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Article *in* Indian Journal of Science and Technology · December 2016

DOI: 10.17485/ijst/2016/v9i46/107145

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ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 9(46), DOI: 10.17485/ijst/2016/v9i46/107145, December 2016*

Hidden Node Scenario: A Case for Cooperative Spectrum Sensing in Cognitive Radio Networks

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Abstract

Objective: Cognitive radio technology allows the opportunistic usage of licensed spectrum resources by unlicensed users. The most important function of the cognitive radio technology is spectrum sensing. In hidden node scenarios, cooperation among cognitive radio nodes is needed to improve the sensing performance. In this work, the benefits of cooperative spectrum sensing are illustrated in a hidden node environment. **Methods/Statistical Analysis:** The distributed cooperative sensing approach was adopted for the implementation. Universal Software Radio Peripheral was used in collecting spectrum data and results were analysed using MATLAB software toolkit. **Findings:** Cooperative spectrum sensing among cognitive radio nodes operating at the same frequency improves the probability of detection, and the overall efficiency of the system. Results shows that the cooperative sensing scheme outperforms the individual sensing approach keeping in mind the number of collected samples as the key performance indicator. **Applications/Improvements:** The results obtained show that the frequency spectrum is underutilised. There is a need to explore the present spectrum holes and improve on the available sensing techniques for the implementation of cognitive radio networks in the future.

Keywords: Cognitive Radio, Cooperative Spectrum Sensing, Hidden Node, Spectrum Sensing

1. Introduction

The increase in the use and development of wireless devices, technologies and services has created the issue of spectrum scarcity. There is an appreciable interest in the study of cognitive radio (CR), first introduced by[1]. As defined in ETSI 2013[2], a CR is capable to obtain the knowledge of radio operational environment and established policies and to monitor usage patterns and users' needs. Furthermore, it dynamically and autonomously adjusts its operational parameters and protocols. CR has been identified as an enabling technology that allows unlicensed (secondary) users to operate in the licensed (Primary) user bands. This can help to mitigate spectrum scarcity in wireless communications. Spectrum Sensing (SS) is a key function of cognitive radio systems for improving the spectrum's utilization. According to[3] SS enables the secondary usage of the spectrum resources, provided it does not cause any form of destructive interference with the licensed users of the spectrum.

Individual secondary user can conduct SS and make decision by itself. However, hidden node and receiver uncertainty degrades the sensing performance of cognitive radio. Previous works have suggested cooperation among sensing nodes as an effective method to improve the detection performance as discussed by[4]. According to ETSI 2013[2], Software Defined Radio

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(SDR) can be defined as a radio whose operating frequency range, modulation type, or transmitted power can be altered using software. Alternatively, Wireless Innovation Forum 2013[5] defined SDR as a radio in which some or the entire physical layer functions are software defined. These technologies allow the upgrade and addition of new functionalities on existing radio systems without hardware overhauling. The Universal Software Radio Peripheral (USRP) is a low cost radio systems developed by Ettus Research™ LLC for commercial and research applications. The USRP operates as a high bandwidth software radio with digital baseband and Intermediate Frequency section within the hardware. It has a daughterboard attached to the main board that enables the RF front-end to operate over a wide range of spectrum band. The GNU Radio is open source software that provides a development environment for building signal

Processing blocks using a low cost configurable radio like the USRP in a real-time environment. This paper addresses the implementation of a cooperative sensing algorithm on USRP B200 using GNU Radio. Sensing decisions are based on energy detection method and a distributed cooperative spectrum sensing model was adopted based on the secondary user consensus. Unlike many existing models as shown in[6], in the distributed cooperative sensing model, a common receiver or central fusion centre is not needed for data fusion and decision making. In this work, spectral occupancy is measure for the 2.4GHz ISM band using the energy detection method. Results from real time data collected in a hidden node scenario are compared in two cases: (i) cooperative sensing; and (ii) without cooperation (single sensing node). This rest of this paper is organized as follows: Section 2 briefly describes the hidden primary user problem. Section 3 presents the cooperative sensing schemes. Section 4 explains the experimental set up, the test bench (USRP) description and hardware implementation related issues. Section 5 explains our simulation and measurement results. Lastly, a conclusion is given in Section 6.

2. Hidden Node Problem

The problem caused by a hidden primary user can be compared to the hidden node problem in Carrier Sense Multiple Accessing (CSMA). This is caused by many factors which includes shadowing or multipath fading that is observed by a secondary user observe while sensing frequency bands occupied by primary users. Figure 1 illustrates the hidden node problem. In the illustration below the CR device could not ascertain the state of the primary user due to its position.

