REM-Based Indoor Wireless Network Deployment - An Experimental Study

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Abstract. In this paper we discuss the results of the conducted experiment, where dedicated databases have been used for management of deployment of indoor small-cells. As the transmission has been realized in the TV band, the ultimate goal of the study was initialize new data transmission in a spectrum sharing mode while protecting the DVB-T signal. Every time when the cognitive user wanted to initiate new transmission, it asked the database for permission and for a set of parameters defining transmit opportunities. The experiment has been carried out with two sets of USRP N210 devices.

Keywords: Vertical spectrum sharing · Radio environment maps
Experiments and trials

1 Introduction

The intensive research on cognitive radio technology has been conducted for almost two decades, starting from 1999 and 2000 when Mitola III published his key concepts on environment-aware radios [1,2]. As the idea of dynamic and more intelligent spectrum access seemed to be a good solution towards better spectrum utilization in next wireless communication networks, numerous research centers and laboratories have concentrated on specific aspects of the so-called cognitive cycle. Even, new visions on the functionality delivered by the cognitive radios have been proposed (see e.g. [3]), as it has been revealed that the pure cognitive radio that relies on the spectrum sensing will not be reliable enough in practical realizations. As a consequence, the application of advanced, database oriented spectrum management systems have been proposed as an alternative to this problem [4,5]. These databases are often called geolocation databases (GLDB) or radio-environment maps (REMs).

Two approaches are of practical interest today, the licensed shared access (LSA) concept [6], which is mainly considered in Europe, and which assumes the presence of the incumbent license owner, who decided to share its spectrum with other users. The second widely accepted solution is the one proposed in US and called Citizens Broadband Radio Service (CBRS) with Spectrum Access System (SAS) [7], where three tiers of users are considered, and the devices assigned to

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the lowest tier operate in pure cognitive manner [8,9]. Let us highlight the recent updates on CBRS interfaces released in June and July 2017 by WInnForum [10,11].

During the last years great achievement have been made in the context of utilization of vacant TV channels (known as TV White Spaces,TWVS) for wireless communications. Numerous trials and pilots have been realized all over the world, showing the applicability of this transmission scheme to various use-cases. The good summary and lists of these trials can be find in [12,13]. In our paper we present the results from the conducted experiment, where we have utilized the REM database for management of the cognitive indoor small-cell wireless network operating in TV band. The database has been prepared based on the measurement campaigns carried out in Poznan, Poland, where the power of the all detectable received DVB-T signals has been measured in certain locations inside and in close vicinity of the building. Based on these measurements, kriging algorithm has been applied to calculate the approximated values of the received power in any place inside the building. Once such a reception map has been created, it is used for calculation of the maximum allowable transmit power of the new wireless transmitter operating in a selected TV channel, as shown in [14,15]. As comparing to these past works, the key novelty of this paper is that such remote database, available via internet connection, has been applied for real-time management of the deployment of new white-space wireless transceivers. Two active white-space connection have been established in an arbitrarily selected laboratory in Poznan, Poland, following the decisions made by the REM-manager.

The rest of the paper is organized as follows. First, we briefly revise the database structure and its assumed role in spectrum management. Next, we discuss the setup for the considered experiment, and present the achieved results in last chapter. Finally, we draw some conclusions on applicability of REM databases.

2 REM Database Description

Numerous researches conducted in recent years have proved that application of sole spectrum sensing as a tool for detection of the presence of the primary user signal is not sufficient enough for practical implementation. The reliability of single-node spectrum sensing, especially in low signal-to-noise ratio regime, is either too low or too complicated or it takes too much time to acquire enough samples for stable decision. In that context, Radio Environment Map (REM) is a tool frequently envisaged to be one of the technical enablers for practical deployment of secondary systems operating in the legacy bands. However, in order to guarantee the required quality of service of both systems (but mainly to protect the legacy system from harmful influence originated in secondary systems), the map has to be properly designed, utilizing detailed knowledge about the parameters of the incumbent system that has to be protected. Depending on application, various types of maps can be created and stored for better management of new white-space systems. These include, e.g., coverage maps, signal-to-interference-and-noise (SINR) ratio, maps of allowed maximum transmit power, trajectory maps etc. In all mentioned cases, however, it is not possible to measure any value with infinitesimally small granularity, thus various spatial approximation methods have to be applied. In our experiment we have implemented a kriging algorithm that takes into account the presence of indoor and outdoor walls, as defined in [15,16]. Once such a spatially approximated map is created it can be used for calculation of the maximum allowable transmit power of the secondary user on each possible point inside building. Thus, the process of creation of a REM database and the whole procedure introduced and discussed in [14,15], and applied in our experiment can be summarized in a nutshell as follows:

