Performance analysis of multi-radio routing protocol in cognitive radio ad hoc networks under different path failure rate

Z Che-aron[1], A H Abdalla[1], K Abdullah[1] and W H Hassan[2]

[1]Department of Electrical and Computer Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia
[2]Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia (UTM), Jalan Semarak, 54100 Kuala Lumpur, Malaysia

E-mail: one_zamree@hotmail.com

Abstract. In recent years, Cognitive Radio (CR) technology has largely attracted significant studies and research. Cognitive Radio Ad Hoc Network (CRAHN) is an emerging self-organized, multi-hop, wireless network which allows unlicensed users to opportunistically access available licensed spectrum bands for data communication under an intelligent and cautious manner. However, in CRAHNs, a lot of failures can easily occur during data transmission caused by PU (Primary User) activity, topology change, node fault, or link degradation. In this paper, an attempt has been made to evaluate the performance of the Multi-Radio Link-Quality Source Routing (MR-LQSR) protocol in CRAHNs under different path failure rate. In the MR-LQSR protocol, the Weighted Cumulative Expected Transmission Time (WCETT) is used as the routing metric. The simulations are carried out using the NS-2 simulator. The protocol performance is evaluated with respect to performance metrics like average throughput, packet loss, average end-to-end delay and average jitter. From the simulation results, it is observed that the number of path failures depends on the PUs number and mobility rate of SUs (Secondary Users). Moreover, the protocol performance is greatly affected when the path failure rate is high, leading to major service outages.

1. Introduction

Traditional fixed spectrum allocation policies have been proposed to allow each wireless service to use certain frequency bands [1]. With the widespread usage of wireless devices, the spectrum bands become rapidly congested. Moreover, the tremendous growth in low-cost wireless applications that utilizes the unlicensed spectrum bands (e.g. ISM bands) leads to the increasing congestion and scarcity of unlicensed radio spectrum resources.

In addition, the experiments from the Federal Communication Commission (FCC) [2] reveal that the spectrum usage is concentrated on certain portions of the spectrum while a significant amount of the spectrum remains unutilized. Consequently, the emerging field of Cognitive Radio Networks (CRNs) [3, 4] is geared towards addressing the problems of spectrum scarcity and spectrum underutilization by enabling the unlicensed users, known as Secondary Users (SUs), to opportunistically utilize the vacant licensed spectrum, such as frequencies licensed for television

---

[1] Corresponding author: Zamree Che-aron

broadcasting, in such a manner as not to cause harmful interference to the licensed users (or Primary Users (PUs)), i.e. the SUs need to immediately vacate the licensed band being used once a PU is detected.

Various routing protocols have been proposed in order to provide efficient routing performance for mobile ad hoc networks [5, 6]. However, with the distinctive characteristics of Cognitive Radio Ad Hoc Networks (CRAHNs) (see Figure 1) that are wireless, multi-hop, self-organized, dynamically topology changing and spectrum availability varying networks [7], the routing protocol must provide multi-radio communication support so that the SUs are able to access multiple radio spectrum bands (both unlicensed and licensed bands) for data delivery.

