A Database Approach to Extending the Usable Ka Band Spectrum for FSS Satellite Systems

Wuchen Tang, Paul Thompson and Barry Evans

Institute for Communication Systems (ICS), University of Surrey,
Guildford GU2 7XH, Surrey, United Kingdom
Email: {w.tang, p.thompson, b.evans}@surrey.ac.uk

Abstract—**Broadband access by satellite in Ka band will become constrained by spectrum availability. In this context, the EU FP7 project CoRaSat is examining the possible spectrum extension opportunities that could be exploited by a database approach in Ka band via the use of cognitive mechanisms. The database approach utilising spectrum scenarios between Fixed Satellite Services (FSS), Fixed Services (FS) and Broadcast Satellite Service (BSS) feeder links are considered. Database statistics for several EU countries are also provided for database analysis. Interference in the downlink scenarios are evaluated by the database approach using real databases and propagation models. The importance of using correct terrain profiles and accurate propagation models is shown. For the case of BSS interference to the FSS downlink (17.3-17.7GHz), it is demonstrated that in the UK, an area of less than 2% is adversely affected. FS interference into the FSS downlink 17.7-19.7GHz is shown for the UK to only affect a small percentage of the band at any location. Thus, using a database approach to allocate frequencies, it is possible to use most of the band across different locations.**

Keywords–Database approach; frequency sharing; propagation model; area analysis; spectrum analysis.

I. INTRODUCTION

The demand for higher rate and reliable broadband communications is accelerating all over the world. Within Europe the Digital Agenda sets a target for universal broadband coverage of at least 30 Mbps across the whole of Europe by 2020 and 100 Mbps to at least 50% of the households [1]. Fixed connections and cellular cannot alone meet this target, particularly in the rural and remote areas but also in some black spots across the coverage. In these latter regions, satellite broadband delivery is the only practical answer as satellite will cover the whole territory. Some recent studies of the roll out of broadband have shown that up to 50% of households in some regions will only have satellite available as a means of accessing broadband and thus 5-10 million households are potential satellite customers [2]. Current Ku band satellites do not have the capacity to deliver such services at a cost per bit that makes a business case and thus the satellite community has turned to High Throughput Satellites (HTS) operating at Ka band and above. Examples of early HTS Ka band satellites dedicated to such services are Eutelsats KaSat [3] and VIASAT 1 [4]. These satellites employ multiple (around 100) beams using four- fold frequency reuse over the coverage area to achieve capacity of the order of 100 Gbps per satellite. The latter is limited by the exclusive spectrum available to satellite (FSS) of 500 MHz in both the up and downlinks and this limits the feasible user rates to 10-20 Mbps. Thus, looking ahead to the increased user demands we have to look to larger satellites (maybe up to a Terabit/s [5], [6]) and to more spectrum. Moving up to Q/V bands has already been suggested for feeder links but, for user terminals, the additional expense is not considered desirable. So we return to the problem of getting more usable spectrum at Ka band.

The Ka-Band exclusive bands for satellite are 19.7 to 20.2 GHz in the downlink and 29.5 to 30 GHz on the uplink. In these bands FSS terminals can operate in an uncoordinated manner, which means that they do not have to apply for and be granted a licence by the national regulators, provided they meet set performance characteristics. The issue in other parts of the Ka band is that the spectrum is allocated, not just to FSS but also to fixed links (FS) and to BSS (uplinks for broadcast satellites) as well as mobile services (MS). This spectrum is allocated by the ITU in three regions of the world as shown in Table 1 for Ka band (Europe is Region 1). In these so-called 'shared bands', the different services need to co-exist and this is usually done by the process of coordination. For example, a larger gateway or feeder link may use this band but is coordinated and then licensed to operate and receives protection from interference from other service users.

Within Europe the CEPT [7] have adopted decisions that expand those of the ITU and produce tighter regulation as follows;

- 17.3-17.7 GHz: the BSS feeder links are determined as the incumbent links but uncoordinated FSS links are also permitted in this band.
- 17.7-19.7 GHz: FS links are considered incumbent but FSS terminals may be deployed anywhere but without right of protection.
- 27.5-29.5 GHz: CEPT provide a segmentation of the band between FSS and FS portions as shown in Figure 1. Within each segment there is a specified incumbent but for instance FSS terminals can operate in FS portions provided they do not interfere with the incumbent FS.

