on two main objectives:

i) maximizing the overall throughput;

ii) maximizing the availability.

Such Spectrum Exploitation approaches can use database derived interference levels and/or measured and processed SINR values as inputs to the algorithms. For example, in the former case, the SINR of each user over each carrier is exploited to compute the achievable rate, and the Hungarian algorithm is used to maximize the system sum-rate [i.52] and [i.53]. As for maximizing the availability, the minimum SINR demand is added as a constraint to the previous problem.

It may be combined with link parameters adaptation to improve tolerance to interference at specific terminal locations.

7.1.4.4 Advanced Interference mitigation techniques

- Additional interference mitigation approaches can be adopted. Examples are:-Use of site shielding and clutter loss
- Beamforming to reject interference

Site shielding technique

Careful installation of the earth station taking advantage of the terrain and the use of site shielding can provide typically up to 20 - 30 dB protection with respect to a co frequency transmitter in the vicinity

Beamforming

A beamformer is a spatial filter which operates on the outputs of an antenna array in order to form a desired beam pattern [i.54]. The signals induced at the different elements of the array are combined to form a single output of the array. The beamforming operation can be divided into the following two steps (i) synchronization, and (ii) weight-and-sum. The synchronization step ensures the coherent transmission or reception of the signals from the different antenna elements and the weight-and-sum step determines and controls the steering direction towards the intended receiver as well as controls the beamwidth of the mainlobe and the characteristics of the sidelobes. Beamforming techniques can be implemented either in the terminal-side or in the satellite-side. It should be noted that the implementation of a beamforming technique requires a significant upgrade in the existing FSS system. In the terminal-side beamforming, a major upgrade in the terminal side is needed since a terminal equipped with multiple antennas is required to create a desired beam pattern.

Similarly, at the space segment, it requires a significant upgrade in the payload subsystem since it should be able to employ full frequency reuse and perform advanced signal processing such as precoding.

7.1.5 Mapping of cognitive radio solutions to the scenarios

The satellite network described in clause 7.1 operates in Ka band spectrum chunks allocated to satellite services. Some of the spectrum chunks are shared with incumbent services (e.g. Fixed Service).

In order to make best possible use of the available spectral resources and fulfil the service availability requirements, the network implements a selection of spectrum awareness and spectrum exploitation techniques among the one described in clause 7.1.2.

The types of techniques will depend on the frequency band scenarios A [17,3 GHz - 17,7 GHz], B [17,7 GHz - 19,7 GHz] and scenario C [27,5 GHz - 29,5 GHz] and their respective regulatory context as well as on the forward or return link to communicate with each terminal.

The cognitive satellite network generates a set of beams. For each beam, a spectrum chunk exclusively allocated to satellite services and a spectrum chunk shared with another incumbent service (e.g. Fixed Service) are assigned. This allows to ensure service availability for terminals in adverse interference context from incumbent service.

Forward link (Scenario A and B) - Database, spectrum sensing and channel allocation

In scenario A incumbent BSS transmitters, and in scenario B FS transmitters create interference into the FSS downlink hence affecting the reception of FSS terminals, and consequently the efficiency and performance of the Ka-band satellite system.

For this, spectrum awareness techniques are recommended to acquire knowledge about the incumbent transmitters characteristics:

- Regulatory data bases provide total or part of the incumbent transmitters characteristics (location, frequency band, RF power, bandwidth, direction, etc.). This information can be used to avoid or minimize the negative effect of incumbent transmitters on the cognitive receivers. This is possible given that BSS and FS transmitters are usually subject to long term deployment. This means that a database access is considered feasible during the FSS terminal planning or provisioning phase with the aim to avoid any harmful interference from the incumbent FS transmitters or BSS Earth Station deployments.

- Spectral sensing methods based on existing system trackers such as the signal to noise and interference ratio (SINR) measurements to cope with incorrect/incomplete data base or unexpected change of the incumbent transmitter context. These are potentially already available or can be added to the system with a minimum change. It should be noted that no specific knowledge of the incumbent transmitters is necessary.

- A combination of both techniques is envisaged as these are complementary approaches that may be used together. The database approach may lack up-to-date information or could be based on obsolete data, which can be complemented by spectrum sensing. Furthermore the spectrum sensing approach alone is considered not fully sufficient to fully address the system requirements because the incumbent user may use different transmission standards and physical layer parameters and a collaboration between the incumbent user and the cognitive user is not considered at this stage.

The FSS satellite system network is designed to control all transmissions from a central Network Control Centre (NCC), this includes forward transmissions with all terminals. This NCC transmission controller acts as intermediate interface to the regulatory databases and spectrum sensing (SS) based on transmission parameters such as signal to noise ratio and signal power for the spectrum awareness of the incumbent transmitters.

Assuming DVB-S2 or DVB-S2X with ACM on the forward link of the satellite system, a change of carrier is performed via the NCC using the MPEG tables to redirect the FSS terminal to return to another forward link carrier. This dynamic channel allocation mechanism is a proven working mechanism for the FSS network that can be built on DVB-RCS2 compliant network access mechanism.

Return link (Scenario C) - Database, Channel Allocation and transmit power adaptation

For the scenario C [27,5 GHz - 29,5 GHz] on the return link, the identified constraint in the usage of the band by the satellite FSS network is the capability to control the interference power at the input to the FS receivers that may operate in the vicinity of the transmitting FSS terminals.

The return link of the Satellite system is based on DVB-RCS2 or equivalent mechanisms, which allow the flexible configuration of frequency and power.

A regulatory database can also be used in the scenario C context to inform the FSS satellite networks about the locations of the incumbent FS link receivers and their orientation and receive parameters.

The controller in the NCC has to ensure that all return link transmission plans respect the interference limitation at the known FS link inputs to each identified interferer.

For this purpose the considered approach is that the terminals within a certain cognitive zone (distance within the surroundings of the FS receiver) are allocated to the exclusive bands of the return link capacity group.

In this manner the FS receiver input interference limit is well respected and the aggregate interference in the FS link is kept under control.

This approach, based on the frequency channel allocation techniques as defined in DVB-RCS2 and on an interface to regulatory databases is a mature and conservative approach that relies only on the accuracy of the database information.

All FS receivers registered in the regulatory databases are protected and taken into account in the configuration of the FSS terminal transmission plans.

Furthermore the transmit power and bandwidth management of the terminals may be used to further improve the spectral efficiency on the transmit side. This may be achieved using a dynamic allocation of the capacity on the transmit side in a cognitive transmit manner.

Table 1: Baseline enabling cognitive spectrum access solutions for the scenarios

Recommended cognitive techniques for the Ka band satellite network	Scenario A (space to earth: Downlink)	Scenario B (space to earth: Downlink)	Scenario C (earth to space: Uplink)
Spectrum Awareness	Database in combination with Spectrum sensing	Database in combination with Spectrum sensing	Database with FS receiver locations and parameters
Spectrum Exploitation	Channel Allocation	Channel Allocation	Channel Allocation and transmit power management

7.2 Technical parameters and implications on spectrum

7.2.1 Status of technical parameters

7.2.1.1 Current ITU and European Common Allocations

CEPT/ERC Report 25 [i.13] contains the European Common Allocations Table. From Satellite service point of view, the Ka band is defined in the present document as:

- 17,3 GHz - 20,2 GHz for space-to-Earth communications.
- 24,65 GHz - 30 GHz for Earth-to-space communications.

These frequency bands, their respective radio service allocations (and footnotes for the bands and allocations) and applications as in the European Common allocation Table are provided in the following tables.

Table 2: Space to earth Frequency allocations: Ka band

Frequency band (incl. footnotes of CEPT/ERC Report 25 [i.13])	Allocations (incl. footnotes of CEPT/ERC Report 25 [i.13])	Applications
17,3 GHz - 17,7 GHz	FIXED SATELLITE (EARTH-TO-SPACE) (SPACE-TO-EARTH) (5.516)	Feeder links Defence Systems
17,7 GHz - 18,1 GHz	FIXED	Feeder links FSS Earth stations Fixed ESOMPs
17,7 GHz - 18,1 GHz	FIXED-SATELLITE (EARTH-TO-SPACE) (5.516)	Feeder links
17,7 GHz - 18,1 GHz	FIXED-SATELLITE (SPACE-TO-EARTH) (5.484A)	Feeder links FSS Earth stations Fixed ESOMPs
18,1 GHz - 18,3 GHz (5.519)	FIXED-SATELLITE (SPACE-TO-EARTH) (5.484A)	ESOMPs Fixed FSS Earth stations Feeder links Weather satellites
18,1 GHz - 18,3 GHz (5.519)	FIXED	ESOMPs Fixed FSS Earth stations Feeder links Weather satellites
18,1 GHz - 18,3 GHz (5.519)	METEOROLOGICAL-SATELLITE (SPACE-TO-EARTH)	ESOMPs Fixed FSS Earth stations Feeder links Weather satellites
18,3 GHz - 18,4 GHz (5.519)	METEOROLOGICAL-SATELLITE (SPACE-TO-EARTH)	FSS Earth stations Feeder links Fixed ESOMPs
18,3 GHz - 18,4 GHz (5.519)	FIXED	FSS Earth stations Feeder links Fixed ESOMPs
18,3 GHz - 18,4 GHz (5.519)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.520)	FSS Earth stations Feeder links Fixed ESOMPs
18,3 GHz - 18,4 GHz (5.519)	FIXED-SATELLITE (SPACE-TO-EARTH) (5.484A)	FSS Earth stations Feeder links Fixed ESOMPs

Frequency band (incl. footnotes of CEPT/ERC Report 25 [i.13])	Allocations (incl. footnotes of CEPT/ERC Report 25 [i.13])	Applications
18,4 GHz - 18,6 GHz	FIXED-SATELLITE (SPACE-TO-EARTH) (5.484A)	ESOMPs Fixed FSS Earth stations
18,4 GHz - 18,6 GHz	FIXED	ESOMPs Fixed FSS Earth stations
18,6 GHz - 18,8 GHz (5.522A)	EARTH EXPLORATION-SATELLITE (PASSIVE)	Passive sensors (satellite) FSS Earth stations Fixed ESOMPs
18,6 GHz - 18,8 GHz (5.522A)	FIXED	Passive sensors (satellite) FSS Earth stations Fixed ESOMPs
18,6 GHz - 18,8 GHz (5.522A)	FIXED-SATELLITE (SPACE-TO-EARTH) (5.522B)	Passive sensors (satellite) FSS Earth stations Fixed ESOMPs
18,8 GHz - 19,3 GHz	FIXED	ESOMPs Fixed FSS Earth stations
18,8 GHz - 19,3 GHz	FIXED-SATELLITE (SPACE-TO-EARTH) (5.523A)	ESOMPs Fixed FSS Earth stations
19,3 GHz - 19,7 GHz	FIXED	Fixed FSS Earth stations ESOMPs
19,3 GHz - 19,7 GHz	FIXED-SATELLITE (SPACE-TO-EARTH) (EARTH-TO-SPACE) (5.523B) (5.523C) (5.523D) (5.523E)	Fixed FSS Earth stations ESOMPs
19,7 GHz - 20,1 GHz	Mobile-Satellite (space-to-Earth)	ESOMPs MSS Earth stations HEST FSS Earth stations LEST
19,7 GHz - 20,1 GHz	FIXED-SATELLITE (SPACE-TO-EARTH) (5.484A) (5.516B)	ESOMPs MSS Earth stations HEST FSS Earth stations LEST
20,1 GHz - 20,2 GHz (5.525) (5.526) (5.527) (5.528)	FIXED-SATELLITE (SPACE-TO-EARTH) (5.484A) (5.516B)	MSS Earth stations HEST LEST FSS Earth stations ESOMPs
20,1 GHz - 20,2 GHz (5.525) (5.526) (5.527) (5.528)	MOBILE-SATELLITE (SPACE-TO-EARTH)	MSS Earth stations HEST LEST FSS Earth stations ESOMPs

