Application of the CBRS model for wireless systems coexistence in 3.6-3.8 GHz band

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Abstract. In this paper we discuss the results of the experiment conducted in Poznan, Poland, where the performance of CBRS spectrum sharing model in 3.6-3.8 GHz band has been verified. Three-tier model has been tested, where the highest priority has been assigned to the fixed WiMAX users, whose transmit parameters cannot be modified. Second tier of users was constituted by the peer-to-peer microwave line, whereas the third tier of lowest priority covered the low-power cognitive small-cells. The whole system has been managed by the dedicated remote database located in Finland. Experiments have been carried out in the laboratory, where mainly the functionality of the management of the third tier user has been tested, while protecting the users assigned to two higher tiers.

Key words: Vertical Spectrum Sharing, CBRS, Trials

1 Introduction

The concept of cognitive radio technology has recently celebrated it maturity, as it has been first proposed in 1999 by J. Mitola [1, 2]. During these two decades of intensive research work (see e.g., [3]), it has been revealed that the pure cognitive radio that relies on the spectrum sensing will not be reliable enough in practical applications. The application of advanced, database oriented spectrum management systems have been proposed to solve this problem [4, 5]. Two key concepts are of practical interest today. Licensed shared access (LSA) concept [6] is mainly considered in Europe. It assumes the presence of the incumbent license owner, who decided to share its spectrum with other users. In the alternative approach, proposed in US and called Citizens Broadband Radio Service (CBRS) with Spectrum Access System (SAS) [7], three tiers of users are considered. While the first two tiers are similar to the LSA concept, the lowest tier of users operates in a cognitive manner, so they are allowed to transmit as long as they do not cause harmful interference to the other users from higher tiers. In our paper we consider the application of the second approach, as this is the case tailored to the 3.5 GHz band and assumes the presence of three types of users. Such a model seems to be well-suited to the business case considered for practical application by the network operator INEA, who delivers services in Greater Poland area in Poland. WiMAX deployment at INEA has started in 2010 and so far it provided fast and affordable connectivity for Internet and telephony services to almost 6000 households across the 30,000 sq km region. Currently the WiMAX technology is considered to be *dead*, but INEA's WiMAX network still operates and occupies radio spectrum resources. Therefore INEA would like to utilize allocated spectrum in a more efficient way by sharing it with other radio systems.

In particular, INEA would like to evaluate vertical spectrum sharing model, i.e., the coexistence of the existing WiMAX 802.16e working in the 3.5 GHz band together with the microwave radio-links serving corporate users. It was observed that corporate users require more capacity during the day time and residential users served by WiMAX require more capacity outside office hours. The residential and corporate users are collocated on the same geographical area and the two radio systems are active simultaneously. However, both radio systems can be configured with various channel bandwidth. Therefore, LSA system can direct the two radio system to modify their channel bandwidth (allowing also some overlapping) and transmit power in order to shift capacity but at the same time maintaining limited interference levels. It is assumed that each radio system maintains a small amount of capacity at all times.

Moreover, it has been decided to use a next tier of users (as GAA users in SAS) in order to verify if it is feasible to utilize the frequency resources in a more efficient way. These third tier users are realized by the means of Universal Software Radio Peripheral (USRP), which needs to obtain permission for transmission opportunity in a given geographical and frequency location from an LSA controller. USRP will start some data transmission in such a way that the primary users will not be affected.

Thus the goal of this sharing scheme is to utilize the daily traffic patterns of the WiMAX clients and offer the unused fragments of band to the corporate clients via radio-links while verifying additional spectrum access opportunities using USRP.