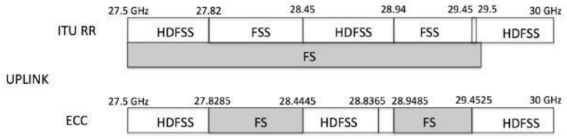


Figure 1. CEPT 27.5-29.5 GHz Segmentation.

The work reported in this paper has been conducted within the EU FP7 project CoRaSat [8]–[11], which examines ways in which FSS satellite terminals in the Ka band can co-exist with FS and BSS links given the regulatory regime discussed above.

TABLE I. ITU-R TABLE OF ALLOCATION

Frequency bands	ITU Region 1	ITU Region 2	ITU Region 3
17.3-17.7 GHz (Scenario A)	FSS (space-Earth) BSS (feeder links) Radiolocation	FSS (space-Earth) BSS (feeder links) Radiolocation	FSS (space-Earth) BSS (feeder links) Radiolocation
17.7-19.7 GHz (Scenario B)	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
27.5-29.5 GHz (Scenario C)	FSS (Earth-space) FS MS (Mobile Services)	FSS (Earth-space) FS MS	FSS (Earth-space) FS MS

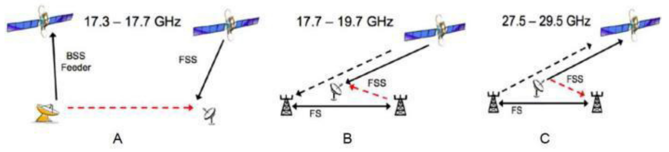


Figure 2. Scenarios in CoRaSat.

Specifically, a database approach for such coexistence schemes is investigated and demonstrated to exploit the frequency sharing opportunities for uncoordinated FSS terminals and verify its applicability. The aim is to show that future satellite systems can access additional spectrum beyond the exclusive bands that is needed to deliver cost effective broadband services.

This paper is organised as follows. In Section II, we describe the scenarios and the database approach for each. In Section III we provide analysis of various databases, and in Section IV, the applications of the databases to scenario A and B and the results of additional bandwidth availability. Finally, we provide conclusions in Section V.

II. SCENARIOS AND DATABASE APPROACH

Within the CoRaSat project, three scenarios have been investigated that reflect the three spectrum components detailed in the previous section. In Figure 2, we illustrate the interference paths in these scenarios. Two of the scenarios are downlink for the FSS; scenario A, 17.3-17.7 GHz where the potential interference is from BSS uplinks and scenario B, 17.7-19.7 GHz where the potential interference is from incumbent FS transmitters. In both of these cases the FSS is permitted to operate but is not protected by the regulatory regime and thus it is important to ascertain the level of the interference and its effect on the FSS received signal. The third scenario C, is in the transmit band of the FSS from 27.5-29.5 GHz and the interference is from the FSS transmitting earth station into the FS receivers which are protected. The latter is more critical in that we need to demonstrate that the FSS does not contravene interference limits imposed by the regulatory regime. The forward link, e.g. the downlink, can be considered more important in that the ratio of downlink broadband to uplink broadband as operated via satellite is currently at around 6:1 and thus the acquisition of more spectrum here is key. In addition to this, operation in the downlink bands does not require regulatory changes but merely a reassurance to FSS users that services need not be impaired.

The calculation of interference can be performed if the corresponding accurate database had been obtained, which includes that the characteristics and locations of the potential interferers are known by using accurate models of the equipment, propagation and the path details.

