FP7 PROJECT CoRaSat intermediate results and standardization strategy: Cognitive radio techniques in Ka band SatCom context

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***Abstract*—The objective of this paper is to discuss the applicability and benefits of Cognitive Radio techniques in the context of satellite communication systems operating in the Ka band where spectrum chunks are allocated to Fixed Satellite Services with other services. The paper reports about ongoing technical analysis and standardization activities in the context of the FP7 ICT project "CoRaSat", which aims to assess the potential gain of Cognitive Radio techniques to improve the spectrum use and to assess the need for the implementation of possible adaptations to the existing regulatory framework.**

Keywords— Satellite communications, Cognitive Radio techniques, Ka band

I. INTRODUCTION

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

The CoRaSat project [1] is currently investigating the applicability of cognitive radio techniques in the context of SatCom and in particular SatCom operating in Ka band. The project already initiated standardization activities with the objective to upgrade the regulatory framework and enabling the deployment of such features.

An ETSI System Reference document (SRdoc) [2] on "Cognitive radio techniques for Satellite Communications operating in Ka band" is being developed in ETSI by the Technical Committee "ERM - ElectroMagnetic Compatibility and Radio Spectrum Matters" with the support of the Technical Committee "SES – Satellite Earth Stations and systems" to analyze the potential of CR concepts in Ka band satellite communications context, in order to improve coexistence scenarios in selected Ka band spectrum chunk allocated to SatCom services. This ETSI document has been developed on the basis of the CoRaSat activities reported in the CoRaSat deliverables [1].

The SRdoc aims at supporting the co-operation between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT) to identify and address the possible changes to the regulatory framework.

In this framework, this paper provides an overview of the system concept and reports about on going CoRaSat technical and standardization activities.

II. SYSTEM CONCEPT OVERVIEW

The ETSI System Reference document identifies the potential regulatory impacts associated to the implementation of cognitive radio techniques in SatCom solutions addressing mass deployed terminals without prior individual frequency coordination. It addresses different Ka bands (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 other incumbent system already deployed and operating in a given frequency band, 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) and regulatory issues.

The Ka band is mainly considered by the SatCom industry for the deployment of satellite high speed broadband networks (> 30 Mbps) to bridge the divide in un-served and under-served areas. According to Point Topic [4] the average percentage of total European households which will take up a satellite broadband connection in 2020 is expected to be between 5 and 10 Millions. This represents a market potential for several satellite systems and creates the need to access extra spectrum, including the chunks shared with other services, to accommodate the increasing bandwidth demand. IN this perspective, there is a clear rationale in exploring Cognitive radio techniques in SatCom context to allow the exploitation of shared frequency bands under the constraint to minimize or event avoid inter-system interference.

We consider a reference system made of a satellite network operating in the Ka band and providing broadband access to fixed terminals (Residential home, SME premises in rural or remote areas) and mobile terminals (on mobile platforms such as trains, vessels or aircrafts). The satellite network is based on the DVB-S2/RCS2 radio interface and provides connectivity between the terminals and anchor gateways, which are also connected to the Public Internet.

The system's multi beam geostationary satellite also named "high throughput satellite" typically generates between several tens and several hundreds beams to achieve high transmission and reception gains towards the terminals distributed across its service area.

We consider 2 possible frequency plans based on a 4 color scheme as reported in Table 1.

Table 1 - Frequency plan options for the satellite user links

Frequency plan	Nominal	Alternative
user downlink	Total frequency band: 17.3 – 20.2 GHz Spectrum per beam: 1.4 GHz	Total frequency band: 17.3 – 20.2 GHz Spectrum per beam: 1.4 GHz

User uplink	Total frequency band: 27,5 – 30.0 GHz Spectrum per beam: 1.25 GHz	Total frequency band: 28,4465 - 28,9465 GHz and 29,5 - 30 GHz Spectrum per beam: 0.5 GHz

