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An Effective Resource Utilization for Multi-Channel Multi-Radio Environment in Cognitive Radio Wireless Mesh Networks

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Abstract: ***Cognitive Radio (CR) is phenomenon pertaining to wireless communication where transceivers have intelligence to detect the availability of free channels instantly to make well informed decisions on channel usage. Resource utilization in terms of spectrum access is given paramount importance in Cognitive Radio Wireless Mesh Networks (CRWMN's). Cooperative opportunistic spectrum allocation is the basis for secondary users to promote cooperative functionality by utilizing the unused spectrum, without causing interference to primary users. Secondary users often try to use best channels out of idle channels licensed to primary users. Priority based resource utilization is essential to ensure high quality communications in cognitive radio networks. On the other hand, Multi-Input and Multi-Output (MIMO) is the antenna technology where both transmitter and receiver use antennas to optimize data speed and minimize errors. Towards this end, in this paper, we proposed a methodology for building a MIMO Cooperative CRWMN's coupled with Time-Division Multiple Access (TDMA) for effective channel access and spectrum allocation. Universal Software Radio Peripheral (USRP) devices provided by National Instruments (NI) with data sets are used for experiments. We built a prototype application using LabVIEW to demonstrate proof of the concept. The experimental results revealed that the proposed methodology enhances the utilization ratio of spectrum resources.***

Index Terms: Cognitive radio, Mesh network, resource utilization, TDMA, USRP.

I. INTRODUCTION

Radio networks with two way communication allow sharing of many similar components and technologies. Such network might have fixed transmitters and receivers co-located or transceivers. A transceiver is a node which can act as both transmitter and receiver. Cognitive Radio (CR) is one of such wireless communication network where nodes can act as transmitters and receivers. Important characteristic of CR is that a transceiver is capable of detecting the communication channels which are not vacant and determine moving to such channels instantly. Thus already occupied channels are avoided with well informed intelligence. This feature in CR network is known as spectrum sensing. It's another characteristic is cooperative communication. Hence it is known as Cooperative Cognitive Radio Network (CRN). Cooperative communication is achieved with the concept of having two kinds of users. They are known as primary user and secondary user. Primary user is the user who has direct access rights to access channels while the secondary users need to use channels with cooperation with primary users. In other words, primary users make use of secondary users as relay nodes to cooperatively render primary traffic. Primary user has legacy rights or higher priority over a part of spectrum. The secondary users, on the other hand, do have low priority and allowed to gain access to spectrum cooperatively without causing interference or issues to primary users. This phenomenon satisfies delay and rate constraints associated with CRN [26].

CRN is expected to render heterogeneous services. The major challenge to fulfil this requirement is resource utilization and channel assignment. Resources are generally radio frequency spectrum, channel and bandwidth. In telecommunications, radio spectrum is a part in electromagnetic spectrum which has a range of 3 Hz to 3000 GHz. In the given frequency range electromagnetic waves are known as radio waves. In addition to resource utilization, the CRN needs to support multi-input and multi-output (MIMO). It does mean that it sends data to multiple nodes and receives data from multiple nodes. Meeting rate and delay constraints with optimal resource utilization in CRN is very challenging problem to be addressed. In the literature it is found that there was considerable research in the area of cooperative CRNs as explored in [1], [2], [4], [6], [7], [14], [22] and [26]. Many resource utilization techniques came into existence. However, considering new trends in technology innovations, increase in the usage of CRN, diversified needs of users, and to meet the needs of data-intensive applications of contemporary era, there is need for further optimization of resource utilization.

Considering resource utilization in CRN is an open optimization problem, we proposed a system model and an algorithm for dynamic and efficient resource utilization. We understood the need for priority based resource utilization in MIMO-CRNs. The Universal Software Radio Peripheral (USRP) devices provided by National Instruments (NI) are considered for implementation of a prototype application to demonstrate proof of the concept.

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Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is used as the platform for the implementation of the proposed system model. It also explores the utility of clustering, Time-Division Multiple Access (TDMA) for effective channel access and spectrum allocation. Towards this end, our contributions in this paper are as follows.