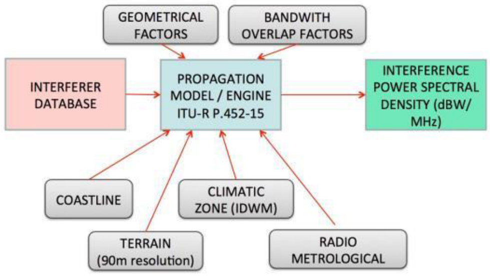
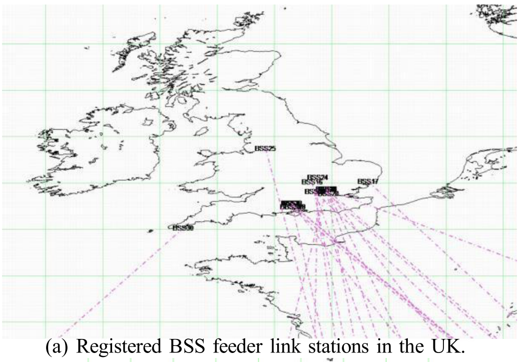


Figure 3. Interference modelling by ITU-R P.452-15

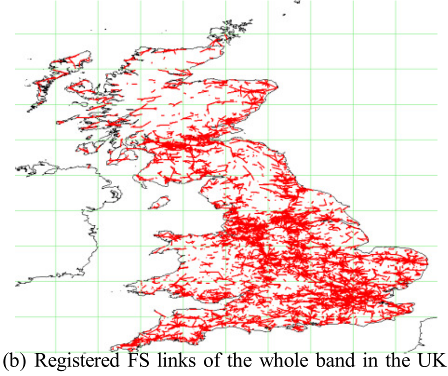
Similar ideas have been employed in TVWS systems [12] to allow UHF frequencies to be used in the gaps between TV transmission regions. For scenario A, the number of BSS uplinks in Europe is small and thus a database system is similar in magnitude to that of TVWS. However, for scenario B and C, the number of FS links runs into the tens of thousands and the database is much more complex. 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.

The information of a real interferer database is interfaced to an interference modelling engine which uses ITU- Recommendation P.452-15 [13] procedures plus terrain databases. This is the latest version of this ITU Recommendation that contains a prediction method for the evaluation of path loss between stations. 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, which is illustrated in Figure 3. The typical interference threshold we determine 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 [14] and [15].

Having determined the interference level at the FSS (in scenarios A or B) it can be compared with the regulatory threshold. The action is then taken in the resource allocation at the gateway where a new carrier can be assigned either in another part of the 'shared band' where interference is



(a) Registered BSS feeder link stations in the UK.



(b) Registered FS links of the whole band in the UK.

Figure 4. Registered BSS and FS links in the UK.

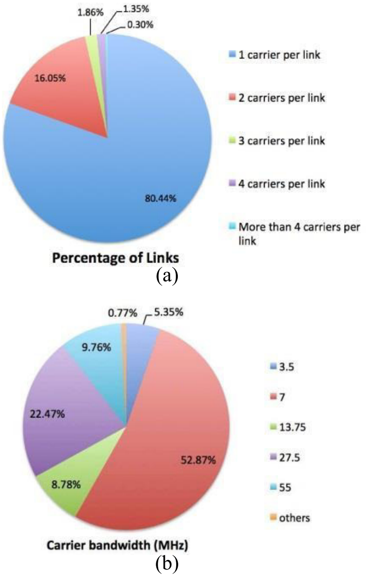


Figure 5. Pie chart of (a) FS carrier number of each link and (b) carrier bandwidth (MHz).

