Research Journal of Applied Sciences, Engineering and Technology 6(7): 1276-1282, 2013
DOI:10.19026/rjaset.6.3944
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: November 09, 2012 Accepted: December 15, 2012 Published: July 05, 2013

Research Article

The Performance Evaluation of AODV-based and DSR-based Multi-radio Routing Protocols in Cognitive Radio Ad Hoc Network

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Abstract: Due to the huge advancement of wireless technologies, the radio spectrum is one of the most heavily used and costly natural resources. Cognitive Radio (CR) is a promising technology to solve the problem of radio spectrum shortage and spectrum underutilization by enabling unlicensed users to opportunistically access the available licensed bands in an intelligent and cautious manner. In Cognitive Radio Ad Hoc Networks (CRAHNs), which operate without centralized administration, the data routing is one of the most important issues to be taken into account and requires more study. In this study, we analyze and evaluate the performance of AODV-based and DSR-based multi-radio routing protocols (AODV-MR, extended DSR and MR-LQSR) in CRAHN using simulations in NS-2. The metrics used for performance analysis are average throughput, average end-to-end delay and average jitter. From the simulation results, it is observed that the MR-LQSR protocol provides better performance in term of average throughput and gives smallest number of dropped packets. Whereas the extended DSR gives better results of average end-to-end delay and average jitter.

Keywords: Cognitive radio ad hoc network, MR-LQSR, multi-radio AODV, multi-radio DSR, performance evaluation, routing protocol

INTRODUCTION

With the rapid development of wireless technologies, the radio spectrum becomes one of the critical and scarce natural resources in current world. Cognitive Radio (CR) (Haykin, 2005; Akyildiz *et al*., 2006) is an emerging technology with an aim to enhance the spectrum utilization and solve the spectrum scarcity problem by allowing unlicensed users (also called CR users or secondary users: SUs) to opportunistically access the available portions of the spectrum bands, which are underutilized by licensed users (also known as primary users: PUs), for data communication with an intelligent and cautious manner (no harmful interference to the licensed users).

A Cognitive Radio Network (CRN) can be deployed as an infrastructure-based network and an ad hoc network. However, a wireless ad-hoc network (Sarkar *et al*., 2007) is a good architecture to investigate routing metrics in cognitive radio networks. The Cognitive Radio Ad Hoc Networks (CRAHNs) (Akyildiz *et al*., 2009a) are wireless, multi-hop, self-organized, dynamically topology changing and spectrum availability varying networks in which SUs can communicate with each other via ad hoc connection (without any centralized entities). In CRAHNs, each SU is required to act as a router and able to forward packets towards the destination through both licensed and unlicensed spectrum bands as shown in Fig. 1. Therefore routing protocol is a challenging issue in such dynamic environment.

Recent studies on CRN (Le-Thanh and Bao, 2011; Long *et al*., 2011; De-Domenico *et al*., 2012; Sadeghi *et al*., 2012) have mainly focused on spectrum sensing and sharing issues (on PHY and MAC layer) for collecting spectrum information, detecting unused spectrum and providing fair spectrum scheduling method among coexisting CR users (Akyildiz *et al*., 2009b). Consequently, a research on routing protocol (at network layer) for CRN has been largely unexplored.

Many routing protocols have been proposed (Gupta and Gupta, 2010; Bakht, 2011) in order to provide better routing performance for mobile ad hoc networks. The ad hoc routing protocols generally have two routing approaches: proactive (or table-driven) and reactive (or on-demand) routing protocols. By applying table-driven routing protocols, each node in the network maintains a table which contains up-to-date lists of all nodes and their routes. However, the main drawbacks of table-driven strategy include high bandwidth consumption and great routing overhead for maintenance as well as slow reaction on route recreating and failures. As for on - demand routing

