A DYNAMIC CLUSTER BASED ARCHITECTURE FOR COGNITIVE RADIO NETWORKS

Nafees Mansoor[1], A.K.M. Muzahidul Islam[2], and Alan Yudhahutama[3]
[1,2]Malaysia-Japan International Institute of Technology (MJIIT)
Universiti Teknologi Malaysia (UTM), Kuala Lumpur, Malaysia.
[1]nafees@nafees.info, [2]akmmislam@ic.utm.my, [3]alan.yudha@hotmail.com

ABSTRACT

To encounter the emergent necessity of radio spectrum, which is a limited natural resource, proper utilization of the radio spectrum is a must. Introduction of cognitive radio networks can play a vital role to solve the spectrum scarcity. Cognitive radio uses an open spectrum allocation technique to make more efficient utilization of the wireless radio spectrum and reduce the bottleneck on the frequency bands. To deploy Cognitive Radio, a robust architecture is preconditioned. A dynamic cluster-based architecture is proposed for cognitive radio network in this paper. The proposed architecture breaks the Ad-hoc architecture of cognitive radio network into cluster for load balancing and efficient routing. The communication protocols for the proposed architect are ease to deploy so that it can be used for communication in natural calamities such as tsunami, earthquake, etc.

Keywords— Cognitive radio network, network architecture, cluster networks, communication protocol

1. INTRODUCTION

Radio spectrum is a limited precious natural resource. The demand for radio spectrum is ever increasing with the rapid surge in wireless technologies. Today's radio spectrum allocation uses a fixed spectrums allotment policy, which allows only the licensed user to use the radio spectrum. Moreover, numerous surveys on spectrum utilization show that radio spectrum is underutilized with a variance of frequency, time and space [1,2].

The main idea of cognitive radio is to use the underutilized radio spectrum in an opportunistic manner. J. Mitola III pioneers cognitive radio [3]. Having the knowledge of the surrounding communication environment, Cognitive Radio Network, an intelligent wireless communication system has the capability to orient itself to the situation, decide on the course of action and apply this course of action by making corresponding changes in certain operating parameters such as transmit-power, carrier frequency, and modulation strategy etc. in run time. It ensures spectrum utilization and security. In the context of communication technologies, the cognitive radio network employs heterogeneity [7].

There are two types of users in Cognitive Radio Network (CRN), primary user and secondary user [4]. Primary User (PU), also known as the licensed user, has the exclusive right on the radio spectrum. On the other hand, Secondary User (SU) is the unlicensed user, also known as the cognitive user, who has to vacate the spectrum band as soon as a PU appears. In cognitive radio system, the secondary user seeks the opportunity to use the spectrum holes or the free spectrum when the primary user is not active [11]. In other word, Cognitive User is allowed to use the licensed spectrum in a given time and location when and where the PU is idle [5]. This system autonomously coordinates the usage of spectrum. When the radio spectrum is unused, cognitive radio uses the spectrum in an intelligent way based on the observation. In CRN, the SU can use the spectrum temporarily. So SU is an important component in CRN architecture [8].

The spectrum holes identifying process is known as spectrum sensing. Selecting the best channel from the unoccupied channels for communication is the main task in spectrum sharing [7].

Clustering scheme in cognitive radio networks can improve network effectiveness. It also deals with low maintenance, mobility awareness, and load balancing. Network clustering can also lead to a simple and stable cluster backbone, which facilitates control in higher protocols. Low maintenance clustering schemes focus on reducing the frequency of maintenance events, such as re-clustering, merging, splitting, leaving, and joining. Adjusting the transmission range of cognitive nodes, communication reliability can also be increased in clustering.

This research work proposes a dynamic cluster-based architecture for cognitive radio network with a Dynamic Cluster Base Station. The other components of the proposed architecture are Cluster Head, Cluster Members, and Cluster Gateways. Dynamic Cluster Base Station acts as the controller and the fusion center for the proposed architecture.

The paper is organized as follows. In section 2, a brief review on different recently developed architectures for cognitive radio network is discussed. The proposed dynamic architecture for cognitive radio network is described in section 3. In section 4 deals with the simulation results of the proposed architect. Future works and conclusion has been discussed in section 5.