Table 3: Earth to Space Frequency allocations: Ka band

Frequency band (incl. footnotes of CEPT/ERC Report 25 [i.13])	Allocations (incl. footnotes of CEPT/ERC Report 25 [i.13])	Applications
24,65 GHz - 24,75 GHz	FIXED	SRR Radiodetermination applications BFWA Fixed
24,65 GHz - 24,75 GHz	FIXED-SATELLITE (EARTH-TO-SPACE) (5.532B)	SRR Radiodetermination applications BFWA Fixed
24,75 GHz - 25,25 GHz	FIXED-SATELLITE (EARTH-TO-SPACE) (5.532B)	Fixed BFWA SRR Radiodetermination applications
24,75 GHz - 25,25 GHz	FIXED	Fixed BFWA SRR Radiodetermination applications
25,25 GHz - 25,5 GHz	FIXED	Radiodetermination applications BFWA SRR Fixed
25,25 GHz - 25,5 GHz	INTER-SATELLITE (5.536)	Radiodetermination applications BFWA SRR Fixed
25,25 GHz - 25,5 GHz	MOBILE	Radiodetermination applications BFWA SRR Fixed
25,5 GHz - 26,5 GHz (5.536A)	MOBILE	SRR Space research BFWA Fixed Radiodetermination applications
25,5 GHz - 26,5 GHz (5.536A)	INTER-SATELLITE (5.536)	SRR Space research BFWA Fixed Radiodetermination applications
25,5 GHz - 26,5 GHz (5.536A)	SPACE RESEARCH (SPACE-TO-EARTH) (5.536C)	SRR Space research BFWA Fixed Radiodetermination applications
25,5 GHz - 26,5 GHz (5.536A)	FIXED	SRR Space research BFWA Fixed Radiodetermination applications

Frequency band (incl. footnotes of CEPT/ERC Report 25 [i.13])	Allocations (incl. footnotes of CEPT/ERC Report 25 [i.13])	Applications
25,5 GHz - 26,5 GHz (5.536A)	Earth Exploration-Satellite (space-to-Earth) (5.536B)	SRR Space research BFWA Fixed Radiodetermination applications
26,5 GHz - 27 GHz (5.536A) (EU27)	Earth Exploration-Satellite (space-to-Earth) (5.536B)	Radiodetermination applications Space research SRR Defence systems
26,5 GHz - 27 GHz (5.536A) (EU27)	FIXED	Radiodetermination applications Space research SRR Defence systems
26,5 GHz - 27 GHz (5.536A) (EU27)	SPACE RESEARCH (SPACE-TO-EARTH) (5.536C)	Radiodetermination applications Space research SRR Defence systems
26,5 GHz - 27 GHz (5.536A) (EU27)	MOBILE	Radiodetermination applications Space research SRR Defence systems
26,5 GHz - 27 GHz (5.536A) (EU27)	INTER-SATELLITE (5.536)	Radiodetermination applications Space research SRR Defence systems
27 GHz - 27,5 GHz (EU27)	INTER-SATELLITE (5.536)	Defence systems
27 GHz - 27,5 GHz (EU27)	MOBILE	Defence systems
27 GHz - 27,5 GHz (EU27)	Earth Exploration-Satellite (space-to-Earth)	Defence systems
27 GHz - 27,5 GHz (EU27)	FIXED	Defence systems
27,5 GHz - 28,5 GHz (5.538) (5.540)	FIXED	Feeder links FSS Earth stations BFWA Fixed ESOMPs
27,5 GHz - 28,5 GHz (5.538) (5.540)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.484A) (5.516B) (5.539)	Feeder links FSS Earth stations BFWA Fixed ESOMPs
28,5 GHz - 29,1 GHz (5.540)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.484A) (5.516B) (5.523A) (5.539)	ESOMPs BFWA Fixed FSS Earth stations Feeder links
28,5 GHz - 29,1 GHz (5.540)	FIXED	ESOMPs BFWA Fixed FSS Earth stations Feeder links
28,5 GHz - 29,1 GHz (5.540)	Earth Exploration-Satellite (Earth-to-space) (5.541)	ESOMPs BFWA Fixed FSS Earth stations Feeder links

Frequency band (incl. footnotes of CEPT/ERC Report 25 [i.13])	Allocations (incl. footnotes of CEPT/ERC Report 25 [i.13])	Applications
29,1 GHz - 29,5 GHz (5.540)	Earth Exploration-Satellite (Earth-to-space) (5.541)	Feeder links FSS Earth stations BFWA ESOMPs Fixed
29,1 GHz - 29,5 GHz (5.540)	FIXED	Feeder links FSS Earth stations BFWA ESOMPs Fixed
29,1 GHz - 29,5 GHz (5.540)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.516B) (5.523C) (5.523E) (5.535A) (5.539) (5.541A)	Feeder links FSS Earth stations BFWA ESOMPs Fixed
29,5 GHz - 29,9 GHz (5.540)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.484A) (5.516B) (5.539)	ESOMPs SIT/SUT HEST LEST MSS Earth stations
29,5 GHz - 29,9 GHz (5.540)	Earth Exploration-Satellite (Earth-to-space) (5.541)	ESOMPs SIT/SUT HEST LEST MSS Earth stations
29,5 GHz - 29,9 GHz (5.540)	Mobile-Satellite (Earth-to-space)	ESOMPs SIT/SUT HEST LEST MSS Earth stations
29,9 GHz - 30 GHz (5.525) (5.526) (5.527) (5.538) (5.540)	MOBILE-SATELLITE (EARTH-TO-SPACE)	FSS Earth stations HEST LEST MSS Earth stations SIT/SUT ESOMPs
29,9 GHz - 30 GHz (5.525) (5.526) (5.527) (5.538) (5.540)	FIXED-SATELLITE (EARTH-TO-SPACE) (5.484A) (5.516B) (5.539)	FSS Earth stations HEST LEST MSS Earth stations SIT/SUT ESOMPs
29,9 GHz - 30 GHz (5.525) (5.526) (5.527) (5.538) (5.540)	EARTH EXPLORATION-SATELLITE (EARTH-TO-SPACE) (5.541) (5.543)	FSS Earth stations HEST LEST MSS Earth stations SIT/SUT ESOMPs

Figure 12 shows the spectrum allocation for satellite services in Ka band, according to ITU.

ITU Regions corresponds to:

- Region 1: Europe (incl. Russia) and Africa and Arabic Peninsula.
- Region 2: Americas.
- Region 3: Asia Pacific.

ITU has identified specific bands suitable for the deployment of advanced broadband communications in the FSS (see RR footnote 5.516B CEPT/ERC Report 25 [i.13]).

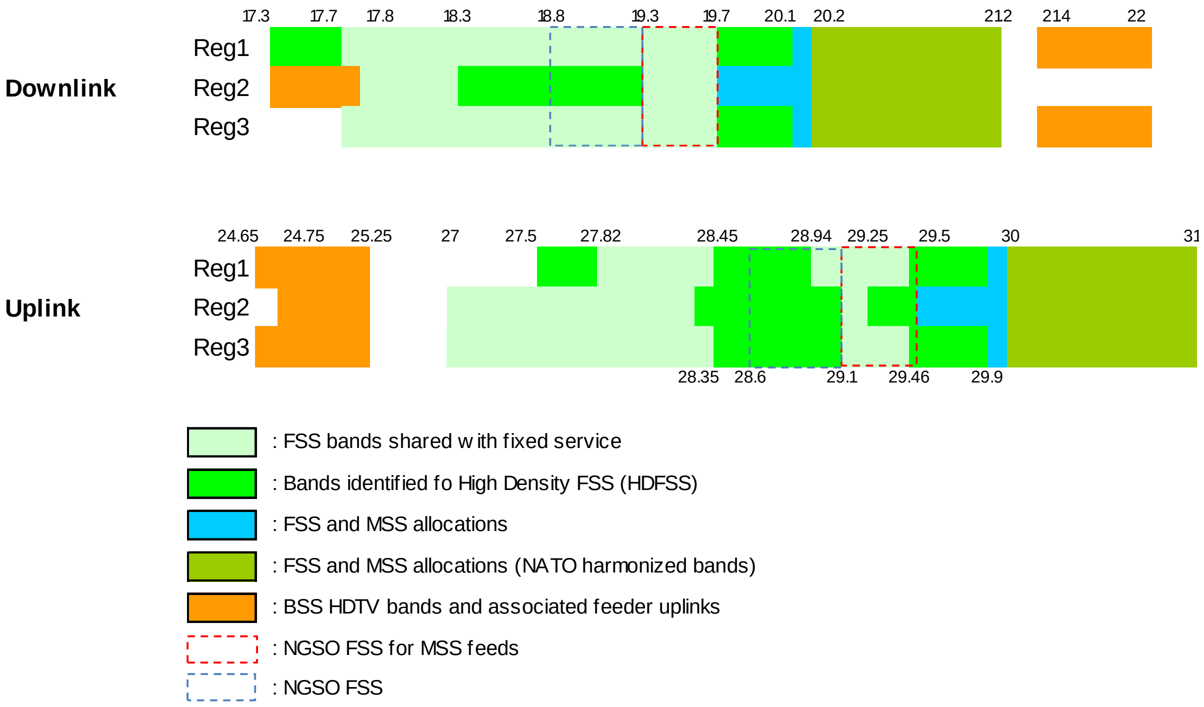


Figure 12: ITU Ka-Band Frequency allocations for satellite services

7.2.2 Transmitter parameters

7.2.2.1 FSS earth stations

7.2.2.1.1 Introduction

This part includes the transmitter characteristics of FSS earth stations operating in the bands 29,5 GHz - 30,0 GHz and 27,5 GHz - 29,5 GHz (non-exclusive bands).

7.2.2.1.2 Transmitter Output Power/Radiated Power

The compliance to ETSI EN 301 459 [i.17] is considered as baseline for the transmit parameters.

The reference transmit chain is: Modulator - HighPowerAmplifier - Antenna.

Transmission Mask (TM), (measured at modulator output): As specified in ETSI EN 302 307 [i.3] and subsequent updates.

Adjacent channel power (ACP): The adjacent channel power limitations are defined by the satellite operator and regulator and depend on the power class and type of terminal used.

Power control (PC): Power control is an option in the user terminal and if implemented it is taken into account in the requirements of the UT as outlined in ETSI EN 301 459 [i.17].

Spectral Power Density (SPD): In-band on-axis spectral power density is limited by satellite system operator constraints and regulatory requirements.

7.2.2.1.3 Antenna Characteristics

Transmission mask considered follows defined reference requirements in ETSI EN 301 459 [i.17], clause 4.2.3.

7.2.2.1.4 Operating Frequency

As per the frequency plan presented in clause 7.1, FSS earth stations transmit in the bands 29,5 GHz - 30,0 GHz and 27,5 GHz - 29,5 GHz (non-exclusive bands).

7.2.2.1.5 Bandwidth

Transmit bandwidth allocations depend on the achievable link budget (efficiency) as well as the required margins and the throughput to be achieved. The configurable range is:

- Minimum Tx bandwidth allocation per user terminal: 32 kHz.
- Maximum Tx bandwidth allocation per carrier and per user terminal: 2 MHz (27 MHz per Multi Frequency Time Division Multiplexing Access group of carriers).
- Maximum Tx bandwidth allocation per carrier group: 20 MHz - 36 MHz.

7.2.2.1.6 Unwanted emissions

Spurious emissions: Reference specification is ETSI EN 301 459 [i.17].