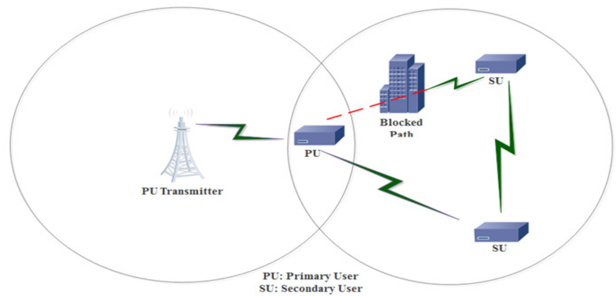

Figure 1. Illustration of the hidden node problem in spectrum sensing.

This will cause an unwanted interference to the primary user. As a result of the hidden node problem, a CR would require higher detection probability during sensing to overcome the receiver's uncertainty. Therefore, the receiver's uncertainty caused by the hidden node can be mitigated when more users share their spectrum sensing information and cooperatively make a decision if the primary user is present or absent.

2.1 Cooperative Spectrum Sensing

In CR networks, spectrum sensing can be achieved either by individual CR or a combination of CRs. From literatures, cooperation among CRs during spectrum sensing has been discussed as a solution to the problems due to hidden node, receiver uncertainty, multipath fading and shadowing. The probabilities of mis-detections and false alarms are decreased considerably as a result of cooperative spectrum sensing. Also, cooperative spectrum sensing mitigates the hidden primary user problem and decreases the sensing time as discussed by[7] and[8]. Since CR acts without prior knowledge about the location of the primary users during sensing, this degrades the performance. Thus a need for cooperation among CRs. In the cooperative sensing approach, each CR performs spectrum sensing and the results are combined in such a way that more accurate detection can be achieved with respect to the status of the primary user. Basically there are two ways to model the cooperative sensing scheme.

2.2 Centralised node approach

In the centralised cooperative sensing model, CRs report their results to a centralized node. However, in the centralized cooperative sensing, a control channel is needed by the cooperating CRs and the centralized data fusion centre (FC) for information exchange. Data are combined either by the soft- combining techniques or hard- combining techniques.

2.3 Distributed sensing approach

In the distributed approach, each CR exchanges its sensing measurement with the neighbours, so that decision about the status of the primary user presence is made with no the need of a central fusion centre. In the distributed cooperative sensing method CRs share sensing information among themselves based on an algorithm. CRs combine its own data with the data received from others users, and then a local criterion is used to make decision about the status of the primary. If the local decision criterion is not met, CR users would have to resend their combined results and this process is repeated until a decision is reached.

3. Experimental Setup

The Software Defined Radio (SDR) hardware used in the experiments is the USRP B200 from Ettus Research and GNU Radio as the SDR software used for signal processing. The USRP B200 has two main boards (mother board the daughter board) with a continuous frequency range covering from 70–6 GHz. The mother board does Analog to Digital Conversion and Digital to Analog Conversion with a sampling rate of 64MS/s. The daughterboard acts as the radio frequency front-end of the SDR. It is designed for low-cost experiments; it is fully integrated with a transceiver for direct conversion supporting up to 56 MHz of bandwidth in real-time. It also has a reprogrammable FPGA (Spartan6), coupled with a USB 3.0 interface. GNU radio is open source software consisting of signal processing blocks and modules for implementing SDRs. The GNU radio is used with USRP B200 to measure or record real time spectral information and implements other SDR applications. The USRP digitizes the data collected and passes it to the GNU radio installed on the system via USB 3.0 interface. The data collected is demodulated and filtered using GNU radio signal processing blocks and then saved as a file. MATLAB is used for signal analysis and plotting graph. The experimental setup for this work is shown in Figure. 2.

