COGNITIVE RADIO TESTBED FOR SPECTRUM SENSING APPLICATION IN WIRELESS COMMUNICATION

Mr. S. B. Gholap[1], Dr. R. V. Kshirsagar[2], Dr. Y. V. Chavan[3]
[1]Research Scholar: Department of E & Tc Engineering, PCE, Nagpur, MS- India
[2]Principal, Priyadarshani Indira Gandhi College of Engineering, Nagpur, MS-India
[3]HOD, Department of E & Tc Engineering, Government Polytechnic, Osmanabad, MS-India,
Email:sharadgh@gmail.com[1], ravi_kshirsagar@yahoo.com[2], chavan.yashwant@gmail.com[3]

Abstract

This paper described the concept, architecture and development of a real time, Cognitive Radio (CR) test bed for spectrum sensing experiments. It is based on a reconfigurable wireless 4-transmit and 4-receiver multiple input and multiple output (MIMO) Smart Antenna Software Radio Test System (SASRATS) platform. The Xilinx University Program (XUP) Vertex 5 Field Programmable Gate Array (FPGA) development boards is used to enhanced the SASRATS platform and which is called as eV5SASRATS as Cognitive Radio Test bed. The eV5SASRATS platform is used for verification of cognitive experiments and the use of cyclostationarity for spectrum sensing and reorganization applications in wireless communication is also explained.

Index Terms: Cognitive Radio; Cognitive radio Test bed; spectrum sensing; Smart Antenna Software Radio Test System; cyclostationarity.

I. INTRODUCTION

It is mentioned that at any given time only 14% of the radio spectrum is used though the very huge portions of spectrum that are assigned to Television stations but are not utilized fully [1]. This under-utilization of the spectrum can be drastically improved through the use of Cognitive Radio (CR). CR is an ultimate radio system that can sense, adapt and learn from the environment in which operates. It is able to sense where and when the spectrum holes exist and to use them appropriately without the interference to the others [2]. The spectrum holes are the radio spectrum which is not utilized.

The developed CR test bed will enable to conduct real-time experiments to test and verify the algorithms used for spectrum sensing, adaptation and interoperability in wireless communication applications.

II. EXPERIMENTAL REQUIREMENTS

A CR test bed implementation is an architectural enhancement to an existing MIMO Smart Antenna Software RAdio Test System (SASRATS) platform [4, 5] originally designed to test and verifies various space time architectures and algorithms. As the transmit and receive systems of SASRATS platforms are Software defined and modular in design, the architecture is changed to allow the conduction of real-time CR experiments [3]. The Field Programmable Gate Arrays (FPGAs) and Digital Signal Processors (DSPs) are used effectively for conducting CR experiments. The XUP Xilinx Vertex 5 FPGA development board as architecture for CR test bed and called as enhanced Vertex 5 SASRATS platform or eV5SASRATS for short. Number of experiments can be performed on CR eV5SASRATS platform such as:

- Seamless interoperability between radios having different operating frequencies, modulation and protocols.
- Spectrum sensing to determine the presence of primary users (PU) and availability of spectrum holes.
- Determination of modulation and multiple access features (type, baud rate) of users.
- Continuous monitoring (tracking) of spectrum to protect the reappearance of the PU.
- Receiver diversity combining or transmit diversity algorithms to mitigate the fading.
- Interference cancellation algorithms such as beam- forming and beam-nulling.
- MIMO CR algorithms.

A. Interoperability

Interoperability between radios having different operating characteristics is a "must have" feature in a CR. In disaster situations following a major earthquake, tsunami, forest fire or flood, first responders need to establish voice and data communication with other first responder. Emergency responders from various districts, jurisdictions or countries will have to communicate effectively to get the rescue efforts going. Victims may call for help on their AM Citizen Band Radio, cell phones, walkie-talkies (narrowband FM family Radio Service radios) or even cordless phones but this is not possible if the respective telecommunication infrastructure of the affected area is knocked out. Thus the ability to detect and establish communication interoperability seamlessly is a key feature. To this effect, a real-time CR experiments can be conducted on CR test bed to test various detection algorithms and to establish a communication bridge and interoperability between 2 PUs extending to 4 users. Here both the half-duplex and full-duplex links are considered.

