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Jitter Performance of Routing Protocol in Cognitive Radio Wireless Mesh Networks

Shamimul Qamar

Department of Computer Networks and Communication Engineering

King Khalid University,Abha, KSA

Abstract—Cognitive Radio (CR) has emerged a potential solution which addresses the challenges of radio frequency (RF) spectrum scarcity, underutilization and inefficient utilization. Due to recent advancements in multimedia, social networking, wireless applications and mobile application technologies, the demand of RF spectrum has increased exponentially. The CR technology enables the RF spectrum to be shared amongst the licensed and unlicensed users in an intelligent and opportunistic manner. However, the conception of a shared spectrum evolution has introduced a number of unique challenges in wireless networking, requiring efficient novel techniques to transmit data in wireless networks. A Wireless Mesh Network (WMN) is a collection of wireless mesh nodes that communicates with each other without using any existing infrastructure, access point or centralized controller. In WMN, as nodes moves in and out of the network, the topology of the network changes frequently and thus, routing becomes a challenging task. A variety of routing protocols with varying network conditions are analyzed to find an optimized path from a source to destination.

The focus of this paper is on the routing layer of the multi- hop cognitive radio based wireless mesh networks. Routing in multi-hop networks plays a vital role in the establishment and maintenance of communication routes. We analyze and evaluate the performance of the three candidate routing protocols, namely: Ad-Hoc On-Demand Distance Vector (AODV), Inter Zone Routing Protocol (IERP). The three routing protocols are evaluated using the end-to-end delay, jitter, throughput, packet delivery ratio and normalized routing overhead metrics. We simulated the performance of the these protocols using NS2 with Cognitive Radio Cognitive Network (CRCN) patch. The numerical results obtained show that the proposed IERP protocol offered better performance in term of the end- to-end average latency, throughput and packet delivery ratio. It also attained the lowest routing overhead as compared to the AODV and CRCN Inter Zone Routing Protocol (IERP), reserving more bandwidth for data transmission.

Keywords — Cognitive Radio, Cognitive Radio Network, IERP Radio Frequency Spectrum, Routing Protocol, Wireless Networks

I. INTRODUCTION

The idea of ubiquitous computing has brought greater innovation and developments in many areas of technology. Over the past decade alone, we have seen both the wired and wireless technologies advance to support applications such as social networking, online gaming, mobile voice over Internet protocol (VoIP), mobile cloud storage, videoconferencing, etc. These applications and many others require high speed communication infrastructure for effective and efficient support. Statistics provided by [1] estimates that by 2020 the wireless and mobile traffic data will increase 1000 fold with respect to half a decade ago or a doubling of wireless/mobile data traffic almost every year. Continuous growth of this magnitude requires significant increase in the capacity and performance of wireless networks. Furthermore, the natural radio frequency (RF) spectrum resource is becoming more and more crowded, resulting in spectrum scarcity [2][3]. Such problems of spectrum scarcity and inefficient utilization of spectrum in wireless communication environments can be solved by Cognitive Radio (CR) technology. CR provides intelligent platform to enhance utilization of the RF spectrum and other network resources, thus providing the capacity and capability required in wireless communication environments. The

International Telecommunication Union (ITU) defines CR system as a radio transmitter or receiver employing the technology that allows RF operating parameters such as frequency range, modulation type, or output power to be dynamically set or changed by the software [4]. This CR technology allows opportunistic spectrum channel sharing between unlicensed users referred to as secondary users (SUs) and licensed users also referred to as primary users (PUs).

Unlike the traditional wireless networks, the multi-hop CR networks pose unique challenges due to high fluctuation of the available spectrum, mobility of nodes, limited resources, and the diverse quality of service (QoS) requirements required by different applications. Each CR user in the network must therefore deal with the following conditions [5 - 7]:

[5] Determine a set of available channels in a given RF spectrum band.

[6] Select the best available channels and links to transmit network traffic.

[7] Coordinate access to a channel with other users in the network.

[8] Vacate the channel as soon as the PU activity is detected to avoid any harmful interference.

The potentials of CR technology can be applied in different environments and in this paper, we consider a multi- hop cognitive radio wireless mesh networks (CR-WMNs). The key issue in such CR-WMN environment is the routing problem due to, but not limited to, dynamic resource availability, uncertain activities of PU, limited spectrum resources, resource constraints, as well as dynamic topology caused by node mobility in the network. These dynamics can easily affect or degrade the performance of a routing protocol employed in the network. The routing protocol must also satisfy the requirements of both the traditional wireless ad- hoc networks as well as CRNs because the CR-WMNs combine features of both technological environments. We evaluate and analyze the performance of three routing protocols, namely: Ad-Hoc On-Demand Distance Vector (AODV), Cognitive Radio Cognitive Network (CRCN EIRP , and Inter Zone Routing Protocol (IERP) based on CRCN. The IERP was proposed by authors in [5] and its design is based on a combination of AODV and CRCN EIRP routing protocol.

