Cooperative Spectrum Sensing for Geo-Location Databases

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Abstract. Spectrum sensing techniques are the key components for identifying and exploiting unused radio spectrum resources in the perspective of the cognitive radio paradigm. Based on the centralized cooperative sensing techniques, vast generalized databases named geo-location databases (GL-DB) can be deployed in order to centralize sensing and general radio spectrum data for the benefit of secondary cognitive radio users. The authors propose a hybrid conceptual application that involves spectrum sensing and a Human Network Interaction (HNI) model with the purpose of perceptually representing, in an immersive way, the available GL-DB information from a specific location for a natural user perception and interaction with the area of interest.

Keywords: Spectrum sensing, Geo-location Databases, Cognitive Radio, Spectrum Management, 3D Virtual Environments.

1 Introduction

The general trend of the current regulations and standardization efforts for the cognitive radio (CR) paradigm is the deployment of large geo-location databases (GL-DBs). In the US, the FCC has already commissioned the creation of geo-location databases, which can be accessed by any CR device without the use of additional resources. The database entries will provide, for a certain location (geographical coordinates), the list of available channels and the allowable maximum effective isotropic radiated power (EIRP) useful to transmit without providing harmful interference [2]. Even if these GL-DBs are upgraded on a daily basis, the values corresponding to a specific geographical point are still the results of calculations based on a traditional signal propagation models and estimated power levels. Due to this static (for short term at least) approach, the provided data might be inaccurate for different reasons such as variable atmospheric conditions or multipath and fading phenomena [3, 4].

A possible approach to alleviate the above-mentioned shortcomings could be the implementation of a cooperative spectrum sensing architecture [1], based on sensor networks. This scenario is applicable both for outdoor and indoor applications.

L. Atzori, J. Delgado, and D. Giusto (Eds.): MOBIMEDIA 2011, LNICST 79, pp. 78–83, 2012.

Cooperative spectrum sensing is typically divided into operational networks, handling cognitive transmissions, and sensing networks. The latter would involve a set of sensors deployed in an area of interest, which would sense the spectrum and would relay the process' results to a Cognitive Radio Controller (CRC) [5, 6]. The CRC further processes the collected data and sends the sensed area of interest's spectrum occupancy information to a GL-DB, to which it is connected, in a transparent way, through Future Internet typical infrastructure [7]. The database centralizes all the sensing information from its attached CRCs and serves as a general register that secondary users, who no longer require their own dedicated sensing equipment, can inquire for accessing sensing information for their particular area of interest.

The focus of this paper is a proof-of-concept on the use of spectrum sensing for populating a GL-DB by implementing and deploying a sensor network – based sensing architecture and extending the functionality of the GL-DB towards human users. This approach features the concepts of cluster radio mapping and natural sensing information perception through 3D Virtual Reality (VR) representations of the GL-DB relevant information for the benefit of a spectrum manager or developer.

The structure of the paper is divided into 5 chapters. The first chapter is an introductory one that sets the tone for the current survey and states the goal of our implementation to a conceptual application that integrates Spectrum Sensing with Virtual Reality - specific methods and equipments for the end result to be an immersive Dynamic Radio Spectrum Management application dedicated to spectrum managers and developers. Chapter two presents the general idea of a radio configuration management system that centralizes the spectral information. The third chapter shows how the previously mentioned functionality can be implemented on the basis of a deployed wireless sensor node, in a specific area of interest and the interpretation of the gathered data with the help of a Virtual Environment design tool. The fourth chapter quantifies the results as a consequence of the functional implementation from the previous chapter. The final chapter contains the quantified results, portraying an appropriate context and expressing possible future developments and research opportunities.

2 The Dynamic Spectrum Management Model

Radio Mapping techniques are employed in an attempt to predict and graphically represent network coverage on the basis of a number of connection measurements from locations in an area of interest. A cluster is defined by an area where there is an active CRC and a number of deployed spectrum-sensing sensors. This translates into a real-time electromagnetic profile of the specific area where the sensing sensors are deployed. This profile serves for the design and development of radio architectures over the considered area, and reveals such data as optimum transmission pathways, radio propagation obstacles and, especially, sensing information.

