## Collaborative project

# *Deliverable D5.1*
# *CoRaSat Technology Roadmap*

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# 1 EXECUTIVE SUMMARY

This deliverable presents a roadmap for the development of the technologies that will eventually be used in the operational system. For each scenario the applicable technologies are indicated and their state of art requirement are described. The developments that will be necessary to bring them to market and the corresponding description of modifications necessary for the implementation are outlined and produced, respectively. This applies to hardware, software and processes e.g. standards and regulations.

A roadmap is given for each of the techniques discussed in scenario A, B and C. Essentially to use the additional spectrum new satellites will need to be designed to extend the bandwidth and new terminals and/gateways extended in frequency bands. The Technology Readiness Level (TRL) of the ground segment is quite high and there are no major issues. However the lead time on the satellite is longer. Satellite operators would need to incorporate the additional spectrum in their future satellite procurements and hence it is unlikely that we would see enhanced satellites until closer to 2020. The TRL of the equipment itself is however quite high.

For the database systems the TRL is again quite high and the issues are more in the operational side than technology. Spectrum sensing TRLs are lower but this technique may not be needed expect for cases of close proximity to an incumbent system. For beamforming the TRL is quite high but in this case the cost may be the determining factor in use. For the resource allocation the TRL is moderately high and again the technology is well developed but needs to be validated.

In summary we show that for the individual technology the TRL’s are in general quite high but the acceptance of database systems by the satellite operators is key to the progress and adoption of such systems.

# 2 SCOPE AND STRUCTURE OF THE DOCUMENT

This deliverable presents a roadmap for the development of the technologies that will eventually be used in the operational system. The applicable technology is indicated for each scenario and their state of art requirements are described accordingly. The developments that will be necessary to bring them to market and the corresponding description of modifications necessary for the implementation need to be outlined and produced, respectively.

In Section 3 we summarize the scenarios with selected technology based on previous deliverables. Applicable technologies and the state of art are described in Section 4. Implementation of the technologies for the WP4 testbed is discussed in section 5 as well as the roadmap for the eventual terminal produces. Finally we discuss modifications needed for the technologies and their implementation with their associated TRL chart.

# 3 SCENARIO DEFINITIONS USING SELECTED TECHNOLOGIES.

In this section we review at a high level the techniques that we are evaluating as they apply to the three scenarios that we are addressing. The aim is to give the reader a top level view of which technique is applicable to each scenario.

## 3.1 Scenario A

In this scenario we propose that the database approach is the major technology and as the number of BSS links are relatively small per country this in itself may be sufficient. A detailed evaluation has been completed for the UK and could be replicated for other countries given that a database is made available. The areas around the BSS stations where interference above the threshold is experienced is small, often less than 10km and rarely above 30km. A simple exclusion zone could be applied as advice to FSS installers. Although mitigation techniques such as beamforming and spectrum sensing could be applied this may not be needed and the increased protection could be engineered by repositioning the antenna and making use of natural environmental shielding.

As demonstrated in D 3.3 for the UK a very small area, less than 5% of the total area, would be affected by BSS interference and these areas are mainly in regions where other terrestrial broadband connections would be preferred. This should also apply to other countries but needs to be checked.

Thus the use of the 17.3 to 17.7GHz downlink bands for FSS looks feasible and would add another 400MHz to the existing 500MHz exclusive bands – an 80% increase. Both satellite transponders and FSS terminal equipment would need to be manufactured with this in mind. There would be a roadmap for the development of such equipment which is addressed in a later section.

The roadmap for the detailed database evaluation is quite short as the software for the modeling is already available and just needs to be run in each EU country. Each country could run their own database or this could be done via the CEPT FM44 group. Current TRL is at 7 and can be lifted to 8 within one year.

## 3.2 Scenario B

We have demonstrated in D3.3 the FS interference in the UK and shown that considerable bandwidth in the 17.7 to 19.7 GHz band is free from interference but not the same portions at all locations. The running of the full database on line has been shown to be too exhaustive but using the techniques developed in D 3.3 an interference map can be stored on a regional basis. This has been demonstrated for the UK and again can be replicated for other countries given the availability of a FS database. There has been some reluctance on the part of regulators to make the detailed databases available and this problem needs to be solved. CEPT FM 44 has suggested to make the software available to the regulators to run off the data themselves. Another possibility would be to have a trusted third party do this job. Unless this is done across the majority of the EU, manufacturers would not invest in the development of the equipment. The technology is available to do the job now but the process has to be sorted out by the administrations via the CEPT and could take some time. Thus TRL level 6 now and lifting to 8 in 3 years.

A database approach could be sufficient and would certainly give the current free spectrum available at a location. It is true that FS operators could increase their use of the spectrum but this would have to be signaled to the regulators in good time before operation and the databases updated and frequencies moved if adverse interference resulted. It is recognized that the data base technique doesn't provide the FSS user with sufficient protection but the ability to move carrier frequencies gives fairly good probabilities.

Mitigation techniques such as beamforming and spectrum sensing can be used in areas where there is little likelihood of finding free spectrum as given by the database.

## 3.3 Scenario C

Operation in the uplink 27.5-29.5 GHz is more problematic outside those bands already allocated for HDFSS in the CEPT plan. Work still needs to be done in evaluating this band and has proved difficult due to the inability to source actual databases. Work will continue on the small number of databases available in the BR-IFIC. The idea is to calculate the maximum transmit Equivalent isotropic radiated power (EIRP) at an FSS location such that there will be no intolerable interference to incumbent FS. This procedure would need to be agreed by the regulators and would take longer to realize. It may also be possible to calculate geographical areas in which an uncoordinated approach could be agreed but this is future work. To get approval for such a database approach in this band is likely to take much longer and be very political.

As an interim solution it is noted that in the SRdoc [1] we have proposed an alternative scenario which incorporated one of the HDFSS bands—28.4445 to 28.9465 GHz, which is shown as Figure 1. In this band according to ECC/DEC/(05)01 dated March 2013 [2] all but four or five countries in the EU have agreed the use of uncoordinated FSS stations. Those countries that have not agreed e.g. the UK, have in some cases sold off potions of the bandwidth and thus it is no longer under the regulator control making it impossible for them to accede. Given that this represents only 4/27 countries and that an additional 500MHz is available to the remainder it is worth to proceed on this basis as an interim solution. As there is no shared band involved we would not in this instance need to look to cognitive solutions on the uplink in the majority of countries. Indeed in the latter countries the use of the exclusive bands could be used as priority. This seems to be a reasonable first step if we look at the predictions of broadband traffic on satellite at the moment the ratio of down to uplink is around 4:1 and some comment as much as 6:1(Avanti source) [3]. This means that the requirement for spectrum on the uplink is much less and the use of one HDFSS band on the uplink would give a 3.4:1 ratio which would meet the demands in asymmetry currently predicted.

We intend to continue to work on cognitive solutions for the full shared band in the uplink as a longer term alternative.