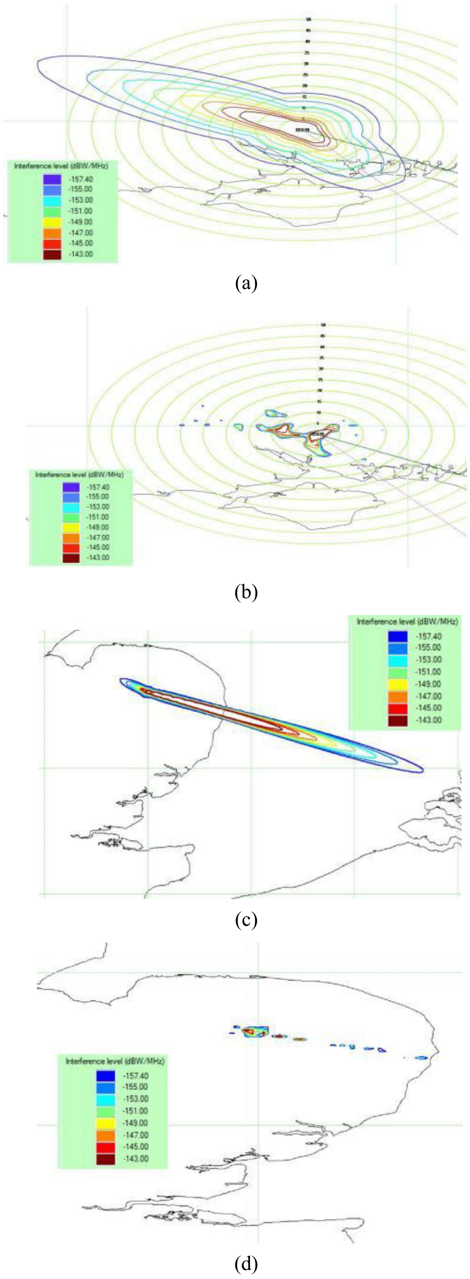


Figure 6. Example of cognitive zone for (a) BSS with free space loss model (b) BSS with full ITU model (c) FS with free space loss model (b) FS with full ITU model.

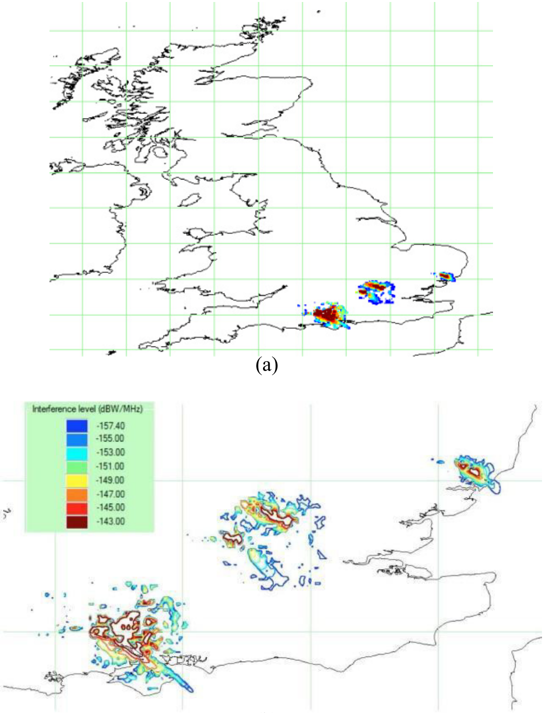
acceptable or in the exclusive band. For scenario C the situation is different as the interference is caused by the FSS into the FS. Here, the database is used to calculate the maximum permissible power that can be transmitted from the FSS in the vicinity in order to retain the threshold condition at the FS receivers. More details of the database approach are given in the following sections.

III. DATABASE ANALYSIS

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. When the database relates to satellite terminals the database should also contain 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

TABLE II. AREA ANALYSIS (sqkm) OF THE BAND 17.3-17.7 GHz

17.7−17.3GHz	*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%)
17.7−17.3GHz	*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 7. Example of cognitive zones for the sub-band 1 (17.3-17.34 GHz) based on full ITU model.

defined in ITU Recommendations for use in regulatory work or ETSI standards. In addition, transmission power and equivalent isotropic radiated power (EIRP) may also be included.

A UK BSS database made available for this study is used for scenario A and 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 4(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-84 dBW and all antenna radiation patterns are as defined in ITU-Recommendation S.465 [16] or S.580 [17].

FS databases at 18 GHz are required to evaluate scenario B. Again, an FS database was made available to this project (under the UK Freedom of Information Act). This database for the UK FS in the band 17.7 to 19.7 GHz is much larger than that for the UK BSS and contains 12,712 links with 15,970 carrier recorded in the UK. A French database has also been examined at 18 GHz and is based on the latest ITU-R terrestrial services BR IFIC database [18], which contains 11,548 links with 17,384 carriers recorded. Figure 4(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.