- We proposed a CRN model which facilitates clustering, MIMO, TDMA with priority based resource utilization to ensure cooperative communication with optimized resource utilization.
- An algorithm is proposed for priority based resource utilization for in the context of heterogeneous service needs, rate and delay constraints.
- A prototype application is built using LabVIEW in order to demonstrate the proposed CRN model. It shows the utility of priority based resource utilization with intelligent spectrum sensing and channel allocation.

The remainder of the paper is structured as follows. Section II makes of a review of literature on cooperative CRNs and related issues. Section III provides preliminaries with definitions and problem definition. Section IV presents the proposed methodology. Section V provides the details of implementation of prototype using LabVIEW. Section VI presents experimental results and evaluation. Section VII concludes the paper and provides directions for future scope of the research.

II. RELATED WORKS

This section reviews literature relevant to cognitive radio and resource utilization for opportunistic spectrum access. Tsiropoulos *et al*. [1] explored resource utilization techniques for efficient sharing of spectrum in cognitive networks. They also presented cognitive radio (CR) optimization methods for the purpose. Service criteria they used yield good performance. Radio Frequency (RF) energy harvesting is proposed by Xiao *et al*. [2] for dynamic spectrum access for improving performance in CR networks. The energy harvesting capabilities are given to secondary users for better sharing of spectrum in cognitive ratio networks (CRNs). Similar kind of study was made by Lee *et al*. [13]. Bilal *et al*. [3] studied CRN in terms of hardware requirements, CRN architecture, and CR base station and CR mesh networks. They also explored the software needs of CRN and different scenarios. Tragos *et al*. [4] made a good review of CRN for its spectrum assignment. They presented a topology of CRN that contains co-located with primary networks. They also presented overview of spectrum access approaches, criteria, techniques, and challenges. Thayammal and Linda [5] studied wireless network and various means of improving Quality of Service (QoS) in such networks. Especially they focused on effective resource utilization in wireless networks. They classified different QoS approaches used for leveraging wireless networks in the real world. Salem *et al*. [6] considered cognitive radio ad hoc networks for studying opportunistic spectrum access. They presented the concept of spectrum holes and various challenges caused in CR networks. They also presented spectrum management framework that can be used in CRNs besides exploring spectrum sensing. Ahmed *et al*. [7] studied cognitive radio mesh networks for distributed channel assignment that is spectrum-aware. They proposed an algorithm known as Channel Aware Spectrum Assignment (CaSa). They employed the algorithm and evaluated in multi-radio multi-channel CRNs. When large number of channels is present, the performance of CaSa was better. Khan *et al*. [8] explored the usage of CR for smart grids. They described their research in terms of network protocols, spectrum sensing mechanisms, and architectures. They presented smart grid architecture and the utility of CR in such networks. It includes home area network, neighbourhood area network and wide area network. Arshad *et al*. [9] investigated the approaches used for resource management in CR networks. Besides, they focused more on the QoS support for effectiveness in CRNs. CR networks might have security challenges. Fragkiadakis *et al*. [10] focussed on the security threats in CRNs and various techniques to detect such threats. They studied on reconfiguration vulnerabilities and provided mechanisms to prevent attacks. In presence of primary users, secondary users and QoS needs, Masonta *et al*. [11] studied the means of improving spectrum decision making in CRNs. They studied reconfiguration parameters for improving decision making and ensuring the required QoS. Zhang et a. [12] on the other hand focused on different optimization mechanisms and self-organization approaches to be used in CRNs for better resource utilization and performance. Liang *et al*. [14] studied cooperative overlay approach for effective spectrum access in CR networks. They improved the network by reducing interference between primary and secondary users. They used both cooperative and non-cooperating gaming approaches to study such network with cooperative overlay spectrum access. Saleem *et al*. [15] provided various models for primary user activities in CR networks. By modelling the activities of primary users, they tried to have a generalized approach for understanding modelling of primary users. Li *et al*. [16] focussed on spectrum sensing through clustering. They found that clustering improved the spectrum access in cooperative environment. They formally investigated the problem of robust clustering and proposed a methodology to have such investigation in CRNs. Gavrilovska *et al*. [17] studied and classified MAC protocols that can be used in CR networks. Peng *et al*. [18] on the other hand explored fog computing based approaches in CRNs, their issues and challenges. Aktar *et al*. [20] studied CR networks and focused on something known as white space for exploiting opportunities pertaining to spectrum access. They found that proper understanding of whitespace can improve spectrum access capabilities. Hossain *et al*. [19] studied the contemporary approaches in CR networks and presented possible future trends in which CR will get improved. Farooqi *et al*. [21] investigated the possibilities of using network coding phenomenon in CR networks. They compared network coding feature from traditional wireless networks an emerging network known as CR networks. They also studied the problem network coding in Peer-to-Peer networks. Dai *et al*. [22] investigate the problems in secondary spectrum access and provided a mechanism known as cooperative transmission for better spectrum access for secondary users. Similar kind of research is made by Naeem *et al*. [23]. El-Sherif *et al*. [24]