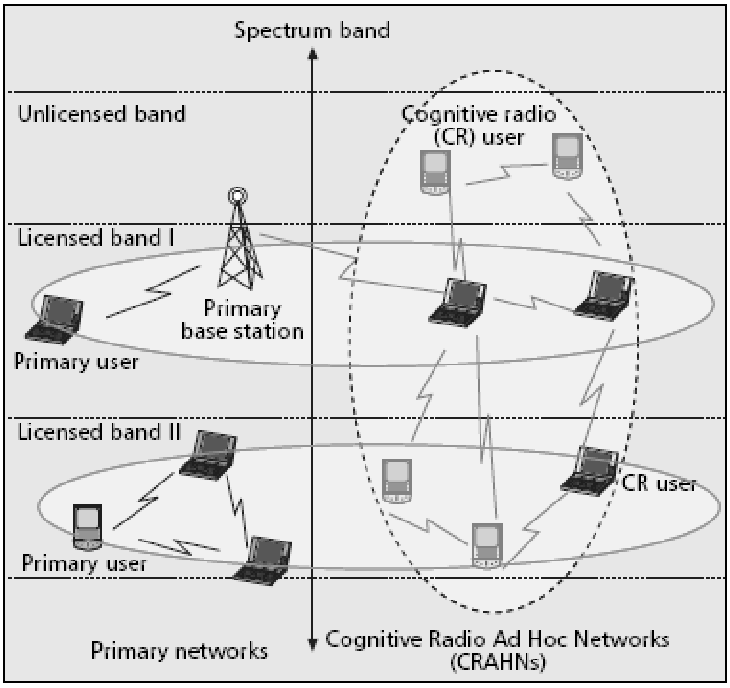

Figure 1. Cognitive radio ad hoc network architecture [7].

In this paper, we evaluate the performance of the Multi-Radio Link-Quality Source Routing (MR-LQSR) protocol [8] in CRAHNs based on different path failure rate by means of simulation using NS-2 [9]. Our evaluation metrics include average throughput, packet loss, average end-to-end delay and average jitter.

The remainder of the paper is organized as follows. We briefly review the MR-LQSR protocol in section 2. The simulation model and parameters are described in section 3. Finally, we present the simulation results and discussion in section 4 followed by the conclusion in section 5.

2. Multi-Radio Link-Quality Source Routing (MR-LQSR) protocol

In [8], the MR-LQSR protocol was proposed by Draves *et al.* that provides multi-radio communication support for multi-hop wireless ad hoc networks. The MR-LQSR is an extension of the Link-Quality Source Routing (LQSR) protocol [10] which is a source-routed link-state protocol derived from DSR (Dynamic Source Routing) [11]. The new routing metric called WCETT (Weighted Cumulative Expected Transmission Time) was presented to provide better route selection by taking into account for not only the link loss rate and bandwidth but also the interference among links that use the same spectrum channel as well as the channel diversity.

The protocol is mainly composed of four components: 1) discovering the neighboring nodes, 2) assigning the weight to links connected with the neighboring nodes, 3) broadcasting the links' weight information to other nodes in the networks, and 4) selecting the optimal path towards the desired destination based on the link weights. For the first and the third component, the MR-LQSR does not require any modification to the DSR's corresponding components. However, the MR-LQSR utilizes the WCETT metric to select a transmission path, while the DSR assigns equal weight to all links in the network and chooses the shortest path for data delivery.

In MR-LQSR protocol, each link is assigned a weight which is equal to the expected time it takes to transmit a fixed-size packet on that link called Expected Transmission Time (ETT). It is defined as:

$$ETT = ETX * \frac{S}{B} \tag{1}$$

where S is the packet size , B is the link bandwidth, and ETX [12] is the expected number of transmissions needed to send a unicast packet on a link, which can be calculated as follows:

$$ETX = \sum_{K=1}^{\infty} K \times S(K) = \frac{1}{(1-P_f)(1-P_r)} \tag{2}$$

where P_f and P_r is the packet loss rate of forward link and reverse link respectively, $S(K)$ means the total packet loss rate of the link, and K is the number of retransmissions.

For a path consisting of n links with assuming that the system has a total of k channels, the definition of WCETT routing metric can be estimated as follows:

$$WCETT = [(1-\beta) * \sum_{i=1}^{n} ETT_i] + [\beta * \max_{1 \le j \le k} X_j] \tag{3}$$

where β is a tunable parameter subject to $0 \le \beta \le 1$ and X_j is the sum of ETT of links using channel j which can be defined as:

$$X_j = \sum_{\text{All links using channel } j} ETT_j \tag{4}$$

For the MR-LQSR protocol, the source node always selects a path with the lowest value of WCETT for data transmission (low WCETT value implies better routes). However, the different values of β can impact the protocol performance. The WCETT uses β as the weight given to the channel-diversity component. When the value of β is high, the protocol always selects paths with more channel diversity. On the other hand, with low value of β, the shorter paths are more preferred.