1. If the map of interest relies on any measured value (such as power of the received signal), the dedicated measurement campaign should be conducted;
2. Once the measurements of a certain metric are finished, the spatial approximation algorithm, such as kriging, has to be applied to calculate the values of the considered metric in any prospective location of interest;
3. Calculated map has to be stored with required granularity and precision which define a tradeoff between the accuracy of the map and storage size;
4. Stored maps (in our case distribution of the observed signal power of any detectable DVB-T signal) can be applied for various purposes; in the experiment carried out for this paper we have used the SINR map for calculation of the maximally allowed Equivalent Isotropical Radiated Power (EIRP) value for any location in the considered building; this maximum EIRP value is computed in such a way that the new wireless link does not infer too much interference to the legacy, DVB-T system; in order to assess the interference observed by the primary user, the propagation model defined in [15,16] has been implemented.

3 Experiment Setup

As it has been already mentioned, the ultimate goal of the conducted experiment was to increase the spectrum utilization by establishing new indoor white-space wireless links in TV band such that the DVB-T signal is not distorted. The experiment has been carried out in the ground floor in the premises of Faculty of Electronics and Telecommunications at Poznan University of Technology, Poland, in last day of April 2017. The white-space transmitter was implemented in GNU Radio environment that steered the connected USRP N210 board equipped with the WBX board. Some of the functions have been delivered by National Instruments in form of dedicated blocks in GNU Radio Companion, however the new blocks (e.g., those for database querying) have been implemented in C. For data transmission we have selected freely available *Big Buck Bunny* media sequence, which was streamed via UDP port, coded and modulated with GMSK modulation scheme. Such a selection gives us a possibility to analyze the influence of potential interfering signals observed by the white space receiver, thus we do not apply any coding or advanced modulation schemes. In other words, we can observe, how the potential interference coming from primary system and other simultaneous secondary systems influences the white space receiver, and vice-versa - how the out-of-band transmission of simple modulation scheme impacts the primary system[1]. If allowed, the GMSK signal was delivered to the USRP block and broadcasted over the air inside the building using omnidirectional antenna.

Analogous approach has been applied to the white-space receiver, whose connection diagram is shown in form of a screen-shot in Fig. 1. Beside the blocks similar to those applied at the transmitter (such as GMSK demodulator, decoder), one may observed the presence of the parallel chain of blocks used for maintaining the connectivity with remote database. Moreover, it can be noticed that the software spectrum analyzer has been also applied, which shows the power spectral density (PSD) of the received GMSK signal. Finally the VLC player is visible that visualizes the decoded stream collected at UDP port.

Please note that the whole communication was steered by the remote database, implemented on dedicated laptop with Matlab installed on it. This REM server was accessible via Ethernet connection and was responsible for granting access to the white-spaces depending on the given location. In order to guarantee connectivity between the remote REM server and the white-space devices, each computer emulating such white space device, was equipped with dedicated WLAN-dongle. Such a solution was necessary as the only way to provide communication between USRP and personal computer is via Ethernet cable, so two simultaneous network connections were needed. The experimental scenario has been illustrated in two consecutive figures, Figs. 2 and 3.

In a broader scope the experiment consisted of two key phases: first step was to establish the first white-space connection with the use of REM databases and observe the spectrum inside the room by means of the R&S FLS6 spectrum analyzer; in the second step, another white-space link was established in the same room such that neither the DVB-T signal nor the existing white-space transmission was distorted. Each key phase consisted of a sequence of smaller steps:

1. first, the new white-space transmitter sends a query to the remote database (via WLAN connection) with request for new transmission grant;
2. second, after receiving the request, the database calculates the allowed maximum transmit power and sends this message back to the transmitter; at the same time the database stores the parameters of the new prospective link (including center frequency etc.); this information will be then later delivered to the white-space receiver;
3. third, the white-space receiver periodically checks the database for any new entry indicating that new transmissions to it; the reception parameters may be adjusted if needed according to the stored parameters.