Out-of-band emissions: Defined by satellite system operator, typical 1 dBW / 4 kHz (ETSI EN 301 459 [i.17]).

Cross-polarization discrimination: 25 dB (min).

7.2.2.2 BSS earth stations

7.2.2.2.1 Transmitter Output Power/Radiated Power

The transmitter of the present link is the earth station for uplink to the BSS satellite.

No power limitations exist within the band, since it is not shared with other services.

A separate high power amplifier (HPA) processes the single carrier that is uplinked to one transponder. The HPA output power capability is in the range 100 W to 750 W. A typical example for the output power, at the antenna flange, is 19 dBW.

It is assumed BSS earth stations do not exceed EIRP levels greater than 84 dBW as specified in table 3A2 of the Radio Regulations' appendix 30A [i.15].

7.2.2.2.2 Antenna Characteristics

The antenna gain pattern mask defined in Recommendation ITU-R S.580 [i.18] does usually apply. This mask, together with the referenced Recommendation ITU-R S.465 [i.19] and under the assumption of a large antenna diameter, is defined as follows:

$$
\begin{aligned}
G(\varphi) &\le 29 - 25\log\varphi \ \text{dBi} && \text{for} \quad \varphi \le 20^\circ \\
&\le -3.5 \ \text{dBi} && \text{for} \quad 20^\circ < \varphi \le 26{,}3^\circ \\
&\le 32 - 25\log\varphi \ \text{dBi} && \text{for} \quad 26{,}3^\circ < \varphi \le 48^\circ \\
&\le -10 \ \text{dBi} && \text{for} \quad 48^\circ < \varphi \le 180^\circ
\end{aligned}
$$

(Off-axis EIRP masks are based on a slightly different gain pattern mask, but do not exist for the frequency band considered here.)

Satellite operators might request a more stringent gain pattern mask, where the (29 - 25 log φ dBi) envelope extends to 36,3°.

Typical antennas have a diameter of 9 m and an efficiency of 60 %. This leads to an antenna gain of 62 dB at 17,7 GHz.

7.2.2.2.3 Operating Frequency

According to scenario definition, the operating frequency range is 17,3 GHz to 17,7 GHz.

BSS feeder links are operated also in the 17,7 GHz to 18,1 GHz band. This band is considered in scenario B.

7.2.2.2.4 Bandwidth

With BSS, each transponder processes a single modulated carrier. The carrier bandwidth may exceed the nominal transponder bandwidth, but should not exceed the transponder spacing. The carrier bandwidth comprises the occupied bandwidth of an ideally modulated carrier and imperfections that slightly exceed the occupied bandwidth.

Transponder bandwidth and spacing combinations are as follows.

Table 4: Transponder Bandwidth and spacing combinations

Transponder bandwidth	Transponder spacing	Remark
27 MHz	38,36 MHz	Obsolete BSS frequency plan
33 MHz	38,36 or 39 MHz	Currently BSS frequency plans

Typical carrier characteristics with QPSK or 8PSK modulation (on the transponders in use) are as follows.

Table 5: Typical carrier characteristics with QPSK or 8PSK modulation

Symbol rate	Roll-off	Ideal occupied bandwidth
27,5 MBd	35 %	37,125 MHz
29,5 MBd	25 %	36,875 MHz
30 MBd	25 %	37,5 MHz

It appears appropriate to take into account only the ideal occupied bandwidth and neglect the carrier imperfections.

7.2.2.2.5 Unwanted emissions

Unwanted EIRP emissions outside the assigned bandwidth are restricted to 4 dBW/4 kHz. This EIRP applies to the on-axis direction of the uplink antenna, whereas the EIRP towards a cognitive radio earth station is determined by the antenna gain pattern.

7.2.2.3 FS stations

7.2.2.3.1 Introduction

FS transmitters characteristics can be found in Recommendation ITU-R F.758-5 [i.20].

7.2.2.3.2 Transmitter Output Power/Radiated Power

In addition to Recommendation ITU-R F.758-5 [i.20], information on FS power levels can be found in ETSI TR 102 243-1 [i.21].

7.2.2.3.3 Antenna Characteristics

Antenna characteristics can be found in Recommendations ITU-R F.699-7 [i.22] and F.1245-2 [i.38]. The choice among these two recommendations depends upon the type of sharing studies to be carried out.

7.2.2.3.4 Operating Frequency

Operating frequencies are given by channelling arrangements defined in ERC/REC(01)03 [i.23] for the band 17,7 GHz - 19,7 GHz, and in ERC Recommendation T/R 13-02 [i.33] for the band 27,5 GHz - 29,5 GHz.

7.2.2.3.5 Bandwidth

The bandwidth used by FS are according to the channelling arrangements described in ERC/REC(01)03 [i.23] for the band 17,7 GHz - 19,7 GHz, and in ERC Recommendation T/R 13-02 [i.33] for the band 27,5 GHz - 29,5 GHz.

Typically the channel bandwidth ranges from 7 MHz to 50 MHz.

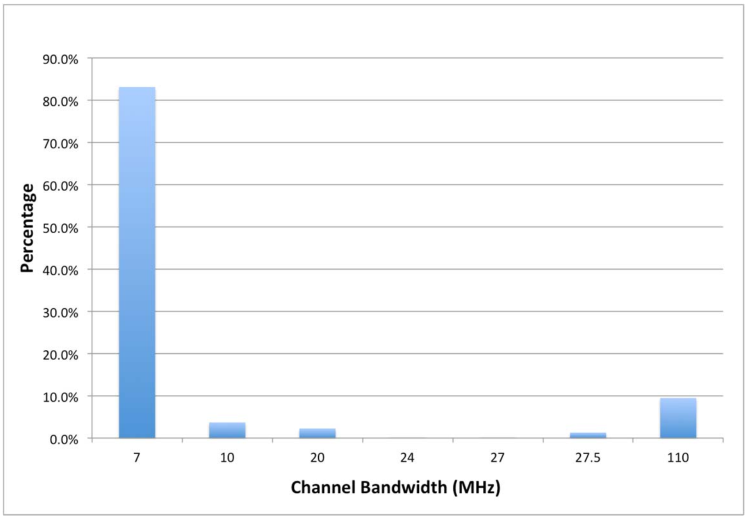


Figure 13: Bandwidths from UK 18 GHz database

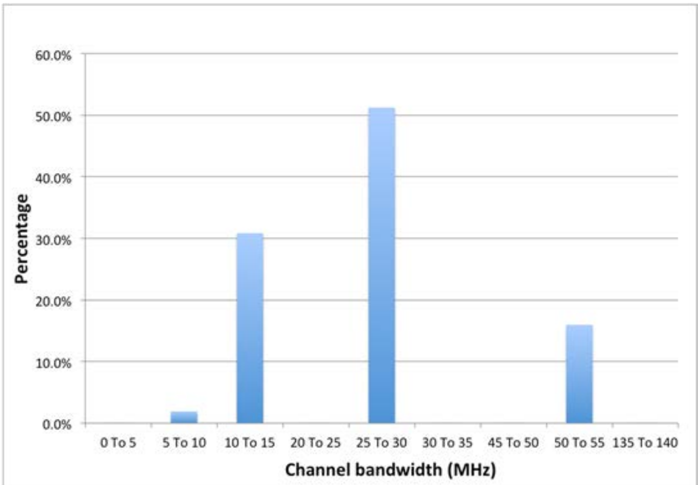


Figure 14: Bandwidths from the BRIFIC 18 GHz database for France

7.2.2.3.6 Unwanted emissions

Emission masks for FS are defined in ETSI EN 302 217-2-2 [i.24], clause 4.2.4.

7.2.3 Receiver parameters

7.2.3.1 FSS earth stations

This part includes the receiver characteristics of FSS earth stations operating in the bands 17,3 GHz - 17,7 GHz and 17,7 GHz - 19,7 GHz.

Table 6: Receiver baseline parameters

Parameter	Description	Specification
LNB gain	Low Noise amplifier	55 dB to 65 dB (typical)
Typical system noise temperature	Reference system noise temperature used to evaluate the noise figure	290 K
Noise figure	Noise figure over the receive band range tuned to (i.e. 500 MHz - 600 MHz)	1,5 dB maximum over tuned frequency band
Blocking	Maximum LNB input power aggregated allowed (above which non-linear region of LNB)	-75 dBm (typical) to -60 dBm (max)
Tuner flexibility	The receiver is adjusted to a specific part of the frequency band to optimize noise figure A segmentation of the frequency band into 500 MHz band regions is proposed	500 MHz (typical) to 600 MHz (maximum)

7.2.3.2 BSS earth stations

The receiver of the present link is the input section of the BSS satellite payload.

The signals transmitted by the FSS satellite of a cognitive radio satellite system might cause interference to the receiving satellite of a BSS feeder link. Interference from the FSS satellite of the cognitive radio system is an issue of frequency coordination like interference from an FSS satellite of any conventional system. Therefore, receiver parameters of the BSS feeder link are not relevant here.

7.2.3.3 FS stations

FS receiver characteristics can be found in Recommendation ITU-R F.758-5 [i.20].

7.2.4 Channel access parameters

7.2.4.1 Introduction

These parameters are system level parameters and relate to the ability of the receiver to insert into the system context of a receiver that shares the frequency access with other receivers.

It is assumed that the end user terminal of the cognitive system is capable of changing its frequency and modulation and coding parameters (physical layer channel parameters) on the forward (outbound) and on the return (inbound) link. The frequency, the modulation and coding as well as the transmit power settings can be changed as required by the system network control centre (NCC) of the cognitive system.

7.2.4.2 FSS earth stations

The FSS earth station, the terminal of the cognitive system, has a reconfigurable air interface in forward and return link. The earth station is capable of accessing the frequency resources assigned by the system and to change its frequency assignments and power density parameters without losing the link to the system controlling gateway station.

The response time of the terminal to a change in its allocated capacity is defined as the "duty cycle" of the cognitive system, the time period required by the system to respond to a changing interference condition on the channel. Within the considered reference system, it should take about 1 second to change from one frequency carrier to another in order to minimize impact on the Quality of Service.

The typical minimal frequency agility on the transmit side of the terminal is defined to be at least 20 MHz.

7.2.4.3 BSS earth stations

The channel is used by a single transmitter, which is the FSS satellite of the cognitive radio system. Therefore, channel access parameters are not relevant.

7.2.4.4 FS stations

Channel access parameters are not relevant in this case, since the FS system is incumbent and is assumed not be required to adapt to the changing environment.

7.3 Information on relevant standard(s)

As per FSS earth stations as well as ESOMP (Earth Stations on Mobile Platforms), the following harmonised standards applies in Ka band allocation.

- ETSI EN 303 978 [i.25]: "Satellite Earth Stations and Systems (SES); Harmonized EN for Earth Stations on Mobile Platforms (ESOMP) transmitting towards satellites in geostationary orbit in the 27,5 GHz to 30,0 GHz frequency bands"; 2012-12.
- ETSI EN 301 459 [i.17]: "Satellite Earth Stations and Systems (SES); Harmonized EN for Satellite Interactive Terminals (SIT) and Satellite User Terminals (SUT) transmitting towards satellites in geostationary orbit in the 29,5 GHz to 30,0 GHz frequency bands"; 2007-06.
- ETSI EN 301 360 [i.26]: "Satellite Earth Stations and Systems (SES); Harmonized EN for Satellite Interactive Terminals (SIT) and Satellite User Terminals (SUT) transmitting towards geostationary satellites in the 27,5 GHz to 29,5 GHz frequency bands"; 2006-02.
- ETSI EN 301 359 [i.27]: "Satellite Earth Stations and Systems (SES); Satellite Interactive Terminals (SIT) using satellites in geostationary orbit operating in the 11 GHz to 12 GHz (space-to-earth) and 29,5 GHz to 30,0 GHz (earth-to-space) frequency bands"; 1999-04.
- ETSI EN 301 358 [i.28]: "Satellite Earth Stations and Systems (SES); Satellite User Terminals (SUT) using satellites in geostationary orbit operating in the 19,7 GHz to 20,2 GHz (space-to-earth) and 29,5 GHz to 30 GHz (earth-to-space) frequency bands"; 1999-04.