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

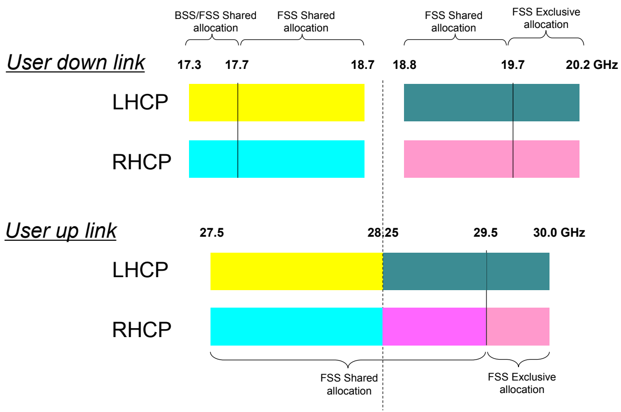


Fig. 1. Nominal frequency plan for the FSS satellite system

In the Ka band, the following three different Cognitive Radio Techniques 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 complicated 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/Cognitive Zones: Furthermore, 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. Cognitive 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 (Sensing/Beamforming): 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 either using protection through licensing or by continuously monitoring the vacant bands through periodic sensing and adaptation.

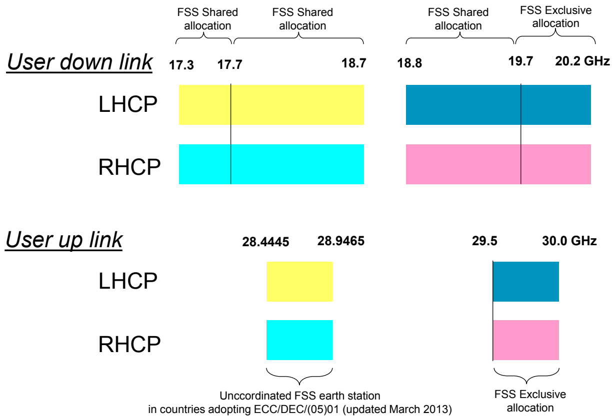


Fig. 2. Alternative frequency plan for the FSS satellite system

Three cases of frequency sharing scenarios with interference issues are identified and are illustrated by figure 3:

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 regulations, no interference from the FSS onto the FS is foreseen. 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 : frequency sharing between the FSS and the FS. Interference may if the FSS terminal transmits on a frequency that a nearby FS link uses as well.

III. TECHNICAL ROADMAP

In the frequency sharing scenarios discussed above, the sharing of the same frequency band between terrestrial and satellite communication has to respect protection requirements between the two systems. On one hand the incumbent (terrestrial or satellite) communications has to be protected from the cognitive (satellite) communications, if active. At the same time, in order to achieve an acceptable reliability, the cognitive (satellite) link has to ensure that any incumbent (terrestrial or satellite) does not degrade its service. The protection requirements take into account those defined by ITU-R and ERC/ECC regulatory bodies. In addition both the incumbent and cognitive systems have to respect emission limits specified by the regulatory body in order to avoid harmful interference. 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 CoRaSat the main techniques that can be used to support such protection in each scenario have been evaluated and mapped. These techniques include data bases, interference modeling, cognitive zones, spectrum sensing, beamforming and carrier allocation. Cognitive zones are a concept proposed in CoRaSat that are defined as the geographical area around an incumbent user station where cognitive radio technique should be employed to mitigate the interference to an acceptable level. In other words, the interference outside of this area is below the interference threshold thus cognitive radio techniques are not necessary. In all three scenarios data bases and interference modeling have been explored to produce cognitive zone contours and then cognitive means can be applied inside the cognitive zones in order to evaluate the range of interference reduction advantages that are possible for the types of carriers involved. The implementation of beamforming is also considered as another means of reducing side lobes and thus counteracting interference. Finally, resource allocation schemes are being further investigated to be applied having determined that a carrier needs to move due to interference considerations.

