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Radio Environment Map for the Cognitive Radio Network Simulator

Piotr Bednarek, Damian Bicki, and Jerzy Lopatka

***Abstract*—Military wireless tactical systems has faced the problem of limited spectrum resources. This is a reason why Cognitive Radio (CR) is one of the most popular topic studied by research institutes in the field of mobile telecommunications. CR technology is based on cognitive cycle, used for making decisions based on observation and orientation. To support this activity, radios need also information on current position, electromagnetic situation, legal issues etc. These functions can be provided by Radio Environment Map (REM) database. It enables more flexible spectrum utilization and coexistence of Primary and Secondary Users (PUs, SUs) without harmful interferences. This paper presents a proposal of REM database structure and graphical user interface (GUI). It also describes GUI implementation in MATLAB and data structure. Database was implemented using the database engine – SQLite. The proposed REM database is a part of cognitive radio network simulator developed in the Institute of Telecommunications.**

Keywords*—Cognitive Radio, REM database, G-REM, L-REM

I. Introduction

CR (*Cognitive Radio*) is a technology using cognitive cycle, capable of search and use of frequency bands which are not currently used. In case of detection emission from PU (*Primary User*), CR should dynamically change frequency according with DSA (*Dynamic Spectrum Access*). CR should also have capability to adopt own configuration to actual conditions [1] To provide situation awareness CR uses different sensing methods which give image of actual electromagnetic situation, however, CR needs an access to own experience which can be used in decision making process. In the literature we can find a consistent definition showing REM as a geolocation database, which is a source of important information for cognitive radio networks operation [2] [3].

REM is one of the ways to provide information about the radio environment for CR and in particular, information about PUs [4]. Another feature of the REM is the ability to use the information contained therein to create coverage maps using an appropriate radio propagation models for the selected area.

Data from REM are used by the cognitive engine in most measures of cognitive radio: creating awareness, adapting to the conditions, gaining experience, planning and decision-making [5] [6]

Authors are with Military University of Technology, Poland, (e-mail: jerzy.lopatka@wat.edu.pl).

In practice, REM acts as a database server that supports structured query language SQL.

REM database, to fulfill its role and provide a complete and reliable image of the radio environment, must contain a number of thoughtful and appropriately grouped information. Lack of information in the database may lead to a situation in which cognitive radio unaware of the presence of a PU begins to disturb him. On the other hand, unnecessary information may increase the size of the database and increase the response time.

II. REM

The principle of CR operation is based on the periodically repeated series of steps. It is a series of cognitive adaptations that allows CR accommodate to the environment observation, orientation, planning, deciding and use of the gained experience.

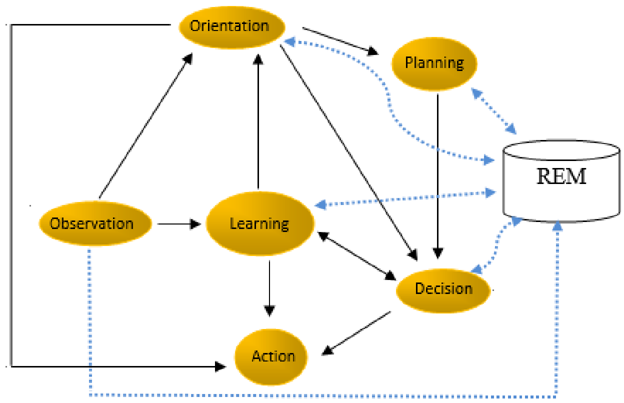


Fig. 1. REM role in the cognitive cycle [4]

Observation is the first phase of the whole cycle. It enables monitoring of significant radio environmental parameters, whereas orientation is an analysis of the current situation. Depending on the assessment of the position, the radio can go to the phase of planning, decision or action. Action is often called immediate mode that is used in situations where the stability of the connection is compromised. CR should then immediately take action to maintain connections and transmitted data. This mode can be also used in case of problems with the power supply (e.g. low battery). In this situation CR preserve open processes and stores settings.

The planning is the next phase after orientation. In this phase, all the transmitter's and receiver's parameters are defined to determine the capabilities of the device. Moreover radio interferences are considered and methods for estimating the characteristics of radio channels.

On the basis of the results and the data from the database REM, CR in the fourth phase of the cycle takes action such as channel change, adaptation of the coding and modulation scheme, change the emitted power, etc. All activities strive for the implementation of specific services while maintaining adequate quality [7] [8]. The final step is the execution of planned action.

One can see that REM database is involved in almost all activities included in cognitive cycle, and what is more, REM database is a source of data for learning process.

Application network unequivocally binds to the demand for certain information and safety requirements. Specific requirements apply to military networks in which you must find a compromise between precise information about users of the network, their location, security information and threat of sensitive information acquisition by not authorized persons. What is more, network which is able to change the area of action, needs additional procedures retrieving information about the area in which currently is located.