In half-duplex bridge experiment, the CR bridges 2 radios operating at 2 different frequencies (f_1, f_2) and using two different modulations (m_1, m_2) and protocols (p_1, p_2). In half duplex mode, each radio transmits and receives using one unique frequency. When one transmits other listen. This mode is adopted mostly in walkie-talkies and also in Citizen Band radios. The CR bridge must detect when either one of the radio transmits, determines which radio it is, tune into receive, demodulate the received signal and modulate transmitter according to the other radios modulation scheme. Appropriate detection, demodulation, modulation, protocol and control algorithms need to be implemented and tested. The test bed should also be able to conduct 3 way half duplex voice communications between the CR test bed and two radios. This means that the test bed must have capability to simultaneously transmit through 2 transmitters at frequencies f_1 and f_2, modulation m_1, m_2 and protocols p_1, p_2 respectively. The test bed should also have the ability to accept another receiver if there is a need to implement diversity combining algorithms to mitigate fading or beam-forming to improve reception of a desired signal or beam-nulling to cancel out a stronger receiver.

The Cognitive Radio test bed must also be able to perform full-duplex communication interoperability. A full-duplex communications uses a separate transmit (f_1, f_2) and receive (f_3, f_4) channels for communications. The requirement is to link 2 radios where each radio transmits and receives at different frequencies, modulation and protocols to have seamless and simultaneous talk or listening capability. In disaster situation victims may try to get help on their cellular or home cordless phone and the ability to scan and receive their full-duplex system is a must. The most basic full duplex test bed will consist of 2-receivers and 2-transmitters controlled by cognitive algorithms. This will enable the test bed to bridge two different radios and also establish full-duplex communications with both of them. With additional receivers added on to the test bed, direction finding algorithms can estimate the direction at arrival of these signals to help rescues locate them.

B. Spectrum Sensing

The CR needs to sense where the spectral holes are and to use them to establish communication between emergency responders. The CR should also have the ability to determine the frequency, type of modulation and protocol used by emergency responders and also the signals send out by victims seeking help so that communication and interoperability can be established.

To perform spectrum sensing, several non-coherent detection approaches such as energy detection and cyclostationarity can be used [6]. Energy detection uses the approach used in spectrum analysis and can be implemented in the cognitive baseband processor by averaging frequency bins of a Fast Fourier Transform (FFT). To resolve the narrow band signals, the sample size of the FFT must be increased to improve the resolution. To detect the weaker signals, signal-to-noise ratio (SNR) can be improved by increasing the averaging time. The drawback to this method is that the energy detected must be compared to some threshold which will determine the probability of detection. This method however cannot easily distinguish between the desired modulated signal, noise or interference and therefore does not work for spread spectrum signals. The FFT energy detector method however is still a good first approach to spectrum sensing problem as it is a non-coherent detector and is relatively simple to implement in DSP or FPGA on the CR test bed. A more sophisticated method that exploits the cyclostationarity properties of the detected signal provides more information regarding the modulation type, data rate and other spectral signature of the unknown signal is proposed.

Digital transmission exhibits a distinct cyclostationarity signature that can be exploited to detect and determine their modulation format and baud rate. This occurs because digitally modulated signals have periodicity associated with their baud rate, modulation schemes, training sequences, cyclic prefixes, spreading or hopping sequences. Signals are said to exhibit cyclostationarity if their cyclic autocorrelation or cyclic conjugate correlation functions are non-zero either at some time delay or at some frequency shift. This frequency shift is known as the cyclic frequency *(α)*.

A signal, *x (t)*, has second-order periodicity only if it's non zero cyclic autocorrelation, shown in (1) exist [7] as

$$R_x^\alpha(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t+\tau/2)x^*(t-\tau/2)e^{-j2\pi\alpha t}dt \qquad (1)$$

The Fourier transform of the cyclic autocorrelation function is the cyclic spectral correlation density (CSCD) function [8]. In this paper, discrete (sampled) signals are used. The CSCD for discrete signal is defined in (2) and is a function of both.

$$S_x^\alpha(f) = \sum_{-\infty}^{\infty} R_x^\alpha(\tau)e^{j2\pi f t} \qquad (2)$$

For *α=0,* $S_x^\alpha(f)$ is the power spectral density (PSD) of the signal but for non-zero α values, the CSCD is cross-spectral density of that signal and its frequency shifted version. The CSCD at $\alpha = \pm 2f_c \pm 1f_b, \pm 2f_c \pm 2f_b, \pm 2f_c \pm 3f_b\ldots$

Practical implementation of the CSCD method for signal signature detection is shown in Fig.1.