2 Proposed Vertical Spectrum Sharing Model for 3.6-3.8 GHz

2.1 Multi-tier Spectrum Sharing - Scenario definition

In our exercise we consider a multi-tier spectrum sharing model based mainly on the CBRS solution discussed above. The ultimate goal is to utilize the spectrum in 3.6-3.8 GHz band in a more efficient way. Currently, this fragment of spectrum is mainly associated with WiMAX transmission, where high power WiMAX base station covers wide geographical area (of a few kilometers radius) and deliver services to fixed customer-premises equipment (CPE). However, as the development of WiMAX system has lost its momentum in favor of LTE/LTE-A bases systems, it is widely treated as *dead*. However, due to the legal commitments, this network cannot be simply turned off, and still it provides some revenues (although decreasing) to the network operator. From that perspectives, we consider to reuse the spectrum in efficient way, mainly to deliver point-to-point transmission via microwave link. The WiMAX users will constitute the highest priority users (first tier), whereas the microwave links will be treated as incumbents which do not interfere to the WiMAX system. However, in our multi-tier experiment we also consider the presence of third tier of users, which we call general authorized access (following the CBRS nomenclature). In such approach, the GAA subsystem will operate in the same frequency band as WiMAX and microwave link do, but their priority will be the lowest from these three. It means that by assumption the GAA transmission cannot distort neither WiMAX nor microwave link. The considered scenario is shown in Fig. 1, where a fragment of the area covered by WiMAX base station is presented.

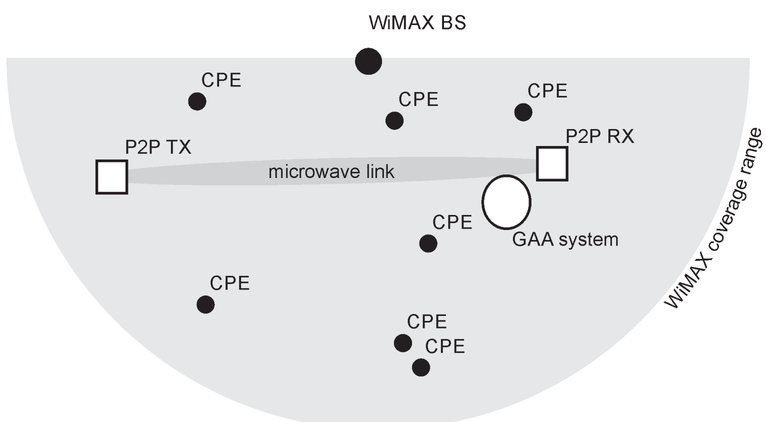

Fig. 1. Considered scenario for multi-tier spectrum sharing

The coexistence of such three types of networks will be probably not possible if these networks will be fully autonomous. Thus, we consider the presence of dedicated database-oriented management system, which will be used to coordinate and control the three networks. The graphical representation of the concept is shown in Fig. 2. One can observe, both WiMAX and microwave link communicate with the database-focused management system via Simple Network Management Protocol (SNMP), where all the steering and control instructions will be sent via management information base messages (MIBs) by addressing appropriate object identifier (OID). At the same time, as GAA subsystem works in a typical cognitive manner, it will communicate with the database by application of the pure CBRS protocol.