2. RECENTLY DEVELOPED ARCHITECTURES

This part of the paper discusses about different architectures for cognitive radio network, which are proposed in various papers in recent years. Along with the architectures, we also discuss the communication protocols for cognitive radio networks.

In the paper [4], the general structures for cognitive radio networks (Fig. 1) have been presented. Infrastructure, Ad hoc, and Mesh, these are the three basic types of architectures in CRN. Cognitive Terminal (CT)/ Mobile Station, Cognitive Base Station (CBS)/ Access Point (AP)

and Backbone Network are the key component for these structures. In Infrastructure architecture/ Network-centric architecture (Fig. 1 (Black Dashed Circle)) a Secondary User (SU)/ Mobile Terminal (MT) can only communicate with the Base station. The backbone network is used for inter-cell communication. A diverge communication standards/protocols can be used at the BS/ AP to meet the demands of the MTs.
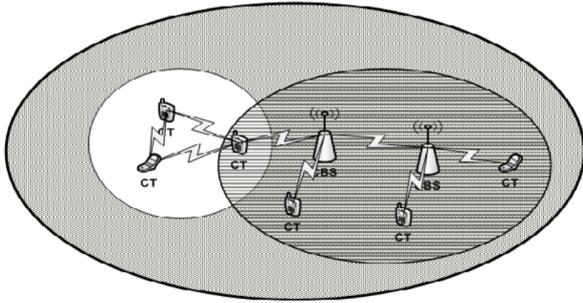

Fig: 1. General structures for cognitive radio networks [4].

In case of the Ad-hoc architecture (Fig. 1 (White Circle)), any sort of infrastructural establishment is absent. When MT identifies the nearby presence of other MTs. MTs can setup the communication links among themselves with applicable communication standards/ protocols and form an Ad-hoc network. Similar to the Hybrid Wireless Mesh Networks [10], the Mesh architecture (Fig. 1 (Gray Circle)) of CRN is the combination of the infrastructural and Ad-hoc architecture. Communication between the BS and MT can be single hop or multi hop. BSs/ APs can act as the gateway when they are connected to the wired backbone networks. If the probable number of spectrum holes is larger, the BSs can have enough wireless communication links to act as the wireless backbone for the network.

Paper [14] presents architecture for CRN where communications between nodes are done without the common control channel to reduce co-channel interference Figuring out the home channel of a neighbor is the main challenge for the architecture. Each node can freely select its home channel. In the architecture [13], every node has the set of accessible channels (SAC) of the neighbors. Whenever any node updates its own SAC, it puts a timestamp and exchanges the SAC database with other nodes when they meet in a channel. The proposed algorithm for the selection of the home channel of the neighbor uses a controlled pseudo-random algorithm. This home channel selection of a neighbor is basically a set of repetitive experiments. Using the SAC list, it is possible to compute the home channel of a node without an up-to-date SAC. One of the main limitation of this architecture is it requires extra memory to store the SAC list. Calculating the home channel, from the SAC list, is also an operational surplus for the network.

A self-organized cognitive radio network architecture on multi agent systems (MAS) is presented in the paper [15]. This architecture divides a big network into smaller groups. Spectrum allocation is done separately in each group. Collaborative-Max-Sum-Bandwidth rule is used to allocate

spectrum in each group. There is a master node in each group, which coordinates the group behavior. These master nodes form the gateway that is used for the communication among groups. Selecting the cutting edge between two groups is the main challenge for this architecture. Depending on the scenario, an edge can integrate two groups, and forms a new group. If an edge has the maximum balance degree in the group then the group is divided into two new groups by the edge and two new master nodes will be elected for the groups. According to the architecture in [15], when there is a necessity to remove an edge, the edge information is sent to the master node. When a master node removes an edge, it needs to check whether it is fit to be the master node or not. To evaluate the system utility, Max-Sum-Bandwidth (MSB) is used.

