A Stable Cluster-Based Architecture For Cognitive Radio Ad-Hoc Networks

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***Abstract*—With the rapid development of wireless technologies, the demand for radio spectrum is ever increasing. Along with the spectrum scarcity problem, radio spectrums are also under utilized. Cognitive radio practices an open spectrum allocation technique, which can ensure efficient handling of the frequency bands. Suitable network architecture is a must for the implementation of cognitive radio networks. This paper presents stable cluster-based architecture for cognitive radio ad-hoc network. The proposed architecture splits the network into groups of clusters where the spatial variations of spectrum availability are considered for clustering. Set of free common channels resides every cluster for smooth shifting among control channels. We introduce a parameter called Cluster Head Determination Factor (CHDF) to select cluster-heads where clusters' operations are coordinated by cluster-heads. Each cluster comprises of a secondary cluster-head to combat the re-clustering issue for mobile nodes. Conclusively, to evaluate the performance of our proposed scheme, simulation is conducted and comparative studies are performed.**

Keywords— Cognitive radio networks; ad-hoc networks; cluster-based network; re-clustering

I. INTRODUCTION

There is a rapid growth in wireless applications and technologies, which carries an ever-increasing demand for radio spectrums. However, radio spectrum is a limited natural resource and is almost fully distributed. Therefore, there lies spectrum scarcity problem for the forthcoming wireless technologies. On the other hand, due to the current command-and-control based spectrum allocation method, radio spectrum is underutilized with variance of frequency, time and space [1].

J. Mitola III initiates Cognitive Radio Network (CRN), where utilization of the unused spectrum in an opportunistic manner is the main objective [2, 3]. In real time, cognitive radio network, an intelligent wireless communication system, has the ability to adjust itself on the situation and to make relevant changes in operating parameters such as carrier frequency, transmit-power, modulation strategy, etc. In CRN, licensed users are considered as Primary Users (PUs) and Secondary Users (SUs) are the unlicensed users who use the free spectrum opportunistically.

A decentralized and self-configured wireless network is considered as wireless ad-hoc network, where the network does not depend on preexisting infrastructures [4]. The decentralized feature of wireless ad-hoc networks allows the network to be more scalable than of wireless managed network. Moreover, swift deployment and minimal configuration make wireless ad-hoc networks suitable for emergency situations like natural calamities or military conflicts [5]. Mobile Ad-hoc Networks (MANETs) and Wireless Sensor Networks (WSN) are the two popular types of wireless ad-hoc networks [5-7]. However, both of these two technologies use fixed spectrums, which limit users to dynamically use unused spectrum. Due to the flexible and dynamic spectrum usage behavior over other ad-hoc technologies, CRN has received a profound interest to communication network researchers in the last few years.

Clustering is a widely practiced scheme to scale down ad-hoc networks, where cluster-based network exhibits various advantages compare to flat network. In cluster-based network, nodes are divided into logical groups, where adjacent nodes in same geographical location are grouped based on certain criteria. The grouping criteria usually based on network characteristics and application requirements. For example, clusters in a dynamic environment are formed to maintain network topology simpler and stable where network-wide updates are not triggered by local changes. Another common objective for clustering is to construct lesser number of clusters so that number of nodes in the network backbone is remained less.

Due to the flexible and dynamic spectrum usage behavior over other ad-hoc technologies, cognitive radio network has received a profound interest to communication network researchers for the last few years [8]. In this paper, we present stable cluster-based spectrum aware network architecture for cognitive radio ad-hoc network. The proposed architecture splits the network into clusters where the spatial variations of spectrum availability are considered for clustering. Set of free common channels resides every cluster for smooth shifting among control channels. A parameter called Cluster Head Determination Factor (CHDF) is introduced to select cluster-heads where clusters' operations are coordinated by cluster-heads. Each cluster comprises of a secondary cluster-head to combat the re-clustering issue for mobile nodes. The components of the proposed cluster-based architecture are Cluster-Heads (CHs), Secondary Cluster-Heads (SCHs), Cluster Members (CMs), and Forwarding Nodes (FNs). Simulation results show that the proposed cluster-based architecture outperforms other recently developed clustering approaches by upholding a reduced number of clusters in the network where number of common channels in each cluster also remains steady.

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The paper is organized as follows. In section II, a brief analysis on different recent architectures for CRN is presented. The proposed cluster-based architecture for cognitive radio network is described in section III. In section IV, simulation results of the proposed architecture are presented and compared. Conclusion and future works have been discussed in section V.