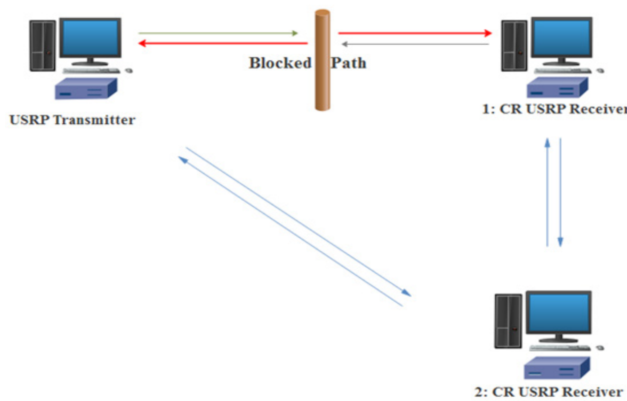

Figure 2. Measurement Setup[9]

The two receivers (computer systems with two USRPs) and a transmitter (computer system with one USRP) transmitting at a centre frequency of 2.425GHz (ISM band). The two computer systems are placed at a distance of four meters from each other. An artificial hidden node scenario was created using one of the USRP receivers. Data was captured using two USRP receivers at a centre frequency 2.425 GHz via GNU Radio flow graph (Figure. 3) on the receivers. Noise level and received signal level were both captured by each of the receiver and save in a file sink. Table 1 shows the parameters used for measurement during data capturing. The energy detection spectrum sensing method was implemented using a sample number consisting of 1024 FFT data.

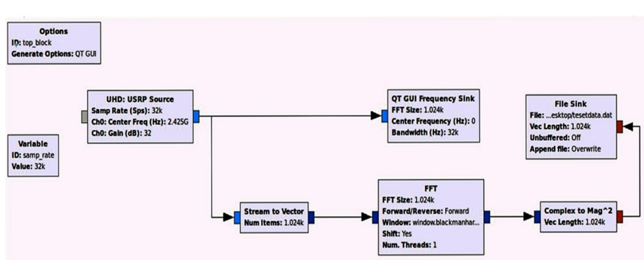

Figure 3. GNU radio flow graph used for capturing spectrum data[9]

Table 1. Parameters used for USRP implementation

Parameter	Value
Sample rate	32Msps
Centre Frequency	2.425GHz
FFT Size	1024
Number of samples	1000
GNU Radio Companion Version	3.8.9 1git-64-g23dd54bf
USRP Version	USRP B200

The measurement was taken at the P03, Level 5, Digital Communication Laboratory, and University Technology Malaysia (UTM).

4. Results and Discussion

The first task was to design the GNU Radio flow graph and output the FFT plot of the spectrum as shown in Figure 4 and Figure 5. The results in Figure 4 shows the FFT plot where there was no hidden node problem while Figure 5 shows the plot where one of the CRs experienced the hidden node problem. The highest noise spike is around -80.0dB for the two experiments. From Figure 4, a spike can be observed in the FFT plot of CR A (Serial = USRP F5726A) and CR B (Serial = USRP F5724F) after -80.0dB indicting that the spectrum is in use between the range of frequencies corresponding to the spike level. Unlike the scenario illustrated in Figure 4, Figure 5 shows CR B under a deep fade caused by the hidden node and as a result, CR B cannot make accurate decision about the spectral occupancy.

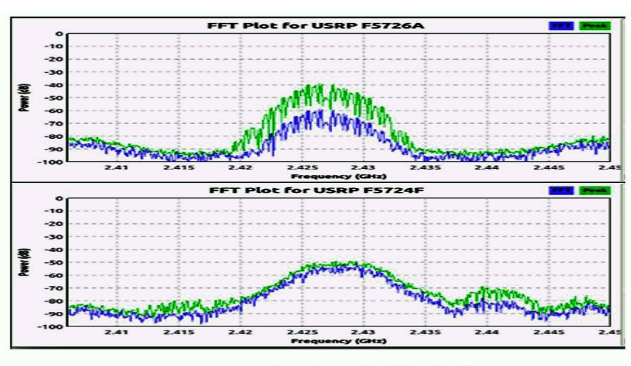

Figure 4. FFT plot showing CRs without hidden node problem

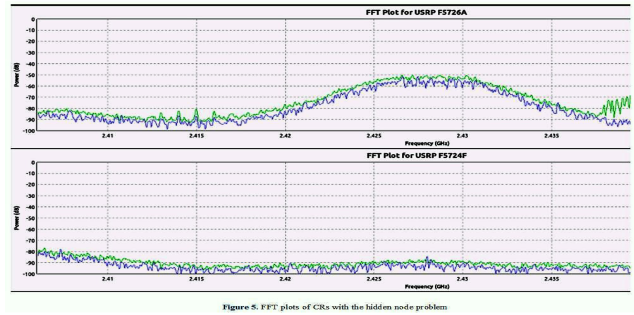

Figure 5. FFT plots of CRs with the hidden node problem

The hidden node scenario experienced by CR B in Figure 5 can thus be compensated for cooperative spectrum sensing among the two CRs. Monte Carlo method discussed in[10] was used in modelling the MATLAB simulator used for performance comparison. In this approach, the probability of detection (PD) and probability of false alarm(PFA)are calculated at different values of detection thresholds. The detection threshold is equally distributed between the minimum threshold value and the maximum threshold value. The minimum threshold value is calculated based on the assumption that that the primary user is absent while the maximum threshold value is calculated under the assumption that the primary user is present.

