VOL. 12, NO. 17, SEPTEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ENERGY DETECTION BASED COOPERATIVE SPECTRUM SENSING SYSTEM FOR EMERGENCY NETWORKS

A. Hadi Fikri A. H., Paulson E. N., Rozeha A. Rashid, Kamaludin Mohamad Y. and Mohd Adib Sarijari
Advanced Telecommunication Technology (ATT) Research Group, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
E-Mail: rozeha@fke.utm.my

ABSTRACT

During emergencies, a number of rescue teams come to the field and setup their own radio communication systems. If the deployed communication setup does not coordinate among themselves properly, they may interfere with each other when using the same RF channels known as co-channel interference. Spectrum sensing is the most important and complex job for cognitive radios. Cooperation among cognitive radio nodes is needed to enhance the sensing performance. In this paper, we present an experimental study of this solution. A Software Defined Radio comprising of GNU Radio and USRP were used to capture the signal samples to build a database profile of the spectrum condition. MATLAB communications toolbox was used to analyze the data and examine the spectrum pertaining to the condition in emergency networks. The benefits of cooperative spectrum sensing in avoiding co-channel interference during emergency situations are illustrated. Cooperation among cognitive spectrum sensing nodes operating at the same frequency improves the probability of detection, and the overall efficiency of the system. Results show that the cooperative sensing scheme outperforms the individual sensing approach. It can increases the probability of detection relative to the collected samples as the key performance indicator.

Keywords: software defined radio, energy detection, cooperative spectrum sensing, emergency network.

INTRODUCTION

Current studies have shown that most of the allocated spectrum is underutilized. The growing number of wireless multimedia applications has also lead to a spectrum scarcity. Software defined radio (SDR) is a radio whose channel modulation waveforms are defined in software. This will permit users to operate the radio in diverse environments and functions. Since SDR is reconfigurable, the radio itself would become adjustable to a wide range of conditions, depending on the needs of the users. The SDR concept leads to the Cognitive Radio (CR) idea [1, 2]. CR was proposed by Mitola [2], it is a SDR that senses its surroundings, track variations, and responds according to its discoveries. CR is generally regarded as being the subsequent step in the development of radio systems, since it can adjust itself to every condition, substituting the old single function radios. Spectrum sensing is one of the exciting techniques of modern wireless systems to utilize the vacant spaces. In CR, spectrum sensing is done in order to detect the unused spectrum section and these sections can be optimally used without provided it does not cause destructive interference to the certified user.

Human existence has always been threatened by natural disasters like earthquakes, tsunamis, hurricanes etc. Most times, these natural hazards can't be evaded but valuable human lives can be protected by quick and effective rescue efforts. The significance of communication systems cannot be over emphasized during disasters. Usually telecommunication infrastructures are destroyed during most of these disasters. Furthermore, during these disasters, the present public network is often gets encumbered by apprehensive residents with frequent calls for help within a very little time. Although, different emergency channels are assigned to prevent the emergency facilities from being too reliant on the public network, but they too often get jam-packed with the calls as they have an inadequate bandwidth [3]. Telecommunication service providers typically set their individual wireless networks to synchronize among the mobile teams.

Due to the limitation in the number of wireless channels for emergency communications, there is a possibility of having two teams are using the same wireless standards with identical physical provisions. The consequence of this is severe interference between networks that impedes the rescue efforts. There is a likelihood of experiencing hidden node in this situation. This is caused by many other factors which includes shadowing or multipath fading that is observed by a secondary user observe while sensing frequency bands occupied by primary users [4]. Individual radios can conduct spectrum and make decision by itself. Previous works have suggested cooperation among sensing nodes as an efficient technique to improve the detection performance in these situations [4]. Although present day communications structures are the most advanced, conditions like limited bandwidth, hidden node, interference and heavy congestion can put a strain on them. CR is an evolving technology that will permit public security officials to interchange information seamlessly during emergencies. With the CR ability of sensing and detection of spectrum holes, the free space in spectrum can be used to make an emergency call. Thus, the unused spectrum in the existing networks can be put to the optimum use. Furthermore, CR can detect all transmitting and receiving signals in the neighbourhood and apply them to the maximum. This does entails an entirely new approach to the radio spectrum as an alternative to the current approach. In order to deliver the cognitive features which comprise spectrum sensing and spectrum mobility, the unlicensed (secondary) user must have a very flexible radio transceiver. The most suitable means to realize the CR technology is through the use of SDR [5, 6]. There are numerous existing SDR platforms such as FLEX SDR, Berkeley Emulation Engine 2 (BEE2), GNU Radio and universal software radio peripheral (USRP) from Ettus Research and Eric Blossom and Kansas University Agile Radio (KUAR). The GNU Radio project has emerged as one of the most exciting SDR development project. The GNU Radio technology provides an open source software platform which together with low cost hardware called USRP can be used to develop and implement various software radio applications. GNU Radio and USRP can be used to develop and implement a wireless spectrum sensor [7, 8]. In order to enable a fast development of technology, the usage of an open SDR platform is required. The challenge is to develop a programmable software radio to meet the specific requirements in a real experimental system.