II. Related Works

Cognitive radio network has been receiving profound interest to communication network researchers for the last few years. This section of the paper discusses various lately proposed network architectures for CRN. Ad-hoc CRN architecture can be divided into two groups, one is non cluster-based architectures and other is cluster-based architectures. Both groups of architectures are vital for the concrete deployment of CRN.

Most of the non cluster-based network architectures for ad-hoc CRN suffer from enlarged communication overheads and inefficient to multi-hop scenario [9-11].

To solve the issues associated to non cluster-based architectures, cluster-based architectures are introduced. Spectrum awareness and local control channel assignment are the main two concerns for reviewed architectures. A spectrum aware cluster-based architecture is presented in [12] , where the architecture interferes PU transmission before transferring to new channel. As clusters are formed with lesser number of common channel (often equal to 1), frequent re-clustering is another main drawbacks of [12]. A self-organized CRN architecture that divides the network into groups [13] uses a broker agent. Re-grouping is dominant in [13] with the presence of the PU, as the architecture considers global control channel.

Base on affinity propagation message-passing technique, clusters are formed in [14] with reduced number of clusters. Latency in intra-cluster communication and re-clustering for mobile nodes are the main limitations of [14]. In the architecture presented in [15], clustering is done based on energy and decision fusions. The architecture turns out to be unrealistic with fading control channel. Moreover, the architecture suffers from the re-clustering problem for mobile nodes [15].

A degree based clustering method is presented in [16] where 2-hop communication is considered within a cluster. Every node in the network requires extra processing power as node maintains complete network information. Moreover, once the node is mobile, the re-clustering issue is acute in [16]. Proposed cluster-based architecture in [17] performs stable with varying spectrum availability. However, the architecture adds extra delay in intra-cluster communication as cluster size can be huge and re-clustering is essential for mobility of nodes in [17]. ID based clustering protocol for CRN is presented in [18], where a buffering technique is used to reduce the packet loss. Re-clustering issue is dominant in this architecture both for varying spectrum availability and for mobile nodes.

A cluster formation algorithm based on available channels, physical location and spectrum occupancy history is proposed in [19] that suffers from re-clustering issue for varying spectrum availability and for mobility of nodes. A distributed cluster agreement algorithm called Spectrum-Opportunity Clustering (SOC) is proposed in [20] where clusters are formed based on common idle channels. Although the method provides desirable balance between common channels and cluster size, however, [20] can produce a huge number of clusters. Moreover, re-clustering for mobile nodes is another shortfall for SOC [20].

One of the widely conversed cluster-based CRN architecture is CogMesh [21], where clusters are constructed around a specific local channel called master channel and originating node becomes the cluster head. CogMesh practices licensed spectrum for control messaging, which may interfere PU transmission. The architecture in [21] has some provision for nodes' mobility. However, not all the clusters have the mechanism to deal with the re-clustering issue for mobile nodes. A Dynamic clustering scheme for cognitive radio ad-hoc network is presented in [22]. Re-clustering issue is dominant in this architecture both for varying spectrum availability and mobile nodes. Nodes' mobility is considered in cluster-based architecture for CRN [23]. However, the architecture suffers from the frequent re-clustering problem with varying spectrum availability.

The recent proposed architectures attain several critical topics for concrete development of CRN. However, a stable architecture in terms of varying spectrum and nodes' mobility is still due for CRN.

III. Proposed Architecture

A. Network Model

Our assumed ad-hoc networks comprised of self-organized Cognitive Radios (CRs)/ Secondary Users (SUs), where SUs have the capability to sense and utilize available free spectrums independently. In the network, SUs are location aware and coexist with PUs. The CRs have the processing capability to calculate own CHDF value. CRs are also aware of the CHDF values of their neighboring CRs.

The spectrum band is divided into non-overlapping orthogonal channels with unique channel ID for each channel. Licensed spectrum of the PU is only accessible to SUs if the PU's transmission is absent. Subject to the physical location, channel availability varies for SUs. We consider that a SU detects available spectrum by sensing free frequency bands using methods such as energy detectors, cyclostationary feature extraction, or eigenvalue-based feature extraction [24].