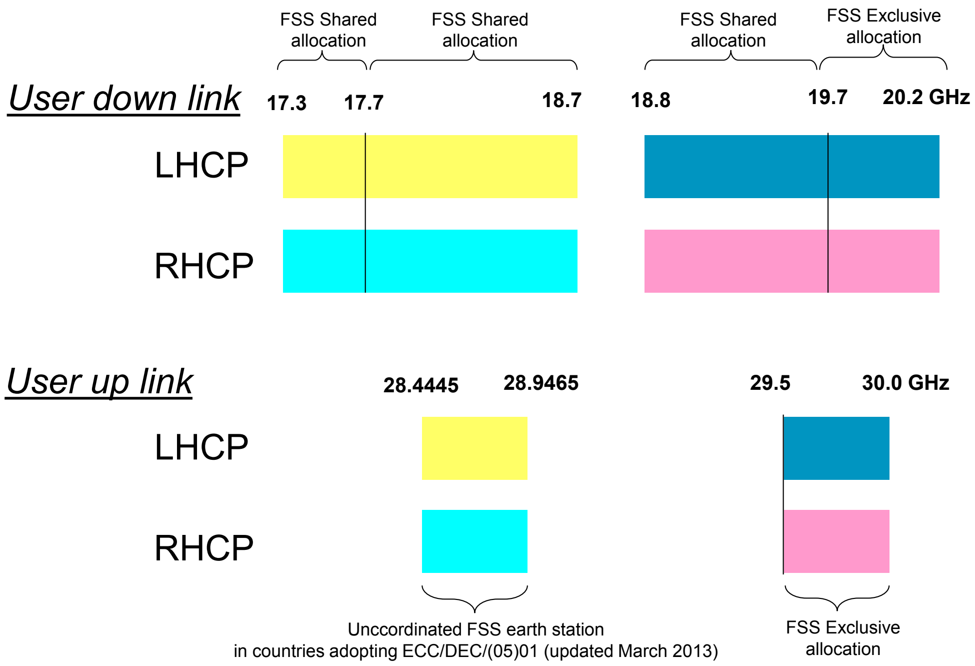

Figure 1 - Alternative scenario C in SRdoc

# 4 TECHNOLOGY DESCRIPTION OF SELECTED TECHNIQUES

In this section we define the state of the art of the technologies as they currently exist and their approximate TRL level. In doing so we address the technology itself, as well as the processes needed to be undertaken in order to bring the technology into an operational state. It should be realized that we are proposing the operation in new parts of the spectrum which will mean both new satellites to be designed and launched that cover these bands as well as the development and manufacture of new FSS satellite terminals. In order to get to this stage there will need to be regulatory agreements in place that will give the confidence to manufacturers to embrace the new bands in their system designs.

## 4.1 Databases

### 4.1.1 Database availability

Databases are created and maintained by national regulators within the EU. They are not normally freely available as some contain material that is considered confidential. Most of the databases have similar characteristics as discussed in D 3.3 but there is not complete uniformity amongst the regulators as to the entry of data. In some countries the regulators have sold off portions of the spectrum (e.g. the 27.5 to 29.5GHz band in the UK) and are no longer responsible for these portions. The technology needed for a Europe-wide database operation is essentially available but not under single ownership. In order to bring this together the CEPT would need to be involved under SE or FM sub committees to get agreement. CoRaSat has engaged with FM-44 in this respect and the latter have produced a paper [4] to start discussions on ways that regulators might make available material. In the UK there is intention to make databases freely available on the Web where possible and it will be interesting to see whether other administrations will follow suite.

### 4.1.2 Modelling

The modelling that we have used in D 3.3 to interface with the database is from ITU-R P.452-15 [5]. The propagation models themselves are freely available but must be used with terrain height data in some cases. Again the latter can be sourced from the Web. The ITU update the models from time to time with new and improved versions and thus there is a maintenance aspect to the modelling software.

### 4.1.3 Software production and operation.

The modelling software is interfaced with the relevant data base and interference can be calculated for a specific location for each interferer. For scenario A where the interferers are BSS stations this is quite straight forward as there are relatively few BSS stations across Europe. Unlike other cases if the EU BSS data were made available this could be done as an EU exercise and the results made available to all regulators and be freely available. It would have to be repeated at intervals as new BSS come on line but this is not considered a major job.

For scenario B and C, the data bases contain many more FS links and we have devised a means to rapidly reduce what would otherwise be an exhaustive process that could be adopted. Again the software could be run by national regulators, trusted third parties or by satellite operators to calculate the interference.

### 4.1.4 Testing and validation

Within CoRaSat we have attempted to verify our software by running it against other versions. However there should be a more rigorous evaluation of the calculation of interference and if possible some verification by measurements although this is very difficult. In scenario’s A and B this perhaps wouldn’t concern the regulators but in scenario C which is the transmit band we would envisage that this would be necessary.

### 4.1.5 Regulatory acceptance and processes

There are no specific regulatory acceptance issues in scenario's A or B although we envisage that there would need to be agreement amongst the regulators that the satellite systems were operating in this mode.

For scenario C we would need to obtain acceptance that the mechanisms used did not result in interference to FS links that were already protected. There would thus have to be a much more rigorous acceptance via an EU wide body such as the CEPT/ERC. As already stated this can be mitigated in the short term by operating in the HDFSS band on the uplink where uncoordinated earth stations are permitted in the majority of countries in the EU and for those in which it is not to use the exclusive band.

### 4.1.6 Relevant standards

Currently there are no standards specific for the selected scenarios. The majority of cognitive radio related standards such as IEEE 1900.6 and IEEE 802.22 are mainly for the use of cognitive radio techniques in other wireless environments or for other applications. It is worthy to mention that the latest amendment of IEEE 1900.6, IEEE1900.6b, is on the topic of the use of spectrum sensing information to support spectrum databases, which is quite relevant to the cognitive radio application in CoRaSat. We will follow on these relevant updates as standard references for the work in CoRaSat.

As far as the database approach is concerned the basic technology is available today. It is the mechanisms of operation that are not in place and will take time to achieve acceptance.

## 4.2 Spectrum Sensing

One of the most important functions of the cognitive radio is the spectrum sensing. The aim of spectrum sensing is the detection of the incumbent user signal by scanning selected frequency bands. This mainly 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) that would be necessary for achieving an accurate degree of certainty in its detection. Spectrum sensing techniques aim at discerning between the presence and the absence of incumbent signals.

The Spectrum Sensing problem has been discussed approached in the literature several times [6], by considering different approaches in terms of matched filtering, energy detection, cyclostationary detection, and waveform and radio identification based sensing; as well as, some enhanced techniques considering cooperation among different devices.

Among several alternatives the focus has been firstly put to the Energy Detector and the Cyclostationary feature detector for their simpler applicability to the satellite context [7].