As per BSS earth stations, the following harmonised standards applies in Ka band allocation:

- No harmonised standard exists. BSS uplink earth stations are treated individually by administrations.

As per FS transmitters/receivers the following harmonised standards apply in Ka band allocation:

- ETSI EN 301 751 (V1.2.1) [i.56]: "Fixed Radio Systems; Point-to-Point equipments and antennas; Generic harmonized standard for Point-to-Point digital fixed radio systems and antennas".
- ETSI EN 300 430 (V1.4.1) [i.57]: "Fixed Radio Systems; Point-to-point equipment; Parameters for radio systems for the transmission of STM-1 digital signals operating in the 18 GHz frequency band with channel spacing of 55 MHz and 27,5 MHz".
- ETSI EN 300 431 (V1.4.1) [i.58]: "Fixed Radio Systems; Point-to-point equipment; Parameters for radio system for the transmission of digital signals operating in the frequency range 24,50 GHz to 29,50 GHz".

The principles of cognitive radio techniques for SatCom operating in Ka band will also be considered during the revision of existing harmonised standards or development of new harmonised standards in ETSI in line with the results of the considerations in CEPT/ECC. The description of the precise technical details of these techniques may be subject to inclusion in harmonised standards whereas the ECC harmonisation measure (ECC Decision or Recommendation) will identify the applicability of the technique in the respective frequency range.

7.4 Sharing and compatibility

7.4.1 Sharing and compatibility studies (if any) already available

Existing studies in CEPT.

Table 7: List of existing studies in CEPT

Description of document/title	Application
ERC Report 099 on FWA [i.11]	Point-to-Multipoint
ECC Report 32-Improving co-existence Multipoint FS [i.12]	Point-to-Multipoint
ECC Report 76 Cross-Border coordination of Multipoint Fixed Wireless Systems in frequency bands from 3.4 GHZ to 33.4 GHz [i.14]	MWS
ECC Report 152-Fixed Satellite Systems [i.9]	FSS Earth stations
ECC Report 184 on the use of ESOMPs operating with GSO Satellite Networks [i.32]	ESOMPs
ECC Report 198 on adaptive modulation and ATPC operations in fixed P-P systems [i.34]	Fixed
Summary of the WGFM Questionnaire on the 17.7-19.7 GHz Fixed Service [i.35]	Fixed
Responses of FS use of 28 GHz [i.40]	Fixed
ECC Report 211 Technical assessment of the possible use of asymmetrical point-to-point links [i.36]	Fixed
ECC Report 173 on Fixed Service in Europe.Current use and future trends post 2011.Excel Worksheet (Inventory & Forecast) [i.37]	Fixed

According to the analysis of allocations in Ka band reported in the clause 7.2.1.1 and the detailed description of the reference satcom system in the clause 7.1, three cases of frequency sharing scenarios with interference issues are identified and are illustrated by figure 15 below:

- Scenario A - Band [17,3 - 17,7] GHz: frequency sharing between the FSS and BSS. FSS could interfere BSS in certain conditions, but it is a matter of coordination on GSO. Interference from BSS to FSS may limit the use of the shared band by FSS.

- Scenario B - Band [17,7 - 19,7] GHz: frequency sharing between the FSS and the FS. Since the SatCom system is designed so as to yield to Ground Power Flux Density complying with the Article 21 of ITU Radio Regulations [i.15], no interference from the FSS onto the FS is foreseen by design. On the contrary interferences stemming from the FS onto the FSS may occur, owing to the following causes:

  - Reception of a FSS signal that overlaps with one of several FS channels.

  - Reception of a FSS signal in a band that is adjacent to one or several FS channels.

  - Saturation of the FSS terminal front-end by one or several FS channels (or BSS channels in the band [17,3 - 17,7] GHz).

- Scenario C - Band [27,5 - 29,5] GHz (**nominal** frequency plan): frequency sharing between the FSS and the FS. Interferences between FSS and FS may occur in the following circumstances:

  - Sub-bands [27,5 - 27,8285] GHz, [28,4445 - 28,8365] GHz, [29,4525 - 29,5] GHz identified primarily for FSS use as per decides 1 of ECC/DEC/(05)01 [i.30]: interference may occur into FS in CEPT countries not implementing the ECC/DEC/(05)01, and authorizing the operation of FS links in those bands.

  - Sub-bands [28,8365 - 28,9485] GHz identified primarily for FSS use as per decides 2 of ECC/DEC/(05)01 [i.30]: interference may occur into FS in CEPT countries not implementing ECC/DEC/(05)01 in the band [28,8365 - 29,9485] MHz, where the FS links licensed in some countries before 18 March 2005 could require protection, but not after 1st January 2020.

  - Sub-bands [27,8285 - 28,4445] GHz, [28,9485 - 29,4525] GHz identified primarily for FS use as per Decides 3 of ECC/DEC/(05)01 [i.30]. Interference may occur if FSS earth stations transmit in the vicinity of a FS link receiver operating in the same band. ECC/DEC/(05)01 decides 5 explicitly forbids administrations to authorize uncoordinated FSS transmit stations in this band.

  - The FS/FSS receiver Adjacent Channel Selectivity is not sufficient to remove out-of-band emissions from the FSS/FS station.

- Scenario C - Band [28,4465 - 28,9465] GHz (**alternative** frequency plan): frequency sharing between the FSS and the FS. Interferences between FSS and FS may occur, only if:
  - CEPT Decision ECC/DEC/(05)01 [i.30] is not implemented in the band [28,8365 - 29,9485] MHz, where the FS links licensed in some countries before 18 March 2005 could require protection, but not after 1st January 2020.
  - The FS/FSS receiver Adjacent Channel Selectivity is not sufficient to remove out-of-band emissions from the FSS/FS station.

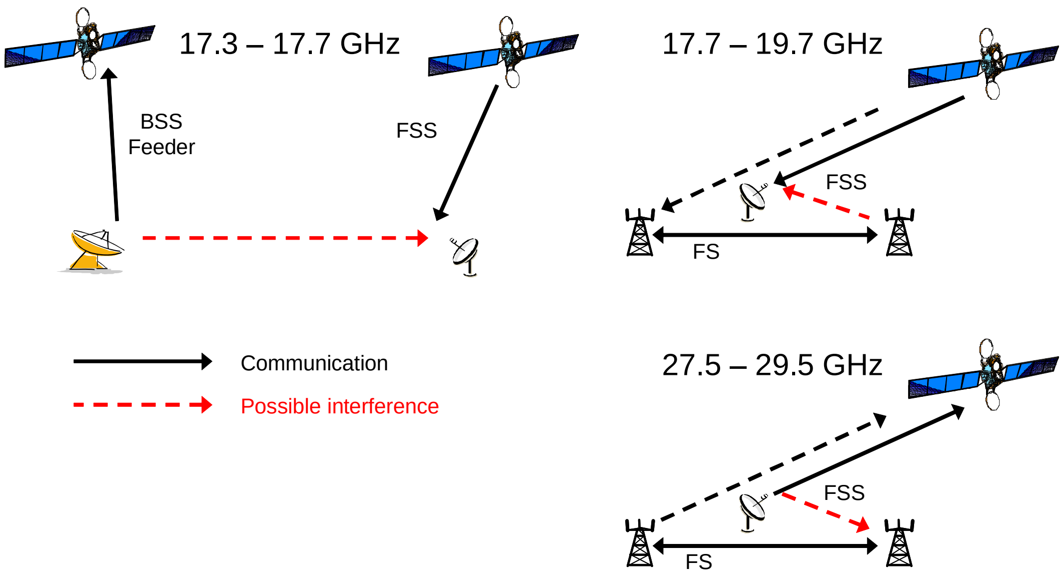


Figure 15: Interference scenarios in Ka band

Available sharing studies are identified below:

Band [17,3 - 17,7] GHz:

In this frequency band, the main sharing issue for FSS receive terminals corresponds to uplink Earth stations used for Feeder-links of BSS systems.

ECC/DEC/(05)08 [i.31] is applicable in this band and indicates however that:

- that FSS earth stations transmitting in 17,3 GHz -17,7 GHz for BSS feeder links are located at a few tens of known locations in CEPT countries.
- that the area around an FSS earth station transmitting in 17,3 GHz - 17,7 GHz for BSS feeder links where interference to an uncoordinated FSS receive earth station may be created is limited to a few tens of kilometres.

Band [17,7 - 19,7] GHz:

Sharing studies have been undertaken in CEPT SE40, and are reflected in ECC Report 232 [i.59] "Compatibility between FSS uncoordinated receive Earth Stations and the FS in the band 17,7-19,7 GHz". This report investigates the availability of spectrum for FSS earth stations in areas with FS deployment.

Furthermore, the ECC is expected to adopt by early 2016 the following deliverables:

- ECC Report 241 [i.60]: Enhanced access to spectrum for FSS uncoordinated Earth Stations in the 17,7 GHz - 19,7 GHz band. This report investigates technical and regulatory measures to enhance the conditions of operation for uncoordinated FSS earth stations in the 17,7 GHz - 19,7 GHz band, including the use of FS assignment information.
- Revised ERC/DEC(00)07 [i.29]: The shared use of the band 17,7 GHz - 19,7 GHz by the fixed service and Earth stations of the fixed-satellite service (space-to-Earth).

Band [27,5 - 29,5] GHz:

In this frequency band, FS and FSS are co-allocated at the ITU level. In CEPT, a band segmentation scheme has been implemented between FS and uncoordinated Earth stations of the FSS through the adoption of ECC/DEC/(05)01, which last revision has been adopted in January 2013.

This decision defines frequency bands where uncoordinated FSS earth stations may be operated, and guard bands with the Fixed Service.

Uncoordinated FSS earth stations should not have their occupied band edges closer than 10 MHz from the edges of the bands identified for use by Terrestrial services (Fixed Service).

Sharing studies were conducted between the Fixed Service and ESOMPs. These studies can be found in ECC Report 184 [i.32]. In ITU, a proposed methodology can be found in Recommendation ITU-R SF.1719 [i.16].

7.4.2 Sharing and compatibility issues still to be considered: Key Performance Indicators

In order to assess the sharing compatibility among terrestrial and satellite systems a proper methodology has to be defined and considered, to compare different sharing techniques.

The sharing of the same frequency band between terrestrial and satellite communication will respect some protection requirements between the two systems. On one hand the incumbent (terrestrial or satellite) communications will be protected from the cognitive (satellite) communications, if active. At the same time, in order to achieve an acceptable reliability, the cognitive (satellite) link will be protected from the presence of any incumbent (terrestrial or satellite) communication. The protection requirements takes into account those defined by ITU-R and ECC.

At the same time the incumbent and cognitive systems respect some emission limits in order to avoid harmful interference towards different users. Mostly emission limits refer to in-band power limit, when the emission limit refers to the power emitted in the used frequency portion, and out of band power limit, when the emission limit refers to the power emitted outside the used frequency portion.

In order to assess the sharing compatibility some input parameters are required. The system parameters refers to those input information to be taken into account for setting up the cognitive satellite system. The system input parameters can be grouped into three main classes: the geographical parameters, the terminal parameters and the radio interface parameters:

- Geographical parameters:

EXAMPLE 1: Coverage and Capture Areas of the incumbent and cognitive systems for a geographical point of view.