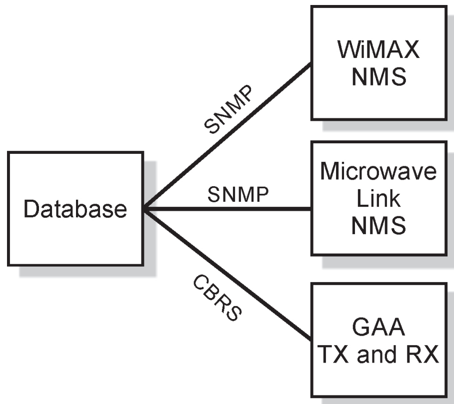

Fig. 2. Database management system for considered scenario

2.2 Database Structure and Functionality

In the Spectrum Management System, SNMP client communicates with WiMAX and Microwave (MW) Link Network Managements systems through a Virtual Private Network client. SNMP client stores the status data in Structured Query Language (SQL) Database (DB). Clocked Control uses SNMP client to change the center frequency and channel bandwidth of WiMAX and MW devices based on the daytime. Citizens Broadband Radio Service (CBRS) Spectrum Access System (SAS) serves the spectrum resource request coming from General Authorized Access (GAA) Citizens Broadband radio Service Devices (CBSD) using SAS-CBSD protocol specified by Wireless Innovation Forum. SAS server reads protocol information from SQL DB and stores protocol information there. Spectrum Inquiry, Grant, and Heartbeat requests in SAS Server invoke DB Engine. DB Engine queries the measurement data from WiMAX and MW links with SNMP client. DB Engine evaluates the interference risk to WiMAX and MW links caused by requesting CBSD. The evaluation is based on an assumed propagation model. Modeling is enhanced with WiMAX and MW link measurement information.

The detailed version of the logic applied in the database for controlling third-tier of users is shown in Fig. 4.

2.3 GAA Subsystem Functionality

At the same time the GAA subsystem, i.e., USRP device in our case, applies the following algorithm for accessing the spectrum:

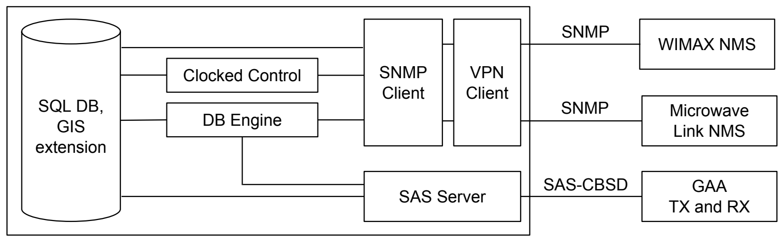

Fig. 3. Structure of Spectrum Management System database

1. *Step 1* First, the GAA transmitter sends the registration request (following the implemented CBRS protocol), where it asks for registration in the whole system. As a response it receives a dedicated device identification number. The coordinates of the devices are also delivered to the system.
2. *Step 2* After registration, the GAA subsystem inquires the database for a set of parameters defining its transmit opportunities (like maximum EIRP value) for a list of selected subbands, e.g., it may ask for these sets of parameters for three 2 MHz wide frequency subbands with center frequency of 3.64 GHz, 3.70 GHz and 3.75 GHz. As a response the GAA subsystem receives the limits of the allowed parameters.
3. *Step 3* The GAA transmitter sends the request for granting transmission by the database, where the proposed transmit parameters are defined. The database either grants the transmission with the proposed parameters (see Step 5 then), or blocks the request (see Step 4).
4. *Step 4* If the GAA device does not receive a positive grant response, it may either modify the transmit parameters (e.g., proposed transmit power) in the considered frequency band or switch to other band of interest. In both cases the new grant request is sent to the database with new set of parameters.
5. *Step 5* The device will start transmission (please note that until now there was no wireless activity in the GAA subsystem, as the communication with remote database was guaranteed via external control channel). After agreed

