Construction of a Robust Clustering Algorithm for Cognitive Radio Ad-Hoc Network

Nafees Mansoor, A.K.M. Muzahidul Islam(✉), Mahdi Zareei, Sabariah Baharun, and Shozo Komaki

Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia
nafees@nafees.info, {muzahidul.kl, sabariahb, shozo.kl}@utm.my, m.zareei@ieee.org

Abstract. With the swift expansion of wireless technologies, the demand for radio spectrum is ever growing. Besides the spectrum scarcity issue, spectrums are also underutilized. Cognitive radio customs an open spectrum allocation technique, which ensures efficient handling of the frequency bands. However, suitable network architecture is must for the implementation of cognitive radio networks. This paper presents a robust cluster-based architecture for cognitive radio ad-hoc network. Considering the spatial variance of the spectrum, the proposed architecture splits the network into groups of cluster. Set of free common channels resides every cluster that enables smooth shifting among control channels. The paper also introduces a parameter called Cluster Head Determining Factor (CHDF) to select 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 the proposed architecture, simulation is conducted and comparative studies are performed. From the simulation result, it is found that the proposed cluster-based architecture outperforms other recently developed clustering approaches by upholding a reduced number of clusters in the network.

Keywords: Cognitive radio networks · Ad-hoc networks · Cluster-based network · Network architecture · Re-clustering

1 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. This leads to a 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 the idea of Cognitive Radio Network (CRN), where utilization of the unused spectrum in an opportunistic manner is the main objective [1, 2]. Cognitive radio network, an intelligent wireless communication system, has the

M. Weichold et al. (Eds.): CROWNCOM 2015, LNICST 156, pp. 759–766, 2015.
DOI: 10.1007/978-3-319-24540-9_63

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 run-time. 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. The decentralized feature of wireless ad-hoc networks allows the network to be more scalable than of wireless managed network. Mobile Ad-hoc Networks (MANETs) and Wireless Sensor Networks (WSNs) are the two popular types of wireless ad-hoc networks [3]. Due to the flexible and dynamic spectrum usage behavior over other ad-hoc technologies, CRN has received a profound interest to the network researchers for the last few years. To scale down ad-hoc networks, clustering is a widely practiced scheme, where nodes are logically grouped based on certain criteria.

In this paper, a robust cluster-based spectrum aware network architecture for cognitive radio ad-hoc network is presented. The proposed architecture splits the network into clusters where the spatial variations of spectrum availability are considered for clustering. A parameter named Cluster Head Determining Factor (CHDF) is introduced to select cluster-heads where clusters' operations are coordinated by the cluster-heads [4, 5]. Each cluster comprises of a secondary cluster-head to combat the re-clustering issue for mobile nodes. The cluster components of the proposed architecture are Cluster-Heads (CHs), Secondary Cluster-Heads (SCHs), Cluster Members (CM), 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.

The paper is organized as follows. In section 2, a brief analysis on different architectures for CRN is presented. The network model of the proposed architecture is discussed in section 3. The proposed cluster-based architecture for CRN is described in section 4. In section 5, simulation results of the proposed architecture are presented and compared. Conclusion and future works have been discussed in section 6.

2 Related Works

Cognitive radio network has received an intense interest to network researchers for the last few years. This section discusses various lately proposed network architectures for CRN.

Ad-hoc CRN architectures can be divided into two groups, one is non cluster-based architectures and another one is cluster-based architectures [6]. Both groups of architectures are vital for the concrete deployment of CRN.

Most of the non cluster-based network architectures for CRN suffer from enlarged communication overheads and inefficient to multi-hop scenario [7-9].

To solve the issues associated with non cluster-based architectures, cluster-based architectures are introduced. Spectrum awareness and local control channel assignment are the main two concerns of reviewed architectures. Spectrum aware cluster-based architecture presented in [10] suffers from frequent re-clustering problem as clusters are formed with lesser number of common channel (often equal to 1). Regrouping is dominant in [11] with the presence of the PU, as the architecture considers global control channel. Latency in intra-cluster communication and re-clustering for mobile nodes are the main limitations of [12], where clusters are formed based on affinity propagation message-passing technique.