The proposed clustering mechanism is autonomous to any specific PU activity model. We consider Semi-Markov ON–OFF model to evaluate the performance of the proposed architecture. Semi-Markov ON-OFF process is modeled on any channel for the PU traffic. Busy (ON) or idle (OFF) are the two states that we have considered for any channel [25]. The activation period of any channel is assumed to be an independent random variable. This assumption is realistic when spectrum bands are licensed to independently operating

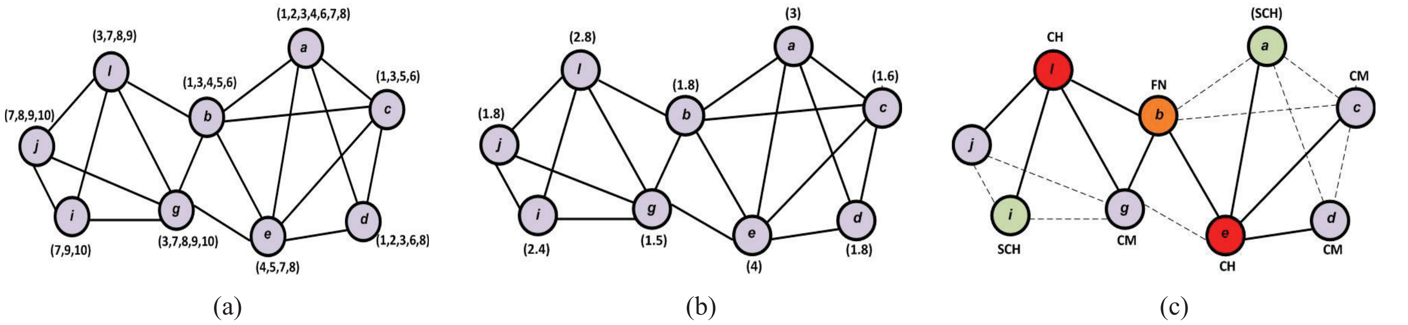

Fig. 1 (a) Connectivity graph of a Cognitive Radio Ad-hoc Network with the accessible channels sets in the brackets.(b) CHDF value for each node, (c) Proposed cluster-based network.

PUs (e.g., channels operated by different TV stations). We consider IEEE 802.22 standard for the operating frequencies of the system, where SU uses a free channel opportunistically and vacates the channels whenever PUs presence is sensed.

To avoid interference with PUs, we assume the presence of a simple interference avoidance model in the system. We also consider there are two transceivers in each CR, where one is used for control and the other one is used for data transmission. With the ability for least switching delay, each transceiver is spectrum aware. Equal transmission range is considered for all the cognitive radios. A link exists between two radios *iff* they are in each other's communication range and share at least one common channel.

We also assume that there is a global common control channel exists in the network. Each cluster declares its own control channel once the cluster formulation is completed. Intra-cluster and inter-cluster communications are coordinated by the Cluster Heads (CHs). For inter-cluster communication, Forwarding Nodes (FNs) are used. FNs are those nodes that are positioned at the edge of two neighboring clusters and can hear beacons from both clusters.

B. *Cluster Formation*

Upon the completion of neighbor discovery, nodes share ACLs C_i and neighbors list N_i among 1-hop neighbors (where $i = 1,2,3,\ldots, n$). Then the cluster formation stage starts. We define our proposed clustering scheme as a maximum edge biclique problem [8]. Based on neighbor list N_i and accessible channels list C_i, each CR_i constructs an undirected bipartite graph $G_i(A_i, B_i, E_i)$. Graph $G (V, E)$ is called bipartite if vertices set V can be split into two disjoint sets A and B where $A \cup B = V$, such that all edges in E connect vertices from A to B. Here, $A_i = CR_i \cup N_i$, and $B_i = C_i$. An edge (x, y) exists between vertices $x \in A_i$ and $y \in B_i$ if $y \in C_i$, i.e., channel y is in the channel list of CR_i. Fig. 1 (a) presents the connectivity graph of a CRN with the accessible channel set in the brackets. From the bipartite graph, each node in the network constructs its own maximum edge biclique graph.