- Terminal parameters:

EXAMPLE 2: Locations/elevation/azimuth, antenna patterns, polarization of both the incumbent and the cognitive terminals.

- Radio interface parameters:

EXAMPLE 3: Link budget values, the channel rasters.

System input parameters along with protection requirements and emission limits work as an input for the CR techniques to be used for assuring an effective sharing between satellite and terrestrial components.

The different CR techniques, applied to the scenarios to be taken into account, can be compared by exploiting two main system level KPIs:

- *Satellite System Capacity:* The system capacity stands for the overall capacity that the system can support by taking into account both the incumbent and the cognitive systems. On one hand the cognitive techniques would allow to exploit those unused resources by the incumbent system thus increasing the overall system capacity. On the other hand the coexistence between incumbent and cognitive needs to be carefully designed for reducing the mutual interference that could result in no or low gain with respect to the system capacity. The system capacity is a good KPI because allows to compare different cognitive techniques aiming to consider that or those that allow its maximization.

- *Geographical availability of the Satellite Service:* The geographical availability stands for the overall area where the cognitive system can operate. This KPI is also a function of the incumbent stations density, however, given a certain density, the higher the geographical availability the higher is the value of the impact of the cognitive systems to the final users. The geographical availability allows to compare different cognitive techniques for each selected scenario with aim of selecting that technique that allow to maximize the area in which the cognitive system can be used. The KPI also relates to the "Cognitive zone" which is defined as the geographical area around an incumbent user station where cognitive radio technique should be used by the cognitive system to mitigate the interference to an acceptable level. Regarding different scenarios, the incumbent station might be either the transmitter who causes interference or the receiver who receives interference. Generally, the determination of cognitive zone depends on the acceptable interference threshold (ITU defined) and interference modelling.

7.4.3 System capacity gain assessment

An end-to-end system capacity gain evaluation has been performed [i.44] with an example and realistic satellite multi beam coverage over Europe and assuming the available scenario A [17,3 GHz - 17,7 GHz], B [17,7 GHz - 19,7 GHz] data sets available for UK and France. For the scenario C [27,5 GHz - 29,5 GHz] the data evaluation has been performed over Slovenia and Finland.

For the multi beam coverage a 4 color frequency reuse scheme has been assumed with an allocation of 1 450 MHz capacity per beam and the channelization usage of the 20 carriers per transponder. This number can be reduced in the future systems with the availability of chipsets capable of wideband reception.

The resulting evaluation has been performed assuming the usage of a database as well as spectrum sensing where database sets are not available and in combination with the possibility to allocate the capacity of the end-to-end system over a set of forward link carriers that are configured in the system over the non-exclusive and exclusive frequency bands.

Based on these mature technology basis of database (DB) and channel or resource allocation (RA) strategies, the achieved system capacity is significantly increased in the assessed scenarios for the UK and FRANCE reference cases and based on the overall assessment. In table 8, the results of the comparison of a reference Ka-band multi spot beam system with the assumed additional usage of the scenario A and B frequency bands [17,3 GHz - 17,7 GHz] and [17,7 GHz - 19,7 GHz] in combination with the exclusive bands [19,7 GHz - 20,2 GHz] are summarized.

Table 8: Capacity increase estimates per considered coverage area assuming a typical multi-spot beam satellite configuration

System gain scenario	Exclusive band only	Exclusive band + shared band with Cognitive radio techniques	Capacity increase
Downlink: coverage area in France/U.K.	Capacity = 168 Gbps extrapolated over European coverage using the exclusive band [19,7 GHz - 20,2 GHz]	Capacity = 845 to 884 Gbps extrapolated over European coverage using the exclusive band + cognitive radio techniques in shared bands [17,3 GHz - 17,7 GHz] (scenario A) and [17,7 GHz - 19,7 GHz] (scenario B)	400 % capacity increase
Uplink: coverage area Finland/Slovenia	Capacity per beam = 1,1 Gbps Using the exclusive band [29,5 GHz - 30,0 GHz]	Capacity per beam = 5,5 Gbps Using the exclusive band + cognitive radio techniques in the shared band [27,5 GHz - 29,5 GHz]	400 % capacity increase

From these assessments using as basis a realistic state-of-the art satellite design assumption as well as the dataset available from regulatory contexts for the scenario B as basis for potential interference assessment and assuming a transmission plan on the basis of a feasible channelization of 62 MHz, a significant gain can be reached with the scenario A and B frequency bands.

The availability of the additional frequency bands for scenario A [17,3 GHz - 17,7 GHz] and B [17,7 - 19,7 GHz] would achieve an additional throughput of over 400 %, which more than quadruples the overall system throughput.

On the return link, with the introduction of the scenario C [27,5 - 29,5 GHz] in addition to the exclusive return link band [29,5 - 30,0 GHz], the throughput has been assessed as well. The usage of a proposed power and carrier allocation technique, which allows to manage the return link transmissions such that the overall throughput at the input of the FS receivers is limited to the ITU limit defined.

The overall assessment demonstrates on the basis of available FS link deployment data over Finland and Slovenia in these bands [27,5 - 29,5 GHz] that a 400 % increase in capacity can be expected over the scenario of using the exclusive band only.

From these practical assessments it can be concluded that the usage of the scenario A [17,3-17,7 GHz], scenario B [17,7 - 19,7 GHz] provides a significant additional capacity for the Ka-band FSS satellite broadband access services. The availability of these frequency bands are key to further develop high throughput Ka-band satellite capacity for broadband access. The capacity increase expected, evaluated under realistic interference conditions would still at least quadruple the overall system capacity with the usage of mature and developed cognitive radio techniques, such as database access and flexible channel or resource allocation. This is achieved without causing interference risks to the incumbent users and without assuming any changes to the frequency access of the incumbent users.

As noted earlier scenario C (27,5 - 29,5 GHz) up link may not be needed in the shorter term except for the HDFSS portion protected for satellite. However it is possible to achieve around 4 times the capacity compared to the use of the exclusive band alone assuming the long term interference scenario and data bases for Slovenia and Finland. However the data bases used are quite sparse and thus more investigation will be needed for this scenario should more spectrum than in the HDFSS portion be needed.

The introduction of these techniques in the architecture of exiting satellite access systems has been verified and shown to be feasible. A detailed review of the FSS satellite system implementation requirements has been performed in the CoRaSat project under the work presented in deliverable D3.4 [i.51] and for the mentioned cognitive techniques the feasibility of implementation on a state-of-the-art satellite system has been considered and reviewed.

The additional developments have been identified and the development risk evaluated. The spectrum sensing technique was adapted in its implementation to include typical FSS system calibration and operational constraints. The implementation of the considered techniques, the database access (DB), the system parameter based spectrum sensing technique (SS-SNIR), which was adapted to the FSS system calibration constraints, as well as the resource allocation (RA) have been evaluated and are considered well feasible in the context of a practical system setup in the near future. The system adaptation conclusion is that there are quite minor technical risks related to these developments.

In addition this proposed approach is without practical interference risks for incumbent FS systems in the scenarios A [17,3 - 17,7 GHz] and [17,7 - 19,7 GHz]. The interference risks in the scenario C case [27,5 - 29,5 GHz] are also very low and the centralized transmission plan considering the spectrum awareness obtained from database can be used with sufficient margins to fulfill the required protection levels on the transmit side.

Further techniques such as the spectrum sensing and beamforming at the terminal reception side can be used to further "fine tune" the system capacity and optimize the practical usage of the additional bands.

The cost/benefit of using the additional frequency bands in Ka-band has been evaluated as well in the context of the work performed under CoRaSat. Realistic satellite payloads were assumed that cover the additional frequency bands and the delta cost has been evaluated. Furthermore the additional benefit of using these frequency bands has been assessed through the gain evaluation. The assessment of example projects with and without the implementation of the additional frequency bands have been compared leading to the conclusions that the additional availability of the scenarios A and B bands [17,3 - 17,7 GHz] as well as [17,7 - 19,7 GHz] respectively can significantly improve the business case factors and this under different assumptions on the uncertain factors in the business case review. This means that the additional gain provided by the introduction of scenarios A and B largely overweigh the additional costs and risks and this under a large range of realistic business case assumptions for a consumer residential broadband access service.

The usage of scenario C [27,5 - 29,5 GHz] under the assumption of consumer grade residential broadband networks is less obvious as the return link capacity need is largely covered by the availability of the HDFSS band [28,4465 - 29,9465 GHz] in addition to the exclusive frequency bands [29,5 - 30,0 GHz]. However the introduction of the scenario C [27,5 - 29,5 GHz] band as a shared band is considered technically possible with adequate cognitive techniques to mitigate and manage the interference into the FS receivers in this band. This can be considered an attractive approach to introduce new, improved satellite services in the future, provided that the management of the interference into the FS receivers is based on practically proven techniques.

7.4.4 Geographical availability assessment

7.4.4.1 Introduction

The aim of this analysis is to determine maps of excess interference from BSS/FS incumbents (scenarios A & B) at potential FSS sites across the coverage area. Then to evaluate the percentage of the coverage area per country that would be potentially impacted by any excessive interference. From this the area not affected by interference can also be determined. This KPI is not dependent on the satellite system characteristics and thus applies for all Ka band satellite systems.

The data on the positions and the characteristics of the BSS and FS are generally held by national regulators and these need to be available for a database system to work. For scenario A the number of BSS uplinks in Europe is small and thus a database system is similar in magnitude to that of TVWS. However for scenario B the number of FS links runs into the tens of thousands and the database is much more complex.

Most of the assessment below used data bases of BSS stations for scenario A and of FS stations for scenario B provided by OFCOM UK under the UK Freedom of Information Act.

Other data base for other European countries have also been examined at 18 GHz and are based on the latest ITU-R terrestrial services BR IFIC database [i.48].

The information of a real interferer database is interfaced to an interference modelling engine which uses Recommendation ITU-R P.452-15 [i.42] procedures plus terrain and climatic databases. This is the latest version of the ITU Recommendation that contains a prediction method for the evaluation of path loss between stations. Recommendation ITU-R P.452-15 includes all the propagation effects on the surface of the Earth at frequencies from 0,1 GHz to 50 GHz. In addition, other factors which affect interference calculation, such as terrain height, bandwidth overlapping are also considered in the proposed database approach. The typical interference threshold determined is based on the long term interference which can be expected to be present for at least 20 % of the average year and it is set at 10 dB below the noise floor. The interference thresholds for FSS reception and for FS reception are therefore -154 dBW/MHz and -146 dBW/MHz, respectively as given in [i.45] and [i.20].

Having determined the interference level at the FSS location (in scenarios A or B) it can be compared with the threshold indicated above. If the excess is significant then one of several measures can be taken to mitigate the interference. One such approach is to adopt an interference based resource allocation approach at the gateway where a new carrier can be assigned either in another part of the 'shared band' where interference is acceptable or in the exclusive band [i.46].