Architecture presented in [13] turns out to be unrealistic with fading control channel and suffers from the re-clustering problem for mobile nodes. Degree based clustering method presented in [14] requires extra processing time and re-clustering issue is acute for mobile nodes. Proposed cluster-based architecture in [15] shows up stable performance for varying spectrum availability. However, the architecture adds extra delay in intra-cluster communication because of the larger cluster size and re-clustering is essential for mobility of nodes. One of the widely conversed cluster-based CRN architecture CogMesh [16] constructs clusters around a specific local channel called master channel. CogMesh practices licensed spectrum for control messaging, which may interfere PU transmission. The architecture in [16] has some provisions for nodes' mobility. However, not all the clusters have the mechanism to deal with the re-clustering issue for mobile nodes. Re-clustering issue is dominant in the dynamic clustering scheme presented in [17] both for varying spectrum availability and mobile nodes. Though nodes' mobility is considered in the architecture presented in [18], however, the architecture suffers from frequent re-clustering problem with varying spectrum availability.

Thus, 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 [6] .

3 Network Model

Our assumed ad-hoc network comprised of self-organized Cognitive Radios (CRs)/ Secondary Users (SUs), where SUs have the capability to sense and utilize available free spectrums autonomously. Co-existing with PUs, SUs are location aware and have the processing ability to calculate own CHDF value. CRs are also aware of the CHDF values of the neighboring CRs. The spectrum band is distributed over non-overlapping orthogonal channels with distinctive channel ID for each channel. Licensed spectrum of the PU is only available for SUs if the PU's transmission is absent. Subject to the geographical location, channel availability differs 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 [19].

The proposed clustering mechanism is independent from 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 [20] are the two states that we have considered for any channel. 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 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, where FNs are those nodes that are positioned at the edge of two neighboring clusters and can hear beacons from both clusters.

4 Cluster Formation

CRs need to alter different channels to discover the neighbors. Upon the completion of neighbor discovery, nodes share Accessible Channel Lists (ACLs), C_i and neighbors lists N_i among 1-hop neighbors (where i = 1,2,3,…, n). Then the cluster formation stage starts, where the proposed clustering scheme is defined as a maximum edge biclique problem [5, 21]. 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 vital for the proposed architecture as CHDF of a node is calculated only using these two 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 Determining Factor (CHDF) to select cluster heads. Every CR calculates CHDF based on equation (1) (Fig. 1 (b)).

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

where, Ci is the number of free common channels and Ni is the number of neighboring nodes of CRi. A node announces itself as cluster head if its own CHDF value is higher than all its neighbors. Once the CHDF value of a node CRi is lesser than any of its neighbor, CRi joins the neighboring CH and becomes a 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 deceases re-clustering possibility. 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 neighboring CHs. In the proposed architecture, intra-cluster communications are performed using the local common channels.

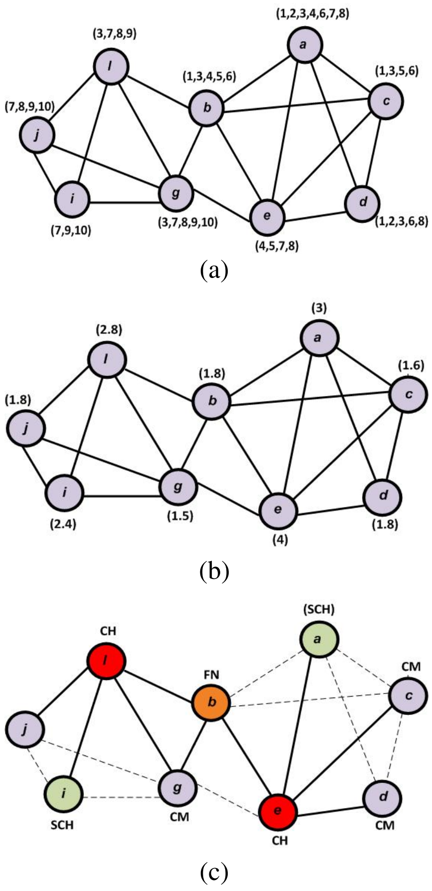

Fig. 1. (a) Connectivity graph of a Cognitive Radio Network with the accessible channels sets in the brackets.(b) CHDF value for each node, (c) Proposed cluster-based network.