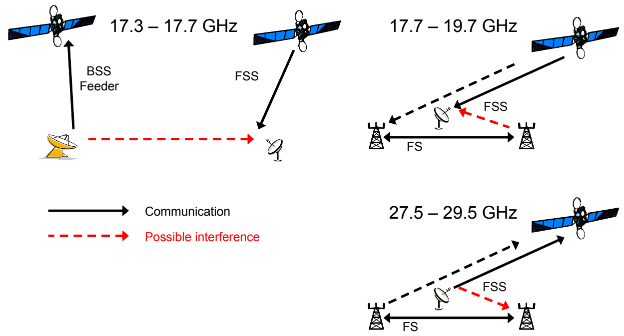


Fig. 3. Interference scenarios in Ka band

Cognitive zones are also being applied to the scenarios in order to evaluate the areas in which FSS terminals can operate with interference below the threshold and also using cognitive gain, the increase in overall system capacity. This can be evaluated within a country or region as the extra capacity that the system can provide. The output of the interference analysis and the cognitive gains in conjunction with the required QoS will be used to determine a methodology for such calculation.

The content of this and of the following sections is mainly based on the outcomes of the CoRaSat project reported in the project deliverables [1]

A. Data bases

To explore the actual activity of incumbent users, data bases of the involved transceivers such as earth stations and microwave links, were required. Unfortunately data bases may not fully reflect reality – they can be out of date or they can represent an aspiration of use which has not been taken up. However, data bases of incumbent systems are still necessary to evaluate the interference scenarios accurately. These data bases are at the moment held almost exclusively by national regulators. For example data bases in the UK are held by OFCOM who are the national communication regulator and competition authority of UK. Similarly in other countries the national regulators hold such data bases. They are not generally available to the general public.

The information in a database is normally listed on a carrier by carrier basis for a frequency of interest. All carriers are usually detailed with their frequencies and channel bandwidth. When the database relates to satellite terminals, we also need to relate this to details on the associated satellite in terms of satellite longitude and the earth stations azimuth and elevation angles. Polarization and antenna gain are also required along with the antenna radiation patterns as defined in ITU Recommendations for use in regulatory work.

In addition, the emission designations are defined by the ITU in Appendix 1 of the Radio Regulations. Formulae and examples of emissions designated in accordance with this Appendix are given in Recommendation ITU-R SM.1138 [6]. The Earth Station antenna radiation pattern for BSS are defined in the Radio Regulations along with other parameters in Appendix 30A of the Radio Regulations which is specific to BSS feeder links (see also Recommendation ITU-R BO.1295). Such stations are also presented in the data bases as complying with ITU-R Recommendation S.580 [7] or ITU-R Recommendation S.465 [8]. FSS terminals are considered to comply with one of the latter two Recommendations. The FS antenna radiation patterns are assumed to comply with ITU-R Recommendation- F.699 [9].

A database for BSS earth stations in the UK has been supplied in confidence to CoRaSat by OFCOM for research purposes. This data base shows that there are 442 carriers from a total of 31 BSS uplink earth stations at 8 sites, to 12 different satellites. The number of carriers of each BSS earth station range from 1 to 42. The carriers span the range 17.3195 GHz to 18.349375GHz. The bandwidths of the carriers that belong to the BSS earth station range from 26 MHz, 33 MHz, and 36 MHz to 66MHz. The equivalent isotropically radiated power (EIRP) of these BSS earth station antennas ranges from 69dBW - 84dBW and all antenna radiation patterns are defined in ITU Recommendation S.465 or S.580.

FS data bases at 18 and 28GHz are required to evaluate scenarios B and C respectively. OFCOM in the UK is making available a UK data base (17.7 to 19.7GHz). This data base will be much larger than the BSS with some 13,000 entries for the UK. The French regulator (ANFR) has released an 18GHz data base for France valid in 2012 which contains 10,212 FS entries. However this is only partially complete as it does not include, for example, the exact carrier frequencies, antenna radiation patterns, and details of the receiving link or the transmitted EIRP. In addition, the latest ITU-R terrestrial services BR IFIC data base is available and the BR IFIC of Terrestrial Services [10] is a consolidated regulatory publication issued by the ITU-R Radiocommunication Bureau. It contains information on the frequency assignments/allotments submitted by administrations to the Radiocommunication Bureau for recording in the Master International Frequency Register and in the various regional or worldwide Plans. However it does not represent all of the FS links in operation in the respective countries.