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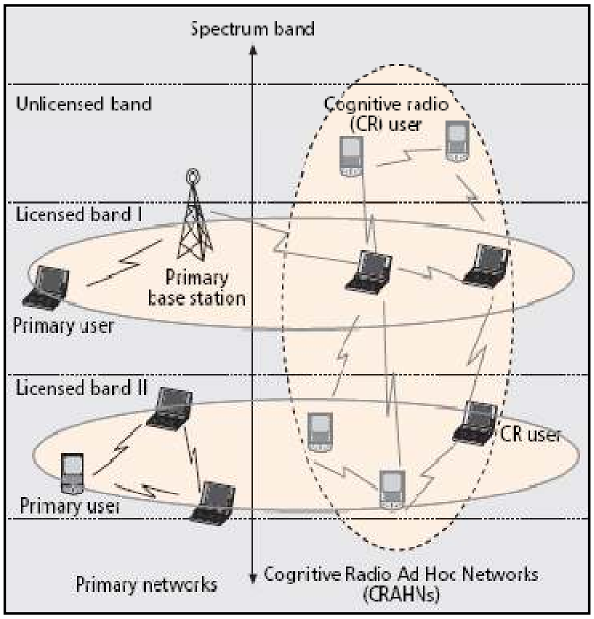


Fig. 1: Cognitive radio ad hoc network architecture (Akyildiz *et al.*, 2006)

protocols, the routes are established only when they are desired by a source node, as a result, the routing overhead is small. The two prominent on-demand routing protocols are Ad hoc On-demand Distance Vector (AODV) (Perkins *et al.*, 2003) and Dynamic Source Routing (DSR) (Johnson *et al.*, 2007). With the unique characteristics of CRAHNs, multi-radio support must be provided by ad hoc routing protocols. In this study, we evaluate the performance of AODV-based and DSR-based multi-radio routing protocols in CRAHN based on varying simulation period. Our evaluation metrics include average throughput, average end-to-end delay and average jitter. To the best knowledge of the authors, our work is the first evaluation of the AODV-MR (Pirzada *et al.*, 2006), the extended DSR (Biaz *et al.*, 2007) and the MR-LQSR protocol (Draves *et al.*, 2004a) in CRAHN by means of simulation using NS-2 (ISI, 1989).

MULTI-RADIO AODV

The Multi-Radio Ad-hoc On-demand Distance Vector (AODV-MR) routing protocol (Pirzada *et al.*, 2006) has been developed for multi-radio dynamic wireless mesh networks as a multi-homing extension to AODV protocol (Perkins *et al.*, 2003). The AODV-MR makes efficient use of the multi interfaces for multi-radio communication support to improve spectrum utilization and reduce interference as well as contention in the network. Each radio can operate only on one of non-overlapping channels.

The transmission route will be created on demand (only when it is required) by flooding the network with Route Request (RREQ) packets. In contrast to the original AODV, if a source node needs to transmit data to a destination node whose route is not known, it will broadcast a RREQ packet through all interfaces. After the RREQ packets are received by intermediate nodes which do not know the information of fresh route towards the destination, the nodes update their routing information and forward the RREQ packet over all interfaces except the one on which the packet is previously received in order to form a multi-hop path composed of links using non-overlapping radios. When the RREQ packet are arrived at the destination or any intermediate nodes that has a fresh route to the destination, a Route Reply (RREP) packet will be generated and forwarded back along the reverse path using same interfaces, as used by the RREQ, to the source node. Once the RREP packet reaches the source node, the transmission path is established and then the data transmission process is activated. As similar to AODV, the hop-count is used as routing metric implying that the protocol always selects the shortest path for data communication. In case a link failure for a next hop on the transmission route is found, the node that detected the link break generates a Route Error (RERR) packet and sends it to all its neighbors which are using the route for data delivery. Subsequently, the route recovery mechanism will be launched.

In a node's routing table (Fig. 2) that contains the necessary information for forwarding a packet toward its destination, the "Network Interface" field stores the interface number that indicates the network interface through which a data packet is sent to a next hop along the transmission path. The "Precursors List" field contains the list of neighboring nodes to which a RREP packet was forwarded. The expiration or deletion time of a route entry is kept in a field of "Lifetime".