Figure 5 provides pie charts of numbers of carriers per link and carrier bandwidths based on the UK FS database in (a) and (b), respectively. It is indicated that more than 80% of links have only one carrier and more than 96% of links have up to 2 carriers. The majority of carriers have a bandwidth from 3.5 to 55 MHz. As a consequence, it can be deduced that at a particular location in the UK, little spectrum resource from the available 2 GHz band is used by the FS at a specific location. Thus, we are optimistic that spectrum available for FSS on a micro scale geographical basis is significant and can be exploited if the information of spectrum occupancy is known from the analysis of the database or is detectable by other mechanisms. A similar situation also exists for France.

We have implemented the ITU-R.P452-15 propagation and interference modelling to provide cognitive zones around incumbent terminals based on the available database. A cognitive zone here is defined as the geographical area around an incumbent user station where cognitive radio techniques such as spectrum sensing and beamforming should be employed to mitigate the interference to an acceptable level. In other words, the interference outside of this area is below the acceptable interference threshold thus cognitive radio techniques are not necessary.

Figures 6(a) and 6(b) show plots of cognitive zones around a BSS Station under scenario A case based on a free space loss model and the full ITU-R P.452-15 model, respectively. Similarly, Figures 6(c) and 6(d) show plots of cognitive zones around a FS Station under scenario B case based on these two models. For the BSS cognitive zone the FSS terminal evaluated points to a satellite at 53 degrees E longitude and the BSS transmitting terminal points to a satellite at 28.2 degree while for the FS cognitive zone the FSS terminal is pointing to a satellite at 20 degrees E longitude and the FS transmitting terminal is pointing at a receive terminal on a bearing of 110 degrees (ETN). Clearly for both cases, the cognitive zones from the full model are much smaller and differently shaped compared with the ones under free space model. On the average the areas are 9 times smaller at the -155 dBW/MHz and 3.5 times smaller at the -145 dBW/MHz thresholds. This is mainly because the diffraction effect based on the terrain data is considered in the full model while the free space loss model only includes line of sight propagation loss, which reflects the fact that the terrain data based diffraction effect is extremely significant in cognitive zone determination.

IV. DATABASE APPLICATIONS FOR SCENARIOS

In this section, we analyse for scenario A the areas that are affected by interference from BSS uplinks and for scenario B the availability of spectrum at FSS locations as a result of FS interference. Typical examples are provided to demonstrate the additional spectrum that could be available.

A. Scenario A: Area Analysis

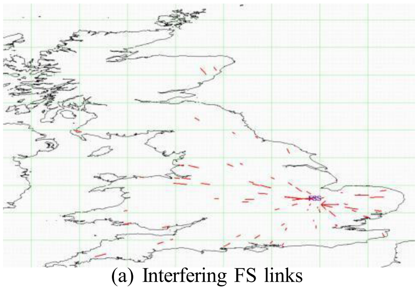
Using the BSS database, area analysis for scenario A in the UK is provided to investigate how much area would be affected by interference from the BSS feeder links. The band of interest is split into 10 x 40 MHz sub-bands ($SB1-SB10$) and the analysis is then conducted in each sub-band to determine the 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 a BSS database with the full ITU-R P.452-15 model employing the terrain and climatic zones and the FSS terminal evaluated points to a satellite at 53 degrees E longitude. The results are for long term interference (normally 20%).

One example of affected area at difference cognitive zone thresholds is shown in Figure 7, which represents *SB1*. Full data on the areas are given in the Table II. 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. Such 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).

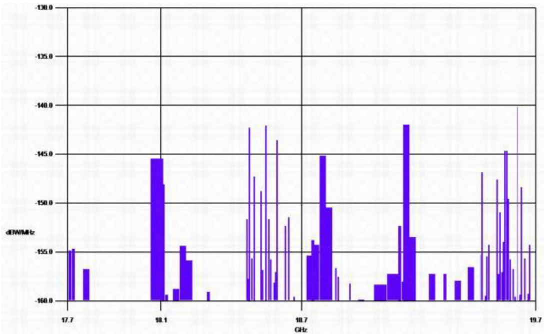
Although we have presented results herein for an FSS terminal pointed at a specific orbit location we have examined a range of orbit locations from the UK and the results are very similar.