### 4.2.1 Energy Detector

The energy detector aims to evaluate the energy of the signals received at the antenna input. In cognitive radios it is a widely studied spectrum sensing techniques. The energy detector is a blind spectrum sensing detection technique that does not need any a priori knowledge of the incumbent signal and therefore it has a general applicability in all the considered scenarios.

The energy detector performance depends on two main parameters:

- *the sensing time (or equivalently the samples that the receiver processes)*. We should fix a minimum and a maximum sensing time. These bounds are related, respectively, to the time necessary to obtain the desired probability of the detection and the fragmentation between cognitive spectrum sensing and the effective secondary transmission;
- *the typical cognitive station characteristics* that influence the energy detector such as noise power estimation, sensed bandwidth, threshold, receiver chain, geographical positions and distance from the incumbent user.

The performance indexes to be considered in an energy detector are the probability of detection, i.e., the probability of detecting a signal of the incumbent system, and the probability of false alarm, i.e., the probability of detecting erroneously a signal of the incumbent system as a function of the signal to noise ratio when the desired probability of false alarm and the sensing time are fixed. Both are a function of the previously introduced parameters. Usually two methods are employed: the CFAR (Constant False Alarm Rate), where a target probability of false alarm is set, and the CDR (Constant Detection rate) where a target probability of detection is set.

Despite its simplicity and general applicability, the energy detector is mainly affected by the SNR wall phenomenon that prevents us from achieving the desired probabilities. This phenomenon is caused by the uncertainty in noise power estimation and in case of a finite observation time the desired probabilities cannot be guaranteed. In our case, we have to guarantee that the SNR wall should be lower than the SNR needed for the detection of the minimum interfering incumbent signal. In fact, if the SNR wall is higher we are not going to detect an interfering incumbent signal causing disruptive interference to the cognitive system; 1dB of uncertainty is equivalent to a variation from the noise temperature of about 20°K and the main causes on which it depends are four: calibration errors, thermal variations, changes in low-noise amplifier (LNA) gain, and interference.

### 4.2.2 Cyclostationary Detector

Another typical detection technique is cyclostationary based detection. Differently from the energy detector it exploits periodic features that could be present in the wireless communication signals presents. These periodicities could be introduced by:

- Pilots, preambles, cyclic prefixes introduced in order to aid synchronization or channel estimation;
- Coding
- Modulation schemes, symbol rate, frequency carries

Thanks to the estimation of the presence of possible interferers by means of its cyclostationary features it is also possible to discriminate between different Incumbent Users.

However the choice in using a cyclostationary based detector is mainly driven by its ability to operate in low SNR environments. In fact, as explained in the case of the energy detector, we have to detect interfering signal which is -10 dB below the noise level for both scenario A and B. Its ability to distinguish a signal also in low SNR conditions is due to of cyclostationary features in the noise.

Moreover, the knowledge of the cyclic frequencies that present cyclostationarity is fundamental in distinguishing the incumbent signal from the noise.

We could evaluate cyclostationary features in the frequency domain from the spectral correlation density function (SCD) that is calculated as the Fourier transform of the CAF.

## 4.3 Beamforming

Beamforming can reduce sidelobes and thus counteract interference but we should be able to justify the likely advantages and levels of improvements that can be obtained in comparison to the complexity increase in the terminals.

Let us first summarize the two main objectives of applying beamforming at the FSS system that we discussed in previous deliverables:

- **Beamforming for sensing**

  In D 3.2, we introduced the possibility of putting an additional omnidirectional antenna (dipole) in addition to the existing satellite dish at the FSS terminal-side for Scenario B. By applying joint signal processing, the receiver beamforming can be used to detect the harmful interfering signal so that the satellite terminal can avoid using the harmful carrier. Since a purely omnidirectional antenna is not practically realizable, we can use a half wave dipole antenna with a gain on 2.15dB. Other alternatives were discussed and discarded in D 3.2 due to a major cost.

- **Beamforming for interference mitigation**

  In Scenario A and B (downlink), beamforming could be applied at both the satellite and the terminal sides. Transmit beamforming can be used at the satellite in order to improve the SINR at the terminals. This needs additional processing algorithms at the gateway and is more suited to the future generation multibeam satellites. In this project, we will explore terminal-side receive beamforming techniques.

  In Scenarios A and B, terminal-side receive beamforming could be used in order to minimize the BSS interference and the FS interference on a terrestrial basis, respectively, by creating a null in the direction of the interference signal.

  It should be noted that the implementation of beamforming techniques requires a significant upgrade in the existing terminal-side FSS system. A terminal equipped with multiple antennas is required to create a desired beam pattern.

  The terrestrial based receive beamforming for Scenario A seems to be reasonable since the FSS terminal has to mitigate the interference coming from the BSS feeder links and there exist only a few of them in a certain geographical region. In this context, the beamformer does not need to create many nulls in the interfering directions. Therefore, the terrestrial based receive beamforming for Scenario A can be readily implemented within the current infrastructure, adding an extra antenna and the joint processing is not complex and not expensive.

  However, in Scenario B, there might be some locations where more than one null needs to be beamformed due to the much larger density of FS links, thus requiring a large number of antennas.

  Beamforming on the FSS transmit side could be employed in Scenario C to reduce the signal in the direction of the FS stations. In its simplest form this could be done by using a larger antenna with reduced sidelobes in the close to horizontal azimuthal direction. This might be a possibility for those FSS positions in which there are close FS links that cannot be avoided in other ways. Active beamforming is likely to be too expensive to be a serious candidate, but needs further evaluation.

As discussed in D 3.3, we will exploit Direction of Arrival aware techniques such as Linearly Constrained Minimum Variance (LCMV) and purely SNR based techniques depending on whether the DoAs of the BSS feeder signals are available or not. If the databases of the both desired and interfering systems are available and the channel is fixed as in FSS links, the DoA values can be calculated from the available database information. In practice, the DoA of desired signal and interfering signals are not perfectly known and we have to use some DoA estimation algorithm. Further, in practice, multipath signals may be present and there may be antenna array imperfections. In these non-ideal situations, different beamformers have different levels of performance and they are different in terms of their hardware implementation as well. Thus, the choice of a particular beamformer actually depends on the desired level of performance, the environment we are working on and the complexity of implementation.

### 4.3.1 Discussion on complexity issues

In the considered transmit/receive beamforming problem, we need the terminal FSS station to be equipped with multiple Low Noise Block Converters (LNBs) at the receive chain or by using additional RF chain. The latter, can be also used as an interference detector for detecting the incumbent FS signal in Scenario B and C.

We consider here the use of fixed reception terminal and a small front-end antenna system. In particular, we propose a terminal system which uses an antenna with multiple synchronized input elements. This choice is motivated by the fact that the use of several input elements is becoming realistic. The cost of a consumer grade single LNB is low and the compact design of multiple LNBs using dielectric feed elements is feasible.

Since it is not feasible to place a large number of antennas at the satellite terminal due to the cost and implementation aspects, the number of nulls that can be created are limited. This becomes an important challenge in regions with dense FS links. In any case, the number of LNBs should be kept low, e.g., 2-3 LNBs, due to cost, mechanical support and electromagnetic blockage issues [8][9].