Destination IP	Destination Seq. No.	Destination Valid Flag	State Flags	Network Interface	Hop Count	Next Hop	Precursors List	Life time

Fig. 2: AODV-MR routing table fields

Source IP	Request ID	Source Radio Index	Destination IP	Route Record Series

Fig. 3: Modified RREQ packet format

MULTI-RADIO DSR

Biaz *et al*. (2007) proposed the extended Dynamic Source Routing (DSR) protocol for multi-radio multi-hop networks to alleviate the limited capacity and poor scalability problem by taking advantage of multi radio feature. Each node in the network is equipped with multiple radio interfaces. In order to avoid the co-channel interference during communication process, the radios are assigned to non-overlapping channels. The extended DSR is an on-demand (reactive) routing protocol which initiates a route discovery throughout the network only when it wants to transmit data packets to the destination and it is also based on the concept of source routing through which a source node determines the complete hop-by-hop route to the destination.

The two main mechanisms of the extended DSR are route discovery and route maintenance, which work together to allow nodes to create and maintain source routes to the destinations. Unlike the traditional DSR, in the route discovery process, a source node that does not know a route to the destination broadcasts a RREQ packet on all its radio interfaces to its neighbors. A REEQ contains the request ID, the address of the source and destination node as well as a route record which records the sequence of nodes on the path from the source to the target node. As shown in Fig. 3, the extra field of “Source Radio Index” is added to the packet header in order to support the multi-radio communication. Upon receiving the RREQ, a node checks if it knows a route to the destination or itself is the destination. In both cases, the node generates a RREP packet and returns it back to the source node by following the reverse path that is generally the reverse of “Route Record” field in the received RREQ packet. Otherwise, the node appends its address to the “Route Record” field and also the radio index to the “Source Radio Index” field indicating on which radio the RREQ will be forwarded before re-broadcasting it to the neighbors. In contrast to the original DSR, a node will not discard a RREQ packet previously seen (further RREQ with same request ID and source address) as long as the hop-count is lower. After the RREP packet is arrived at the source node, it can start transmitting data packets to the target node along the cached route.

In the process of route maintenance, when the transmission path is broken and a node detects the failure, it immediately sends a RERR packet to the source of the route. In such a case, the source node can use an alternative route to the destination, if it knows one, or, otherwise, invoke the route discovery process.

MULTI-RADIO LINK-QUALITY SOURCE ROUTING (MR-LQSR)

In Draves *et al.* (2004a), the MR-LQSR protocol was primarily proposed with an aim to support the multi-radio multi-hop wireless mesh networks. The MR-LQSR is an extension of the Link-Quality Source Routing (LQSR) protocol (Draves *et al*., 2004b) which is a source-routed link-state protocol derived from DSR (Johnson *et al*., 2007). 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:

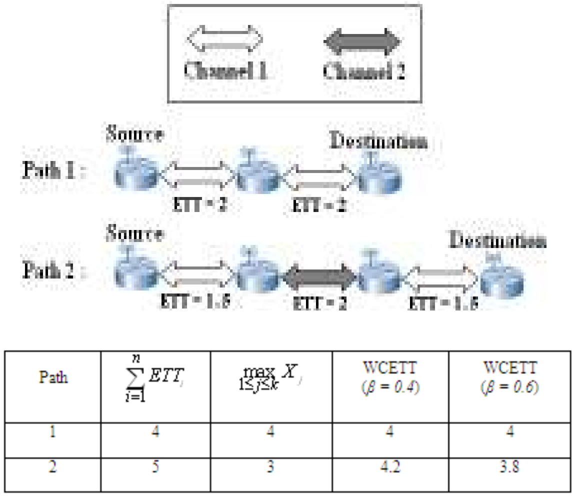
- Discovering the neighboring nodes
- Assigning the weight to links connected with the neighboring nodes
- Broadcasting the links’ weight information to other nodes in the networks
- Selecting the optimal path towards the desired destination based on the link weights

For the first and the third component, the MR-LQSR does not require any modification to the DSR’s corresponding components. As different from DSR protocol, 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, *ETX* (Couto *et al*., 2005) is the expected number of transmissions needed to send a unicast packet on a link, *S* is the packet size and *B* is the link bandwidth.