5 Simulation Results

We use MATLAB as a simulation tool to evaluate the performance of our proposed cluster-based architecture. Moreover, to perform the comparative study of our proposed architecture, we compare the simulation results of our proposed architecture with three other recently developed approaches, namely cluster-based approach [22], spectrum opportunity-based control channel (SOC) approach [23], and CogMesh [16]. The simulation area is considered as 10000 m^2 (square meters), where the cognitive nodes are positioned randomly in the simulation environment. We consider the communication range for each node to 500 meters and also consider 10 channels in the simulation environment.

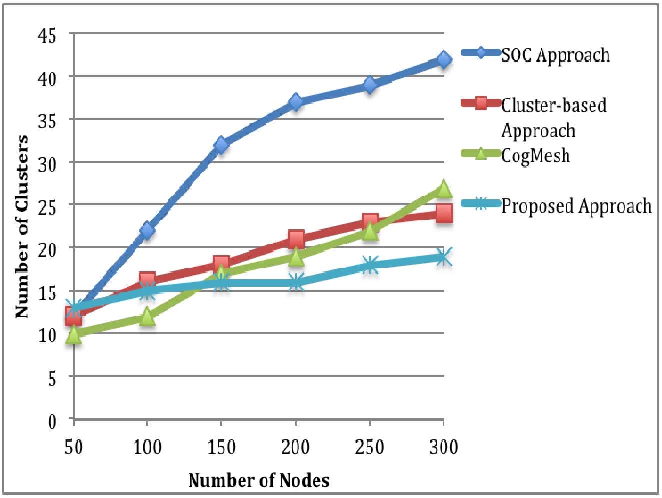

Fig. 2. Performance comparison of the proposed architecture with other approaches (in terms of number of clusters).

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 [22], SOC approach [23], and CogMesh [16]. 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 [22], SOC approach [23], and CogMesh [16] 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 [22], SOC approach [23] and CogMesh [16] construct 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.

6 Conclusion and Future Works

In this paper, we proposed a robust spectrum aware cluster-based architecture that breaks the CRN ad-hoc network into clusters. In the proposed architecture, set of free common channels resides every cluster that enables smooth shifting among control channels. Each cluster comprises with a secondary cluster-head to combat the re-clustering issue for mobile nodes. Conclusively, to evaluate the performance of our method, simulation is conducted and comparative studies are performed. From the simulation, it has been found that our proposed architecture performs better compare with 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 MJIIT Research Grant with Vote No. 4J044 and GUP TIER 1 the research grant of Universiti Teknologi Malaysia (UTM) with Vote No. 05H61 for the year 2014 to 2015.

References

1. Akyildiz, I.F., Lee, W.Y., Vuran, M.C., Mohanty, S.: NeXt generation/dynamic spectrum access/cognitive radio wireless networks: A survey. Computer Networks **50**, 2127–2159 (2006)
2. Mitola, J., Maguire, G.Q.: Cognitive radio: Making software radios more personal. IEEE Personal Communications **6**, 13–18 (1999)
3. Muzahidul Islam, A.K.M., Wada, K., Chen, W.: Dynamic Cluster-based Architecture and Data Congregation Protocols for Wireless Sensor Network. International Journal of Innovative Computing, Information and Control (IJICIC) **9** (2013)
4. Mansoor, N., Muzahidul Islam, A., Zareei, M., Baharun, S., Komaki, S.: A stable cluster-based architecture for cognitive radio Ad-Hoc networks. In: 2014 Annual International Conference on IEEE Region 10 (TENCON), pp. 1–6, (2014)
5. Mansoor, N., Muzahidul Islam, A., Zareei, M., Baharun, S., Komaki, S.: Cluster modelling for cognitive radio Ad-hoc networks using graph theory. In: 2014 International Conference on Applied Mathematics, Modelling and Simulation (ICAMMS), pp. 1–8 (2014)
6. Mansoor, N., Muzahidul Islam, A.K.M., Zareei, M., Baharun, S., Wakabayashi, T., Komaki, S.: Cognitive Radio Ad-Hoc Network Architectures. A Survey. Wireless Personal Communications **81**, 1117–1142 (2015). 2015/04/01
7. Xin, C.S., Cao, X.J.: A cognitive radio network architecture without control channel. In: 2009 IEEE Global Telecommunications Conference, Globecom 2009, vol. 1–8, pp. 796–801 (2009)
8. Chen, K.-C., Peng, Y.-J., Prasad, N., Liang, Y.-C., Sun, S.: Cognitive radio network architecture: part I – general structure. In: Presented at the Proceedings of the 2nd International Conference on Ubiquitous Information Management and Communication, Suwon, Korea (2008)
9. Hu, Z., Sun, L., Tian, H.: A framework of access network architecture for 4G systems based on cognitive radio. In: 2009 5th International Conference on Wireless Communications, Networking and Mobile Computing, vol. 1–8, pp. 1722–1725 (2009)