In the presence of multiple FS links, the considered scenario becomes overloaded since the satellite receiver usually has fewer LNBs than the received co-channel FS signals. In this context, the main issue is the extraction of desired FSS signal from the received samples (measurements). These received samples are corrupted with the receiver noise as well as with the FS interference in Scenario B. In the satellite receiver, joint processing techniques can be applied in order to extract the desired information.

A receiver structure with M number of LNBs has been proposed in [8][9] for broadcast reception under interference environment generated by adjacent satellites. Subsequently, joint processing of desired and interfering signals has been performed in order to provide reliable communication in the presence of multiple interfering signals and it has been claimed that proposed joint spatial and temporal adapted mechanism outperforms the simple combination of existing techniques under interference overloaded conditions.

Similar concept can be applied in order to improve the detection of DVB-S2 signal reception in the presence of multiple harmful FS interfering users. The main difference in the considered scenario from the overloaded scenario considered in [8] is that the harmful FS interference can enter to the FSS satellite terminal from any direction instead of the main lobe.

Clearly, both vertical and horizontal dimensions have to be taken into account for beam pattern adaptation in the considered scenario. This horizontal and vertical beam pattern adaptation is also referred to as 3D beamforming in the literature [10]. In recent years, there has been a strong interest in extending the existing beamforming techniques from exploiting only the azimuth dimension to exploiting both the azimuth and elevation dimensions [10][11][12]. The latter were initially proposed for 3GPP LTE mobile networks. The main issue here is that, 3D beamforming usually requires a 2D array antenna (i.e., arrays with elements in both the elevation and azimuth direction). A first attempt to create multiple sectors within a single array is to create multiple vertical sectors [13].

## 4.4 Resource Allocation

We are particularly interested in allocating the available carrier frequencies including cognitive and exclusive carriers to the users in a specific time and geographical location.

In D 3.2, we described two major approaches in order to perform the carrier allocation: (i) assign carriers so as to maximize the overall system throughput [14], and (ii) assign carriers so as to maximize the fairness/availability, i.e., assigning the available carriers to as many users as possible according to their requested rate [15]. In both approaches, the carrier allocation module receives the SINR for each user over each available carrier as the input and then, employs combinatorial optimization algorithms such as Hungarian algorithm [16] to solve the carrier allocation problem. Although these algorithms are shown to be efficient in solving such problems, however they demand a high computational power. Developing algorithms with lower computational complexity is a subject of further research. In general, SINR-based resource allocation seems to be a feasible approach since it is widely used in current systems.

Further, as mentioned before resource allocation techniques should be adapted to each scenario. However since scenarios A and B both work in downlink, same techniques can be applied. This way, we distinguish the resource allocation for downlink and uplink to accommodate scenarios A and B for the former, and scenario C for the latter.

### 4.4.1 Scenario A & B (downlink)

It should be noted that when the optimal solution can be computed with a combinatorial approach with reasonable complexity, the interference level information embedded in the SINR measurement is sufficient based on the described optimization problems for downlink carrier allocation.

To determine the SINR accurately, the database needs to be accurate and comprehensive. In this way, the information in the database can be used to estimate the interference received at the FSS terminal. However, if the database is not accurate or sufficiently comprehensive, the interference may have to be determined based on worst-case scenarios which limits the overall system throughput.

The other challenge may arise from the fact that the DB becomes outdated by the time. This is particularly challenging in Scenarios B and C where the number of FS terminals changes much faster than the number of BSS links in Scenario A. In some cases it is also possible that the DB is not available at all, e.g. Scenario C band in UK. In such situations for Scenario A and B, the best approach is to apply interference calculation by advanced power estimation techniques. This can be done by both in-band (as in D3.3, Section 5) and out-of-band spectrum estimation. As part of the spectrum monitoring in the network management, users frequently calculate their received SINR, and this information can be send to the network management in order to allocate the carriers. In the current systems, this can be done only in the current used carrier at a terminal, and thus to obtain SINR information of other carriers, extra circuitry is required to perform out-of-band sensing. This can be done by narrow-band serial search over the available bands or wide-band parallel search. The problem arises where a low SINR does not come from the interference but from rain fading, etc. Therefore, the power estimation module should be designed in a way to be able to distinguish between the interfering signal, the FSS satellite beam, and attenuation due to other sources rather than interference. The technique described in D3.3, Section 5 is one of the approaches to achieved interference estimation.

### 4.4.2 Scenario C (uplink)

The main determination of likely FS interference will come from the operation of the database. Unlike the downlink scenario, the SINR values at each user and carrier is not known in advance. The interference of FSS station towards FS links denoted should be less than a specific threshold. This threshold determines the maximum transmission power of the FSS terminal. Should this indicate interference above the threshold another carrier allocation needs to be examined in order to determine whether one can be first found in the shared band or whether a move to the exclusive band is necessary. This would need to be done on a network basis at the gateway as other terminals may be affected. This process is no different from that applicable to Scenario B with the exception that the 28GHz database is involved this time and the database available for this particular band is rather limited.

In D 3.2, the same two major approaches previously described were adapted to Scenario C. However, there are several issues which need to be addressed. For example, in practice the user may have different carrier access priorities, while this has not considered in the previous problem formulations. More specifically, the queue manager can provide a weighting vector for the system users based on the requested rate and acceptable delay according to the agreed SLAs. Extension of the mentioned approaches to the case where the access priorities are taken into account is a subject of further work.

The major challenge, however, arises from the fact that we may have FSS terminals that belong to different satellite operators and, therefore, centralized power control is not possible. In order to ensure that the aggregate interference from all of the active secondary FSS transmitters does not violate the given interference tolerance of the FS system, distributed power control for uplink channels have to be applied.

# 5 TERMINAL EQUIPMENT IMPLEMENTATION ROADMAP

In the following we propose a technology development roadmap for the techniques that are defined and addressed in the WP3 context and described in D3.3 and D3.4.

## 5.1 Selected Technology Implementation Roadmap

The technology development is related to the application of the scenarios selected A, B and C [17.3-17.7GHz], [17.7-19.7GHz] as well as [27.5-29.5GHz] and to the defined end-to-end system we established for broadband consumer access.

Different areas of technology development are identified and need to be addressed in the context of the proposed service solutions for a Ka-band access network.