The key challenges of spectrum sensing (to detect the presence of unknown emitters in emergency situations) are hidden node, short sensing time and mobility of the emitters. Narrowband radio emitters with different standards will communicate side by side in the spectrum. Sensing all the emitters at the same time is another big challenge. A number of techniques have already been developed to detect the primary users in Cognitive Radio (CR) environments. But most of the CRs have some prior knowledge of the primary user location and physical (PHY) parameters [9]. In case of the detection of emergency radios, the sensors have no prior knowledge of the location and PHY parameters of radio emitters. Energy detection (ED) can be a simple and effective solution in this case. In this study GNU Radio and USRP are used to develop ED based cooperative spectrum sensing system.

The main task of this work is to develop a cooperative spectrum sensing system using the GNU Radio tools, MATLAB, and the USRP hardware. The GNU radio is an open source software that has a lot of signal blocks that can be utilized along USRP B200 to achieve simple applications as well as measure actual data. The remaining part of this study includes some technical review and discussions about SDR, cooperative spectrum sensing and related technologies as presented in section 2. The GNU energy detection technique has been briefly described in section 3. 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. Subsequently, section 6 concludes this work.

TECHNICAL REVIEW

Software defined radio

SDR is a radio where the main part of the radio is realized in software. Typical modules such as amplifiers, filters, mixers, modulators / demodulators and detectors that were regularly implemented in hardware, can now be executed in software. This system is characterized by its reconfigurability, owing to the fact that changing its behaviour only needs adjusting or replacing the software. The GNU Radio framework was introduced explicitly for the SDR purposes. Basically it comprises of a signal-processing platform which an operator can use to construct their personal radio. The SDR architecture is illustrated in Figure-1 [10]. It is made up of an RF front end and software to accomplish all the baseband calculations. An RF front end is required to receive the signals. The RF front end consists of the antenna, LNA and filters.Thestrategicnatureofthechosenlocationenablesustoef fectivelymeasurehightrafficspectralactivity.

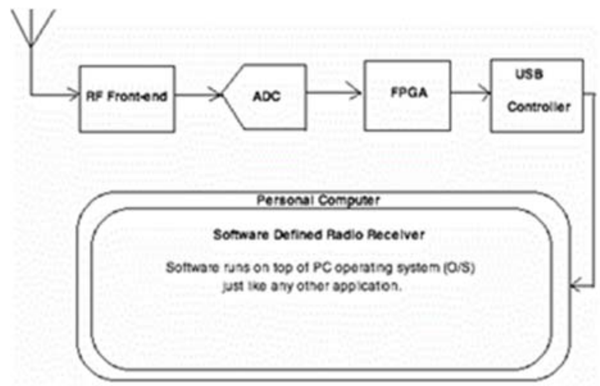

Figure-1. SDR Architecture [10].

Measurement equipment and configuration

The USRP B200 hardware from Ettus Research [11] has been used for thus work. The USRP B200 as shown in Figure-2 provides a fully integrated platform with nonstop frequency coverage from 70MHz-6 GHz. It is designed for low-cost research. It combines a completely incorporated direct conversion transceiver that can provide up to 56 MHz of real-time bandwidth with a fast bus-powered USB 3.0 connectivity.