10. Zhao, J., Zheng, H., Yang, G.H.: Spectrum sharing through distributed coordination in dynamic spectrum access networks. Wireless Communications and Mobile Computing **7**, 1061–1075 (2007)
11. Zhao, Q., Qin, S., Wu, Z.: Self-organize network architecture for multi-agent cognitive radio systems. In: 2011 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery (CyberC), pp. 515–518 (2011)
12. Baddour, K.E., Ureten, O., Willink, T.J.: A Distributed Message-passing Approach for Clustering Cognitive Radio Networks. Wireless Personal Communications **57**, 119–133 (2011)
13. Guo, C., Peng, T., Xu, S.Y., Wang, H.M., Wang, W.B.: Cooperative spectrum sensing with cluster-based architecture in cognitive radio networks. In: 2009 IEEE Vehicular Technology Conference, vol. 1–5, pp. 445–449 (2009)
14. Zhang, J.-Z., Wang, F., Yao, F.-Q., Zhao, H.-S., Li, Y.-S.: Cluster-based distributed topology management in Cognitive Radio Ad Hoc networks. In: 2010 International Conference on Computer Application and System Modeling (ICCASM), pp. V10-544–V10-548 (2010)
15. Asterjadhi, A., Baldo, N., Zorzi, M.: A cluster formation protocol for cognitive radio ad hoc networks. In: 2010 European Wireless Conference (EW), pp. 955–961 (2010)
16. Chen, T., Zhang, H.G., Maggio, G.M., Chlamtac, I.: CogMesh: a cluster-based cognitive radio network. In: 2007 2nd IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, vol. 1 and 2, pp. 168–178, (2007)
17. Mansoor, N., Islam, A.K.M.M., Baharun, S., Komaki, S., Wada, K.: CoAd: a cluster based adhoc cognitive radio networks architecture with broadcasting protocol. In: 2013 International Conference on Informatics, Electronics and Vision (ICIEV), pp. 1–6 (2013)
18. Talay, A.C., Altilar, D.T.: United nodes: cluster-based routing protocol for mobile cognitive radio networks. Iet Communications **5**, 2097–2105 (2011)
19. Yucek, T., Arslan, H.: A survey of spectrum sensing algorithms for cognitive radio applications. IEEE Communications Surveys and Tutorials **11**, 116–130 (2009)
20. Lu, L., Zhou, X., Onunkwo, U., Li, G.Y.: Ten years of research in spectrum sensing and sharing in cognitive radio. EURASIP Journal on Wireless Communications and Networking **2012**, 1–16 (2012)
21. Mansoor, N., Muzahidul Islam, A., Zareei, M., Baharun, S., Komaki, S.: Spectrum aware cluster-based architecture for cognitive radio ad-hoc networks. In: 2013 International Conference on Advances in Electrical Engineering (ICAEE), pp. 181–185 (2013)
22. Li, X., Hu, F., Zhang, H., Zhang, X.: A Cluster-Based MAC Protocol for Cognitive Radio Ad Hoc Networks. Wireless Personal Communications **69**, 937–955 (2013). 2013/03/01
23. Lazos, L., Liu, S., Krunz, M.: Spectrum opportunity-based control channel assignment in cognitive radio networks. In: Presented at the Proceedings of the 6th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, Rome, Italy (2009)