The main groups of information needed for proper work of CR are [4]:

1) *Information about localization*- CR should have an awareness of its position in the form of three coordinates.
2) *Information about geographical environment*- An important factor contributing to the propagation of the signal and the characteristics of the radio channel is a type of geographical environment.
3) *Information about radio environment, waveforms and users*- CR should continuously have an access to information about the current use of spectrum and the presence of PUs and SUs.
4) *Information about mobility and trajectory*- Cognitive device can plan further work by the awareness of the movement. In conjunction with the information about the radio environment, CR taking into account their current speed and track movement, can predict the change in the radio environment and plan ahead to change the channel or mode of operation.
5) *Information about the power source and battery level*- CR must have knowledge of their own power supply and battery for mobile devices.
6) *Information about regulations*- It is important to provide information on spectrum allocation in certain areas and regulations provided by the authorities or the government.
7) *Information about politics*- CR should be familiar with the policy defined by the user or service provider.
8) *Information about capabilities of CRs*- CR should have knowledge about the possibilities of their devices. The information should relate to the sensitivity of devices, operating signal structures and the maximum transmitter power.
9) *Information about actual mission*- CR has the ability to understand the intentions between users and on this basis to predict traffic and its impact on network.
10) *Information about priority*- CR should know the priorities of the users. The priority may relate to the network access technology and limitations in use.

The proposed database has been designed as a two-level database, consisting of the global (G-REM) and local (L-REM) layers. The global layer of REM is a centralized unit, which has preliminary information for the network initialization. It is the master unit in relation to the subordinate local layer REM.

Local layer of REM is a set of databases distributed in the compact form. They contain information that is matched to the location of the radio. The source of the data for the L-REMs is the global layer and locally performed sensing, which is carried out for monitoring of the radio environment.

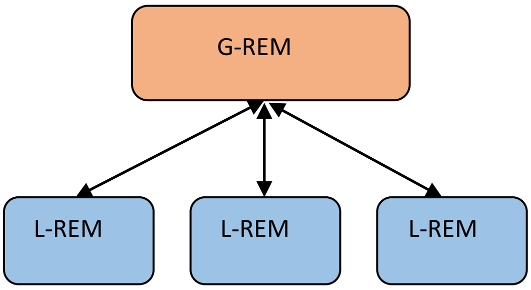


Fig. 2.Two-level REM Database structure

Choice of such architecture is dictated by two main advantages. Firstly, the over-the-air signaling load can be reduced, because large part of incoming requests is distributed, so the response time is shorter. Secondly, G-REM has access to data from several L-REM, so data from different networks provide extended, combined awareness and better cope with the problem of hidden nodes, interference sources localization, mitigation of jamming etc.

Synchronization between REM layers can be performed using dedicated or logical channels organized in cognitive plane [6] [5] Using this interface the L-REM reports information to the G-REM about network characteristics and sensing results, and G-REM provides to L-REM information about the area, neighbors and policies. Information exchanged between G-REM and L-REM depends on resource management algorithms implemented in the network.

III. SIMULATION

Typically L-REM contains a subset of G-REM. However for conducted experiment we assumed that G-REM and L-REM layers are the same in respect of data structure. Both layers consist of five tables that store information on the radio infrastructure, frequency channels, areas, network topology and CRs.

- *Radio infrastructure table*- consists of twelve fields that describe the known radio infrastructure such as base stations for mobile phone systems, TV transmitters, etc. The table contains all the necessary data to perform the simulation using a propagation model: the coordinates of the transmitter, its height, operating frequency, modulation, the maximum transmit power, beam-width and elevation angle in the case of a directional antenna. Field ID Pixel assigns a number of the square where the transmitter is located.

- *Topology table* - assigns each device an individual ID number and stores information about the physical address MAC, IP address and subnet mask. The fields define the membership of the cluster and radio stations function (eg. CH - Cluster Head), and the type of mission, where the device is used. The last three fields allow determining whether the radio has access to additional services such as e-mail, chat or VoIP.
- *Areas table* - divides the area of the network into squares marked on the map. Positions of the square is determined by the introduction in the fields LUC (Left Up Corner) and RDC (Right Down Corner). So particular square has assigned ID number. The table also contains: information about the type of environment in a given geographical square and propagation model corresponding to the type of the environment. It is recommended to use UTM (*Universal Transverse Mercator*) grid and determine the location using MGRS (*Military Grid Reference System*).
- *Channels table* - table with three fields that simplifies frequency management. The user specifies the channel number and frequency limits
- *CRs table*- allows storing information about the location and capabilities of neighboring radio stations, such as the maximum transmission power, receiver sensitivity and frequency range. According to the needs, location devices can be refreshed with a specific frequency. Each device noted in the table receives a unique identification number.
- *Sensing table*– stores sensing results. The table contains information about the device number, which made the measurement, and the number of the cluster to which it belongs. Field "channel" includes the result of sensing the channel. Filed "Measuring time" includes the timestamp of the measurement.