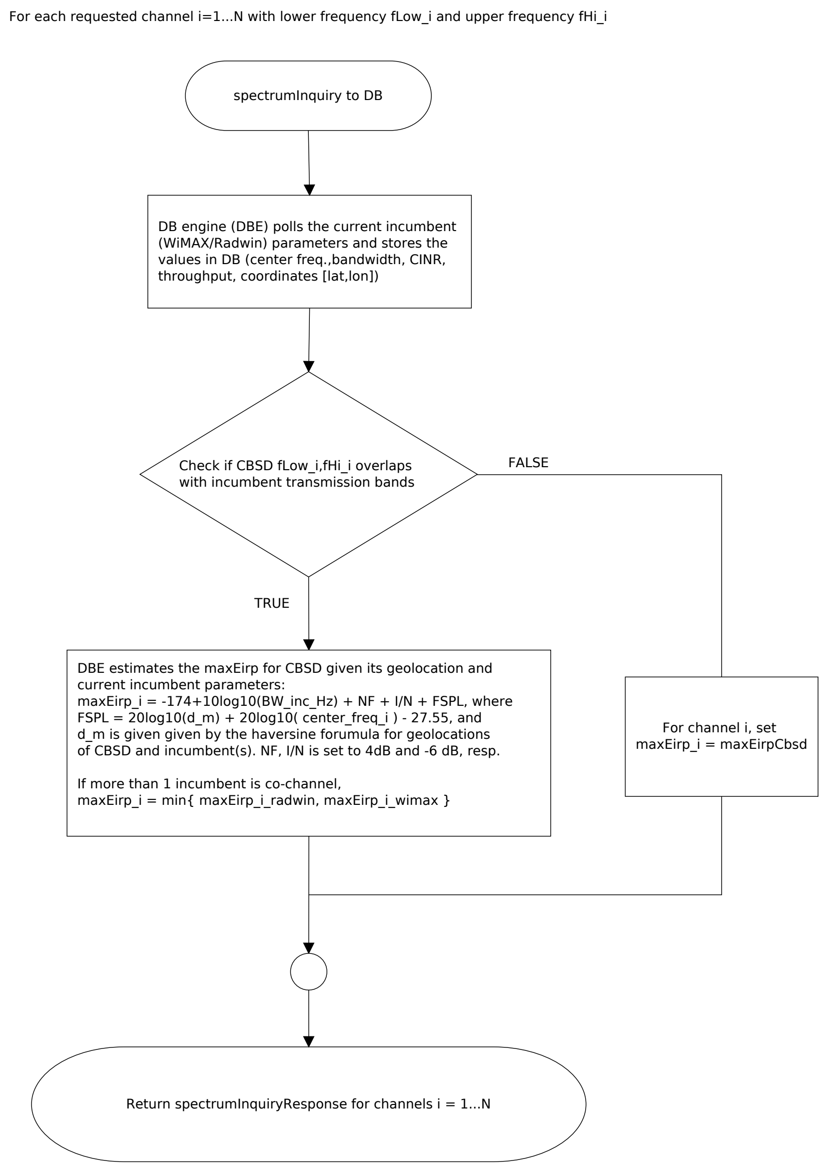

Fig. 4. Algorithm applied at the database side for controlling GAA subsystems

transmission time, the device will analyze the so-called heartbeat response, where the database inform, if the transmission can be continued (then repeat Step 5) or the transmission has to be stopped (then the algorithm goes back to Step 3)
6. *Step 6* Once the device has no data to sent it will deregister from the system, releasing the device identification number.

The algorithm presented above is fully adaptive and tries to maximize the rate of the GAA link in the transmission regime defined by the database. The detailed version of the implemented logic in the GAA subsystem is algorithmically presented in Fig. 5

3 Experiment Results

The whole experiment has been conducted in the INEA laboratory, where both WiMAX test base station with associated CPE has been deployed simultaneously with the point-to-point microwave link and underlying cognitive small-cell (GAA system).

3.1 WiMAX and microwave link setup

Regarding WiMAX the 802.16e-2005 base station (Cambium Networks PMP320) has been selected as the representative of existing operating network in Poznan. Please note that capacity in a WiMAX network is not fixed. Each customer-premises equipment (CPE) operates with spectral efficiency that changes in time and is influenced by three parameters: modulation, forward error correction (FEC) coding and MIMO mode. The network capacity of a given base station depends on the number of CPEs and their spectral efficiency. The WiMAX link worked in 2x2 MIMO mode on a center frequency set to 3.664 GHz with 10 MHz channel bandwidth. The transmit power of the base station may (following the specifications) change in the range from -40 to 27.5 dBm. The applied modulation and coding scheme assumed the 64-point quadrature amplitude modulation with code rate set to $\frac{5}{6}$. The directional antennas had 16 dBi gain. During the simulations only control data have been transmitted. The microwave link manufactured by RADWIN operated at 3.674 GHz center frequency and occupied 10 MHz bandwidth. The applied antennas had 19.5 dBi gain, and allowed for 2x2 MIMO transmission. As can be observed, these two systems did not interfere to each other, as they are separated in frequency domain. Before we start deploying third tier users (GAA subsystems), we have observed both transmitted signal using Rogde&Schwartz spectrum analyzer FSL6. The measured instantaneous power spectral density (PSD) and spectrogram for center frequency set to 3.669 GHz and resolution bandwidth equal to 30 kHz, are shown in Fig. 6.