The rest of the paper is organized as follows: Section II presents related work; Section III presents the design of IERP routing protocol based on multi-radio multi- channel CRN architecture; Section IV presents the methodology and simulation environment. In Section V, we present the analysis of the results. Section VI concludes the paper.

II. RELATED WORK

In the past decade, many researchers working in the area of cognitive radio routing proposed a number of routing protocols to improve routing performance in multi-hop cognitive radio networks [9-14]. A number of these research work attempts to address the unique problems and challenges introduced by the paradigm shift from static spectrum bands to dynamic and heterogeneous spectrum bands. The proposed routing protocols are based on unique or similar design and optimization goals such as, but not limited to, avoiding interference with PUs, minimizing end-to-end-delay, maximizing bandwidth availability and utilization, as well as increasing the throughput rates.

Our work is in parts similar to [15] and [16]. The authors evaluated the performance of AODV and CRCN EIRP routing protocol in Cognitive Radio Ad-Hoc Network (CRAHN) without modification to the two candidates routing protocols. Our work evaluates how the two routing protocols perform in a dynamic multi-hop CRN environment and further extends the EIRP protocol in order to improve its performance in CRN.

The authors in [17] proposed a reactive Cognitive Ad-hoc On-demand Distance Vector (CAODV) protocol for CRAHN environment. Their work focused on the design of routing protocol based on three optimization criteria: avoiding the regions of PU activities, joint path and channel selection at each forwarding node, and exploitation of multiple available channels to improve the network performance. However, the proposed CAODV protocol is based on a common control channel (CCC) strategy which creates another challenge in dynamic CRN environment. The assumption of having the CCC may not be feasible due to the dynamic channel availability.

The authors in [18] proposed a routing scheme that calculates the routes from source to destination node based on the activities and placement of PUs in cognitive radio networks. The likelihood of exploiting multiple RF frequency channels at the same time is explored. The design of the proposed routing scheme is based on joint routing and spectrum selection criteria which calculate the most likely set of routes between the source and the target node. The resource requirements stated by the application are also taken into consideration. However, utilising multiple channels simultaneously implies broadcasting the routing packets on all available set of channels, creating the routing overhead on all channels in the network. Thus, more network resources are consumed and inefficiently utilised.

The authors in [19] attempts to address the problem common to distributed routing protocols in CRNs whereby the path selection and channel decisions are made in sequence. The nodes share channel availability information by adding such information onto each control packet as packets move from one node to the second node. The result of this strategy is multiple traffic flows in the network and higher routing overhead, thus resulting in inefficient usage of bandwidth. Furthermore, the proposed spectrum-aware routing protocol was developed as better routing solution for the cognitive radio mesh network environment. The protocol opportunistically selects channels with higher spectrum availability and high quality while striking the balance between long-term route stability and short-term opportunistic network performance.

More distinguished routing protocols proposed for multi- hop cognitive radio based network environments include the works proposed by authors in [21 -26]. Most of these proposed routing techniques attempt to address the issues and challenges encountered in cognitive radio based multi-hop wireless networks, thereby designing and implementing the most efficient routing algorithms.

III. THE IERP ROUTING PROTOCOL

The authors in [8] proposed a routing protocol called IERP whose design is based on AODV [27] and OLSR. In this paper, we evaluate the performance of IERP routing protocol against the AODV and multi-radio multi-channel OLSR routing protocols. The IERP protocol integrates the features from both the AODV and OLSR protocols and further incorporates the dynamics of multi-hop CRN environment such as dynamic spectrum channels, dynamic topology and intermittent PU activities. We implemented the protocol in NS2 by modifying the OLSR routing protocol provided by the CRCN [28] patch. The IERP protocol selects the best and stable routing paths based on the following metric:

= (1 –)+ [(1 -)] (1)

The *ETT* l_i denotes the expected transmission time for each link from source to destination node, *Pc* represents the probability that channel *c is* unavailable due to PU activities. This factor is based on the PU channel usage pattern (i.e. an assumption that each SU node is able to monitor and compute the probabilistic measure of a channel based on the knowledge of PU channel usage statistics). This route metric is formed by two parts that are considered a trade- off between the throughput and the delay, depending on the value assigned to the tuning parameter (0 :: a :: 1). Finally, the *Xc* represents a set of channels assigned to SUs. Furthermore, considering the PU channel usage statistics, this metric prioritizes stable source-destination routes by avoiding selection of channels that have a higher probability of occupancy.