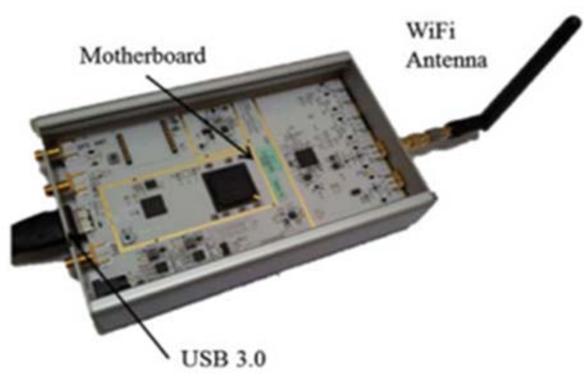

Figure-2. USRP B200 [11].

The USRP B200 hardware collects the RF signal and down-converts it to the baseband for DSP. The USRP B200 design is open and schematics, thus its drivers are freely available, at a cheap cost. It is a valuable choice for researchers who are interested in working with SDR.

ARPN Journal of Engineering and Applied Sciences

Table-1 [11] shows the brief description of the USRP B200 daughterboard used for this work.

Table-1. Features of the USRP B200 [11].

The first fully integrated USRP device with continuous RF coverage from 70 MHz –6 GHz
Full duplex operation with up to 56 MHz of real time bandwidth (61.44MS/s quadrature)
Fast and convenient bus-powered connectivity using SuperSpeed USB 3.0
GNURadio and OpenBTS support through the open-source USRP Hardware Driver™ (UHD)
Open and reconfigurable Spartan 6 XC6SLX75 FPGA with free Xilinx tools (for advanced users)
Early access prototyping platform for the Analog Devices AD9364 RFIC, a fully integrated direct conversion transceiver with mixed signal baseband

Cooperative sensing network

The information sensed by single sensor might be heavily affected by the fundamental characteristics of the wireless channel like multipath fading and shadowing. If the signal emitted by the emitter is deeply faded by channel or blocked by the large obstacles in the environment then the sensor might not be able to detect that signal when it is actually present and also shadowing causes the severe problem called the hidden terminal problem[4]. To mitigate these kind of effect multiple sensor can be designed collaborate in spectrum sensing. This can be termed as the collaborative spectrum sensing or cooperative spectrum sensing. Previous works[4, 12]demonstrated that the cooperation between the sensors or secondary users improves the detection performance, reduce the sensitivity requirement and decrease the detection time. The cooperation among the sensors can be implemented in two fashions, (1)Centralized and (2)Distributed[13, 14].

In centralized sensing, CR sensors will send the sensed information to the central unit where the necessary information is extracted on the basis of the information sent by the sensors. Whereas in case of distributed cooperative sensing, the sensors will share the information with each other but finally the sensor will make its own decision by combining the information sent by the other sensors. Cooperation among different CR users can be modeled by diverse methods. Modelling incooperative sensing is largely concerned with how CR users can cooperate to implement spectrum sensing and yield a good detection result. The most prevalent and governing method initiated from the parallel fusion(PF) model in distributed detection and data fusion [15].Nonetheless, the game theory have been employed by some studies to model the behaviours of cooperating CR users [16]. The PF models gives optimum detection result by employing the distributed signal processing methods to decide how the observations are joined and tested and how the conclusions are arrive at. The game theoretical models focus on enhancing the sensing-parametric function byanalyzing the connections and the cooperative or non-cooperative behaviors of CR users.

Data combination can be done by using OR, AND or M Out-of-N combination methods. The sensors can cooperate with each other and with the central unit by using different strategies [14]. The first one is partial cooperation in which sensor will share only few information to others. The second one in total cooperation in which the sensor will share all its information. The third one is adaptive cooperation in which the sensor can switch between cooperative sensing and non-cooperative sensing depending upon the situation. In emergency situations, it is preferable to setup the network in an ad-hoc manner with minimal setup procedure. Adhoc networks comprises of CR users that are self-organizing and can be installed without any existing infrastructure. This work proposes that CRs operate in distributed cooperative manner during emergencies [3, 7, 9, 13]. If a Mobile Station (MS)with CR abilities identifies that there are some other MS or CR users within reach, they can set up a connection via certain communication protocols. Consequently, this connection forms an ad hoc network. Individual MS or CR user forms a node of the ad hoc network. Each CR user resolves its action based on its own local observation and with information exchanged among other CR users to become aware on the network. Thus, CR users can interconnect with other CR users through the prevailing communication protocols or dynamically using spectrum holes.