In this implementation, the CSCD function is defined [7] as:

$$S_x^\alpha(f) = \lim_{B\to 0} \frac{1}{B} \langle [h_B^f(t) \otimes u(t)][h_B^f(t) \otimes v(t)]^\star \rangle \qquad (3)$$

Where $u(t) = x(t)e^{-i\pi\alpha t}$, $v(t) = x(t)\,e^{+i\pi\alpha t}$, $\otimes$ denotes convolution, h_B^f is the impulse response of band pass filter with center frequency f and bandwidth B with unity gain at the band center. $\langle . \rangle$ is continuous time averaging defined as $\lim_{z\to\infty} \frac{1}{2z} \int_{-z}^{z} (.)dt$.

In this paper, the use of the CSCD function is investigated for signal signature detection of BPSK, QPSK, OQPSK, MSK, and 16-QAM modulated signals. The CSCD function is computed at various values of *f* and *α* to produce surface plots of modulations as shown in Fig.2.

The frequency error results in Table1are based on comparison with actual values of f_c=10 KHz, f_b=5 KHz at 8 samples per symbols and FFT length of 256. The result shows that the CSCD function in second algorithm can be used to successfully estimate both f_c and f_b to a high degree of accuracy.

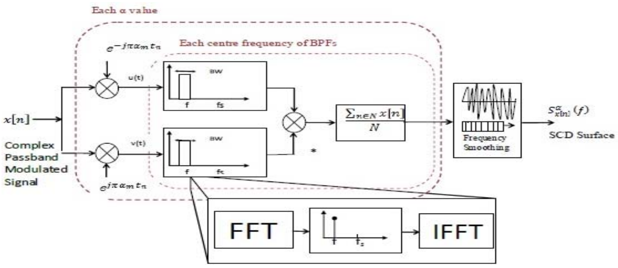


Fig.1: Block diagram of implementation of cyclic spectral correlation function.

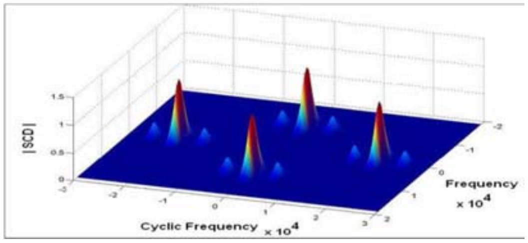
However, the error in estimating fb is large if the error is estimating fc is large. This is reflected in highest execution time (in the case of MSK) in recognizing the signal signature. The execution times are normalized to the BPSK execution time of algorithm 2. If carrier frequency and baud rate are known a priori as shown in the last row of Table 1for algorithm 1, the execution time is very fast and takes only one tenth of the normalized standard time. Better frequency error performance can be obtained at the expense of longer FFT length and higher execution time.

TABLE I. Carrier (f_c) and baud rate (f_b) estimation performance and normalized execution times of signal signature detection algorithms using the cyclic spectral correction density (CSCD) function.

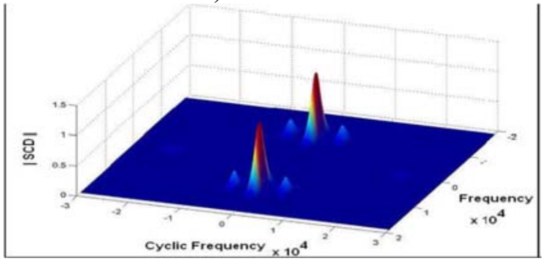
These results show that it is possible to use cyclostationarity in cognitive radio applications. However, use of CSCD function motivates to study and explore other signal signature detection techniques that are less computationally intensive but offer good performance. It is also noted that there is need of a high performance processor for CR test bed to perform the FFT's and IFFT's operation to implement and test the CSCD functions algorithms on test bed.

III. OVERVIEW OF THE TESTBED ARCHITECTURE

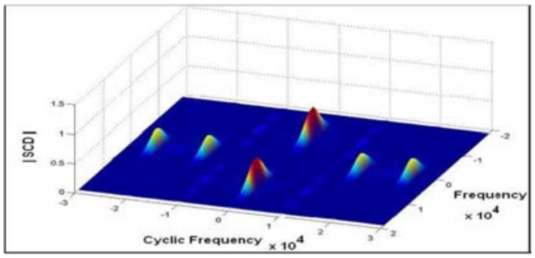
To investigate various aspects of interoperability, spectrum sensing and recognition, diversity and interference mitigation experiments on real time CR test bed can be developed with several options to cater for different levels of capabilities. The architectural options of the Cognitive radio eV5SASRATS platform are shown in Fig. 3.