3. Simulation environment

In this section, we evaluate the protocol performance of the MR-LQSR (at $\beta = 0.6$) in CRAHNs with different number of path failures from 0 to 6 times. The network simulations have been done via NS-2 simulator with Cognitive Radio Cognitive Network (CRCN) patch [13]. The simulations are performed in multi-hop network topology where 25 movable SUs are deployed in an area of 1000 x 1000 m^2. The source-destination node pair is selected to create UDP connections. Each UDP connection transmits CBR traffic with 512 byte packets at packet interval of 0.03 seconds. The IEEE 802.11 standard is used as MAC protocol at bandwidth of 2 Mbps. The Two-Ray Ground model [14] is selected as the wireless propagation type. The simulation time is set to 100 seconds. Table 1 summarizes the simulation parameters.

In addition, we change the number of PUs and the mobility rate of SUs in order to produce different number of path failures occurred during simulation time because, from the simulation results, we observe that the number of path failures varies according to the PUs number and SUs' mobility rate. By increasing the number of PUs or mobility rate of SUs, the number of path failures is higher. During the simulation time, SUs must immediately vacate the channel which overlaps a PU's transmission frequency in order not to cause a harmful interference to the PUs, resulting in a path breakage. Moreover, the increased mobility rate of SUs can make the network topology change more frequent, easily leading to a path failure.

Table 1. Simulation parameters.

Parameters	**Values**
Number of movable SUs	25
Simulation area	1000 x 1000 m^2
Transport layer protocol	UDP
Data packet size	512 bytes
Packet interval	0.03 seconds
MAC layer	IEEE 802.11
Link bandwidth	2 Mbps
Propagation model	Two-Ray Ground
Traffic type	CBR
Simulation time	100 seconds
Interface queue type	DropTail/PriQueue

4. Simulation results and discussion

The simulation results of the MR-LQSR protocol in CRAHNs under different path failure rate are generated in the NS2 output trace files and we analyze the results by using the NS2 Visual Trace Analyzer [15]. The results are displayed in the form of line graphs based on the performance metrics including average throughput, packet loss, average end-to-end delay and average jitter.

In Figure 2, the performance behavior of the MR-LQSR in term of average throughput versus the number of path failures is shown. It is observed that the results of average throughput decrease rapidly when the number of path failures increases. This behavior can be justified because the efficient route recovery algorithm is not provided by the routing protocol. When a transmission path failure is detected, the data traffic is still delivered through the failed path until the source node is informed with a Route ERRor (RERR) packet and finds a new path. As a result, a lot of data packets are dropped in the network, as shown in Figure 3 which exhibits the result of the number of dropped data packets against the number of path failures.

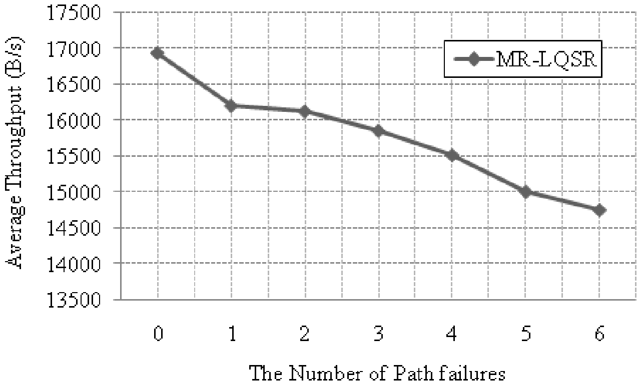

Figure 2. Simulation results of average throughput.