focused on CR mesh networks and investigated on the maximization of throughput in a decentralized approach. They considered the problem as aggregate utility maximization problem and decoupled the problem into a group of sub problems for resolving efficiently. Youssef *et al*. [25] explored issues in
CR networks. They made a survey of metrics that can be used to evaluate performance of CR networks.

III. PROBLEM DEFINITION

CRWMN's is the network where nodes can have ability of spectrum sensing. However, the nodes are involved in wireless communications. Unlike traditional networks, the nodes in CRWMN's face the problem of spectrum sharing constraint. In the presence of primary and secondary users, there are constraints with respect to expected quality of services. The resource utilization should be opportunistic and should not be static. Therefore it is essential to have a resource utilization mechanism that supports priority in the presence of Multi-Input and Multi-Output (MIMO). MIMO is the antenna technology where both transmitter and receiver use antennas to optimize data speed and minimize errors. Minimizing errors and optimizing communications besides satisfying the needs of primary users and secondary users without compromising expected Quality of Service (QoS) is very challenging problem. In other words, effective channel access and spectrum allocation for optimal resource utilization and fulfilling the legitimate expectations of all stakeholders is the main problem to be addressed.

IV. PROPOSED METHODOLOGY

The aim of the proposed methodology is to utilize resources for MIMO-CRWMN's based on CRWMN's with priority. This section presents the proposed system model considered for experiments; we also discuss the procedure and the proposed algorithm used for achieving improved resource utilization.

V. SYSTEM MODEL

The proposed network model of CRWMN's consists of clusters, each cluster having a base station and neighbouring nodes. We propose cooperative priority based resource utilization in each cluster. The rationale behind this is that clustering leverages cooperative spectrum sensing and resource utilization in CRWMN's. Our problem requires a system model similar to that of [26] from which the conceptual model is developed. Our system model is shown in Figure 1. This system consists of base station, five nodes and four cellular channels. The channels legend in Figure 1 shows the channels in different colours. Nodes are connected to other nodes through these channels. These nodes are able to sense spectrum and locate channel which is idle. Each node maintains a list of idle channels. The idea behind this is that the nodes in CRWMN's need to have channel allocation based on the spectrum vacancies. Different channels are allocated at different times by knowing the availability of idle channels which is a dynamic phenomenon.