7.4.4.2 Data base

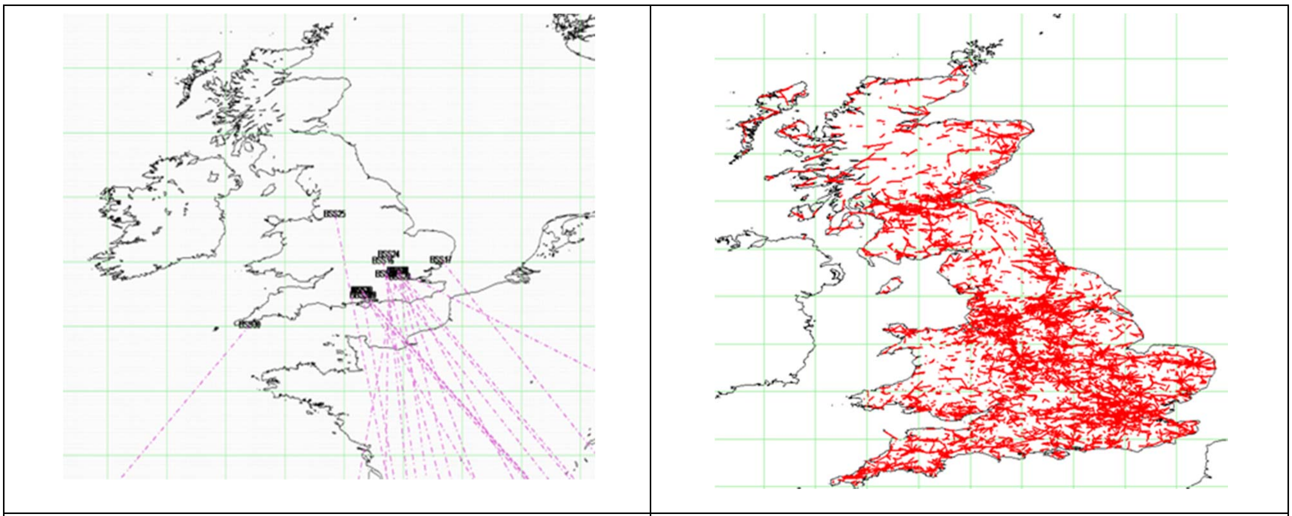
The information in a database is normally listed on a carrier by carrier basis for a frequency band of interest. All carriers are usually detailed with their frequencies and channel bandwidths.

In some cases, the database may provide additional details about the satellite system such as:

- the satellite longitude;
- the earth stations azimuth and elevation angles. Its antenna gain/polarization or even the antenna radiation patterns as defined in ITU Recommendations, the transmission power and equivalent isotropic radiated power (EIRP).

For scenario A, the UK BSS database contains 442 carriers from a total of 31 BSS uplink earth stations at 8 physical sites, to 12 different satellites, which is shown as figure 16(a). The locations of all these 31 BSS earth stations are marked with an indication of the direction of the beam to the satellite. The number of carriers of each BSS earth station ranges from 1 to 42. The carriers span the range 17,3 GHz to 18,35 GHz. The bandwidths of the carriers that belong to the same BSS earth station are the same while those that belong to different earth stations might be different and are typically 26 MHz, 33 MHz, 36 MHz or 66 MHz. The EIRP of these earth station antennas ranges from 69 dBW to 84 dBW and all antenna radiation patterns are as defined in Recommendation ITU-R S.465 [i.19] or S.580 [i.47].

For scenario B, the UK FS database in the band 17,7 GHz to 19,7 GHz contains 12 712 links with 15 970 carrier records. Figure 16(b) illustrates the FS links in the band 17,7 to 19,7 GHz in the UK and it can be seen that the FS links are much denser than for the BSS.



(a) BSS feeder link stations in the UK for scenario A | (b) FS links in the UK for scenario B

Figure 16: Registered BSS and FS links in the UK

7.4.4.3 Scenario A: Area Analysis

Using the BSS database, area analysis for scenario A in the UK was undertaken to investigate how much area would be affected by interference from the BSS feeder links. The band of interest is split into 10 x 40 MHz sub-bands (SB1-SB10) and the analysis was then conducted in each sub-band to determine the area of the contours at different cognitive zone thresholds. These mirror the usual 40 MHz channel spacing adopted for BSS satellites. Area analysis is based on the BSS database with the full Recommendation ITU-R P.452-15 [i.42] model employing the terrain and climatic zones and the FSS terminal considered points to a satellite at 53 degrees E longitude. This corresponds to a pessimistic case given the elevation of the satellite with respect to the targeted coverage. The results are for long term interference (normally 20 %).

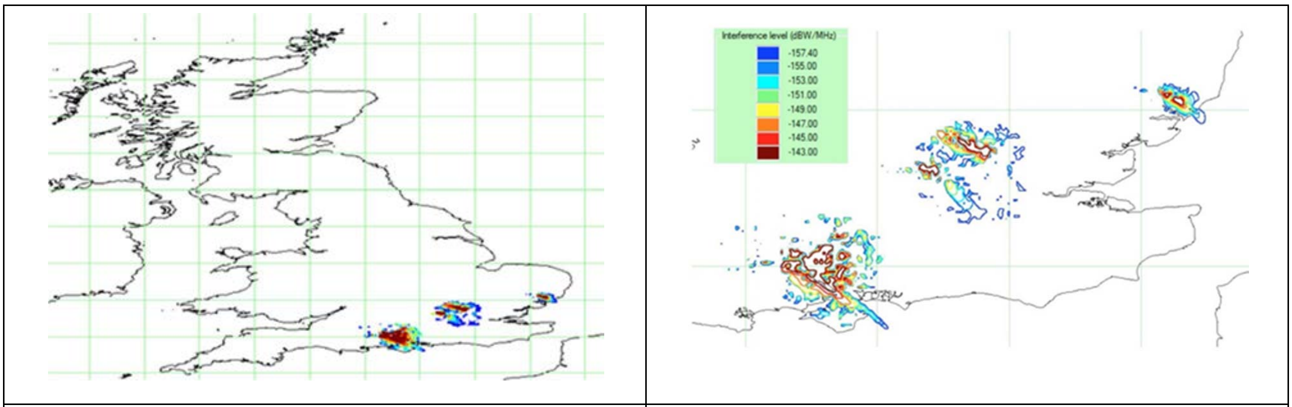
One example of affected area at difference cognitive zone thresholds is shown in figure 17, which represents SB1. Full data on the areas are given in table 9. It can be seen that in general across the sub-bands at a -155 dBW/MHz threshold less than for 2 % of the area of the UK is affected by BSS feeder links and thus more than 98 % of the area of the UK can be used by an FSS terminal without the need for any further action. Some mitigation of excess interference may be required in these affected areas. The mitigation could be achieved by suitable site shielding, beam-forming or reallocation to another frequency that is clear at the specific location. If such mitigation measures result in 10 dB suppression (a very conservative figure) then the remaining affected area would be of the order of 0,4 % of the area of the UK. Re-farming the spectrum of such a small amount of traffic should not represent much of a challenge. This is very promising for future FSS deployment as the additional 400 MHz identified in scenario A (17,3 - 17,7 GHz) represents an 80 % increase over the current exclusive band allocation (19,7 - 20,2 GHz).

The results are very similar for FSS terminal pointing at various orbit locations from the UK. Similar results are obtained with FSS terminals located in Luxembourg. It transpires that the UK results represent the most dense deployment of BSS uplinks and that the results for other EU countries should be similar or better than the UK.

Table 9: Area analysis (sqkm) for each sub bands of the band 17,3 - 17,7 GHz

17,7-17,3 GHz	SB1	SB2	SB3	SB4	SB5
−155 dBW/MHz	2 420,9 (1,06 %)	1 692,4 (0,74 %)	1 692,4 (0,74 %)	1 683,3 (0,73 %)	3 570,9 (1,56 %)
−145 dBW/MHz	683,0 (0,30 %)	544,8 (0,24 %)	544,8 (0,24 %)	541,8 (0,24 %)	926,0 (0,40 %)

17,7-17,3 GHz	SB6	SB7	SB8	SB9	SB10
−155 dBW/MHz	1 683,3 (0,73 %)	2 411,0 (1,05 %)	2 535,6 (1,11 %)	2 367,6 (1,03 %)	2 936,4 (1,28 %)
−145 dBW/MHz	541,8 (0,24 %)	741,3 (0,32 %)	774,2 (0,34 %)	697,5 (0,30 %)	928,6 (0,40 %)



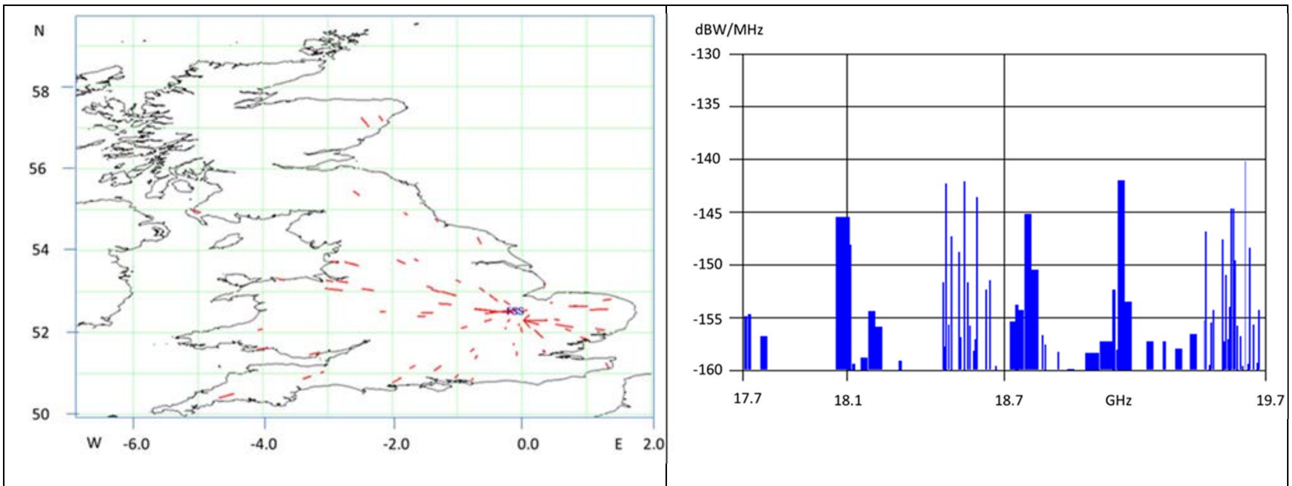
(a) (b)

Figure 17: Example of cognitive zones for the sub-band 1 (17,3 - 17,34 GHz) based Scenario B: Area/spectrum analysis

7.4.4.4 Scenario B: Area analysis

Unlike the situation in scenario A, the UK 18 GHz FS database comprises many more carrier records (15 036 records) over the 2 GHz band from 17,7 to 19,7 GHz. For scenario B, spectrum analysis is performed for a particular location in the UK instead of geographical area analysis across the whole of the UK to determine which carrier(s) can be used by an FSS at a specific location. This information could then be integrated with a mitigation approach such as resource allocation algorithm in the satellite network to assign the carriers to a non-interfered with frequency.

Spectrum analysis results for the UK FS links at 18 GHz at a specified location with latitude 52,5 degrees, longitude -0,1 degree is shown here as an example. The analysis results of the location with both LOS and full model (Recommendation ITU-R P.452-15 [i.42]) are shown as figure 18 and figure 19, respectively.