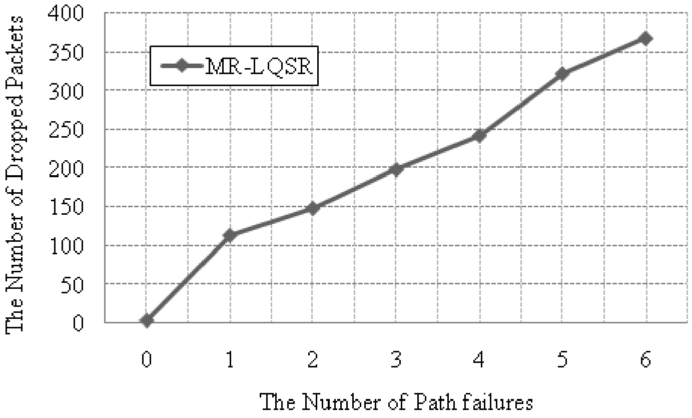

Figure 3. Simulation results of packet loss.

Figure 4 displays the performance behavior of the protocol in term of average end-to-end delay with the number of path failures. From the graph, with increased number of path failures, it is clear that the protocol produces longer average end-to-end delay. With lack of efficient route recovery algorithm, when a transmission path is failed either because of PUs activity or SUs mobility, some data packets are buffered until a new path is discovered, leading to long packet latency. Furthermore, in case a transmission path is broken due to node mobility, the new path which has longer path length is always created for transmitting the next data flows, resulting in higher end-to-end delay.

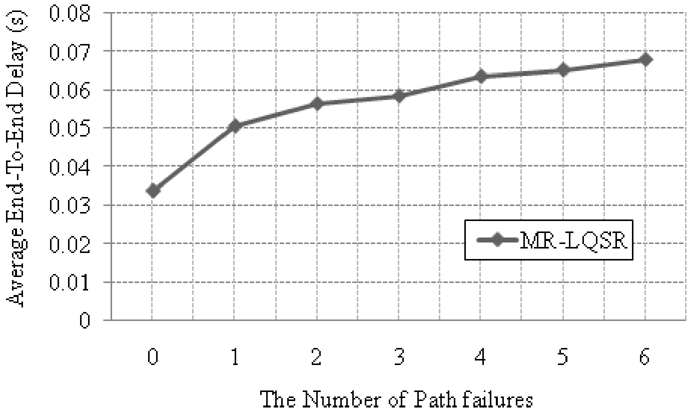

Figure 4. Simulation results of average end-to-end delay.

In addition, the results of average jitter against the increased number of path failures, as shown in Figure 5, exhibit a similar trend to the results of average end-to-end delay. The jitter is defined as a measure of the variability over time of the data packet latency across a network. The average jitter is a significant metric in an assessment of network performance, especially, for a real-time application. A system with lower jitter provides better QoS (Quality of Service). From the graph, it is observed that the results of average jitter rise dramatically when the number of path failures is increased. Due to lack of efficient route recovery mechanism, a path breakage can cause a significant interruption of data transmission, leading to high average jitter.

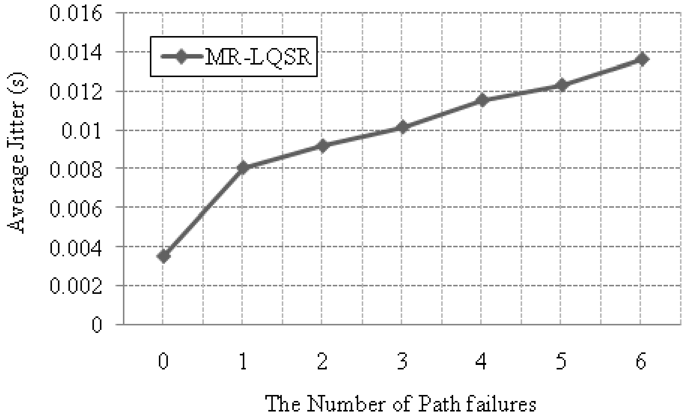

Figure 5. Simulation results of average jitter.