From the maximum edge biclique graph, node determines new C_i and N_i values. These two values are most important for our proposed cluster-based architecture as CHDF of a node is calculated only using these values. Our clustering scheme aims to allocate maximum number of free common channels per cluster with suitable amount of member nodes. We introduce a parameter called Cluster Head Determination Factor (CHDF) to select cluster heads. Every CR calculates CHDF based on equation (1) (Fig. 1 (b)).

$$CHDF_i = \sqrt[C_i]{C_i^{N_i}}\ ; \qquad i = 1,2,3 \ldots n \qquad (1)$$

where, C_i is number of free common channels and N_i is the number of neighboring nodes of CR_i. A node declares itself as cluster head if its own CHDF value is higher than all its neighbors. Once the CHDF value of a node CR_i is lesser than any of its neighbor, CR_i joins the neighboring node that has the highest value as cluster member (CM). After the cluster formation, CH selects SCH from the CMs based on the CHDF value. The SCH takes charge of the cluster if current CH moves out, which shrinks the possibility of re-clustering.

The proposed cluster-based network is presented in Fig. 1 (c), where the solid line denotes the logical link and dotted line denotes physical links. CH defines and upholds operating channels for the cluster. To find the existence of any other clusters in the neighborhood, CMs check their neighbor list for other cluster heads. CM becomes the FN and connects two clusters once it finds other CH in the neighbor list. In our proposed cluster-based architecture, cluster consists of one CH, one SCH and CMs. All cluster members are 1-hop apart from the CH. FN connects two neighboring clusters, where there can be maximum two intermediate FNs between two CHs. Using local common channels, intra-cluster communications are performed.

IV. Simulation Results

We use MATLAB as a simulation tool to evaluate the performance of our proposed cluster-based architecture. To perform the comparative study of our proposed architecture, we compare the simulation results of our proposed architecture with three other recently developed approaches; cluster-based approach in [19], spectrum opportunity-based control channel (SOC) approach in [20], and CogMesh [21]. The simulation area is 10 km^2 (square kilometers), where the cognitive nodes are positioned randomly in the simulation environment. We consider the communication range for each node to 500 meters and 10 available channels in the simulation environment.

Performance comparison of the proposed architecture with other architectures in terms of number of clusters is depicted in Fig. 2, where we compare the simulation result of the proposed architecture with cluster-based approach, SOC approach, and CogMesh. Fig. 2 shows the relation between numbers of nodes with number of clusters for the architectures. From Fig. 2, we realize that with the increasing number of nodes, the number of clusters also increases in all approaches. As shown in Fig. 2, in a network of 50 nodes, proposed architecture constructs 13 clusters, where cluster-based approach, SOC approach, and CogMesh construct 12 clusters, 12 clusters and 10 clusters respectively. When the node's number upturns to 300, proposed architecture gives 19 clusters where cluster-based approach, SOC approach and CogMesh create 24 clusters, 42 clusters and 27 clusters respectively. With the increasing number of nodes, the SOC approach generates higher number of clusters comparing with other three approaches. Meanwhile, comparing with all the approaches, our proposed architecture constructs lesser number of clusters with increasing number of nodes.

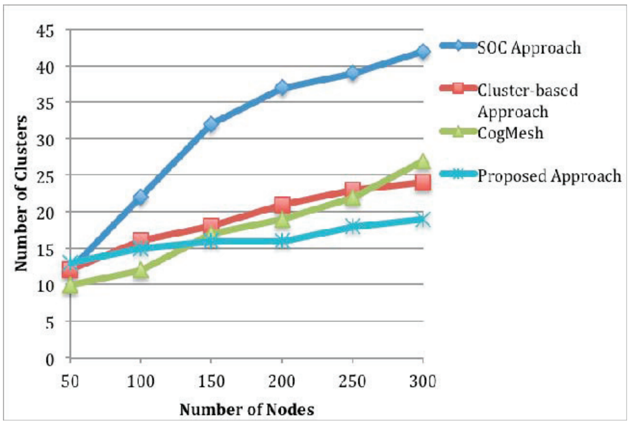

Fig 2: Performance comparison of the proposed architecture with other approaches (in terms of number of clusters).

V. Conclusion And Future Works

In this paper, we propose a stable architecture that breaks the cognitive radio ad-hoc network into clusters. Each cluster comprises with a secondary cluster-head to combat the re-clustering issue for mobile nodes. Finally, to evaluate the performance of our method, simulation is conducted and comparative studies are performed. From the simulation, it has been shown that our proposed architecture performs better compare to other recently developed architectures. Our next research step is to develop routing and broadcasting protocols for the proposed architecture.

Acknowledgment

This research is partially supported by University Research Research Grant of Universiti Teknologi Malaysia GUP Tier 1 with Vote No. 05H61 and GUP Tier 2E with Vote No.09J73 of Ministry of Higher Education (MoHE) year 2014 to 2015.

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