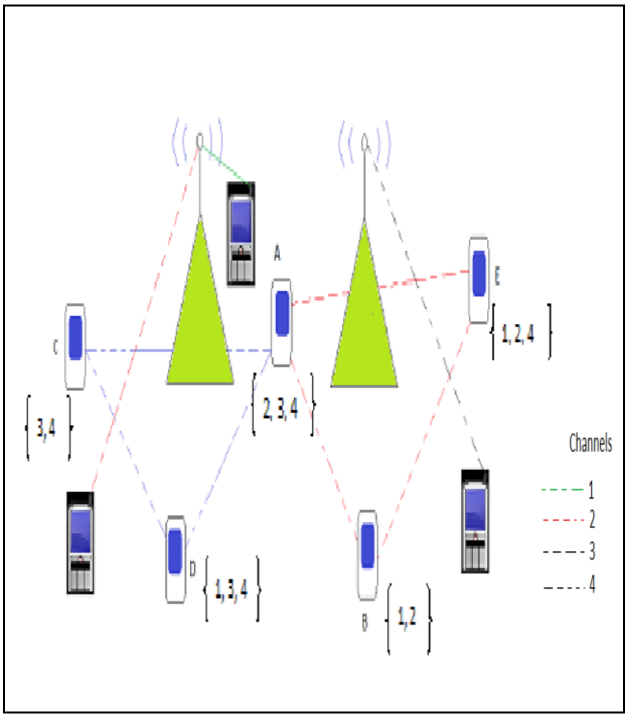

Figure 1: A Typical Cluster with a Base Station and Associated Nodes

In our model, one or more primary users are associated with the CRWMN's. They used spectrum as per the licenses they possess. There are many frequency bands in the licensed spectrum. The following assumptions are considered for conducting tests. First, all bands have same capacity with respect to all channels associated with all CRWMN's nodes. This assumption is considered for simplifying experiments with respect to communication ranges. Next, the connectivity of nodes is not influenced by channel usage. We have also assumed that the node in the network needs to analyze the channel and resources that are idle for having cooperative communications by utilizing services of secondary users. In this context, it is essential to explore the optimal resource utilization and priorities to ensure QoS requirements. Each node in CRWMN's needs to sense spectrum for exploiting and utilize opportunities. In the presence of heterogeneity, constraints and QoS needs, it is assumed that the sensing process is not perfect and needs to be improved. Towards this end a cluster based approach with an underlying algorithm is proposed. The radio network is divided into number of clusters to make opportunistic and cooperative spectrum sensing and utilization easier. The cluster model also helps in maintaining a common idle channel list for more effective decision making. Utilization of resources is one of the important research problems which were addressed in this paper. The resources such as channel, throughput are to be considered for priority based resource utilization for MIMO cooperative cognitive networks. Power allocation to the secondary network is another important requirement for optimal resource utilization.

IV. IDLE CHANNEL DETECTION AND PRIORITY BASED RESOURCE UTILIZATION (ICD-PBRU) ALGORITHM

In the proposed approach, the cluster uses the basic principle to utilize resources as shown below figure 3. Sensing, allocation, transmission are the three phases for allocating resources.

Sensing	**Allocating**	**Transmitting**
Channels Unused by Licensed Users		
Unlicensed users starts sensing for free channels	Every node switches to the allocated channels	CH in each group split time into several slots according to no. of nodes
Allocation of Resources		
Centralised/decentralised manner coordinates all sensing information	Centralised/decentralised manner allocates channels for each node	Manages-member nodes joining or leaving Reselecting of CH

Figure 2- Principle of Utilizing Resources

Before defining the algorithm for ICD-PBRA the network transmission approach used is described here. The system model is MIMO in nature. The transmission is done according to TDMA technique. Data transmission takes place between PT and PR through ST and SR for achieving cooperative communications. The number of channels is denoted as M. Out of them idle channels is identified. The algorithm for ICD-PBRU is shown in Figure 3. The notations used are shown in Table 1.

Inputs: Priorities ***P***, constraints ***C***, Channels ***M***

Step-1: Initialize channels ***V***

Step-2: SU detects idle channels from M

Step-3: SU populates ***V*** and sends to ***CH***

Step-4: CH sends V to BS

Step-5: BS analyzes state of channels from V

Step-6: BS assigns idle channels to SU

Step-7: SU is notified of suitable idle channel

Step-8: Thus multiple SUs get notifications simultaneously

Step-9: Each SU considers P and C and make transmission strategy

Step-10: Based on the C and P analysis BS allocates resources required to SU

Step-11: The SU which is allocated with resources optimally participates in cooperative communication

Figure 3: Channel detection and priority based resource Utilization

PU	Primary User
SU	Secondary User
SN	Secondary Network
PT	Primary Transmitter
PR	Primary Receiver
ST	Secondary Transmitter
SR	Secondary Receiver
BS	Base Station
CH	Cluster Head
V	Vector

Table 1: Notations used in the algorithm

The proposed solution considers constraints, priorities and available channels in order to identify idle channels and consider secondary user or set of users who can fulfil cooperative communication on behalf of primary user without causing interference and which confines of all constraints and priorities.