The two assumptions above can be denoted by the hypothesis H0 (implies the primary user absent) and hypotheses H1(implies the primary user is present). In implementing cooperative spectrum sensing, one of the key input parameter is the noise power. In this work the noise power is calculated by the SNR. The PD and the PFA are two output metrics used in comparing the performance of algorithm implemented.

The Receiver Operating Characteristic otherwise known as the ROC curve is, was helpful in exploring the relationship between the PD and the PFA. The vertical axis represents the PD while the horizontal axis represents the PFA. Also the plot of PD at a constant value of PFA for different values of SNR is another evaluation metric presented in our results. 10% value of PFA was chosen based on the recommendation by[11,12].

The ROC curve from the simulated results for cooperative sensing and single node is illustrated in Figure 6. Where n is the number of samples, (m=1) denotes individual sensing and (m=2) denotes cooperative spectrum sensing. The number of samples (n) affects the PD. Higher number of samples guarantees a better PD and thus a better decision can be reached by the CR. Furthermore, it can also be deduced that cooperative spectrum sensing has a better performance than the individual sensing. Finally, Figure 7 shows the results of the PD verses SNR curve for the same input metric used in the simulation presented in Figure 6. SNR value of -10dB was used during simulation in figure 6 while the PFA value of 10% was chosen for the second scenario in figure 7.

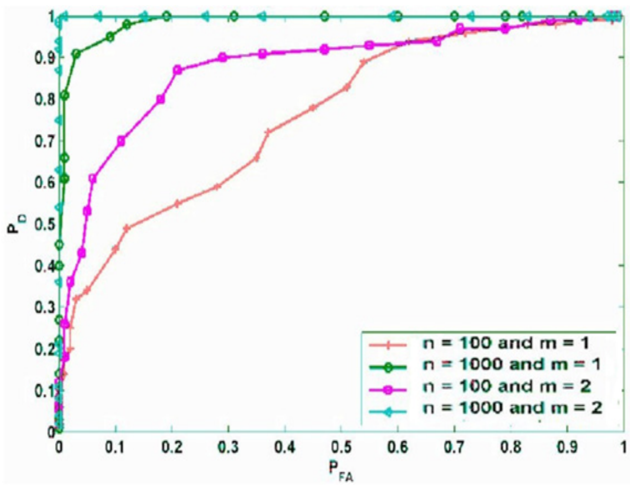

Figure 6. ROC curve showing simulation results of individual and cooperative Sensing

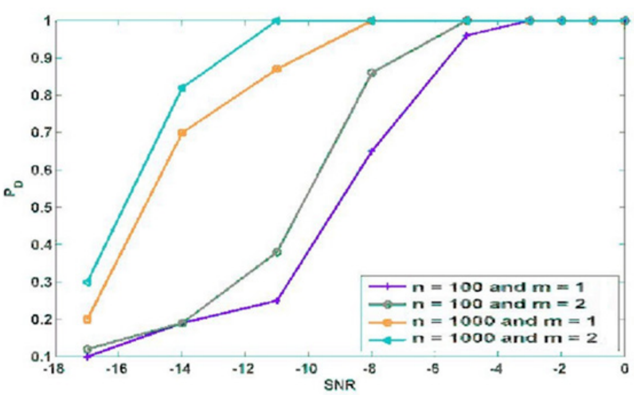

Figure 7. The P_D vs SNR of the simulated results for individual and cooperative spectrum sensing.

5. Conclusion

In this paper we presented cooperative spectrum sensing as an effective method to mitigate the hidden primary user problem during spectrum sensing. Cooperative spectrum sensing improves the detection performance in CRs. The implementation of a Roy´s Largest Root Test (RLRT) sensing algorithm on USRP B200, with the use of GNU Radio was done for hidden primary user problem under a cooperative sensing environment and an individual sensing environment. However, it is recommended that the number of cooperative sensing nodes be increased for a better performance in multi-path environments, thus, high gains can be achieved through cooperative sensing compared to individual sensing.

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