B. Interference modeling and cognitive zone determination

The determination of cognitive zones depends on the acceptable interference threshold and interference modeling. An interference model using ITU R Recommendation P.452-15 [11] is being used for modelling the interference path losses. ITU-R P.452-15 is the latest version of this ITU Recommendation that contains a prediction method for the evaluation of path loss between stations on the surface of the Earth at frequencies from about 0.1 GHz to 50 GHz. Thus all the relevant interference path loss calculation for all three scenarios can be derived by using this model.

In all three scenarios the use of the data bases and the interference modeling to produce cognitive zones is applicable. More explicit, for scenario A, we can use the cognitive zones to produce maps of coverage for the UK where we have a data base. This can be repeated for other countries if a data base becomes available. For scenario B it is more complex as we will have more than 10 thousands FS links but we should be able to produce cognitive zones for the UK and France for which we will have access to data bases. For scenario C we can again produce some example cognitive zones but as at the moment we have no data bases available we will need to fabricate one based on the information available.

An example of a cognitive zone for BSS into FSS (scenario A) is given in Fig. 4. The contours are in dBW/MHz and in this case represent the worst case situation with free space path loss with BSS parameters from one of the UK database records. The area inside the contour is where cognitive approaches will be required to reduce the impact of the interference. Outside of the contour no action is required. It is important to recognize that the figure is an example and is the absolute worst case.

Fig. 5 indicates the cognitive zone for FS interference into FSS (scenario B). The situation is similar to that for scenario A except that it uses FS parameters instead of BSS parameters. The axes in this case are in degrees latitude and longitude. The so called 'keyhole' nature of the interference pattern is clearly visible and we will use this to assess the large number of FS entries in the data base.

After the cognitive zone is obtained, the applicable cognitive radio gain can be applied to reduce it. Thereby increasing the area where joint operation is possible.

C. *Spectrum sensing*

Spectrum sensing is necessary to compensate for the incomplete or inaccurate database information and to respond to possible changing environments in the radio band occupation of the incumbent user.

The aim of spectrum sensing is the detection of the incumbent user signal by scanning selected frequency bands. It refers to the detection of an unknown signal, or a partially known signal, and a trade-off between probability of false alarm and probability of detection (or misdetection) would be necessary for achieving an accurate degree of certainty in its detection. It has been shown that spectrum sensing, using energy and cyclostationary detection is feasible in theory for scenario A and B. Cyclostationary feature detection would provide better performance compared to an energy detector, with providing precise information (modulation, multiple access scheme, etc.) on the structure of incumbent signals. The energy detection technique, which is a blind spectrum sensing technique, does not require this information. But its performance suffers from the noise uncertainty.

In scenario A, we are only interested in detecting the interference received from BSS feeder links. Failed detection of BSS interference means the interference is lower than the harmful level and thus not detectable. However, spectrum sensing in scenario A is limited by a number of factors. The received signal at the FSS main lobe also includes the GEO satellite signal and thus measuring the interference received from the BSS links becomes difficult, if the same antenna is used both for cognitive reception and spectrum sensing. We have thus considered a separate interference detection that will be in the horizontal plane from the terrestrial interferer. Thus we propose an additional antenna with pattern in the horizontal plane e.g. a dipole or bicone antenna. However, this approach requires the need for two RF chains.

In scenario B different bandwidths are allocated to the FS links in this band, ranging from 10 to 220 MHz. There is a need to have validated bandwidth conversion between the FS/FSS links which we are studying.

Some preliminary energy detection results for scenario B are provided in Fig. 6 which shows the performance of the energy detection based sensing in the considered scenario in terms of Receiver Operating Characteristic (ROC) curves i.e., probability of detection versus probability of false alarm. In this result, we have considered different lower values of EIRPs including the worst-case EIRP (-45 dBW). From the figure, it can be noted that the probability of detection increases with the increase in the value of probability of false alarm and better detection is achieved for higher values of FS EIRPs.