GNU RADIO ENERGY DETECTOR

The energy detector (ED) is also referred to as a suboptimal detector. The ED can be used to sense undisclosed signals as previous knowledge on the transmitted is not needed[17]. Figure-3 illustrates the block diagram of the ED used for this work. The ADC block is employed to convert the signal received from analog to digital domain. The Fast Fourier Transform (FFT) and magnitude square function is used to calculate the square magnitude of the digitized signal. The RF signal captured from the environment is down converted to the baseband frequency by the USRP RF front end and then passed to the USRP Motherboard.

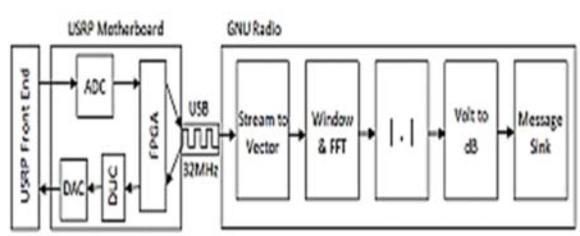

Figure-3. Block-diagram of an energy detector.

In GNU radio, RF signal received from the USRP which is in stream of data format will be converted to vector format. Its job is to take a stream of items as its input and convert it into a stream of blocks having *n* items per block as its output [18]. In this work, *n* items per block is equivalent to the size of the FFT which is 1024. Then,

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

this signal will be pushed into the GNU radio FFT block. In the FFT block, windowing method is used to improve the FFT outcome. Windowing is a method used to adjust the time part of the sampled signal. This is done so as to reduce edge effects. Edge effects causes spectral leakage in the FFT spectrum and increases the spectral resolution the frequency domain [17].The complex output of the FFT block will then be linked to the complex magnitude block. Finally, the result in dB will be sent to a file sink block. The file sink block will pass the value of the power spectral in a file which will be saved in the system for further processing. The GNU Radio companion (GRC) flow graph employed for data capturing is shown in Figure-4.

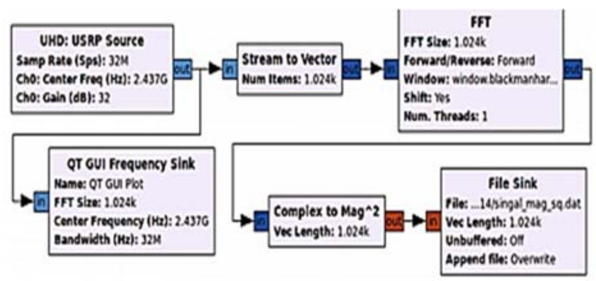

Figure-4.GRC flow graph of the ED.

IMPLEMENTATION

Design setup

Some assumptions[7]were taken into consideration during the experimental set-up design. Such assumptions include disaster occurring in a major city with telecommunication infrastructure collapsed. Emergency rescue teams from various locations are invited. Teams set up their own networks. Each emergency rescue team will be responsible to maintain their own networks. CR users will not interfere with any of the emitters in operation. Sensing network will try to find the frequency and bandwidth occupied by other users. The design used in setting up the proposed system is shown in Figure-5. CR sensors will be placed randomly in the disaster area. Each CR user will detect the presence of emitters by sensing the spectrum within its range. An existing user can be detected by multiple CR users. CRs will transfer the sensed information to a central server to form a cooperative database.

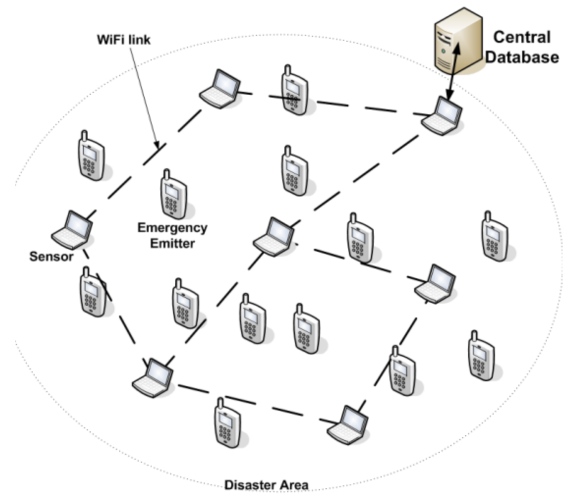

Figure-5. Emergency network layout [7].