[1] Please notice, however, that the selection of the transmission scheme is not critical in our experiment, and one can easily exchange the GMSK modulation scheme with the one widely considered for white space transmission, such as multicarrier schemes (OFDM) from IEEE 802.11af, or its filtered version (FBMC) from IEEE 1900.7 standard.

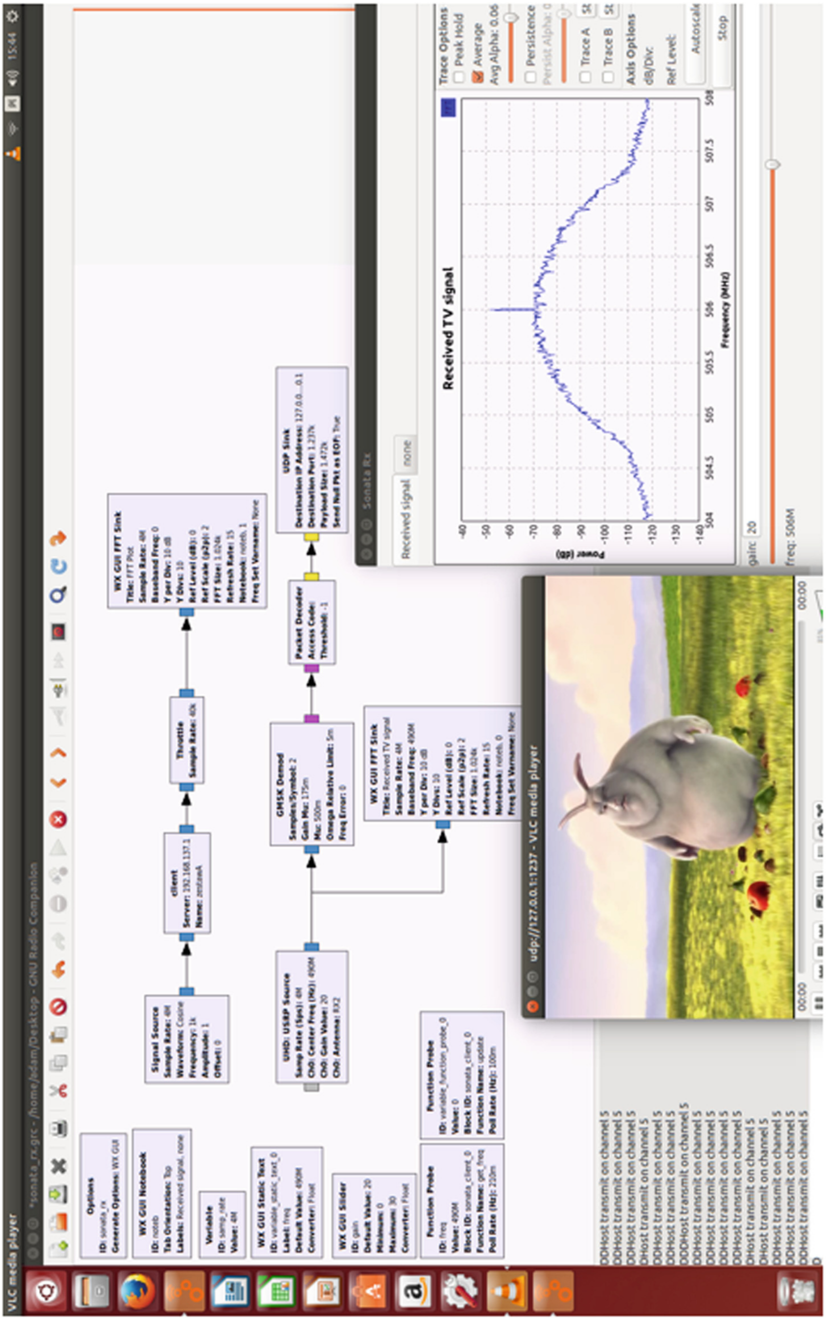

Fig. 1. Screen-shot made from the computer working as the receiver; the GNU Radio based structure is shown jointly with the observed power spectral density of received signal and the decoded film played on vlc media player

Fig. 2. Photograph of the first white-space transceiver (left side computer with USRP board put on it) and REM database (right computer connected with Internet via Ethernet cable); the left-side computer communicates with database using WLAN-dongles stick into it