Database connection with the MATLAB environment was realized based on the mkSQLite interface provided by M. Kortmann and A.Martin [11] . The interface was modified, to increase the maximum number of database connections.

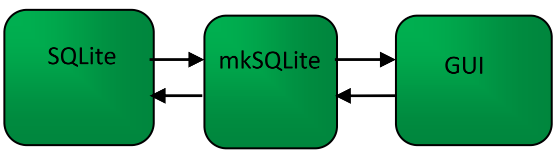


Fig. 3. Schematic of connection between SQLite database and GUI

Control of the database is possible via the graphical user interface. The application allows to preview tables and their contents in both layers. Another feature is the ability to input data to any table. It makes that designed graphical user interface is very flexible tool enabling efficient management of collected data.

Interface making an entry to L-REM, also makes an entry in the G-REM. This provides synchronizations and prevents differences in the contents of two layers. GUI is able to establish connection with several databases at the same time. This allows users to carry out a preview of two layers.

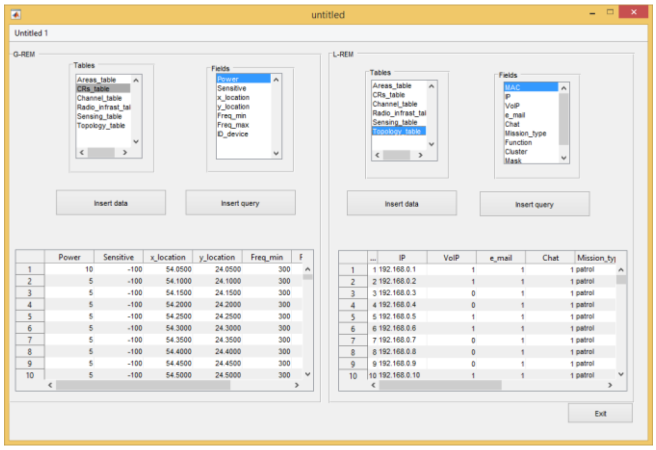


Fig. 4. Graphical User Interface

GUI is divided into two parts. Left one enables preview and management of G-REM database. Right one controls L-REM databases. What is more, user can decide which L-REM currently wants to browse. In each part of GUI actual list of tables and fields is displayed. Contents of a table can be displayed by clicking on its name. Table view can be refreshed during simulation also by clicking on table name. The GUI allows performing more complex SQL queries, but knowledge of SQL syntax is necessary.

IV. Results of Simulation

The figure 6 shows the initial placement of the nodes on the map. CRs are marked white markers. Others markers are PUs. Obstacles like buildings are marked black. This map has been prepared in order to present the example scenario for cognitive network simulation [6] .

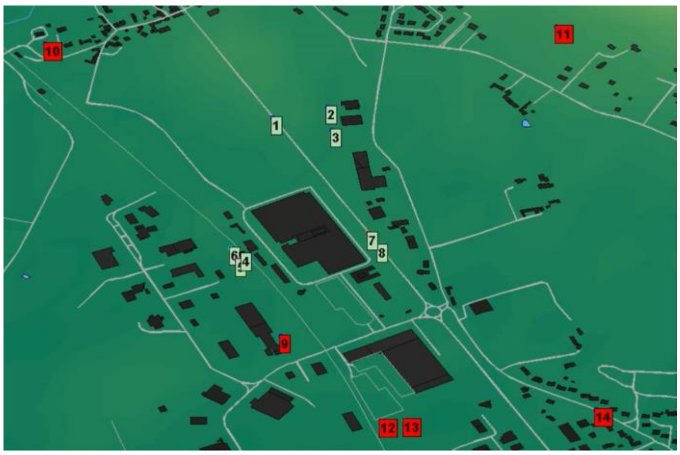


Fig. 5. Initial location of nodes

During simulation some of nodes are changing their location. Their routes are shown in the figure 7.