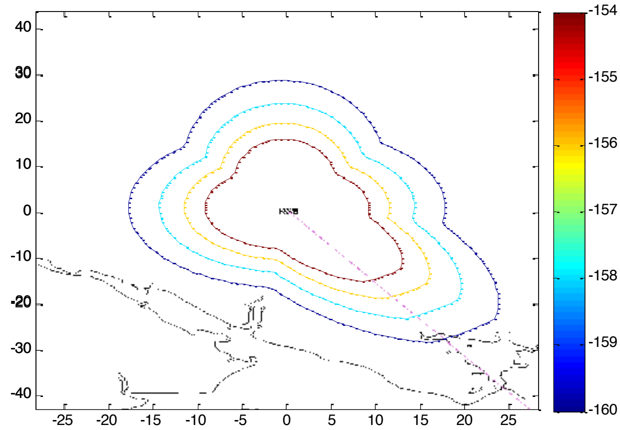


Fig. 4. Example Cognitive Zone for BSS into FSS (Scenario A)

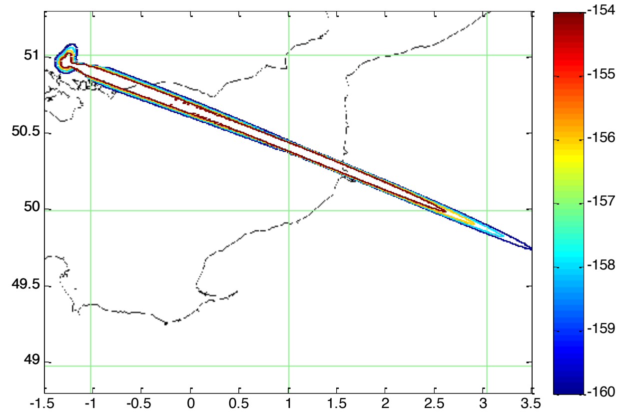


Fig. 5. Example Cognitive Zone for FS into FSS (Scenario B)

Fig. 7 depicts the signal strengths received by an additional dipole/bicone and satellite dish antennas for different values of FS transmitting EIRP. From the figure, it can be noted that for the highest value of FS EIRP (36 dBW), the interference level picked up by the satellite dish antenna is well above the interference threshold and the use of shared spectrum band is not possible (even for very large separation distances) in this scenario. Furthermore, for the lowest EIRP value (-45 dBW), the interference level detected by the satellite dish is well below the interference threshold and the sharing is feasible (even for very small separation distances). For the EIRP value of -12 dBW, it can be observed that the received interference level exceeds the interference threshold for separation distances less than 1 Km. However, for the separation distances above 2 Km, the received interference level is less than the interference threshold and frequency sharing between FSS downlink and FS link is possible. Therefore, it can be concluded that there exists a range of EIRP values of FS transmission for which frequency sharing seems possible between FSS downlink and the FS link. It is to be noted that the path loss model for the results above is free space loss based and is thus the worst case. It is noted that although the energy detection mechanism may encounter challenges when applying it in practice because it requires an accurate noise reference calibration and assumes opportunities when the signal is silent to detect the interference underneath the signal, a detection of the interference is in principle possible. The static interference configuration and therefore possibility to use long sample sequences here is a context that makes interference detection in principle feasible also at low interference levels compared to noise floors. Furthermore the interference detection antenna can be adapted to the considered context of low interference signal levels.