a) SCD of BPSK



b) SCD of QPSK



c) SCD of MSK

Modulation	BPSK	QPSK	OQPSK	MSK	16QAM
Error in f_c (%)	0.024	0.073	0.317	0.904	0.024
Error in f_b (%)	0.170	0.024	1.344	3.688	0.024
Execution time					
Algorithm 1	1	3	1	14	3
Algorithm 2	0.1	0.1	0.1	0.1	0.1

d) SCD of 16QAM

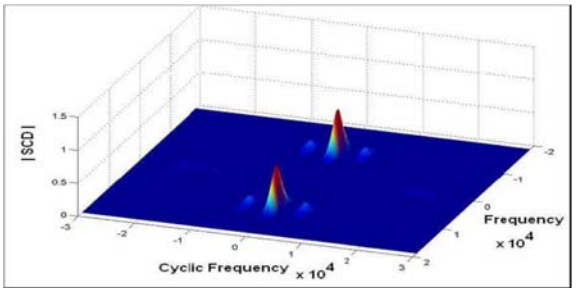


Fig. 2: Cyclic spectral correlation density function plot of BPSK. QPSK, MSK and 16-QAM signals

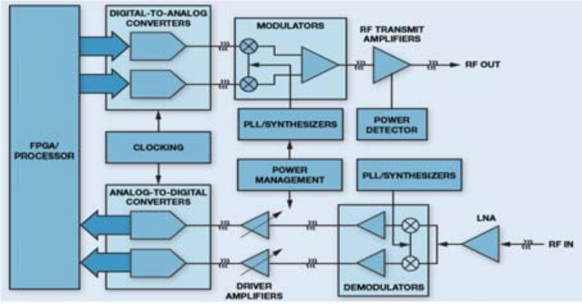


Fig. 3: eV5SASRATS Advanced Radio System Architecture.

At the heart of the Cognitive Radio eV5SASRATS platform is Xilinx University Program (XUP) Virtex-5 development system board. The versatile XUP board has a Virtex-5 XC5VLX110T FPGA with 17,280 Virtex-5 logic slices, 4 tri-mode Ethernet MACs, including one with on board Gbit PHY, 5,328 Kbits of block RAM, 64 DSP slices and 16 Rocket I/O transceivers. The Vertex 5 board is shown in the Fig. 4.

Fig. 4: Vertex 5 XUPV5-LX110T Board

TABLE II. Hardware Resources Vertex 5 LX110T

Slices	Flip Flops	LUTs	Multipliers	Block RAM (Kb)	CMTs
17280	69120	69120	64	5328	6

TABLE III. Clock Frequency for Vertex 5 LX110T

Clock Name	FPGA	Frequency
USER_CLK	AH15	100
CLK_33MHZ_FPGA	AH17	100
CLK_27_FPGA	AH18	27
CLK_FPGA_P	L19	200
CLK_FPGA_N	K19	200

The simplest configuration shown in Fig.3 consists of a set of receiver and transmitter units under the control on FPGA to emulate a PU which if desired can be remotely controlled via the Ethernet. It can also be used as a cognitive radio terminal to bridge two different half-duplex radio systems thus permitting 2-way interoperability. In this mode, the bridge can only listen-in to communication between the 2-way radios but cannot talk to both simultaneously. For 3-way half-duplex interoperability that enables the cognitive radio bridge, the capability to talk to both simultaneously to both radios, will require an additional transmitter to be enabled. If the system is expanded to include an additional receiver at the fourth available port, then algorithms using diversity combining techniques to mitigate fading or beam forming to mitigate an unwanted interference can be added to improve the quality of service. If a transmitter is connected to the fourth part then it is possible to connect 4-way half-duplex interoperability between the CR bridges and 2 primary radios as shown in Fig. 4. If a transmitter is connected to the forth port instead, then it is possible to connect 4-way half-duplex interoperability experiment.

The architecture for full-duplex interoperability between the CR bridge and 2-primary radios requires the two sets of transmitter and receiver units that can be configured to all the available ports on the XUP board. The setup can be duplicated such that a second full-duplex system can be used to emulate another communication bridge or merely used to emulate primary users. The FPGA’s of the two systems can work together by communicating directly using Rocket I/O Gigabit serial port or remotely via Ethernet depending on the nature of the experiments.