What the authors intend is to implement an architecture that will centralize the real-time statistical sensing information, normally intended for secondary cognitive transmitting users who no longer perform the sensing stage, from different areas of interest, in a GL-DB. Also, we will employ novel perceptual representation in order to provide a radio spectrum manager with a way of perceiving and assimilating this statistical information in a natural and efficient way.

In order to validate our above-mentioned approach we have implemented an indoor functional proof-of-concept prototype, able to capture, represent and transmit sensing information towards a GL-DB. Instead of offering this information only to the secondary users, our application will interpret and represent it in 3D Graphic User Interface (GUI) and illustrate it for the benefit of a radio spectrum manager in order to assist, as a development tool, in the optimization of radio spectrum allocation. Basically we will translate the statistic sensing data that a cognitive radio makes use of, into a perceivable and understandable representation.

3 Conceptual Application Implementation

The sensing sensor network employed for the functional implementation of the conceptual application is a Crossbow ZigBee Wireless Sensor Network (WSN) that uses wireless sensor nodes know as MICAz Motes [8]. Although it is limited to central frequencies between 2.405 and 2.485 GHz, with low throughput, ZigBee does have sixteen 5 MHz channels that we used for testing the sensing algorithm. In other words, our testing scenario involves limiting the concept of radio frequency spectrum to the 2.405 GHz - 2.485 GHz domain, and its 16 channels. All the sensors of the WSN have in their transmission stream's frames a Received Signal Strength Indicator (RSSI) slot, which reveals a numerical value of the gateway's signal power as perceived by that particular network node, which we can interpret as a power measurement, equivalent to the energy detection spectrum sensing method. The RSSI is a naturally available resource when dealing with wireless nodes, and can be used to implement obstacle and position detection and estimation algorithms, in dealing with both primary and secondary users of a CR Network [9].

The total number of utilized wireless nodes is 192. The area of interest is split into 1.5 m side squares, disposed as 16 in length and 12 in width. Each square is the sensing area of a specific sensor, positioned in the middles of the square at 0.6 meters from the floor. The position of each node represents an increment of the measurement step, of 1.5 meters. Theoretical values of the detected signal power (and implicitly of the sensed signal RSSI) can be found out by utilizing the logarithmic correlation between received signal strength and distance as was previously done in [10].

It is at this point that we will consider a theoretical division of the WSN Gateway into two distinct functional entities. The first will be considered as an entity that gathers the sensing information from the WSN nodes, and therefore, also performs the CRC characteristic functionality of GL-DB update, while the other will handle the WSN Gateway's transmission and will be considered a typical CR primary transmitting user, using one of the typical ZigBee channels.

To sum up, the measurement and validation scenario enforces the following suppositions:

- the radio spectrum is the ZigBee standard frequency domain with its 16 channels;
- the WSN Gateway is a primary transmitter;
- the sensors are secondary users who employ energy detection sensing (RSSI);
- the WSN Gateway's data gathering and GL-DB update is transparent;

The primary user (WSN Gateway) is placed in the corner correspondent to row 0 and column 0 of the senor grid in the area of interest, at 0.6 m from floor level.

All the sensing information gathered by the sensing sensors is real-time processed and forwarded by the WSN Gateway entity, playing the CRC role, towards the GL-DB, to be made available for secondary users or spectrum managers.

As previously stated in the definition of the concept, our functional implementation aims at modeling and developing a real-time natural perception and interaction GUI that brings additional functional uses for the GL-DB concept. The data, contained in the GL-DB, that was originally intended for cognitive users can be employed by spectrum and network managers in order to better understand, develop and utilize available channels and spectrum resources.

For perceptually representing the gathered GL-DB data, the authors implemented a 3D VR Environment build upon traditional desktop equipment, which portrays the available sensed information. Inside the GUI, along with information perception, the user can interact with relays and switches that control actuators from the area of interest, in so enabling the reconfiguration of the sensing architecture to better suit the user's informational needs. The consequence of the interaction inside the GUI and its implicit sensing sensor pattern reconfiguration is a real-time change in the sensed information and accordingly in its representation. Also inside the 3D GUI, there is a navigation menu that allows the user to move inside the virtual environment in order to gain better perspective and perception of the relevant information.