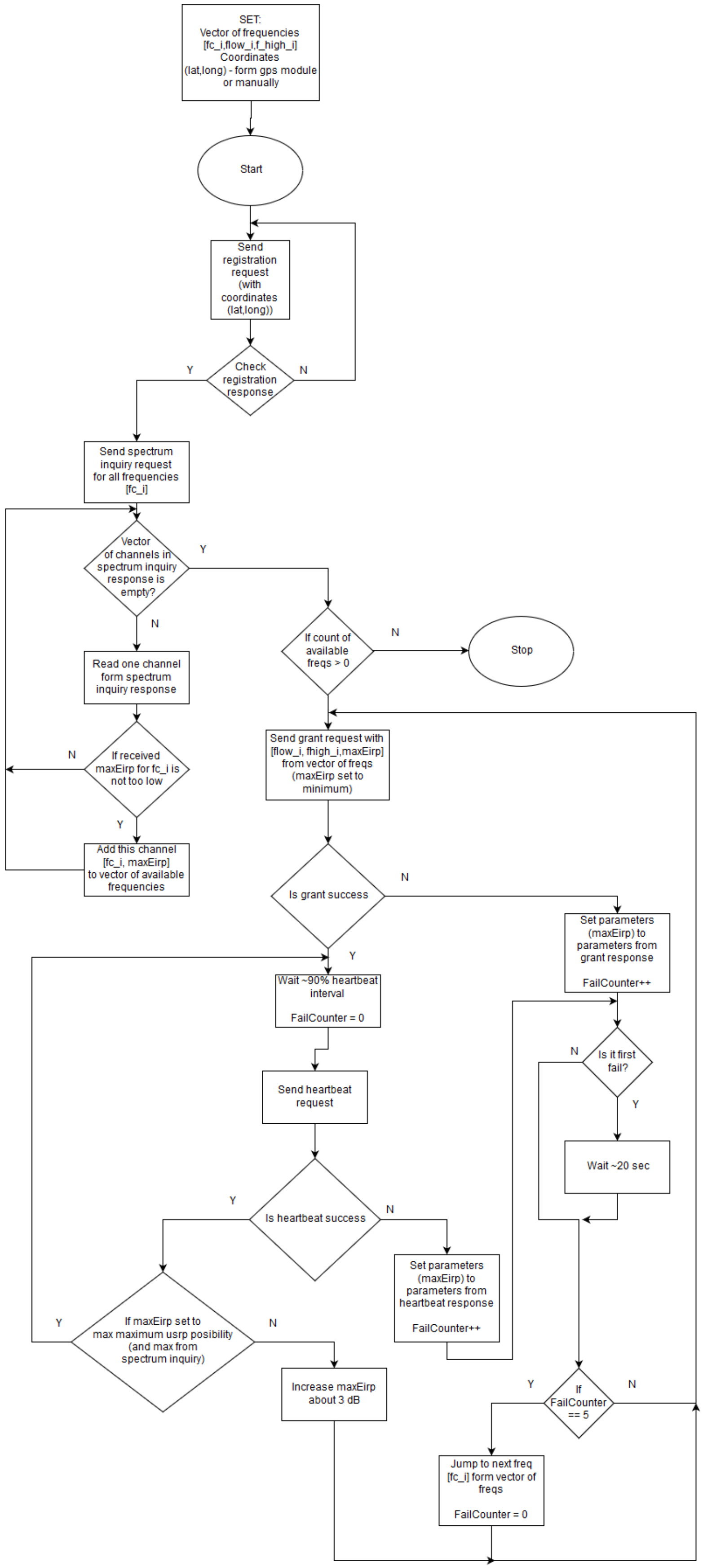

Fig. 5. Algorithm applied at the GAA side for dynamic spectrum access

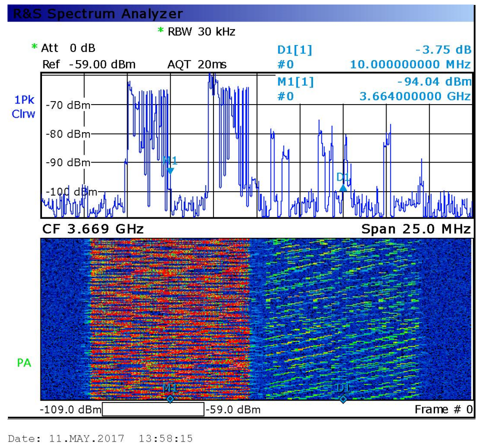

Fig. 6. Instantaneous power spectral density of WiMAX and RADWIN links

3.2 GAA subsystem

In parallel to the two legacy systems, i.e., first-tier WiMAX link and second-tier RADWIN microwave link, we deploy the GAA subsystem. Our ultimate goal is to increase the spectrum efficiency (by application of such advanced spectrum sharing scheme) while guaranteeing the performance of two protected systems. The GAA system is constituted by the USRP N210 platform equipped with the CBX daughter-board operating in the frequency range 1.2 GHz to 6 GHz with a instantaneous bandwidth of 40 MHz. The USRP board has received transmit stream from GnuRadio software that has been connected to the database and followed the algorithm described in the previous section. The database has processed the requests send by the GAA transmitters applying two performance constraints with regard to the WiMAX and RADWIN links, i.e., the GAA transmission may be started (or continued) as long as the observed carrier to interference and noise (CINR) ratio in the WiMAX link was above 20 dB, and as long as the microwave link was active (the quality of the link was high enough to transmit any data). The selection of such limitation parameters was caused due to the limited list of parameters that can be read by the remote database via SNMP protocol.

3.3 Use Case 1 - one active GAA subsystem