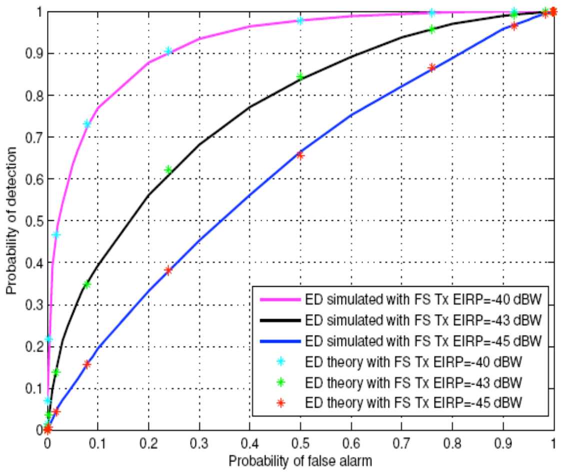


Fig. 6. Probability of detection versus probability of false alarm

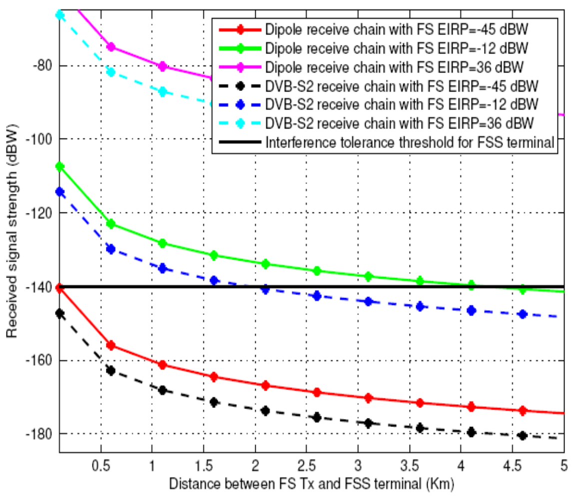


Fig. 7. Total signal strengths received by dipole and DVB-S2 chains for different EIRP values

In scenario C the FSS is transmitting and thus any sensing would have to be performed in the FS. This would mean that the cognitive sensing and cancelling would have to be performed in the incumbent. This is not realistic and thus we investigate the reduction of transmit power of the FSS to remain below the threshold level of interference to the FS. An initial study has been made of scenario C.

Fig. 8 shows a 3D diagram of interference power that would be received by an FS receiver with height 20 m, elevation 0° and allowable interference threshold –146 dBW/MHz (for the reference point-to-point FS parameters recommended in [12] and [13] for interference assessment purposes) from a commercial FSS transmitter (Tooway Viasat Surf beam) with height 2 m and maximum EIRP of 55 dBW (i.e., transmission power P_S = 4.7 dBW/MHz for a terminal with 45.5 dB antenna gain and 3 MHz bandwidth [14]) for elevation in the range $20^{\circ} - 50^{\circ}$ which are the commonly used satellite elevation angles in Europe [15], with several azimuth angles before restricting the FSS transmission power (i.e., the cognitive FSS transmission supplies its nominal 4.7 dBW/MHz power to the antenna regardless of FS receiver requirements). The maximum level of tolerable interference (−146 dBW/MHz) is also shown in the figure. It can be seen that changing the FSS transmitter and FS receiver pointing directions changes the received interference significantly. This interference exceeds interference threshold for separation distances less than 10 km. Increasing the FSS transmitter elevation angle reduces the minimum required separation distance as a FSS transmitter with 50° elevation angle requires 5 km separation to ensure non-harmful interference to the FS receiver. Hence DSA/CR mitigation techniques such as power control are needed in the high interference region to allow increasing the FSS deployment area whilst satisfying FS receiver requirements.

Rotating the FSS transmitter antenna azimuth α by -10° (anti-clockwise) w.r.t. the FS receiver, and FS receiver antenna azimuth β by 10° (clockwise) w.r.t. the FSS transmitter in the horizontal plane b), reduces the interference to acceptable levels except for distances less than 2 km. This behavior is linked to off-bore-sight gain patterns of the FSS transmitter and the FS receiver, which play an important role in achieving objectives of both the incumbent and the cognitive systems. Without these patterns Fig. 8(b) would give results similar to Fig. 8(a), and the deployment area of the FSS system would be reduced inefficiently.