Path	$\sum_{i=1}^{n} ETT_i$	$\max_{1\leq j\leq k} X_j$	WCETT ($\beta = 0.4$)	WCETT ($\beta = 0.6$)
1	4	4	4	4
2	5	3	4.2	3.8

Fig. 4: An example of WCETT

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:

$$WCETT = [(1-\beta) * \sum_{i=1}^{n} ETT_i] + [\beta * \max_{1\leq j\leq k} X_j] \tag{2}$$

where,

β = A tunable parameter subject to $0 \leq \beta \leq 1$

X_j = The sum of *ETT* of links using channel *j* which can be defined as:

$$X_j = \sum_{\text{All links using channel } j} ETT_j \tag{3}$$

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 low, the protocol always selects paths with less channel diversity. On the other hand, with high value of β, the shorter paths are more preferred. As shown in Fig. 4, the source node has the routing information of Path 1 and Path 2 for the destination node. If we consider $\beta = 0.4$, Path 1 which uses only one channel (channel 1) has two hop-counts with WCETT = (0.6 x 4) + (0.4 x 4) = 4. Meanwhile, Path 2 utilizes two channels and has three hop-counts with WCETT = 4.2. Therefore, Path 1 (shorter path) will be selected for data delivery. However, if β is set to 0.6, Path 2 has lower value of WCETT as compared to that of Path 1. As a result, the source node will choose Path 2 (more channel-diversity path) for data transmission instead.

Table 1: Simulation parameters

Parameters	Values
Simulation area	1000 × 1000 m^2
Propagation model	Two-Ray Ground
Traffic type	CBR
Transport layer	UDP
MAC layer	802.11
Number of SUs	10
Number of PUs	2
Data packet size	512 bytes
Packet interval	1 second
Link bandwidth	2 Mbps
Interface queue type	DropTail/PriQueue
Interface queue length	50

SIMULATION ENVIRONMENT

In this section, we evaluate the protocol performance of the AODV-MR, extended DSR and MR-LQSR (at β = 0.6) with varying the simulation time from 25 to 200 seconds. The network simulations have been done via NS-2 simulator (ISI, 1989) with Cognitive Radio Cognitive Network (CRCN) patch (Zhong and Li, 2009). The simulations are performed in multi-hop network topology where 10 SUs and 2 PUs are randomly deployed in an area of 1000 x 1000 m^2. The source-destination node pairs are randomly selected to create random UDP connections. Each UDP connection transmits CBR traffic with 512 byte packets at packet interval of 1 second. The IEEE 802.11 standard is used as MAC protocol at the bandwidth of 2 Mbps. The type of the wireless propagation is Two-Ray Ground model (Eltahir, 2007). Table 1 summarizes the simulation parameters.

The simulation results are generated in an output trace file and we analyze the results by using the NS2 Visual Trace Analyzer (Rocha, 2012). The average throughput, average end-to-end delay and average jitter are the metrics used for performance evaluation.

SIMULATION RESULTS AND EVALUATION

The simulation results are displayed in the form of line graphs which exhibit the result comparison between the three protocols based on the above-mentioned metrics by varying the simulation period.

Average throughput analysis: Figure 5 shows the impact of increasing simulation period on average throughput. We observe that, with the increased simulation period, the throughput improvement is more rising. In comparison, the MR-LQSR gives the highest