1.) End user terminal antenna with extended frequency range and front-end (this roadmap is provided separately as in chapter 5.2)
2.) Interference awareness techniques
    a. Database techniques (DB)
    b. Spectrum sensing (SS-SNIR, SS-ED, SS-CS)
3.) Interference mitigation techniques
    a. Beamforming (at terminal level)
    b. Resource Allocation (RA)
    c. Dynamic Capacity Assignments (DCA)
    d. Additional sensing antenna on the terminals (SA)

Table 1 - Selected Technology Implementation Roadmap

| Item | Current TRL | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| **2.a Database techniques (DB)** | 7 (scenarios A and B)<br>5 (scenario C) | A database demonstrator is working. A standardized approach to the database interface and implementation is agreed within regulatory and standardization context. (scenarios A and B)<br>Scenario C: The DB approach is discussed with regulators. | A pilot phase for a DB implemented access system with a test campaign is defined and executed in agreement and collaboration with regulators. (scenarios A and B).<br>Scenario C: The DB approach is evaluated with regulators. | Scenario A and B: The DB approach is implemented progressively in a deployed system taking into account regulator constraints.<br>Scenario C: The DB approach is tested in a geographically well defined area in collaboration with regulators and terrestrial operators of the scenario C frequency bands. |
| **2.b Spectrum sensing (SS) – SNIR detection (SS-SNIR)** | 3 | The SNIR technique for spectrum sensing is implemented in a lab based demonstration platform.<br>(scenarios A, B) | The SS-SNIR technique is field tested over live satellite for scenarios A, B. | A product implementation is performed and deployed in combination with a DB technique. |
| **2.b Spectrum sensing (SS) – Energy Detection (SS-ED)** | 3 | The SS-ED technique is tested in the lab in combination with options to verify the performance and suitability of the technique. Possible calibration techniques for the SS_ED are tested (addressing the identified shortcomings). | In a lab test environment, depending on the suitability of the technique, further technical improvements are implemented to address the shortcomings identified. | Depending on the outcome of how the identified shortcomings can be addressed, a field trial with prototype terminals can be envisaged at this stage. |

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| **2.b Spectrum Sensing (SS) – Cyclo-stationary detection (SS-CS)** | 2 | In a context in which the incumbent transmissions are well identified, i.e. a new regulatory context requiring the FS transmission technique identification.<br>The SS-CS technique is simulated and adapted further to the context here. | A lab test platform is implemented and evaluated. | Depending on the outcome of the addressed shortcomings, a field trial can be executed to verify the SS-CS performance in real context, in combination with a sensing antenna (for example). |
| **3.a Beamforming (BF)** | 5 (scenario A)<br>4 (scenario B)<br>1 (scenario C) | Antenna front-end and RF technology development prototype available. BF algorithms are tested and evaluated with RF antenna. | A product prototype is ready for field trials with a BF based antenna (reception only (scenarios A and B). | Depending on field trials outcome a first product prototype test deployment in small numbers and with selected customers is possible. |
| **3.b Resource Allocation (RA)** | 7 (scenario A)<br>4 (scenario B)<br>3 (scenario C) | A lab technology demonstration platform is implemented. | A product prototype can be developed. | Product can be on the market. (Sat broadband access platform with RA). |
| **3.c Dynamic Capacity Allocation (DCA)** | 6 (scenario A and B)<br>5 scenario C | A lab technology prototype is developed that demonstrates DCA in all scenarios A, B and C. | A product prototype can be developed for an E2E two way sat system. | A product for the satellite broadband access market can be available on the market. |
| **3.d Additional sensing antenna** | 3 | An antenna prototype can be developed and tested with different sensing techniques. | A product prototype of an integrated satellite antenna with a sensing antenna can be field tested. | A product ready sensing antenna is developed. |

## 5.2 Terminal Technology Implementation Roadmap

The satellite terminal as an end user equipment is an essential part of the technology roadmap to implement new system capabilities and increased capacity. The terminal equipment development is for consumer grade satellite access terminals very constrained by market demand for low cost solutions and therefore it is an overall important system element.

Table 2 summarizes the key terminal technology developments, which are expected to be implemented in complement to the CoRaSat enabling techniques.

Table 2 - Terminal Technology Implementation Roadmap

| **Item (Terminal feature)** | **Current TRL** | **2016** | **2017** | **2018** |
|---|---|---|---|---|
| **Scenario A [17.3-17.7GHz] frequency range coverage (reception)** | 4 | Development of the a demonstration antenna | Prototype product development | Market ready product |
| **Scenario B [17.7-19.7GHz] frequency range coverage (reception)** | 4 | Development of the a demonstration antenna | Prototype product development | Market ready product |
| **Scenario C [27.5-29.5GHz] frequency range coverage (reception)** | 3 | Development of the a demonstration antenna | Prototype product development | Market ready product |
| **Specific sensing antenna for the scenarios A and B** | 3 | Evaluation of different approaches and lab tests | Demonstration setup and field trials campaign | Depending on outcome, prototype development |
| **Anti-blocking filter on the antenna front-end for scenarios A and B** | 2 | Evaluate in lab different implementation approaches | Prototype of a consumer grade product implementation and integration with LNB | Field trials and tests with product prototype and product commercial design |
| **High symbol rates on the forward link (significantly above 60MSps) implemented on consumer grade chipset** | 4 | Lab tests with chipset prototypes (in combination with DVB-S2X) | Second build chipset optimized for product prototype | Possible market ready chipset with DVB-S2X and high baudrates |

| | | | | |
|---|---|---|---|---|
| **Higher bitrates on the forward link (above 200Mbps)** | 4 | Prototype development: Development of new hardware and software for consumer two way modem for higher throughput | Market field trials ready development with optimized design | |
| **Higher symbol rates on the return link (significantly above 5MSps)** | 4 | Prototype development of hardware and software for the multi-carrier demod (MCD on hub gateway side) and the terminal software | Field trials and market ready implementation of the higher return link baud rates. | Market ready product that supports higher return link baudrates and resulting higher peak throughput. |

## 5.3 Testbed related demonstration aspects

To identify key technologies needed to implement the cognitive radio for satellite systems on the basis of the WP4 test bed implementation. This should only relate to the work needed to implement the demo and not a final product. However some discussion on the issues around modifying the terminal bandwidths and also on increasing the bandwidth on future Ka band satellites needs to made.

The cognitive radio techniques that are investigated in the context of WP3 in this project for the scenarios A, B and C require also a dynamic resource control at physical layer to be able to respond to the requirements of a seamless service delivery while using resources that are partially used by an incumbent user.

In the near term we consider the implementation of the main enabling technologies, if an FSS system as defined in D3.4 is implemented. The physical layer technologies that are required to make the system work as expected are the first set of required implementations. This includes mainly forward and return link resource allocation technologies that enable the flexible usage of the frequency resources while keeping the user link. This is the basis for the resource allocation and cognitive adaptive frequency usage. In a combination with a database approach the FSS Ka-band end-to-end system would be able to operate on the frequency bands that are allocated for cognitive usage.

In this context what is implemented in the near future at Newtec in the context of responding to requirements related to cognitive radio are mainly the physical layer and transmission layer capabilities to comply with future Ka-band broadband systems that would be able to use the frequencies as defined in scenarios A, B and C.

This includes a number of technologies that have been identified and are implemented in the process of the work package 4. The details of the implemented techniques are described in the related WP4 document D4.3 and D4.4.