Implementation

The spectrum sensor is implemented by using the GNU Radio and USRP. Spectrum sensing comprises of two steps. Identifying the presence of signals in a channel and extracting the required parameters for that signal. A built-in function of GNU Radio (usrprx cfile.py) was designed using the GRC as shown in Figure for storing the received complex samples in a data file. One of the most relevant tools for spectrum sensing is the GNU Radio spectrum analyzer (usrp fft.py). The analyzer can detect frequency, peaks, average for a multiple frequency range. Central frequency of the spectrum can also be detected by adjusting the decimation and Low Noise Amplifier (LNA) gain. This tool is most suitable for narrowband measurements. Signal is received by the RF front ends (daughterboard) and transferred to the FPGA through a high-speed 12-bit Analog to Digital Converter. The data is captured at center frequency 2.425GHz by implementing the GRC flow graph in Figure-4. The noise data was taken by observing the FFT generated. Figure-4 was used to calculate the noise power and energy threshold for the ED. The USRP outputs the complex IQ data that is transferred to the PC through a USB 3.0 interface.Table-2 is showing the receiver parameters and value used for measurement. MATLAB is used for data processing. The measurements were taken at the Faculty of electrical engineering building, P03, MIMOS UTM.

Table-2. Measurement parameters.

Parameter	Values
Sample rate	Sample rate 32Msps
Center Frequency	2.425GHz
FFT Size	1024
Number of samples	1000
GNU radio Version USRP Version	3.8.9 1git-64-g23dd54bf USRP B200

VOL. 12, NO. 17, SEPTEMBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EXPERIMENTAL RESULTS AND DISCUSSIONS

The results of four experiments of single node spectrum sensing, cooperative spectrum sensing, comparison between measurements and theory for probability of detection, and lastly the effect of number of samples on detection performance have been presented in this section.

Receiver operating characteristic (ROC) curves were used to assess the implemented algorithms, in order to explore the relationship between the sensitivity of sensing through P_d, and the specificity of sensing through P_{fa}. The y-axis is represented by sensitivity (P_d) and the x-axis by the specificity (P_{fa}), both given as percentages.

Experimental result of single spectrum sensing

Independent sensing was performed for a single CR node. Figure-6 depicts the ROC at different inter-user distances with respect to the PU transmitter and the hidden node effect.

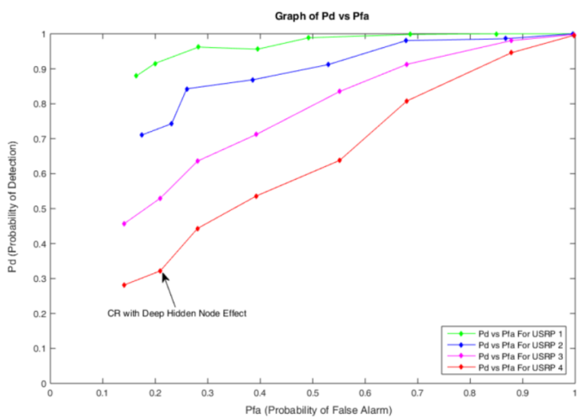

Figure-6.ROC curve showing comparison of measurement results for individual sensing. Number of CR nodes = 4.

As expected, the CR that is closer to the PU and with less obstruction have a better probability of detection. 1000samples were collected at each CR node for our experiment with an average SNR value of -10dB.

Experimental result of cooperative spectrum sensing

CR users were permitted to cooperate by sharing their spectral information in order to improve the spectrum sensing performance. In order to reduce the communication cost, CR share only their final 1-bit results (H_0 or H_1) rather than their result statistics. For easiness, we CR users were assume to experience independent and identically distributed fading with equal average SNR. These assumptions were taken so as to enable analysis as well as practical execution. Figure-7 shows complementary ROC for cooperating CR users.