The deployed 3D Virtual Environment is supported by the VR Media's XVR virtual reality framework [11]. The virtual environment is a 3D replica of the real world area of interest, starting from the RSSI information interpretation, upon which, obstacle and position detection and estimation algorithms were based, can be implemented. A view of the 3D representation of the gathered data is presented in figure 1.

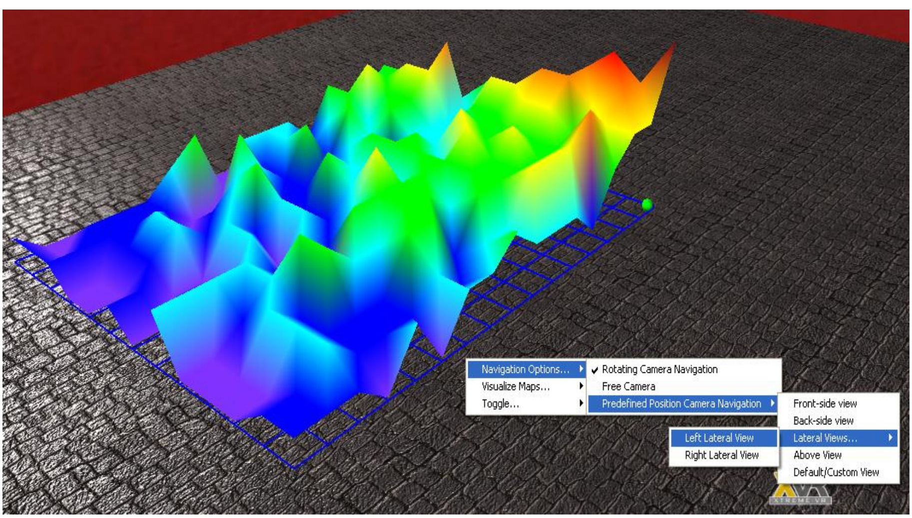

Fig. 1. Radio Map representation of the signal power distribution with smooth transition between colors, inside the area of interest (form Red the highest value to Violet the lowest); The green sphere represents the WSN Gateway primary user

4 Results

The graphic representation describes a Cognitive Radio Network primary user's (WSN Gateway) signal power distribution as received by a sensing WSN. This radio signal is on a typical ZigBee frequency channel, having 5 MHz of bandwidth.

The represented values are expressed in [dBm] and they are subject to the propagation constraints provided by typical electromagnetic indoor obstacles, disposed in the area of interest. The highest RSSI values are color-coded red, and are given a high value on the Y axis (the orthogonal direction from the wireless sensor node arrangement geometry represented as a blue grid plane), in the representation, while the lowest are color-coded violet, and have a value of 0 (null) on the Yaxis. Between the two extremes the values are interpolated, for a smooth transition.

The green sphere marks the location of the transmitting primary user, and, as expected, has the highest RSSI value. While the signal power distribution profile is loosely consistent with Friis' model equations, the inherent anomalies signify electro-magnetic obstacles, typical to indoor environments. The measured Gateway RSSI values were in between a -60 dBm and -100 dBm. The WSN's PER (Packet Error Rate) was established to be 3.4%.

The main result is the added value derived from the hybrid implementation of the Radio Spectrum Management field with Virtual Reality representation and multimodal interaction methodologies.

5 Conclusions and Future Developments

Sensing sensor networks can be extended to the paradigm of Centralized Coordinated Techniques that involve CRCs, if operational networks would be implemented on top of sensing networks (collocated) and additional functionality (from the point of view of the transmission and processing power) would be passed from the CR Controller to the sensor nodes, which can be implemented by employing SDR platforms (USRP2) [12]. This is not an evolution of the Sensing sensor networks approach but rather a parallel alternative for a better-suited purpose scenario, both collocated and separated architectures approach having their pros and cons.