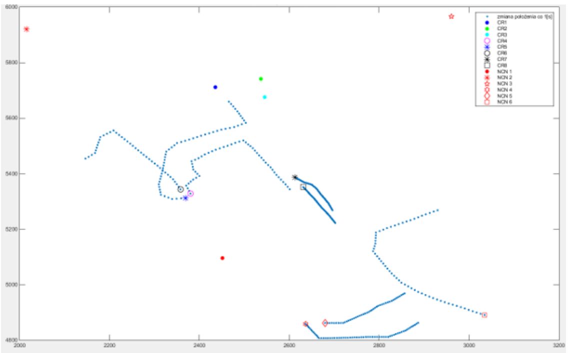


Fig. 6. Change of the nodes position during simulation

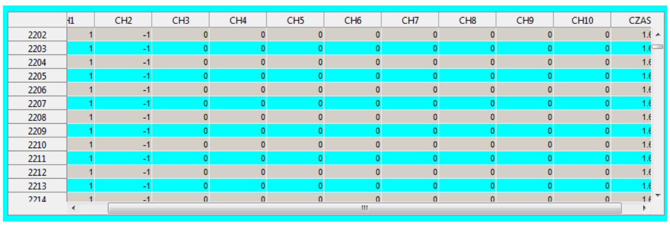
The simulation was carried out for two scenarios. During simulation only sensing table from both layers it was used. Synchronization was kept in a simplified way described in the previous section. Simulation was carried out with and without mechanism validating entered data.

- *Scenario I* - It assumes the existence of only one cluster that includes eight nodes where one of them is a CH. As a result of the simulation 12 800 records to each database were written.
- *Scenario II* - It is assumed that each of the nodes is a CH of another cluster. During simulation one G-REM database and eight databases L-REM were used. During the simulation 12 800 records were created in G-REM and 1600 records in each L-REM.

TABLE I
TIME OF SIMULATION

Simulation without REM	Data validation	Scenario I	Scenario II
20 min 32 sec	On	29 min 35 sec	27 min 16 sec
	Off	27 min 50 sec	26 min 14 sec

Results of simulation indicate that interface works correctly. Simulation time with REM was longer in comparison to the simulation time without a database by more than eight minutes. Noteworthy is results for the scenario II. In both cases time of simulation was shorter than scenario I. This is due to the distribution of traffic for between few databases of a lower layer. It is one of the main advantages of this REM architecture. In case that only one database exists, queries could come faster than database would be able to answer. Such a situation could lead to delays in data exchange.



	H1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CZAS
2202	1	-1	0	0	0	0	0	0	0	0	1.6
2203	1	-1	0	0	0	0	0	0	0	0	1.6
2204	1	-1	0	0	0	0	0	0	0	0	1.6
2205	1	-1	0	0	0	0	0	0	0	0	1.6
2206	1	-1	0	0	0	0	0	0	0	0	1.6
2207	1	-1	0	0	0	0	0	0	0	0	1.6
2208	1	-1	0	0	0	0	0	0	0	0	1.6
2209	1	-1	0	0	0	0	0	0	0	0	1.6
2210	1	-1	0	0	0	0	0	0	0	0	1.6
2211	1	-1	0	0	0	0	0	0	0	0	1.6
2212	1	-1	0	0	0	0	0	0	0	0	1.6
2213	1	-1	0	0	0	0	0	0	0	0	1.6
2214	1	-1	0	0	0	0	0	0	0	0	1.6

Fig. 7. The fragment of filled sensing table

The sensing table was filled with four values. Value 1 indicates that channel is busy by PU or jamming. Value -1 shows channel which is actually used by CRs. Value 0 inform that the channel is available. Based on the filled table is possible to check the CRs behavior in case of PU emission detection.

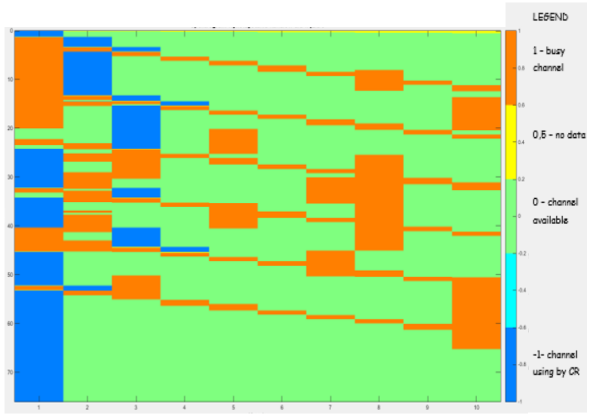


Fig. . 8. Spectrogram for CR5

Analyzing the spectrogram we see multiple changes of the used channel. In most cases, the change is caused by the detection of the PU emission. During most of the time, CR tried use channel 1. When it was impossible, it temporarily changed band. CR was returning on channel 1 as soon as it was possible.

V. CONCLUSION

The main goal was do design a REM database, compatible with the radio network cognitive simulator. Performed test, enabled selection of a suitable SQLite database engine, and the SQLite was selected. Selection of the software and the implemented user interface provide easy access to the data in the database. Moreover, the storage database as a file on computer instead of the server is a very convenient solution dedicated in particular to small platforms and the simulation purposes. Conducted tests showed the proper operation of the created program. Further researches and simulations will include extended part of REM. This will enable full examination of two-layered REM model and its cooperation with nodes, cognitive engines and network managing center. Designed structures will be implemented in a real time demonstrator of cognitive network.

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