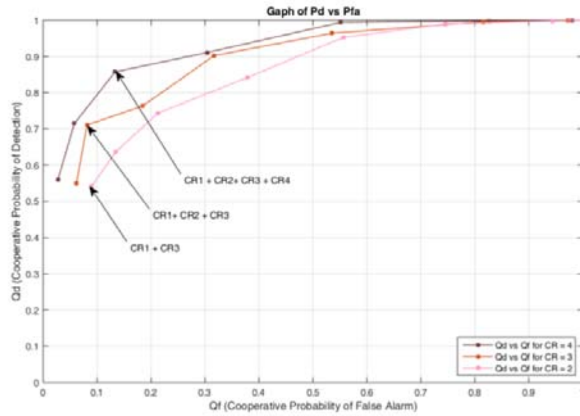

Figure-7. ROC curve for cooperating CR users. Number of CR nodes = 4.

A CR user receives results from n−1 other users and resolves H_1 if any of the total n single resolutions is H_1. This fusion rule is called the OR-rule or 1-out-of-n rule. Probabilities of detection and false-alarm for the cooperative sensing technique is represented by Q_d and $Q_f$respectively and may be expressed as follows:

$$Q_d = 1-(1-P_d)^n \tag{1}$$

$$Q_f = 1-(1-P_{fa})^n \tag{2}$$

where*n* is the number of CR users. *Pd* and *Pf* are the single node probabilitiesof detection and false-alarm.

Comparison between measurement and theory for probability of detection, Pd

This section presents the comparison ROC curve of the theoretical simulation and Roc curve obtained from our experimental simulation. The derived result confirmed that as values of probability of false alarm increases, level of detection probability also increases. For the theoretical simulation, the SNR value is set to -10dB, the same value of SNR assumed for the experimental implementation. Figure-8 presents the comparison between simulation and hardware implementation using USRP.

As expected, there is a performance degradation comparing USRP implementation to simulation results. We claim this is the consequence of analogue RF front-end of USRP. While the digital signal loaded to the SDR might be, in some sense, perfect, once it passes from the digital into the domain of practical devices, it is still vulnerable to non-linear effects and other such worldly imperfections. Such distortions may be the reason for performance gap in Figure-8. Other source of distortion is some imperfection of noise power estimation. Those gaps can be significantly reduced by increasing the numbers of samples.

ARPN Journal of Engineering and Applied Sciences

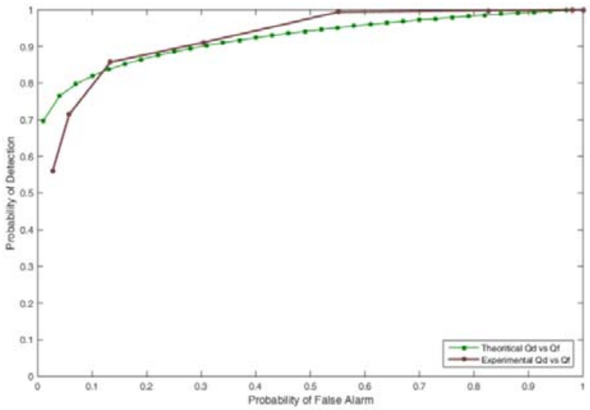

Figure-8. ROC curve of comparison between measurements and theory for probability of detection.

Effect of number of samples on detection performance

As highlighted earlier, the gaps can be significantly reduced by increasing the numbers of samples. Figure-8 shows the ROC curve of simulation results for individual considering different values of samples. As expected, the higher the samples (n) by, the better the quality of detection. We also have clear evidence that cooperative sensing outperforms individual sensing from Figure-9.The value of N has a significant influence on detection performance. Cooperative sensing with few samples N=100 could have lower performance than individual sensing with some more samples N=200, at the cost of longer sensing time.

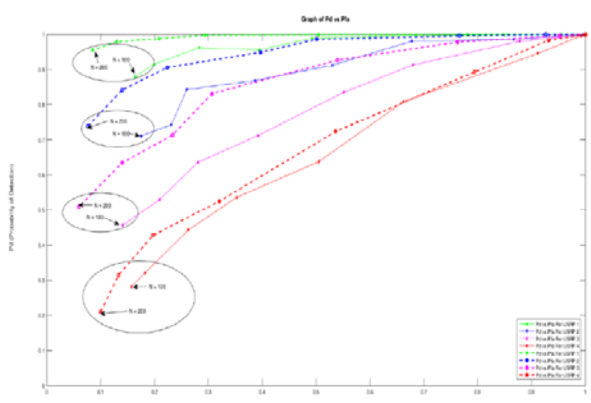

Figure-9. ROC curve showing the effect of number of samples on detection performance.