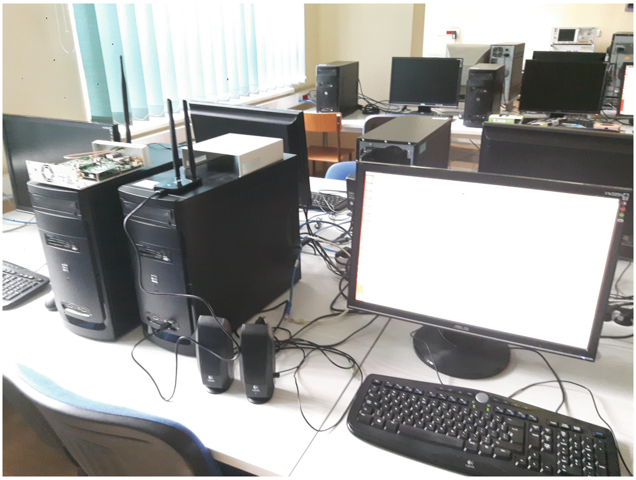

Fig. 3. Photograph of the second white-space transceiver (the one with USRP board laying on it); the computer communicates with database using WLAN-dongles

4 Achieved Results

The procedure described in the previous section has been applied in the real-time experiment. In the first phase, the new white-space device asked for new transmit grants, and once it has received them it started data transmission. Next, second white-space device tries to get positive response for the spectrum access requests. In both cases, centralized remote REM database controlled the whole process. As the messages stored in a log file of the remote database present the consecutive steps of the experiment, we present the key messages of this log file below:

- No new requests //*database awaits new request from new transceivers*
- No new requests
- ...
- New request with coordinates A = $\{20, 276, 468, 5, 0\}$ //Coordinates inside the building
- Allowed transmit power *result* = −8.9391 dBm
- No new requests
- Adding new user A = $\{20, 276, 468, 5, 3\}$
- No new requests
- No new requests
- ...
- No new requests
- New request with coordinates A = $\{21, 310, 407, 6, 0\}$
- Allowed transmit power *result* = −47.8770 dBm
- No new requests
- Adding new user A = $\{21, 310, 407, 6, 3\}$
- No new requests

One may observe that the database provides a periodic update on the status of the whole REM-based spectrum management system. If the new request is provided, it calculates the maximum transmit power in dBm for a provided location, as discussed in Sect. 2 (please see the last bullet in the list). Unfortunately, in the conducted experiment the duration of the server response was long and would not be practically applicable in practice. The response of the database for the spectrum inquiry was of the range of tens of seconds. Such a long server reply is due to the fact that we applied very high accuracy of the applied algorithm - the space granularity (raster) applied for calculation of potential interference induced to the primary system by prospective TVWS transmitter was set to 1 dm, resulting in 10^6 calculation points.

In Fig. 4 the PSD of the observed signal after the first key-phase (once the first white-space link has been established) is shown where the center frequency of the white-space link was set to 507 MHz, relatively close to the observable DVB-T signal spectrum with the center frequency of 522 MHz. We did not observed any noticeable noise increase in the TV band.

In Fig. 5 we show again the PSD of the observed signals, but for a case when two white-space links have been established. The second link operates on the center frequency equal to 514 MHz. One may observe that the allowed transmit power was lower as compared to the previous case, as the database needs to protect now two systems, both DVB-T one and the existing white-space transmission. Again we did not observed visually any changes in the DVB-T spectrum. Also in both white-space links the reception of the transmitted video

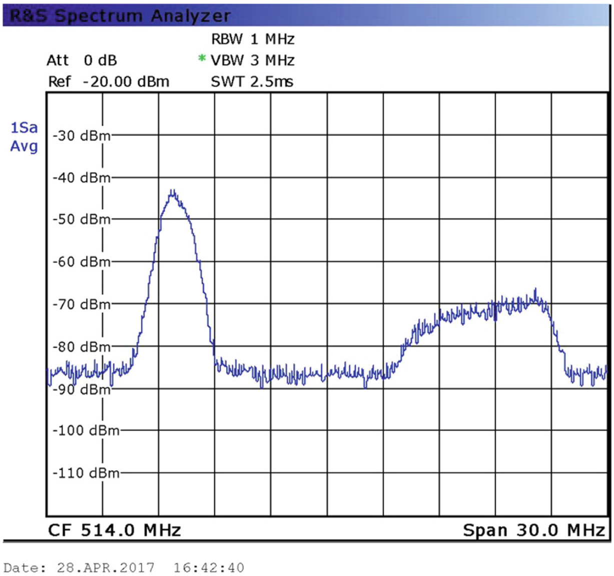

Fig. 4. Power spectral density observed inside the room after the first white-space link has been established