B. Scenario B: spectrum 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 we perform spectrum analysis 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 resource allocation algorithm in the satellite network to assign the carriers.

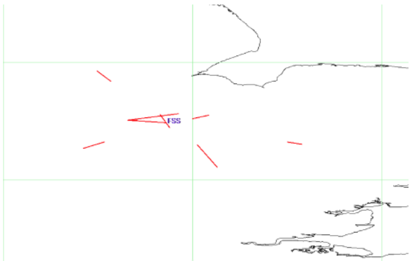


(a) Interfering FS links

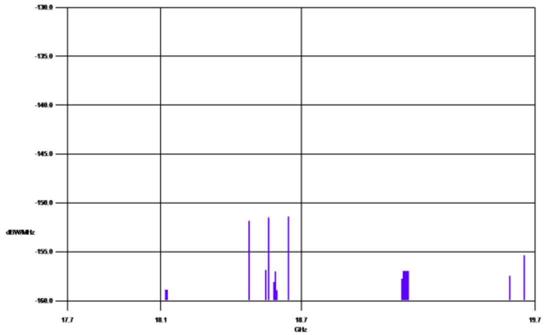


(b) PSD based spectrum analysis

Figure 8. LOS result of all UK FS links, interfering to FSS terminal at latitude of 52.5 degs and longitude of -0.1 degs.



(a) Interfering FS links



(b) PSD based spectrum analysis

Figure 9. Full terrain model Results result of all UK FS links, interfering to FSS terminal at latitude of 52.5 degs and longitude of -0.1 degs.

Spectrum analysis results for the UK FS links at 18GHz 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 (ITU-R P.452-15) are shown as Figures 8 and 9, respectively. 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 arise from FS links much further from the location of interest and these links are ones pointing directly at the location. Only a few point with some offset and these are located very close so that interference is from their side lobes. From the interference PSD in Figure 8, 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 9, 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 band can be used by an uncoordinated FSS VSAT terminal site. The comparison of the increased spectrum available is shown in Figure 9.

A complete map of the locations in the UK has been produced and this can be used as input to 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.

C. Scenario C

Cognitive zones for scenario C are around FS stations and interference is from FSS terminals to FS links. This is a much more difficult case to address if we plan to use the whole of the shared band because we do not have access to an adequate 28 GHz database on which to operate. The techniques and software developed for scenario A and B can be used in a similar manner for scenario C if we have access to such a database. The results would be presented in a slightly different format as they would give the maximum allowable EIRP for the FSS at a given point. However, the HDFSS uplink band has been agreed for uncoordinated earth stations in all except 5 of the EU countries thus perhaps the uplink increase in spectrum is not so urgent at this time. Some preliminary evaluation of scenario C was performed in [19] and the results of this indicated that only very close FS links would be affected and the density of FSS terminals would not cause a problem in the multi interference case. Further evaluation will be done within CoRaSat.

V. CONCLUSION

To meet future broadband access targets, in this paper we have described how the increased spectrum opportunities can be exploited by the proposed database approach together with interference mitigation techniques. We have demonstrated that in 17.3-17.7 GHz spectrum band 400 MHz of additional bandwidth is available across 98% of the UK which houses the densest BSS network in Europe, and similar results were obtained for Luxembourg. The evaluation needs to be repeated in other EU countries, but a similar if not better performance would be expected due to the lower density of BSS. If the FSS is required to be closer to a BSS, then cognitive means can be used to mitigate the interference. We also have explored the availability of the 2 GHz spectrum band between 17.7 to 19.7 GHz downlink and the results have shown that the number of actual interfering FS links are limited due to terrain diffraction effects so that at a particular location substantial parts of the 17.7 to 19.7 GHz are available, but not the same frequencies at all locations. This indicates that a data base interfaced with a resource allocation scheme could give access to the increased spectrum. This was demonstrated for the UK but needs to be validated in other European countries. In the case of the uplink 27.5-29.5 GHz we are still evaluating the potential but early signs look promising.

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