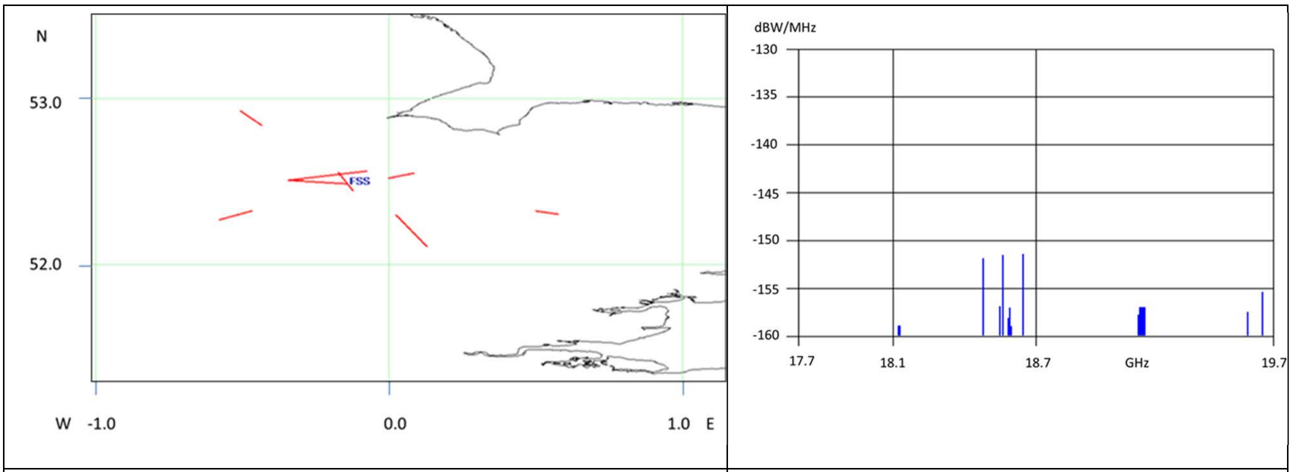


(a) Interfering FS links (b) PSD based spectrum analysis

Figure 18: LOS result of all UK FS links, interfering to FSS terminal at latitude of 52,5 degrees and longitude of -0,1 degrees

The FSS terminal evaluated, points to the same satellite as the previous examples which is located at 53 degrees E longitude. In each figure, a map of the links that exceed an interference level of -160 dBW/MHz is presented along with spectrum analysis as a plot of the interference power spectral density (PSD). Interference PSD is shown per MHz from 17,7 to 19,7 GHz. At this location, it can be seen that with the LOS model the interference can be from FS links much further from the location of interest and these links are ones pointing directly at the location. Only a few points with some offset and these are located very close so that interference is from their side lobes. From the interference PSD in figure 18b, it can be seen that more than half of spectrum resource from 17,7 GHz to 19,7 GHz is available (with interference below the threshold) at this location under LOS model.

However, if the full terrain model is considered as in figure 19, the number of interfering FS links dramatically decreases to less than ten, which means less than 0,1 % of total FS links would cause problem at the location. Therefore the majority of the 2 GHz of bandwidth can be used by an uncoordinated FSS VSAT terminal site.



(a) Interfering FS links (b) PSD based spectrum analysis

Figure 19: Full terrain model Results result of all UK FS links, interfering to FSS terminal at latitude of 52,5 degrees and longitude of -0,1 degrees

A complete map of the locations in the UK (see figure 20) has been produced and this can be used as input to a mitigation approach such as a resource allocation scheme which would then optimize the carrier allocation on the basis of the extra spectrum available. It was noted that although the number of FS links in the data base was large, those that actually caused interference at a specific location and in a particular frequency band were quite small. It should also be noted that the available spectrum is not the same at each location and thus the data base analysis can be used to optimize the carrier allocation as a function of FSS location.

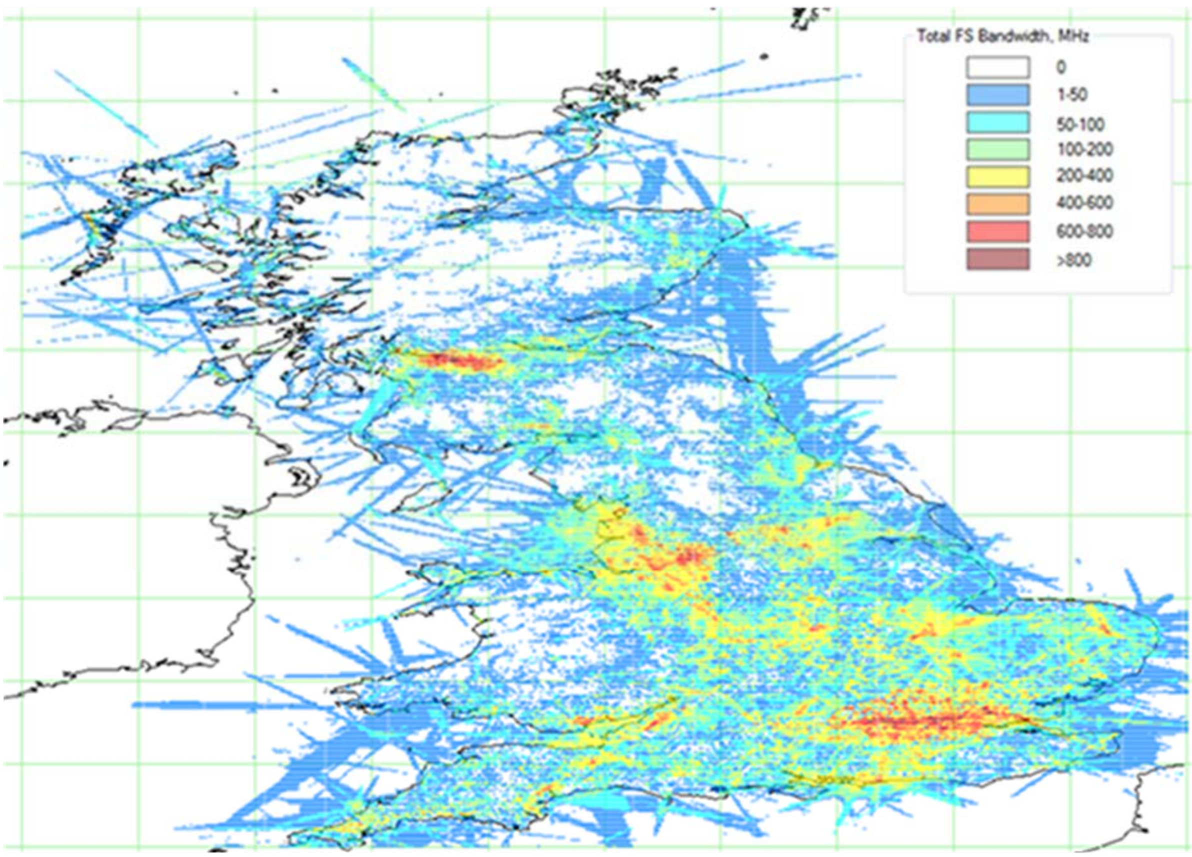


Figure 20: Geographical map of total bandwidth occupied by FS at a particular location

In figure 20, the granularity of the dots is 0,1° in latitude and longitude. It presents a map of the links that exceed an interference level of -154,5 dBW/MHz from 13E geostationary orbit location.

7.4.4.5 Area analysis across European countries

By analysing the interference results for five data bases for countries across Europe it is possible to get an increased insight into the situation. The analysis was conducted over these regions with the full diffraction model and statistics were prepared from the results. To permit a fair comparison between the countries only the results for test points over land were included. The first set of statistics presented is the cumulative distribution function (CDF) of the number of interfering signals that exceed the -154 dBW/MHz threshold at each point. The resulting CDFs are presented in figure 21.

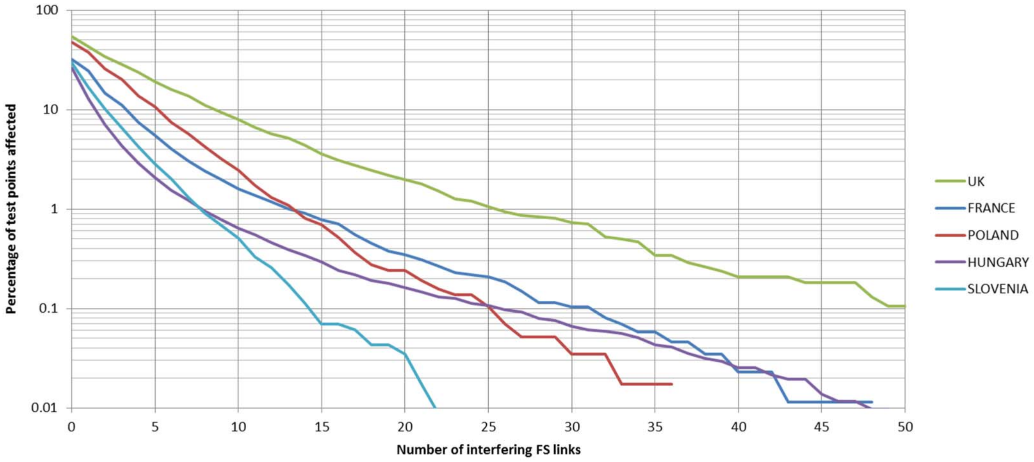


Figure 21: CDF of number of interferers at a test point (for -154 dBW/MHz threshold)

A CDF was also produced for the total occupied bandwidth of the FS interferers at a point over the regions of interest. The resulting CDF is given in figure 22.

NOTE: Also in figure 22 a second horizontal axis at the top indicates percentage of the total spectrum occupied by the FS.

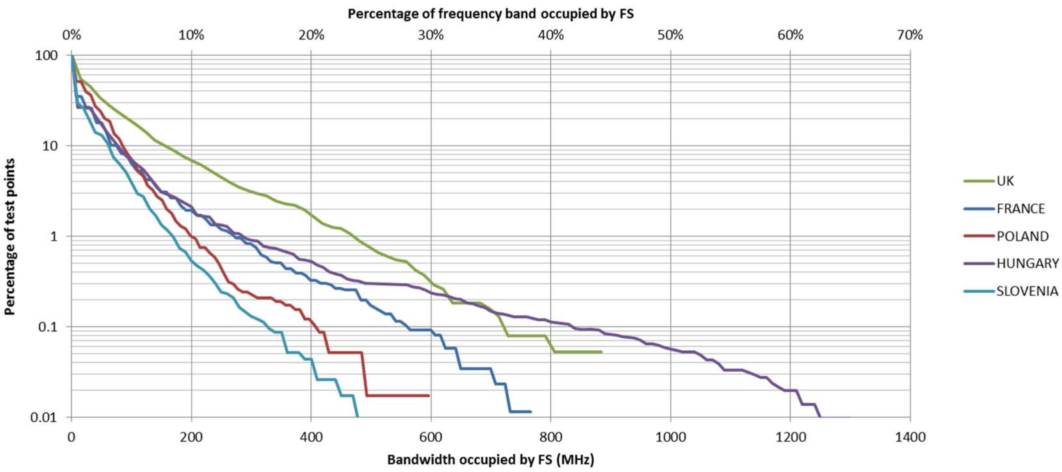


Figure 22: CDF of FS bandwidth by interferers over the five regions (for -154 dBW/MHz threshold)

7.4.4.6 Summary

The area analysis has demonstrated that:

- For Scenario A across Europe less than 2 % of the area would be affected by interference and thus in 98 % of the area an FSS could operate free of BSS interference. In the small number of cases around BSS stations where interference is a problem additional site shielding/beam forming could be used. Maps of the regions will allow operators to determine these areas. This will enable to use an additional 400 MHz of spectrum in the down link.
- For Scenario B, a high percentage of the 2 GHz spectrum (17,7 - 19,7 GHz) is available free of interference (> 90 %) on average to 95 % of the area in the European countries. However the portion of this spectrum varies with location and hence a data base connected to a carrier allocation scheme at the gateway will allow carriers to be re-organized within the shared band or reallocated into the exclusive band to enable use of the extra spectrum.

8 Radio spectrum request and justification

ECC/WGFM has already started the process of revising ERC/DEC(00)07 [i.29] and is also generating a new ECC Report, studying the enhanced operations of uncoordinated FSS Earth Stations operating in 17,7 GHz - 19,7 GHz. The present document is in support of this process. ECC/WGSE is conducting technical studies in PT SE40 in support of this work.

The principles of cognitive radio techniques for SatCom operating in Ka band as set out in clause 7.1.1 should be taken into account in the on-going investigations to find effective solutions that could improve the FS/FSS spectrum sharing.