VI. EXPERIMENTAL SETUP

The aim of the project is to build a MIMO Cooperative Cognitive Radio Network coupled with Time-Division Multiple Access (TDMA) for effective channel access and spectrum allocation. Resource utilization is the cornerstone of the experiments made in this paper. In other words, spectrum sharing with effective approach to ensure that resources are optimally utilized among primary and secondary users is the main objective of the experiments. Towards this end, experimental setup is made with a laptop and multiple USRP devices are connected to form a CRN. Laptop has Windows 10 operating system, Intel Core i5 CPU with 1.70GHz processing capability, and 4 GB of RAM. A VI environment is created for making CRN. It is made using LabVIEW.

VII. ABOUT LABVIEW

Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is the virtual platform for all engineering experiments. It simplifies integration of hardware and supports third party devices to be used for generating and visualizing datasets. National Instruments is the company that created the LabVIEW platform. It supports graphical programming with syntax and semantics provided graphically. The environment is quite intuitive in nature to leverage scientific experiments with ease. Complex systems in the real world can be designed and implemented in cost effective way using LabVIEW. Moreover, the platform is abreast with modern technologies in engineering disciplines and supports measurements with different data acquisition devices. Workflows related to engineering experiments are graphically designed and tested using LabVIEW. It need little programming as Virtual Instrument (VI) is made graphically. Testing and measurement systems once built using LabVIEW can be switched to real time workflows with ease. It can be used with sensors, actuators with different physical systems. It supports validation and verification of various electronic designs. Production test systems can be designed, developed and tested. Industrial equipment and smart devices can be simulated using LabVIEW. Wireless communication systems with different topologies, experiments in engineering can be made simple using LabVIEW. In essence, it accelerates developer productivity by providing access to hardware of different makes from third parties.

V. ABOUT USRP

Universal Software Radio Peripheral (USRP) is a software defined radio device that is provided by National Instruments (NI). It is a family of products with different configurations. USRP 2920 is used for the experiments in this paper. It is an inexpensive hardware platform for software radio used by laboratory experiments. In fact, it is used as part of experimental test bed for investigations into CRN. It makes use of a high speed link to get connected to a host computer. USRP device has both transmitting and receiving capabilities. Hence it is known as transceiver. Some USRP devices can operate stand-alone they contain embedded processor that mimics host computer. USRP motherboard has many subsystems namely DACs, ADCs, FPGAs, power regulation and host processor interface. The block diagram of USRP 2920 is as shown in Figure 1.