Offering energy competency and spectrum efficiency, a design for Cognitive Radio Based Wireless Sensor Networks (CR-WSN) at the smart grid utility is proposed in [16]. The paper also proposes some key modifications of RPL (Routing protocol for low power and lossy networks) to ensemble the proposed architectural requirements. Nodes in a network are classified into three types, spectrum sensors, coordinator and ordinary nodes. Here, only spectrum sensors and coordinators detect the primary user and update the channels back up list. The Geo-locator database provides the information about the white spaces in a given geographical location. This communication is done in a non-Zigbee channel. A coordinator is the root of the network. In the formation of the network one of the 16 Zigbee channels is used. Whenever a new node is joining the network coordinator uses the Zigbee channels to supervise the process. It also has a schedule transmission period for spectrum sensing. Coordinator gathers reports from all the nodes of the network regarding the free channel. If the packet error rate goes beyond the acceptable threshold of a node, coordinator sends the warning message to that particular node. On the other hand, spectrum sensor carries out the PU discovery and issues a channel switch notification whenever there is a PU detected.

The paper [17] proposes a logical architecture for 4G heterogeneous wireless communication systems with adaptable user-centric network scheme. The architecture uses the re-configurability concept, and enables resources sharing among different radio networks. The architecture introduces two new entities for user side and network side naming Resource Manager and Access Controller. Resource Manager is divided into two parts: Resource Unit and Cooperation Unit. The Resource Unit deals with maintaining the QoS of the current network, allocating the common resources among different networks and handover mechanism. Unused resources can be stored in a common logical server, where any network can access the server and borrow the resources from others for load balancing and greater use of the radio resources. Cooperative Unit deals with the common resources issue. When a network wants to share resources to the common resources server, Cooperative Unit determines which resources to be shared and how long it will be shared. Cooperative Unit monitors the status of the borrowed resources and decides the return time of the resources to the first party. Algorithms like

dynamic frequency allocations, spectrum management, and resource management can be installed in the Cooperative Unit. Multiuser access and signaling interactive are the main two tasks for the Access Controller at the network side. Apart from that, the sub unit named Re-configure Unit in Access Controller monitors the network and ensures the communications among different networks. The Resource Unit at the user end manages the resource allocation and monitors QoS of all traffic in the user terminal. Collecting and detecting message of user's preference and service type are the task for the sub unit named Detection Unit under the Resource Unit. The Access Unit at the user end helps the network sided Access Unit to select the best network for a particular user.

The work in [18] allocates dynamic channel among the requesting applications in cognitive radio networks by limiting the transmitted power in the sub-bands using joint power control and link scheduling strategy. A cross layer interaction between the MAC and PHY layers for dynamic channel allocation is the main feature of this architecture. The key benefit of this architecture is the decentralized management scheme where nodes can be added or deleted without the involvement of the central authority where the CR Managers in all nodes make all the central decisions. The Ultra Wide Band is divided into sub-bands by the Channel Scanner, which periodically scans sub-bands for white spaces based upon interference temperature. The Rake Optimization Block computes the number of Rakes or fingers to produce maximum SNR at minimal BER. The Channel Estimation Block monitors the fading condition and the channel error rates. The joint power control and link scheduling strategy help the CR to support high and low priority traffic based on delay sensitivity.

3. PROPOSED ARCHITECTURE

In the mesh architecture, the Cognitive Terminals are deployed in such a way that it forms a flat topology in which a link exist between two terminals as long as they are in communication range of each other. There is no established structure to facilitate efficient communication in such a flat topology. Therefore, clustering is used to leverage the underlying flat CRN topology and to provide a hierarchical organization.
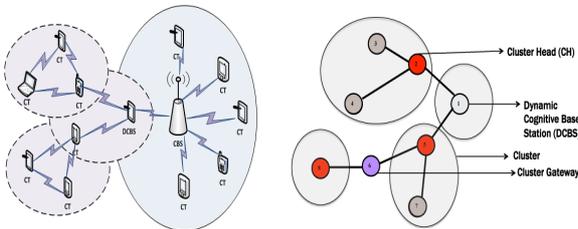

Fig. 2 (a): Proposed Architecture, (b) Graph representation

The proposed architecture reorganizes the mesh architecture, which is the combination of infrastructure and Ad-hoc architecture and divides the network into clusters. In the proposed architecture, clusters are formed with the neighboring nodes in a mesh topology. As shown in Fig.2 (a), node that has the link with the Cognitive Base Station (CBS) acts as a Dynamic Cluster Base Station (DCBS) in

the proposed architecture. Cluster formed by the DCBS consists only the DCBS. Other clusters consist of Cluster Head (CH) and Cluster Members (CM). Within a cluster, single hop communication exists among the CMs and CH. Two Cluster Heads are connected by the Cluster Gateways (CG). In other words, Cluster Gateways are the communication hub for clusters. The will be to connection between any CM with the CG.