Because of the immersive nature, high interactivity and powerful sense of presence, the authors' 3D GUI complies perfectly with the 3D Internet [13] component of the Future Internet that offers users an augmented interaction and navigation metaphor. Also, the wireless nodes network features a functionality that emulates Internet of Things specific scenarios, while the whole conceptual application offers a radio spectrum management service particular to the Internet of Services.

The VR environment could be further developed by employing advanced visualization, sound and haptic devices specific to immersive VR applications (i.e. CAVE [14]).

The first tests, performed in order to validate the proof-of-concept application, using a single frequency, showed that merging exponentially developing domains such as Virtual Reality and its characteristic techniques and devices with the field of spectrum sensing and, generally, dynamic spectrum management, results in added functionality and significant added value for the latter. These initial tests will be continued by analyzing a more extended range of frequencies and by implying more intelligent sensor nodes, for example software-defined radios.

Acknowledgments. The authors would like to thank professor Marcello Carrozzino, from Scuola Superiore Sant'Anna / PERCRO, for his support and guidance. This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/6/1.5/S/6 and by the Young Researchers Grant funded by Region of Sardinia, PO Sardegna FSE 2007/2013, L.R.7/2007, "Promotion of scientific research and technological innovation in Sardinia".

References

1. Thanayankizil, L., Kailas, A.: Spectrum Sensing Techniques (II): Receiver Detection and Interference Management (2008), `http://www.personal.psu.edu/bxg215/spectrum%20sensing.pdf` (retreived on April 22, 2011)
2. Ko, G., Antony Franklin, A., You, S.-J., Pak, J.-S., Song, M.-S., Kim, C.-J.: Channel Management in IEEE 802.22 WRAN Systems. IEEE Communications Magazine (September 2010)
3. FCC Second Memorandum Opinion and Order, FCC 10-174 (September 2010), `http://www.fcc.gov`
4. Arslan, H.: Cognitive Radio, Software Defined Radio and Adaptive Wireless Systems. Springer, Heidelberg (2007); ISBN: 1402055412
5. IEEE SCC 41 - White Paper Sensing techniques for Cognitive Radio - State of the art and trends (April 2009)
6. Shankar, N.S., Cordeiro, C., Challapali, K.: Spectrum agile radios: utilization and sensing architectures. In: DySPAN 2005, Philips Res. Briarcliff Manor, CA, USA (2005)
7. European Commission Information Society and Media, The future of the internet. A compendium of European projects on ICT research supported by the EU 7th framework programme for RTD, `ftp://ftp.cordis.europa.eu/pub/fp7/ict/ docs/ ch1-g848-280-future-internet_en.pdf` (retrieved on December 08, 2010) ISBN: 978-92-79-08008-1
8. Crossbow Technology, XServe Gateway Middleware, `http://www.xbow.com/ Technology/GatewayMiddleware.aspx` (visited on November 03, 2009)
9. Srinivasan, K., Levis, P.: RSSI is under appreciated. In: Proc. of the Third Embedded Networked Sensors (EmNets 2006), pp. 15–20 (May 2006)
10. Stoianovici, V.C., et al.: A Virtual Reality Based Human-Network Interaction System for 3d Internet Applications. In: 12th International Conference on Optimization of Electrical and Electronic Equipment, OPTIM 2010, Brasov, Romania (2010)
11. VRmedia Italy, XVR, `http://www.vrmedia.it/Xvr.htm` (accessed November 2009)
12. Brodersen, R., et al.: CORVUS: A Cognitive Radio Approach for Usage of Virtual Unlicensed Spectrum. Berkeley Wireless Research Center (BWRC) White paper (2004)
13. Alpcan, T., et al.: Towards 3D Internet: why, what, and how? In: IEEE Int. Conf. on Cyberworlds (Cyberworlds 2007), Hannover, Germany (October 2007)
14. Ihren, J., Frisch, K.: The fully immersive cave. In: Proc. 3rd International Immersive Projection Technology Workshop, pp. 59–63 (1999)