The IERP protocol implements the above mentioned routing metric to select the best route from source to destination node. Route discovery and maintenance is quite similar to AODV [27] and the route request (RREQ) and route reply (RREP) messages are used to establish connection between the source and destination nodes. The RREQ control packet is generated and sent on multiple available channels every time the source node wants to communicate with some destination node. The RREQ packets are only broadcast on available channels to ensure non-interference with PUs. During route discovery process, the source node generates RREQ packet and forwards to its neighbour nodes. Each node receiving RREQ packet checks whether the packet is new or it was previously received by comparing the packet against its routing table. If the RREQ entry is new, the node appends the list of available channels onto the RREQ packet and rebroadcasts it. When the destination node receives the RREQ packet, it computes the best route (reverse route) to the source node based on the routing metric presented in (1). The best route is computed according to available set of channels at each node. The destination node sends a RREP control packet back to the source node. The source node then initiates data transmission process and transmits data packets on the path established. Whenever a channel becomes invalid or unavailable, the route error (RERR) control packet is generated and propagated only on free set of channels per node [29][30]

The design of IERP routing protocol is based on the multi-radio multi-channel architecture illustrated in Fig 1. The TCL script is used to configure the number of radios and channels needed for simulations. In our case, the number of radios was set to two and the number of channels was set to four. The primary idea is to create multiple radios and multiple channels through the TCL library invokes the creation of several copies of link layer (LL), queue, MAC, network interface (NetIf), and channels for each radio in C++ library.

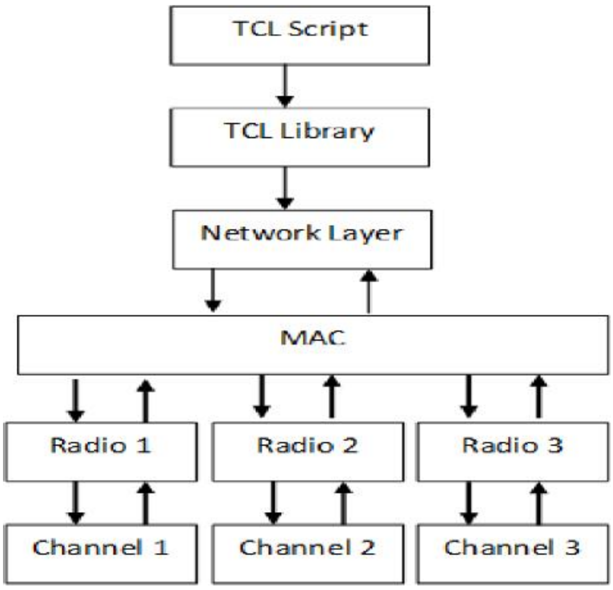

Fig. 1: Design overview of multi-radio multi-channel routing architecture [28]

IV. SIMULATION ENVIRONMENT

The simulation experiments were conducted using the open source object-oriented discrete-event network simulation software called NS-2 version 2.31 [31] with a Cognitive Radio Cognitive Network (CRCN) patch [32] to enable the cognitive radio functionality. The ns-2 simulator was configured to run on Ubuntu 12.04 distribution of the Linux operating system. We employed the awk stream processing language, perl scripting, python scripting utilities to manipulate the output trace files and render the results graphically using Gnuplot.

Our simulation experiment is based on a hybrid multi-hop cognitive radio network topology with both static and dynamic cognitive radio nodes. The network was constructed with 20 secondary user nodes (SUs) and two PU nodes randomly deployed in 1000m x 1000m grid. The PUs represent the primary license-holder of the designated spectrum band and the SUs operate under the constraint that they first need to sense a set of available and unused channels without causing interference to PUs.

The SUs are equipped with two radios, one radio to monitor and sense available channels and the other radio for control messages and data transmission. The total number of channels allocated to SUs is four. The source and destination nodes are randomly selected to create UDP connections and transmit a flow of CBR traffic with 1024 byte packets.

The mobility speed of SUs is varied between 1 m/s – 5 m/s with two-ray ground reflection propagation model. Two SUs can communicate directly when they are both within the radius of 200m, otherwise a multi-hop communication mode must be applied. Other simulation parameters were configured according to Table 1.