The front-end capability to receive the frequency bands [17.3-17.7GHz] as well as [17.7-19.7GHz] are considered for implementation as well as (in longer term and with secondary priority) the potential transmit capability within [27.5-29.5GHz].

In addition, Newtec has developed (outside the context of this project) the high resolution coding (HRC) multi-dimensional medium access control (HRC/MxDMA) mechanism as a return link technology that is highly efficient and adaptive in power, used bandwidth and MODCOD. It is the intention to adapt the resource control of this mechanism to be able to react in a cognitive manner to the resource control that would be required for a cognitive FSS system. This implies the implementation of the network control mechanisms that are capable of reacting to interference situations in a centralized manner for any terminal in the network.

For the context of scenarios A and B [17.3-17.7GHz] and [17.7-19.7GHz] respectively and the FSS system forward link, the FSS system requires a network layer mechanism that can switch terminals between forward link carriers in a fast and seamless manner without creating a service outage as much as possible to keep the service guarantee.

Regarding the signal and signal to noise ratio estimations, this is already implemented in a the current system and can be used as a metric to indirectly detect the presence of interference as caused in the context of scenarios A and B. Improvements and long term observations of the signal quality parameters signal power, BER, SNIR can however improve further the interference environment awareness of the terminals and contribute to the overall incumbent signal awareness context within the environment of a specific terminal for the scenarios A and B.

The database technology interaction with the NCC center is a central and essential interface technology that needs to be implemented to be able to guarantee the overall system’s capability to get incumbent user signal awareness where possible. The implementation is feasible in a near term and the NCC network control server can host the adequate interface to allocate the carriers to the best possible overall carrier configuration. This could be done in a manner similar to the resource allocation (RA) as defined in D3.3 or similar to currently used resource allocations in existing systems.

The spectrum sensing in the terminals and in a collaborative manner in a specific region is a potential technology that can be used to increase the network’s reliability and performance in the long term. This would entail the implementation of the D3.3 defined spectrum sensing techniques such as the energy detection and/or the cyclostationary feature detection.

The implementation of these techniques would enable the application of the system in scenarios where only a partial or no database is available.

More elaborate spectrum awareness techniques can be considered for the long term, such as cooperative detection of the incumbent user environment and the usage of a specific secondary antenna on the outdoor unit to detect the spectrum environment. In addition performance improvement interference avoidance techniques such as beamforming can be considered for the long term as well, in the context of a next terminal generation for the deployed FSS Ka-band.

# 6 MODIFICATIONS TO TECHNOLOGY AND IMPLEMENTATION

In this section we address a detailed description of the modifications necessary for the technology itself and the implementation processes. We attempt to summarise this via technology readiness level charts in each case. This should address the work needed and the timing to take it from the current SoA to products and operational processes.

## 6.1 DataBases

### 6.1.1 Database availability

Databases are available for the BSS stations across EU and there should be no problem in collecting these on a European basis and performing the modelling. This would preferably be done via CEPT, possibly FM44. Databases for FS in the 18GHz band are again available via the regulators but the latter may have issues with releasing them. In our opinion calculations would be better done centrally either via CEPT or the appointment of a trusted third party. However FM 44 are at the moment investigating another option of making software available to the regulators in order to do their own calculations. The results of these would need to be made freely available to users and satellite operators in the form of maps. For the 28GHz databases there are issues in countries that have sold off parts of the spectrum (e.g. UK) and this would have to be resolved.

### 6.1.2 Software aspects

The software to interface with the databases is based on ITU propagation models which are updated from time to time as new knowledge is gained. There is thus a maintenance aspect to the software. In addition the software needs various additional databases e.g. terrain and environmental to be included. These need to be updated and maintained. A complete calculation of all the interference paths would be very exhaustive and thus in D3.3 we have derived a method to reduce the computational complexity which can be incorporated into an eventual commercial software package. Lastly the verification of the software via measurements would be desirable but complex. It is recommended that a commercial software package is developed and approved by CEPT.

### 6.1.3 EU acceptance and operation of schemes

The major requirement with the database process is to get agreement across the EU on how the databases, or the results of calculations will be made available. This is a process agreement which needs to be done via the CEPT. There is an overhead in running and updating material as well as maintaining the software and we would advocate this is done via a trusted third party as the regulators would almost certainly be unwilling to do it themselves. Again this can be agreed within the CEPT committees. The financial arrangements would need to be further considered.

### 6.1.4 Bringing more spectrum into play

*__Scenario A__—is the easiest portion to bring into operation as there are few BSS stations across the EU and there should not be an issue with regulators releasing databases. A common evaluation could be made across Europe and possibly small regions around BSS stations designated as cognitive but vast areas released for use by FSS. We have the software available and thus this could be done within a year.

*__Scenario B__—This scenario will take a little longer as we have to get agreement on the release of the FS databases or agreement that the regulators will do the calculations. This might take a year to get agreement and a further year to make cognitive information freely available. There has to be a decision on the software vendor and its verification.

***Scenario C**—The above scenario's being downlink and the interference being into the FSS do not require any regulatory intervention. However the 28GHz band is segmented and if FSS is going to operate in FS designated portions there will need to be regulatory agreement. This could be difficult in all EU countries due to regulators not managing all of the band. The process of interference calculation and power control will need to be demonstrated and agreed by CEPT on behalf of the regulators as a first step. The process as a whole could be agreed or geographical areas in which it is clear that FSS would have no interference implications designated and maybe uncoordinated FSS be agreed in these rural areas. The process is likely to take a couple of years at least and depending on the degree of success it is difficult to see it being agreed within three years.

From the above it is seen that there could be a phased release of shared spectrum. Scenario A within a year, scenario B after two years and scenario C potentially after 3 years. The processes could be completed in time for the spectrum to available for the design of satellites and earth terminals for the 2020 period.

Table 3 – Databases Roadmap

| **Item** | **Current TRL** | **2016** | **2017** | **2018** |
|---|---|---|---|---|
| **Database availability**<br>**18GHz**<br>**28GHz** | <br>7<br>5 | Complete the collection of databases and agree who produces and runs software. Scenario A available from CoRaSat. | Scenario A and B data available for EU. | Scenario C data available. |
| **Software availability** | 5 | Appoint commercial software provider and do early verification. | Outputs of scenario A and B available. | Software maintained and Scenario C available |
| **EU process agreement** | 3 | Agree process for database collection/calculations -A&B. Appoint software vendor. | Agree process for Scenario C adoption. | |
| **Scenario A** | 6 | EU data available. | | |
| **Scenario B** | 4 | | EU data available | |
| **Scenario C** | 2 | | | EU data available |

## 6.2 Spectrum Sensing

Depending on the selected scenarios the above described Spectrum Sensing techniques can be applied with a different grade of modifications

### 6.2.1 Scenario A

By considering the Scenario A, the spectrum sensing is used by cognitive FSS terminals for obtaining temporal knowledge about the occupancy of a specific carrier in a specific geographical location. One common issue with spectrum sensing in cognitive literature is missing detection of the incumbent users.