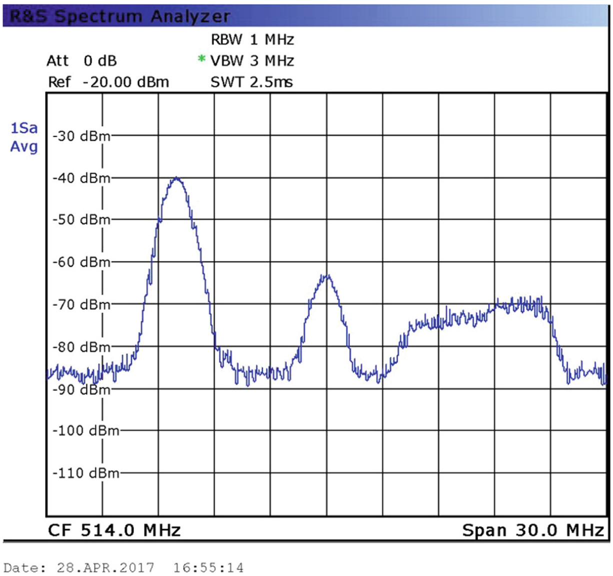

Fig. 5. Power spectral density observed inside the room after the second white-space link has been established

streaming was possible. It means that the out-of-band interference was rather low and negligible. In consequence, such a simultaneous spectrum usage as shown in Fig. 5 is possible.

Finally, once the first white-space transmitter has been granted by the REM based system, the latter has to create a new or update the existing table with the spatial distribution map of the observed signal to noise ratio - see Fig. 6.

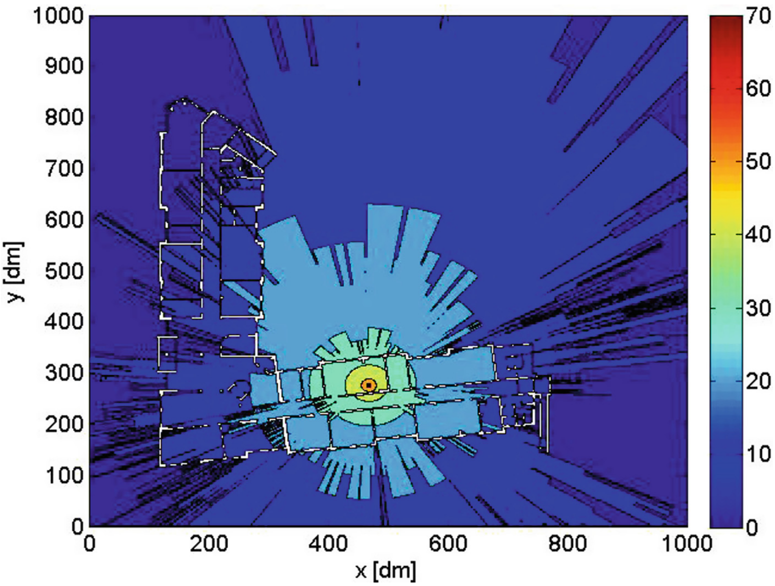

Fig. 6. Spatial distribution of the observed signal to noise ratio when one white-space device is active

5 Conclusions

In this work, we have presented the achieved results of the conducted experiment, where two whites-space links have been established and managed by means of dedicated remote REM database. It may be concluded that it is technically possible to practically deploy real-time indoor cognitive radio systems in parallel to the existing legacy systems. The remote REM based system manages the whole deployment process, in particular it calculates the maximum acceptable EIRP values for any new user and adds this user to the dedicated database. However, the process of calculating new allowed values of EIRP was in our case very slow (in terms of tens of seconds), what makes the application of such a system challenging. This problem is indeed a subject for further analysis and investigation, as the access to database has to be very fast and reliable. In general, however, the experiment has proved that it is justified to consider low range white-space transmission that relies on REM based management system.

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