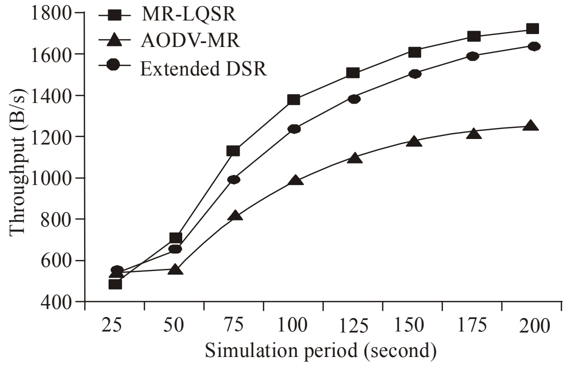


Fig. 5: Comparative results of average throughput

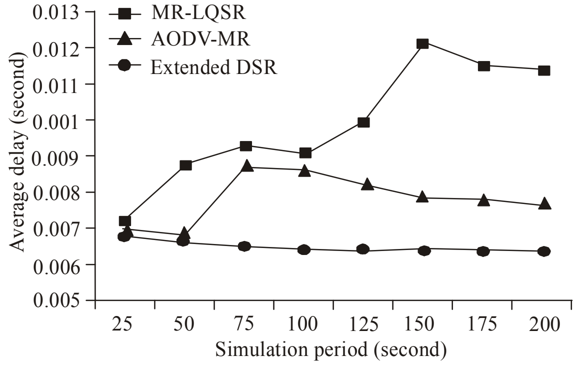


Fig. 6: Comparative results of average end-to-end delay

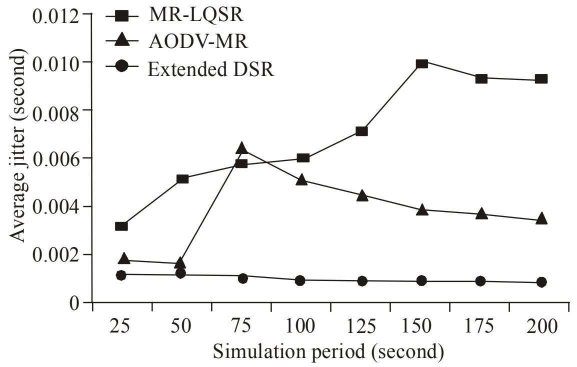


Fig. 7: Comparative results of average jitter

throughput on the average. However, the extended DSR provides higher average throughput than AODV-MR. As expected, since the MR-LQSR considers various factors (not only hopcount as in the extended DSR and AODV-MR) to form a transmission path, the MR-LQSR always create more robust path for data delivery and, as a result, reduce a number of dropped packets due to the interference caused by PU activity. The AODV-MR has a lower throughput than the extended DSR due to higher drop rates. Since the route expiry approach is used in AODV-MR, consequently, when a route expires, many packets are dropped and a new route must be discovered.

Average end-to-end delay analysis: The comparative results of average end-to-end delay against the increased simulation period are exhibited in Fig. 6. As illustrated, the extended DSR performs better than other protocols. The MR-LQSR protocol have the longest delay because their route discovery takes more time as the optimal path is selected based on the link weights (WCETT metric). Furthermore, various factors including link loss rate, bandwidth, interference and channel diversity are taken into account for route selection resulting in producing a longer transmission path as compared to the shortest-path approach in the extended DSR and AODV-MR. However, the AODV-MR provides higher delay than the extended DSR because of giving slower route discovery.

Average jitter analysis: Figure 7 displays a comparison on the basis of average jitter as a function of simulation period. In the simulation, 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, in a real-time application. A system with lower jitter provides better QoS (Quality of Service). From the graph it is clear that the extended DSR outperforms the other protocols in term of average jitter due to the shortest-path scheme and faster route discovery. Although the MR-LQSR provide more robust transmission path, it may suffer from a long path length resulting in high average jitter. As similar to the results of average end-to-end delay, the AODV-MR provides higher jitter as the extended DSR on the average.

CONCLUSION

As the special network characteristics, CRAHNs have received increasing research attention in recent years. Moreover, there are many active research projects concerned with CRAHNs including research on routing protocol (at network layer) since traditional ad hoc routing protocols may not be suitable for the above-mentioned networks. Our work is an attempt towards a comprehensive performance evaluation of AODV-based and DSR-based multi-radio routing protocols in CRAHN. In this study, protocol performance of the AODV-MR, the extended DSR and the MR-LQSR in CRAHN was evaluated under CBR traffic with varying simulation period, using NS-2 simulator. Performance metrics considered are average throughput, average end-to-end delay and average jitter.

From the simulation results, we conclude that the MR-LQSR provide the most robust transmission path since various metrics including link loss rate, bandwidth, interference and channel diversity are taken into account for path selection. As a result, it gives highest average throughput and smallest number of dropped packets. However, it may establish a longer path resulting in high average end-to-end delay and average jitter. On the other hand, the AODV-MR and the extended DSR which utilize the shortest-path approach perform well in term of average end-to-end delay and average jitter. It is clear that the extended DSR outperforms the AODV-MR for all above-mentioned performance metrics because of giving faster route discovery and not using route expiry approach as in AODV-MR.

For the future work, the enhancement of the MR-LQSR protocol on route selection algorithm and route maintenance mechanism in order to address their limitations will be carried out. Furthermore, the protocol performance will be evaluated in extensive complex simulations using more performance metrics.

ACKNOWLEDGMENT

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

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