Since in scenario A, we are only interested in detecting the interference received from BSS feeder links, missing detection of BSS harmful interference means the interference is lower than the harmful level and thus we could not detect it. Therefore, spectrum sensing seems a good candidate for scenario A, particularly when the FSS terminal is located close to the BSS feeder links.

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. One solution is to add an additional omni-directional antenna, or a steering horn-antenna over the horizon to measure the BSS interference. Note that, we assume that the received signal from the satellite at the omni-directional antenna is below the noise floor and thus will not affect the measured BSS interference at the omni-directional antenna. However, omni directional antennas do not exist in practice, and further the omni-directional antenna may be shadowed by the main dish. But note that as we measure the interference over the horizon, as far as the additional antenna is homogenous over the horizon, the sensing performance is good enough.

In order to improve the sensing performance, it is possible to exploit more complex techniques such as feature detectors. However, these schemes rely on a prior knowledge about the BSS signals which might not be available. Further, they seem to be overkill for scenario A as the required level of detection performance is usually satisfied by the energy detection.

Spectrum sensing seems a promising technique for enabling scenario A, however it entails adding an additional receive-chain with an omni-directional antenna which can be overcomplicated for scenario A, taking into account that quite accurate and complete databases might be available.

An additional approach taking into consideration the interference level can be exploited. By using such approach it is possible to have not only the detection of the incumbent signal but also have an estimation of its level. This could be very important allowing to exploit the estimated interference value for having a more efficient exploitation of the cognitive transmission.

The energy detector is able to detect the presence of incumbent users by measuring the received power level and comparing it with a threshold, but does not provide estimates of the power level. Since it is useful also have knowledge of how much interference this produces, apart from the detection of its presence, we extend the concept of spectrum sensing through energy detection with that of energy detection and estimation.

In particular, the estimation process will lead to a description of the overall interference in the scanned bands. After this process, the cognitive system is able to identify the best bandwidth even in the presence of an interferer. Therefore, we can consider this approach as a spectrum awareness technique not only able to distinguish between incumbent presence and absence but also able to provide different degrees of awareness. Moreover, the interference may also exceed the limits of the recommendation since the system is responsible to identify the possibility to transmit in the specified band or not.

### 6.2.2 Scenario B

Spectrum sensing techniques are possible in this scenario. In particular, Energy Detection and Cyclostationary Feature Detection are the selected cognitive techniques to perform spectrum sensing within the CoRaSat context; moreover an additional SINR based estimation sensing could be used allowing to estimate, and not simply detect, the incumbent signal power. There are several aspects to be taken into account with respect to the FS links:

- Different services are deployed in this band, and there is no known reference standard. Without information on the FS transmission (modulation, multiple access scheme, etc.), a cyclostationary feature detection technique might be not feasible. On the other hand, an energy detection technique, which is a blind spectrum sensing technique, does not require this information. However, it provides poorer performance with respect to the more advanced cyclostationary detection (in particular, due to the SNR wall issue related to noise uncertainty).

- 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.
- If the same antenna is used for both cognitive reception and spectrum sensing, two aspects shall be considered: i) the need for an alternate sensing and receiving phases; and ii) the possibility that the incumbent signal is received from a side lobe of the dish antenna at the cognitive terminal. To solve these issues, a different antenna can be implemented to perform spectrum sensing. In this case, the type of antenna shall be defined (omnidirectional, directional). However, this approach would require two RF chains as well as the combination of these antennas, the feasibility of which have to be carefully studied.

A cyclostationary feature detection could provide better performance compared to an energy detector. However, there is no known standard providing precise information on the structure of the incumbent signals. However, it would still be possible to recognize whether, on the sensed channel, there are no incumbent signals (i.e., there is AWGN noise only) or there are incumbents. This is possible as the AWGN noise has no periodic characteristics that would provide peaks in the cyclostationary spectral density, and thus if peaks are presents that would mean that the channel is occupied. The issue in this case would be that, without information on the incumbent signals (i.e., without knowing the cyclic frequencies that they have), it would not be possible to discern between incumbent and other cognitive transmissions.

However, even if the blind cyclostationary detection could permit the determination of the presence of an incumbent signal, it could facilitate the understanding if it is harmful for the cognitive transmission. This issue could be taken into account by exploring a joint usage of a cyclostationary and energy detector (where the latter facilitates a measure of the harmful interference), or by opportunely considering the values of the peaks of the cyclostationarity values.

A possible solution for the applicability of the Energy Detector technique is to use an additional RF chain. In scenario B, the downlink interference from the cognitive satellite to the FS links is taken into account by system planning and can be kept below the defined regulatory limitations in terms of the maximum power flux-density (pfd) at the earth's surface. However, the interference from FS transmitters to the cognitive satellite terminal needs to be taken into account in order to guarantee sufficient Quality of Service (QoS) of the cognitive users. The main challenges for implementing sensing in the considered scenario are to detect the weak levels of the FS interference and to define an appropriate sensing threshold in order to decide whether a harmful FS carrier is present or not. Since all the FS transmissions are not harmful to the FSS terminal, we define the harmful FS carrier as the active FS carrier which affects the normal operation of the FSS terminal by creating interference above its interference tolerance threshold.

In the existing SS literature, the commonly used assumption is that all the cognitive users are silent during the period of sensing and the sensor receives only incumbent users' signal during the sensing interval. Unlike the above assumption, the FSS cognitive terminal under the considered scenario receives downlink transmission from its satellite beam as well as the FS transmission simultaneously. In this context, the main challenge is how to detect the presence of an incumbent signal from the received signal which can be a combination of the desired signal (FSS downlink signal), interference signal (transmit signal from the FS transmitter), and the receiver thermal noise.

To address the above issues, we can exploit the use of an additional Radio Frequency (RF) chain with a dipole antenna having a doughnut shaped gain pattern across the horizon in addition to the existing satellite dish antenna. The difference between two antennas is that the dish antenna used for receiving a satellite signal is directed towards the satellite and the additional dipole antenna can be dedicated for detecting the FS signal coming from the horizontal direction. Based on ITU-R S.465, the dish antenna receiving gain towards the horizon varies from 7 to -6.6 dB while considering GEO satellite terminals located in European continent with 10° to 35° elevation angles. Since a purely omnidirectional antenna is not practically realizable, we consider a half wave dipole antenna which has a gain of 2.15 dB. Other options can be (i) a rotating horn antenna, (ii) a Uniform Linear Array (ULA) with electronic steering, (iii) a 4/6 horn circular detector looking over the horizon, and (iv) several detectors on the back of the reflector. However, these options are quite costly in comparison to the inclusion of a dipole antenna.

For the Energy Detection technique to work reliably, a good long term noise reference is required, which may be difficult to obtain in practice given the fact that the front-end may have a temperature dependent gain and that the surrounding noise floor changes also with the weather. An accurate long term noise calibration would be difficult in practice also because of the problem that a reference is required and that the interference cannot be switched off to calibrate during installation. Therefore, we have also evaluated the performance of the considered Energy Detection technique in the presence of noise uncertainty in order to reflect the practical scenarios.