We assume all the nodes in the clusters are highly dynamic. So the structures of the clusters change very rapidly. In the proposed architecture, control channels are used for the management of the cluster. The CH will have the complete list of potential control channels and selects the operational control channel for the cluster. The CMs will have the information of the current control channel.

Each Cognitive Terminal (CT) does spectrum sensing and selects its own operating frequency. This operating frequency is called the home channel. This home channel will be used to receive information for that particular CT. CTs transmit its home frequency's information through the control channel within the cluster. CHs will maintain a list for the operating frequencies for all the nodes in the cluster. Every CT will listen and talk subsequently. CTs need to listen on its own frequency and control frequency. Nodes will talk in the home channel of the corresponding node and also in the control channel.

Fig. 2(b) gives the graph representation of the proposed architecture for the above-mentioned situation. As mentioned earlier, except the DCBS, all other clusters form with 1 cluster head and one or several cluster members. Communication within a cluster is done through the cluster head using common channels. A new node needs to detect the available channels before joining the network. After detecting the channels, new node sends request message for joining to the neighboring nodes. After receiving the message, neighboring nodes call the select winner procedure [6] to select the winner node from the neighboring nodes. If the CH is the winner, it sends a message to the new node and the new node joins the cluster. If the new node is 2 hops away from the Cluster Head, member node carrying the join request becomes the CG and the new node becomes the CH and forms a new cluster.

4. SIMULATION RESULTS

We simulate a communication system using the proposed dynamic cluster based architecture for cognitive radio networks. For the simulation purpose of the proposed architecture, Omnet++ is used.
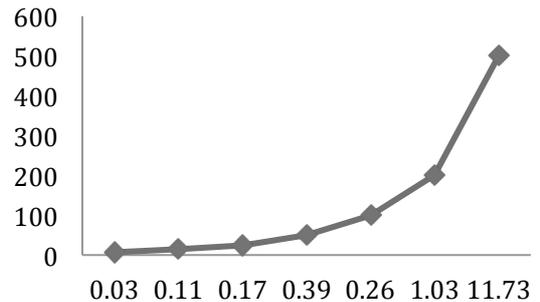

Fig. 3: Execution time for cluster formation.

We have simulated the cluster formation time for 7 nodes to 500 nodes network. We consider a 7-node network as a very small Ad-hoc network. Then we increase the node number to 15, 25, 50, 100, 200, and 500. We consider a 500 nodes network to review the behavior of the architecture for a large network. Cluster formation time with different number of nodes is showed in Fig. 3. In a 7 node network, the execution time for the proposed dynamic cluster based architecture takes 0.12 ms. With a growing number of nodes of 500, cluster formation of the network according to the proposed architecture needs 11.73 ms. The simulation environment shows that execution time for the proposed architecture depends on the nodes of the network.
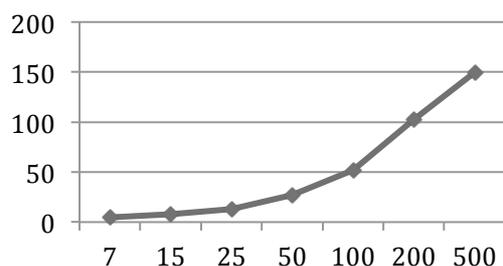

Fig. 4: Correlation of Clusters and nodes

As we are considering the dynamic architecture where the position of the cognitive terminals vary, we take the average result of number of clusters for each simulated networks with 10 random set of orientations. From the simulation result Fig 4, cluster numbers for the proposed architecture increases with the nodes expansions.

5. FUTURE WORKS AND CONCLUSION

The proposed architecture breaks the Ad-hoc architecture of cognitive radio network into clusters. Nodes in the network are considered as dynamic. Development of the proper communication protocols for the proposed architecture will be our next research step. We will also develop a novel spectrum sensing algorithm which will be fully compatible with the proposed architecture.

ACKNOWLEDGEMENT

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