In the first experiment, only one USRP transmitter queries the database for new transmission opportunities for five subbands, each 2 MHz width, with center frequencies as follows: 3.657 GHz (below the WiMAX band), 3.664 GHz (as the WiMAX center frequency), 3.669 GHz (exactly between the WiMAX and microwave links), 3.674 GHz (as the RADWIN center frequency) and 3.682 GHz (above the RADWIN band). The following set of messages send to the database (denoted as *USRP* in the log below) and responses (denoted as *Server*) has been received:

– *USRP* - manual - position: $(52.4075, 16.7853)$ //registration message
– *Server* - Registration completed
– *USRP* - Spectrum Inquiry //inquiry with the list of 5 center frequencies
– *Server* - SI response, freq: 3.657e+09, max eirp: 25.6 //response with the max EIRP value for the certain center frequency
– *Server* - SI response, freq: 3.664e+09, max eirp: -45.3978
– *Server* - SI response, freq: 3.669e+09, max eirp: -30.9539
– *Server* - SI response, freq: 3.674e+09, max eirp: -30.9539
– *Server* - SI response, freq: 3.82e+09, max eirp: 25.6
– *USRP* - Available freq: 3.657e+09, max gain: 31.5 //list of available frequencies and maximum permitted gain to the USRP power amplifier
– *USRP* - Available freq: 3.82e+09, max gain: 31.5
– *Server* - Access granted - gain=0, freq=3.657e+09 //received grant for first frequency and setup of the heartbeat time
– *Server* - Heartbeat set to 60 seconds.
– *USRP* - Heartbeat remaining time: 47 seconds.
– *USRP* - ...
– *USRP* - Heartbeat remaining time: 5 seconds.
– *USRP* - Heartbeat remaining time: 0 seconds.
– *Server* - Heartbeat OK! //after 60s, we can continue transmission, so the USRP tries to get higher power; it increases the transmit power twice, and it got grant again
– *USRP* - Try more...
– *Server* - Access granted - gain=3, freq=3.657e+09
– *Server* - Heartbeat set to 60 seconds.
– *USRP* - ...