Furthermore, in practice, another option to mitigate eventual detection problems is to use other sensing antennas such as a higher gain antenna that has sufficient gain over the horizon to achieve a practical detection.

Also in this case, as explained for the Scenario A, a SINR based estimation sensing is a feasible approach allowing to estimate and not only detect the incumbent signal power. As for the applicability of the SINR based estimation sensing no major issues should be considered apart those described for the Scenario A. Moreover, similarly to the above described modifications for the RF chaining structure for the energy detection and the cyclostationary feature detection, also in this case a similar approach should be considered.

### 6.2.3 Scenario C

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. Alternatively the incumbent would need to signal back to the FSS to reduce its power in order to be within the interference threshold limits. Such solutions put additional imposition to the incumbent and are unlikely to be acceptable. Thus in scenario C we have decided not to employ spectrum sensing.

Table 4 – Spectrum Sensing Roadmap

| **Item** | **Current TRL** | **2016** | **2017** | **2018** |
|---|---|---|---|---|
| **Additional Sensing Antenna** | 3 | Prototype of an integrated terminal with additional antenna for Scenario A | Prototype of an integrated terminal with additional antenna for Scenario B | |

| | | | | |
|---|---|---|---|---|
| **Energy Detection** | 3 | Prototype of an Energy Detector for Scenario A | Prototype of an Energy Detector for Scenario B | |
| **Cyclostationary feature detection** | 2 | | Prototype of a Cyclostationary feature detector for Scenario A | Prototype of a Cyclostationary feature detector for Scenario B |
| **SINR based estimation sensing** | 3 | | Prototype of a SINR estimation algorithm for Scenario A | Prototype of a SINR estimation algorithm for Scenario B |
| **Scenario A** | 3 | Basic Spectrum Sensing prototype | Advanced Spectrum Sensing prototype | |
| **Scenario B** | 3 | | Basic Spectrum Sensing prototype | Advanced Spectrum Sensing prototype |
| **Scenario C** | 1 | | | |

## 6.3 Beamforming

***Scenario A**—is the easiest scenario in terms of beamforming applicability as there are few BSS stations across the EU. In this context, the beamformer does not need to create many nulls in the interfering directions. Therefore, the terrestrial based receive beamforming for Scenario A can be readily implemented within the current infrastructure, adding an extra antenna and the joint processing is not complex and not expensive.

***Scenario B and C**— These scenarios will take a little longer as we may be some locations where more than one null needs to be beamformed due to the much larger density of FS links, thus requiring a large number of antennas. In the presence of multiple FS links, the considered scenarios become overloaded since the satellite receiver usually has fewer LNBs than the received co-channel FS signals. In this context, the main issue is the extraction of desired FSS signal from the received samples (measurements). These received samples are corrupted with the receiver noise as well as with the FS interference in Scenario B. In the satellite receiver, 3D beamforming and joint processing techniques can be applied in order to extract the desired information.

Table 5 – Beamforming Roadmap

| **Item** | **Current TRL** | **2016** | **2017** |
|---|---|---|---|
| **Beamforming for Scenario A** | 7 | Additional LNBs at terminal receiver. | |
| **Beamforming for Scenario B & C** | 3 | | Additional LNBs at terminal receiver.<br>3D beamforming. |

## 6.4 Resource allocation

***Scenario A and B** — In both scenarios, the carrier allocation module receives the SINR for each user over each available carrier as the input and then, employs combinatorial optimization algorithms to solve the carrier allocation problem. In general, SINR-based resource allocation seems to be a feasible approach since it is widely used in current systems.

***Scenario C** — As noted in the previous section, the interference management through power control will need to be demonstrated and agreed by CEPT on behalf of the regulators as a first step.

Table 6 – Resource Allocation Roadmap

| **Item** | **Current TRL** | **2016** | **2017** | **2018** |
|---|---|---|---|---|
| **Resource Allocation for Scenario A** | 7 | Database available to extract SINR. | | |
| **Resource Allocation for Scenario B** | 4 | | Database available to extract SINR. | |
| **Resource Allocation for Scenario C** | 1 | | | Database available to estimate FS interference. Regulatory intervention agreement. |

# 7 CONCLUSIONS

In this interim report we have determined the techniques that can be applied to each scenario (A, B and C) and discussed the state of art as well as current TRL level. We have also provided some idea of the modifications that need to be made in each case to bring them to a level of incorporation into operational systems. In particular a road map is produced for each technique to show the flow of the development needed. The terminal equipment is addressed in more detail as this impacts a hardware change to incorporate the new band. It is also inferred that the satellite design will need to change in order to accommodate the additional frequency band and the new frequency plans. Thus such systems are unlikely to come into operation much before the 2020 series of satellite launches. For the regulatory changes, the use of a database system does not pose too much of a technical problem but will need operational condition to be established in the downlink band. For the uplink band there will need to be some regulatory agreements and this will take longer and so may represent a future phase of the system.

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# 9 DEFINITION, SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| AWGN | Additive White Gaussian Noise |
| ANFR | *Agence Nationale des Fréquences* |
| BSS | Broadcasting Satellite Service |
| CEPT | *Conférence européenne des administrations des postes et des Telecommunications* |
| CR | Cognitive Radio |
| CFAR | Constant False Alarm Rate |
| CDR | Constant Detection Rate |
| CS | Cyclostationary Sensing |
| DB | Database |
| DVB-S2 | Digital Video Broadcasting - Satellite - Second Generation |
| EIRP | Equivalent Isotropic Radiated Power |
| EU | European Union |
| DCA | Dynamic Capacity Assignment |
| ED | Energy Detection |
| ETSI | European Telecommunications Standards Institute |
| FM | Frequency Management |
| FP7 | Seventh Framework Programme |
| FSS | Fix Satellite Service |
| GEO | Geostationary Earth Orbit |
| HRC | High Resolution Coding |
| HDFSS | High Density FSS |
| ICT | Information and Communications Technologies |
| ITU | International Telecommunication Union |
| IEEE | Institute of Electrical and Electronics Engineers |
| LNA | Low Noise Amplifier |
| LTE | Long Term Evolution |
| LNB | Low Noise Block Converter |
| LCMV | Linearly Constrained Minimum Variance |
| MCD | Multi-carrier Demod |
| NCC | Network Controller Centre |
| Ofcom | Office of Communications |
| SNR | Signal to Noise Ratio |
| SINR | Signal to Interference Noise Ratio |
| SS | Spectrum Sensing |
| SCD | Spectral Correlation Density Function |
| SatCom | Satellite Communications |
| TRL | Time Readiness Level |
| WG | Working Group |
| WP | Working Package |

# 10 DOCUMENT HISTORY

| Rel. | version | Date | Change Status | Author |
|---|---|---|---|---|
| 1 | 0 | 28/10/2014 | First Release to European Commission | UNIS |