The analog portion of the receiver amplifier translates and filters, a received radio frequency signal at 2.4 GHz to a received intermediate frequency where digitization and band pass sampling occurs. The output of the analog-to-digital converter (ADC) which digitally down converts (DDC), decimates and filters the input data to produce baseband in-phase (I) and quadrature-phase (Q) signals for further processing in DSP and FPGA. At the transmitter, I and Q data are fed into digital-up converters (DUC) and modulator which output a modulated intermediate frequency signal. The analog portion of the transmitters then filters, amplifies, up converts then power amplifies the transmit signal to 2.4 GHz. The local oscillator (LO) used in test bed for the up and down conversion process is fixed at one frequency which restricts operation in the required Industrial, Scientific and Medical (ISM) band. The receiver and transmitter analog converter design is modulator and wideband and it is thus possible to use separate LO’s if desired, to receive and transmit at frequencies outside ISM band. The receiver is able to receive a large number of channels by digitally tuning at different receive frequencies within the 10 MHz bandwidth of 70 MHz IF filters. At the transmitter, different transmit frequencies are achieved by programming the DUC to different carrier frequencies within the IF bandwidth. Thus the system has the capability to dynamically receive or transmit under the control of cognitive algorithms.

The various cognitive algorithms on the XUP board will be implemented using the Xilinx Integrated System Environment (ISE) foundation suite and also the Xilinx Embedded Development kit (EDK) with the platform studio tool suite. Also the use of various Xilinx Core Generation intellectual property (IP) modules are incorporated within the ISE Foundation toolset to shorten design cycle time ISE and Core Generator are used successfully in many real-time MIMO implementations reported in [9,10,11]. To further reduce the design cycle time, the reuse of transmit and receive firmware and software module developed in these implementations in CR test bed. Also a Xilinx System Generator for DSP for a rapid prototyping is used. It enables to develop highly parallel system in FPGA through system modeling and automatic code generation from Simulink and MATLAB.

IV. CONCLUSION

This paper described the experiments that are important in the evaluation of various cognitive radio operations in wireless communication systems. It is shown that cyclostationarity and in particular the CSCD function can be used to estimate the carrier frequency, baud rate and recognize the modulation often unknown signal. This paper also explained the concept and architecture of a real-time cognitive radio test platform for interoperability and the spectrum sensing experiments based on the reconfiguration of current MIMO platform with the XUP development board to dynamically control transceiver characteristics whilst performing cognitive algorithms.

REFERENCES

[1] N. Sai Shankar, Cordeiro, C., and Challapali, K., “Spectrum Agile Radios: Utilization and Sensing Architectures”, IEEE DYSPAN 2005, Washington DC, USA, Nov. 2005.

[2] C.T. Chou, Sai Shankar, N., Kim, H., and Shin, K., What and How Much to Gain From Spectral Agility, IEEE JSAC, April 2007.

[3] Peter J. Green and Desmond P. Taylor., “A Real Time Cognitive Radio Test Platform for Public Safety,” 18th Annual IEEE Symposium on Personal, Indoor and Mobile Communications (PIMRC’07).

[4] Y.Xing, Chandramouli, R., Sai Shankar, N., and Mangold, S., “Dynamic spectrum access in open spectrum wireless networks,” IEEE JSAC, March 2006.

[5] FCC (2003) Notice for Proposed Rulemaking (NPRM 03 322): Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies. ET Docket No. 03-108, Dec. 2003.

[6] IEEE 80.22 web site: http://grouper.ieee.org/groups/802/22/

[7] Method for point-to-area prediction for terrestrial services in the frequency range 30 MHz to 3000 MHz, ITU-R P.1546-1, Oct. 11, 2005.

[8] “Facilitating opportunities for flexible, efficient, and reliable spectrum use employing cognitive radio technologies,” The FCC Notice of Proposed Rulemaking and Order — ET Docket No. 03-108.

[9] http://www.darpa.mil/ato/programs/XG/rfc vision.pdf – Vision RFC.

[10] C.Bergstrom, Chuprun, S., and Torrieri, D., “Adaptive spectrum exploitation using emerging software defined radios,” IEEE Radio and Wireless Conference 1999, pp. 113–116.

[11] P.K. Lee, “Joint frequency hopping and adaptive spectrum exploitation,” IEEE MILCOM 2001, Vol. 1, pp. 566–570.

[12] J. Mitola, “The software radio architecture,” IEEE Communications, Vol. 33, No. 5, 1995, pp. 26–38.

[13] “White paper on regulatory aspects of software defined radio,” SDR forum document number SDRF-00-R-0050-v0.0.