One may observe that only for the two border frequencies the database provided positive values of maximum EIRP value, as only these two frequencies do not overlap with the first and second tier of users. Clearly, in the CBRS model the GAA system may operate simultaneously with the same frequency band as other legacy systems as long as it does not interfere too much. In our case, however, the location of the GAA transmitter (provided in the first, registration message) was so close to the WiMAX receiver, so that the maximum EIRP calculated by the database was below the transmit possibilities of the GAA transmitter. Once the USRP device receives the response to the inquiry and grant requests, it starts transmission on the first available frequency (GMSK modulation, 2MHz bandwidth). The observed averaged PSD in such a case is illustrated in Fig. 7, where one may observe the spectrum of three simultaneously transmitted signals. Please note that during the experiment the performance parameters were permanently monitored by the remote database, but these were also displayed locally. Once the USRP devices started its wireless activity, the performance of both systems was not violated.

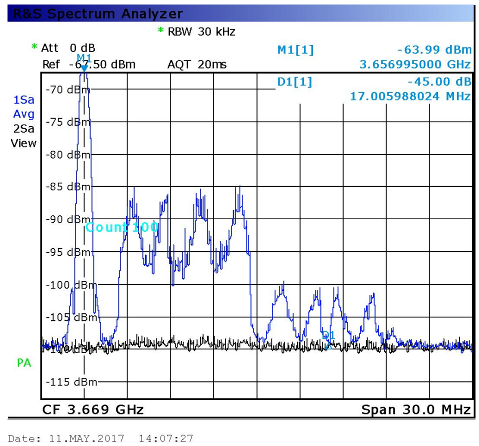

Fig. 7. Averaged power spectral density observed in the first Use Case

3.4 Use Case 2 - two active GAA subsystems

As an extension of the first use case, we decided to verify the behavior of the system when second GAA subsystem is deployed in the same area. Thus, after the first USRP transmitter initiated its wireless transmission, second GAA transmitter send the registration, spectrum inquiry and grant request. When the same set of center frequencies have been selected, both GAA transmitters have transmitted their signals on the same frequency band (i.e., 3.657 GHz), as the database does not have any mechanism for protection of GAA users. Thus, in the second phase we have modified the list of frequencies of interest, and one of the GAA subsystem was not interested in transmitting any data using center frequency of 3.657 GHz. In consequence, both USRP devices were allowed to transmit, however this time first USRP transmitted at the lower frequency (3.657 GHz), whereas the second USRP uses the highest center frequency (3.684 GHz). This situation is observed in Fig. 8. The observed performance of WiMAX and radioline was not deteriorated.

4 Conclusions

This work shows an example of a practical utilization of 3 tier spectrum sharing system in 3.6-3.8 GHz band. The results highlight that a remote database, being able to receive QoS information from incumbent systems can allow GAA system to work increasing spectral efficiency. The experiments prove that while the standardized CBRS protocol structure is relatively simple, much effort is to be put in designing algorithms for both GAA server and GAA device.

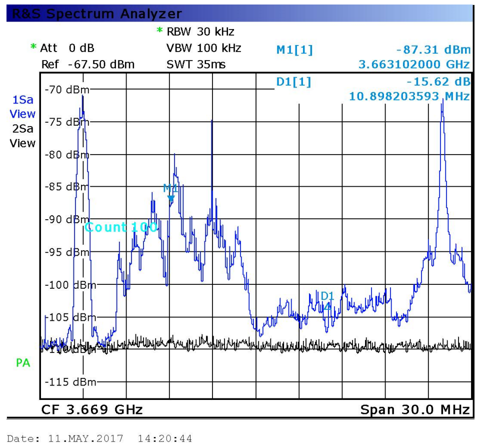

Fig. 8. Averaged power spectral density observed in the second Use Case

4.1 Acknowledgments

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