9 Regulations

9.1 Uncoordinated FSS Earth Stations current regulations

Include, in particular, ITU, EC and ECC applicable regulations.

From the table of service allocations in the ITU-R radio regulation document, the main sharing scenarios are identified in table 10.

Table 10: Sharing of Ka-band according to the ITU-R radio regulation document

Frequency bands	ITU-R Region 1	ITU-R Region 2	ITU-R Region 3
17,3 GHz - 17,7 GHz	FSS (space-Earth) BSS (feeder links) Radiolocation	FSS (space-Earth) BSS (feeder links) Radiolocation	FSS (space-Earth) BSS (feeder links) Radiolocation
17,7 GHz - 19,7 GHz	FSS (space-Earth) BSS (feeder links up 18,1 GHz) FS	FSS (space-Earth) FS	FSS (space-Earth) BSS (feeder links up 18,1 GHz) FS
27,5 GHz - 29,5 GHz	FSS (Earth to space) FS MS	FSS (Earth to space) FS MS	FSS (Earth to space) FS MS

CEPT has adopted a Decision, ECC/DEC/(05)08 [i.31], which gives guidance on the use of the band 17,3 GHz - 17,7 GHz by High Density applications in the Fixed-Satellite Service (HDFSS). The Decision stipulates that the designation of this band is without prejudice to the use of this band by BSS feeder links and that it is not allocated to any incumbent terrestrial service (except in some countries). The deployment of uncoordinated FSS Earth stations is also authorized in these bands. It is to be noted that administrations should exempt from individual licensing and allow the free circulation and use of the uncoordinated FSS earth stations operating in the band 17,3 GHz - 17,7 GHz.

CEPT has adopted a Decision, ERC/DEC(00)07 [i.29], which gives guidance on the use of the band 17,7 GHz - 19,7 GHz 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. Nevertheless the Decision also requires both FS and FSS systems to implement interference mitigation measures. Decision ERC/DEC(00)07 [i.29] is widely implemented within CEPT, and FSS allocations are present in most CEPT countries according to the ECO Frequency Information System (EFIS).

CEPT Decision ECC/DEC/(05)01 [i.30] provides a segmentation between FS and FSS stations in the band 27,5 GHz - 29,5 GHz, which is depicted by figure 23. "Sat" and "Ter" refer to refer to FSS and FS respectively. The main points to be noted from this Decision are:

"...

- *Terminals employing bands labelled "sat" do not need site coordination, and are exempted from individual license.*
- *In the band labelled "sat*" (28,8365-29,9485 MHz) : There are legacy FS in few countries. The FS links licensed in these countries before 18 March 2005 could require protection, but not after 1st January 2020. No new FS links can be deployed in this band.*
- *The out-of-band EIRP radiated by FSS terminals in FS bands below 3° elevation shall not exceed -35 dBW/MHz.*
- *FSS terminals shall operate above 3° elevation.*
- *Power Control is mandatory for FSS terminals. The maximum EIRP of FSS terminals shall not exceed a value in a range from 60 dBW to 55 dBW. The maximum value may be fixed nationally.*
- *FSS terminals shall implement a minimum guard band of 10 MHz from bands identified for FS..."*

It should be noted that ECC Decisions are not mandatory instruments, and CEPT administrations may choose not to implement them.

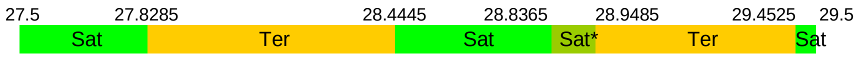


Figure 23: Segmentation of the band 27,5 GHz - 29,5 GHz according to Decision ECC/DEC/(05)01

9.2 Proposed regulation and justification

9.2.1 FSS terminal reception

The regulatory regime in the Ka band for uncoordinated earth stations is largely driven by coexistence considerations with other services. As regards the band 17,7 GHz - 19,7 GHz, the main incumbent use is for the Fixed Service.

Recognizing the increased interest for using the band for FSS uncoordinated earth stations, the CEPT is expected to adopt by early 2016 a reviewed framework, with the following new elements:

- Administrations should authorize uncoordinated FSS earth stations, with no regulatory protection from FS interference. Previously, there was no clear identification of the band for FSS uncoordinated use.
- Administrations are encouraged to provide FS assignment information for FSS planning purposes. The new decision provides the list of desired FS parameters.
- The European Communication Office is tasked to monitor the FS information provided by administrations in order to identify if there is any need for a software solution as described in ECC Report 241 [i.60] (software approach to determine locally available spectrum for FSS use).
- Administrations are required to provide information on the use of the FS duplex gap around 18,7 GHz.

The above measures should be approved by CEPT in early 2016 by a revision of the ERC/DEC(00)07 [i.29], and the companion ECC Report 241 [i.60]. These measures constitute a positive step, although modest. Its adoption by CEPT and the widest possible implementation by CEPT countries at the national level should be promoted.

It has been demonstrated that cognitive techniques may provide their maximum benefit when combining sensing techniques and knowledge of incumbent services deployment, e.g. by interfacing with national assignment data for the Fixed Service. The measures related to the provision FS assignment data in the revised ERC/DEC(00)07 [i.29] rely on administration voluntary action.

The following actions may be considered for the future, to further improve the situation:

- The EU/CEPT should seek to encourage all member countries to make available FS data base information or interference maps generated from them.
- The CEPT should provide or support the development of an harmonized software tool to assist spectrum planning based on FS assignment information. Basic concepts for such a tool are described in ECC Report 241 [i.60].
- Development of sensing techniques should be continued and supported. Cognitive systems should be resilient to the partial or total lack of information on FS deployment.

For the band 17,3 GHz - 17,7 GHz, no changes in the regulations are required. However administrations are encouraged to notify, as stipulated in the ITU Radio Regulations, the transmit earth stations providing feeder links for the Broadcasting Satellite Service, so that FSS systems operating FSS uncoordinated receive earth stations in this band can anticipate any interference issues.

9.2.2 FSS terminal transmission

Bands already identified for uncoordinated FSS use (not shared with Fixed Service):

A subset of the 27,5 GHz - 29,5 GHz band is identified in CEPT for use by uncoordinated FSS earth stations, with an exemption of individual license (see ECC/DEC/(05)01 [i.30]) for satellite terminals. These subbands (see note), where no sharing constraints with other services are expected in Europe, are critically important for FSS services in Ka band. Current FSS systems are operating in these bands, and more systems are planned to become operational.

NOTE: The subbands identified for uncoordinated earth stations in CEPT are 27,5 - 27,8285 GHz, 28,4445 - 28,9485 GHz and 29,4525 - 29,5 GHz as per decides 1) and 2) of ECC/DEC/(05)01.

These subbands should be preserved for FSS uncoordinated use in the long term, without introduction of terrestrial services.

Bands shared with the Fixed service:

ECC/DEC/(05)01 identifies the bands 27,8285 GHz - 28,4445 GHz and 28,9485 GHz - 29,4525 GHz for use by the Fixed Service. With the current regulation, FSS uncoordinated earth stations are not allowed in these sub-bands.

The knowledge of FS characteristics (e.g. carrier bandwidth, power, Tx/Rx locations, etc.) in a data base could be exploited by the satellite cognitive radio technique to transmit in this band while avoiding interference to FS. Provided that the efficiency of cognitive radio techniques could be demonstrated in this context, FSS uncoordinated uplink use of the whole band 27,5 GHz - 29,5 GHz, including the portions used by FS, may be envisaged.

Potential other uses of the band:

WRC-19 may be tasked to identify new spectrum for mobile service above 6 GHz. The 27,5 GHz - 29,5 GHz should be excluded from the possible candidate bands for future mobile use. In effect, given the nature of mobile terrestrial networks, their sharing potential with FSS is very limited, and is considered a serious threat to the existing and future FSS systems.

10 Conclusion

The coexistence of FSS with incumbent service (BSS or FS) in non-exclusive Ka band frequency bands (Scenario A, B and C) is possible under the condition that the FSS system implements at least the following cognitive radio techniques:

- Scenario A and B (Space to earth): Database approach plus dynamic channel assignment, augmented by spectrum sensing to improve the accuracy or use as a stand-alone technique in the absence of a suitable database.
- Scenario C (Earth to space): As per Scenarios A and B with database approach and dynamic channel assignment if HDFSS is insufficient. Spectrum sensing is not considered appropriate.

The CoRaSat project has demonstrated that a data base/spectrum sensing plus resource allocation scheme can be used to allow dynamic carrier positioning in the 17,3 GHz - 19,7 GHz shared bands for the satellite down link. It has also been demonstrated that for the countries examined in Europe that 99 % of the FSS sites considered will have greater than 80 % of the 2 GHz bandwidth from 17,7 GHz to 19,7 GHz available for satellite use.

A dynamic carrier allocation scheme has been shown to allow use of this extra bandwidth provided interference from the FS links can be evaluated from data bases. For the band 17,3 GHz to 17,7 GHz less than 2 % of the area will be affected by interference from the BSS uplinks and in these regions site shielding and beamforming can be used to allow the FSS terminal to operate. Maps of the affected areas in the latter case have been produced.

A simulation has been conducted using a multi beam satellite model of the capacity increase that can be obtained by using the scheme over that available by using the current 500 MHz exclusive band. Taking beams over the UK and France from the satellite system model it was shown that the increase in capacity was 4 times that of the exclusive band only. This is verification that the interference/spectrum availability together with the carrier allocation scheme allows the additional shared bandwidth to be used. The interference from the multi beam satellite antenna in this model exceeds that produced by the FS terrestrial links in most locations and where it does not the carrier allocation can avoid the problem. The carrier to interference distribution across the satellite antenna model used in this evaluation is considered typical of those being proposed for future Ka band HTS satellites.

The focus has been made on the down link bands as this is where the additional capacity is required in future broadband access systems. Currently satellite operators inform us that the asymmetry is something like 6:1. Thus the uplink is not so much of a problem especially in Europe where the CEPT segmented bands allow 1,2 GHz of extra capacity in the HDFSS portions. Although it is possible to use the FS part of the shared bands in the future this will not be needed initially provided the HDFSS bands remain protected. The up-link bands around 28 GHz remain sparsely used at the moment in most EU countries and in some have been sold off by regulators making a data base system difficult to implement. A similar sharing scheme in the up-link to that implemented in the down-link has been evaluated in two EU countries from which data base information was available. The scheme here was to limit the EIRP from the FSS so as to retain the interference threshold at the FS receiver within limits. The result of this exercise also demonstrated that pretty much all of the shared band could be used. It is to be noted that the evaluation was performed on the long term threshold as in the down-link. Further evaluations are needed to ascertain the effects of interference on the QoS in the FS links and to use a wider range of data bases so this remains work in progress.

CoRaSat has fed the results of the work into CEPT groups SE-40 and FM 44 as part of their on-going work in this area. CEPT have taken on board the necessity to provide the data base information from regulators and have proposed a methodology for doing so which is under consultation.

The Way forward:

Sufficient evidence is now available for satellite operators to use the 17,3 GHz to 17,7 GHz band in future satellite procurements and the manufacturers of satellites and ground equipment have no significant problems in producing equipment for this extension.

The use of the 17,7 GHz to 19,7 GHz band awaits the CEPT processes to be completed and decision on who will provide and maintain the EU interference/spectrum maps. The EU needs to exert pressure to ensure that this is resolved in a timely manner. Interested stakeholders should drive the agenda via the CEPT committees.

Satellite and ground station manufacturers should now be taking into account this extra bandwidth and doing design and prototyping ready for the introduction of cognitive satellite systems.

Annex A: Bibliography

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History

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