5. Conclusion

Cognitive Radio (CR) technology holds great promises for addressing the problems of spectrum scarcity and spectrum underutilization in order to meet the increasing demand for radio spectrum. As the special network characteristics, CRAHNs have received increasing research attention in recent years. Since such networks do not require any centralized administration or established infrastructure, they can be deployed for a variety of military and civilian applications.

In this paper, the MR-LQSR routing protocol has been reviewed briefly. Additionally, we have simulated the protocol and evaluated the performance in CRAHNs under different path failure rate, using NS-2 simulator. The considered performance metrics are average throughput, packet loss, average end-to-end delay and average jitter. From the simulation results, since the protocol lacks the efficient route recovery algorithm which can quickly repair the broken paths, when the number of path failure is increased that causes significant interruptions of data transmission, the results of average end-to-end delay, average jitter and packet loss rise rapidly. On the other hand, the throughput results decrease dramatically, when the path failure rate is high.

For further research, we plan to investigate and study on how to improve the protocol performance in CRAHN under high path failure rate. We believe that providing the efficient route recovery approach which can cope with a large number of path failures is the right way to further enhance the protocol.

6. References

[1] McHenry M 2003 Spectrum white space measurements *New America Foundation's Broadband Forum*, http://www.newamerica.net/files/nafmigration/archive/Doc_File_185_1.pdf

[2] Federal Communications Commission (FCC) 2003 Notice of proposed rule making and order, ET Docket No. 03-222

[3] Haykin S 2005 Cognitive radio: brain-empowered wireless communications *IEEE Journal on Selected Areas in Communications* **23** 201-220

[4] Mitola J 2000 Cognitive radio --- an integrated agent architecture for software defined radio, PhD Dissertation, Department of Teleinformatics, Royal Institute of Technology (KTH)

[5] Gupta N and Gupta R 2010 Routing protocols in mobile ad-hoc networks: an overview *Proc. Int. Conf. on Emerging Trends in Robotics and Communication Technologies (Chennai)* (New York: IEEE) pp 173-177

[6] Bakht H 2011 Survey of routing protocols for mobile ad-hoc network *International Journal of Information and Communication Technology Research* **1** 258-270

[7] Akyildiz I F, Lee W Y and Chowdhury K R 2009 CRAHNs: cognitive radio ad hoc networks *Ad Hoc Networks* **7** 810-836

[8] Draves R, Padhye J and Zill B 2004 Routing in multi-radio, multi-hop wireless mesh networks *Proc. 10th Int. Conf. on Mobile Computing and Networking (Philadelphia)* (New York: ACM) pp 114-128
[9] Information Sciences Institute (ISI) 1989 The network simulator (NS-2), http://www.isi.edu/nsnam/ns/
[10] Draves R, Padhye J and Zill B 2004 The architecture of the link quality source routing protocol, Microsoft Research Technical Report MSR-TR-2004-57
[11] Johnson D B, Maltz D A and Broch J 2001 DSR: the dynamic source routing protocol for multihop wireless ad hoc networks *Ad Hoc Networking* ed Perkins C E (Massachusetts: Addison-Wesley Longman Publishing) pp 139-172
[12] De-Couto D S J, Aguayo D, Bicket J and Morris R 2005 A high-throughput path metric for multi-hop wireless routing *Wireless Networks* **11** 419-434
[13] Zhong J and Li J 2009 Cognitive radio cognitive network simulator, http://stuweb.ee.mtu.edu/~ljialian/
[14] Eltahir I K 2007 The impact of different radio propagation models for mobile ad hoc networks (MANET) in urban area environment *Proc. 2nd Int. Conf. on Wireless Broadband and Ultra Wideband Communications (*Sydney*)* (New York: IEEE) pp 30-38
[15] Rocha F 2012 NS2 visual trace analyzer, http://nsvisualtraceanalyzer.wordpress.com/

Acknowledgments

We would like to acknowledge the Research Management Centre (RMC) at International Islamic University Malaysia (IIUM) for their support in this research.