D. *Beamforming and resource allocation*

Within CoRaSat use of beam-forming at the FSS terminal as a means of reducing the side lobes in the horizontal plane and thus mitigating the interference is being investigated as a further technique. This can be considered as a form of mitigation of the interference signal or a cognitive gain that we are also investigating. In addition having detected interference at the FSS we are also considering the overall resource allocation scheme as an action to take. This may manifest in moving the carrier to another in the shared or in the exclusive bands. We can also consider the totality of the carriers as they are interfered and to operate a network carrier allocation that optimizes for the overall interference scenario.

Within CoRaSat we are working towards a demonstration of the cognitive approach in which we will have in a laboratory demonstration the detection of interference and its mitigation by one or more of the techniques described above. This will demonstrate the feasibility of incorporating within the FSS receiver to mitigate interference.

We are also investigating how we can operate with national data bases to advise FSS users of the need or not to incorporate cognitive techniques. We see this as a guideline for users as to the type of FSS terminal that they will need to install at a particular location. There is also the possibility that such data bases could be used by operators to optimize their system performance and this is being further investigated.

IV. STANDARDISATION ROADMAP

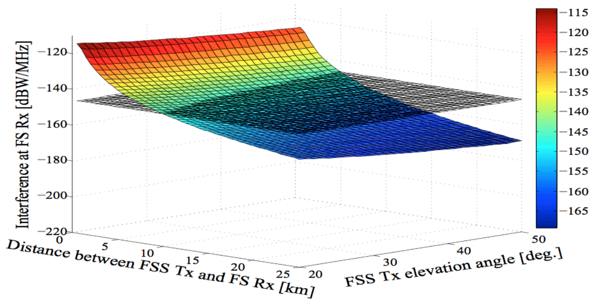
The different CR techniques, applied to the reference system scenarios, can be compared by exploiting two main system level KPIs (Key Performance Indicators):

- 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.

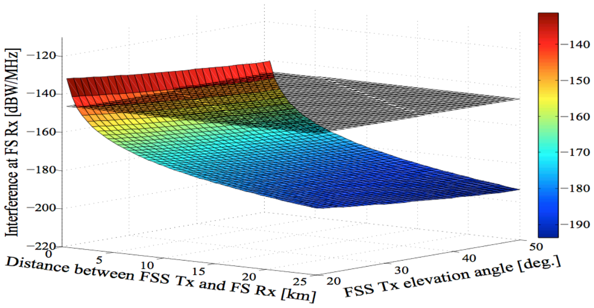
- Geographical availability: The geographical availability stands for the overall area where the cognitive system can be implemented subject to the other constraints. This KPI is also function of the incumbent system density, however, given a certain density, higher is the geographical availability higher is 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.

Already a set of regulatory changes are considered:

- Uncoordinated earth stations in the frequency band 17,7 GHz - 19,7 GHz should be exempt of individual license and should be allowed for free circulation in CEPT (Conférence Européenne des Postes et Télécommunications) countries.
- Any sub-band not used by FS (e.g. duplex gap guard bands) within 17,7 GHz - 19,7 GHz should be identified by CEPT for protected FSS use.



(a) $\alpha = 0°$, $\beta = 0°$



(b) $\alpha = -10°$, $\beta = 10°$

Fig. 8. Interference received by the FS receiver (Rx) from FSS transmitter (Tx) transmits at its nominal non-controlled power.

- 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 optimize the system capacity.

The SRdoc is currently being reviewed within ETSI before it will be addressed in the FM4 group of CEPT in charge of satellite communications. The FM44 will then undertake the sharing and compatibility study with the defined reference system and the proposed KPI for the different CR techniques envisaged.

V. Final Remarks

This paper reports about the on-going standardization and technical activities carried out in the FP7 ICT CoRaSat project. The project is still running and assessing the pros and cons of the presented techniques in the CoRaSat defined scenarios, thorough analytical, numerical, and testbed evaluations that will be continuously reported in the project dissemination documents [1]. This implies that at this stage of the CoRaSat research no final conclusion can be drawn on the feasibility of the coexistence between FSS with other services in Ka band.

Acknowledgments

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