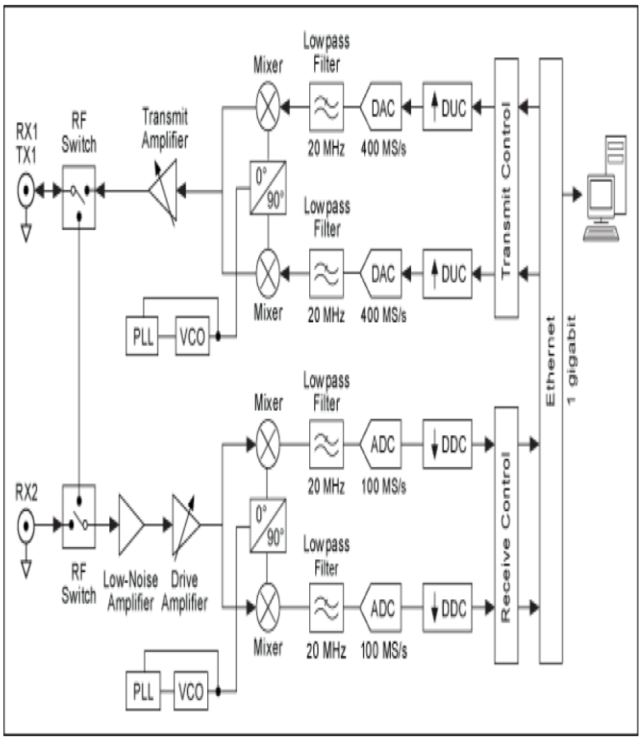

Figure 4: Block diagram of USRP 2920

As presented in Figure 1, there are many individual blocks in USRP device. They are known as Digital Down Converter (DDC), Analog-to-Digital Converter (ADC), Local Oscillator (LO), Voltage-Controlled Oscillator (VCO), and Phase-Locked Loop (PLL). Other blocks in it include Digital-to-Analog Converter (DAC), and Digital Up Converter (DUC). In the receiver path, DDC is used to filter signals to the rate of user specified rate. ADC is used to digitize I and Q data. Reduction of noise is done using low-pass filter. Mixer is used to down-convert signals. Driver amplifier and low-noise amplifier are used to amplify incoming signals. In the transmit path, DAC is used to convert signals from digital to analog format. DUC filters and interpolates signals. The baseband I/Q signals are synthesized and transmitted by host computer. A standard gigabit Ethernet connection is used for connecting to other devices over network.

VIII. EXPERIMENTAL RESULTS

In this division, we are evaluating the impact of the available resources such as usage of channels, throughput. Following figures 5 & 6 explains the detailed evaluation of channels usage & throughput respectively. From these results

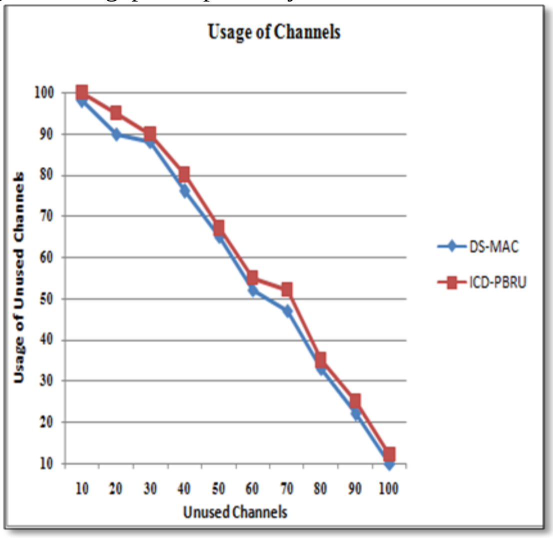

Figure 5: Usage of channels

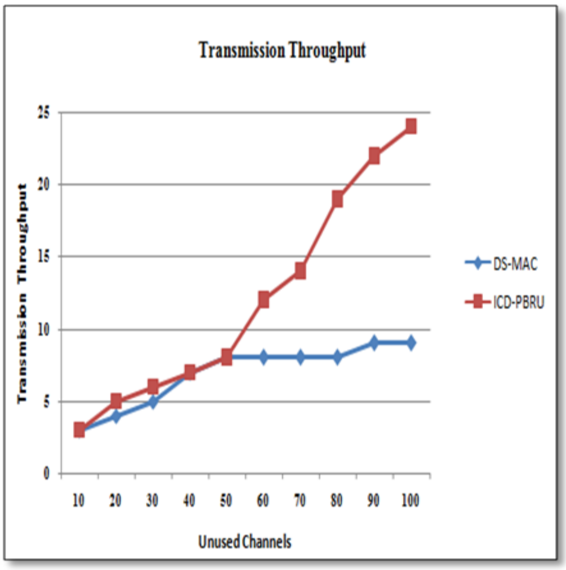

Figure 6: Throughput of the network

IX. CONCLUSION

In this focus, we have displayed the simulated results of the proposed approach which have done in LabVIEW for allocating resources in CRWMN's. For allocating resources the outlined system was encouraged with cognitive and co-operative technique among MC-MR. At the point of the presentation cognitive approach sensibly take the advantage of utilizing resources effectively. The performance of the system was assessed through experimental results by comparing with existed approaches. The outcome demonstrates the correctness of simulation results and shows how capable of allocating resources.

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AUTHORS PROFILE

Anusha Marouthu personal profile which contains their education details, their publications, research work, membership, achievements, with photo that will be maximum 200-400 words.

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