CONCLUSIONS

This study investigated the preliminary implementation issues of spectrum sensing system to detect the presence of RF emitters in an emergency situation. GNU Radio and USRP was used to collect the sensed data. These data were further analyzed in Matlab. We found the USRP to be a potential candidate for implementing the spectrum sensing systems. But, some calibration and controlling issues are still needed to be investigated. Cooperative spectrum sensing mechanism using SDR platform has been successfully implemented. Cooperative decision contributes to the dependability of spectrum decision at individual local sensing node. Therefore, it is anticipated that the cooperative spectrum sensing mechanism will not only improve the spectrum usage, but it also will improve the quality of service experienced especially during disasters or emergency scenarios.

ACKNOWLEDGEMENT

The authors would like to thank all those who contribute their insightful comments. The authors wish to express their gratitude to Ministry of Higher Education (MOHE), Malaysia and Research Management Center (RMC), Universiti Teknologi Malaysia for the financial support of this project under vote no: FRGS/1/2015/TK04/UTM/02/9.

REFERENCES

[1] Haykin S. 2005. Cognitive radio: brain-empowered wireless communications. IEEE journal on selected areas in communications. 23(2): 201-220.

[2] Mitola J. and G.Q. Maguire. 1999. Cognitive radio: making software radios more personal. IEEE personal communications. 6(4): 13-18.

[3] Kolluru Y. and R.R. Kumar. 2013. Cognitive Radio in Public Safety and Emergency Applications. International Journal of Engineering Trends and Technology. 1(4): 881-882.

[4] Numan P.E., *et al*. 2016. Hidden Node Scenario: A Case for Cooperative Spectrum Sensing in Cognitive Radio Networks. Indian Journal of Science and Technology. 9(46).

[5] Milota III, J. 1992. Software radios: survey, critical evaluation and future directions [J]. Aerospace and Electronic Systems Magazine, IEEE. 8(4): 25-36.

[6] Mitola J. 1995. The software radio architecture. IEEE Communications magazine. 33(5): 26-38.

[7] KIM M. and J.-i. TAKADA. Design and Implementation of a Cognitive Radio Based Emergency Sensor Network in Disaster Area.

[8] Sarijari M.A., *et al*. 2009. Energy detection sensing based on GNU radio and USRP: An analysis study. In Communications (MICC), 2009 IEEE 9th Malaysia International Conference on. IEEE.

[9] KIM, M. and J.-i. TAKADA. 2009. Development of spectrum sensing system with gnu radio and usrp to detect emergency radios. IEICE Technical Report.

[10] Costa A., *et al*. 2009. Spectrum analyzer with USRP, GNU Radio and MATLAB. In: 7th Conference on Telecommunication, Portugal.

[11] Ettus M. and M. Braun. 2015. The Universal Software Radio Peripheral (USRP) family of low-cost SDRd. Opportunistic Spectrum Sharing and White Space Access: The Practical Reality. pp. 3-23.

[12] Mishra S.M., A. Sahai and R.W. Brodersen. 2006. Cooperative sensing among cognitive radios. In Communications, 2006. ICC'06. IEEE International conference on. IEEE.

[13] Ku M.-L. 2012. Cognitive Radio and Interference Management: Technology and Strategy: Technology and Strategy. IGI Global.

[14] Akyildiz I.F., B.F. Lo and R. Balakrishnan. 2011. Cooperative spectrum sensing in cognitive radio networks: A survey. Physical communication. 4(1): 40-62.

[15] Varshney P.K. 2012. Distributed detection and data fusion. 2012: Springer Science & Business Media.

[16] Wang B., K.R. Liu and T.C. Clancy. 2010. Evolutionary cooperative spectrum sensing game: how to collaborate? IEEE transactions on communications. 58(3).

[17] Rashid R.A., *et al*. 2011. Spectrum sensing measurement using gnu radio and USRP software radio platform. In: Proc. of the Seventh International Conference on Wireless and Mobile Communications.

[18] Blossom E. 2004. GNU radio: tools for exploring the radio frequency spectrum. Linux journal. (122): 4.