The results of our simulation are presented and analysed in the next section. The network performance metrics used in our study are end-to-end and average latency, jitter, throughput, packet delivery ratio and normalized routing overhead.

TABLE 1: NETWORK SIMULATION PARAMETERS

Simulation Parameter	Assigned Value
Topography	1000 m x
Primary users	3
Secondary users	25
Secondary user radios	2
Secondary user channels	3
Mobility model	Random Waypoint
Secondary user mobility speed	1 m/s – 6 m/s
Transmission range	250 m
Medium access control	Macng
RF Propagation Model	TwoRay Ground reflection
Antenna type	Omni-directional
Traffic type	ACBR/
Packet size	1024 bytes
Routing protocols	AODV, WCETT, EIRP
Simulation time	400 s

V. RESULTS AND DISCUSSION

This section presents the results of our study. In Fig 2, we present the end-to-end latency performance comparative results obtained by the three candidates routing protocols under investigation.

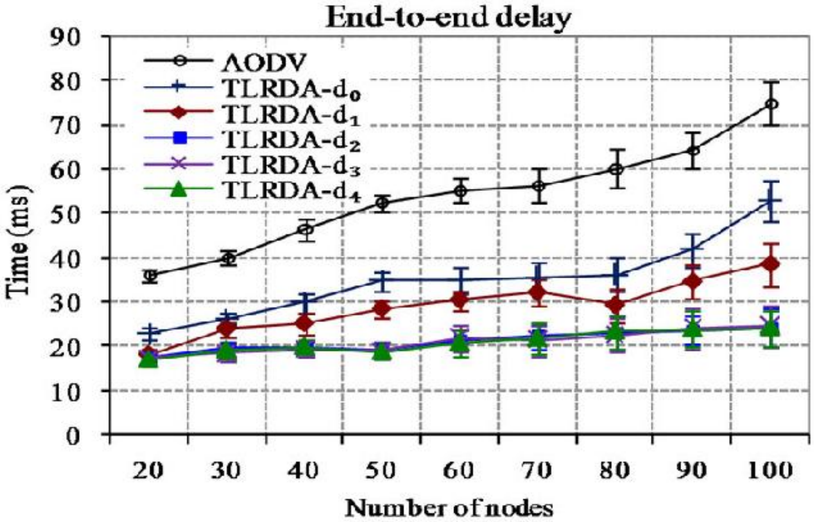

Fig. 2: The end-to-end latency performance comparison

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We observe in Fig 2 that the xWCETT is able to maintain a stable and minimal end-to-end latency in comparison to the AODV and WCETT. This behaviour indicates a stable and robust performance in a multi-hop CRN environment where the random and intermittent PU activities are likely to destabilise network connectivity and degrade network performance.

Fig 3 presents the average latency performance results. We observe in Fig 3 that the latency obtained by xWCETT is minimal on average as compared to the AODV and WCETT. The WCETT protocol has the average latency slightly higher than xWCETT primarily because WCETT protocol was designed for a pure multi-radio multi-channel architecture which may be partially comparable to CRN environment. However, the architecture of WCETT does not take into account the dynamic availability of RF spectrum channel set. Therefore, its performance in a dynamic CRN environment degrades due to the dynamically changing availability of spectrum channels. The presence of random PU activities causes WCETT and AODV to suffer increased end- to-end latency due to the dynamics of CRNs.

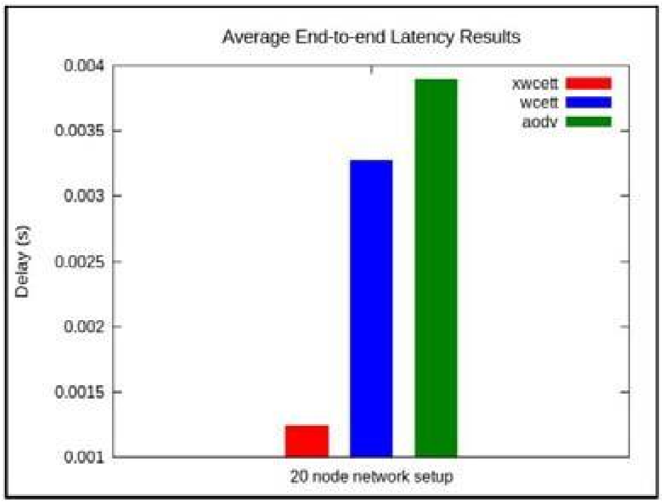
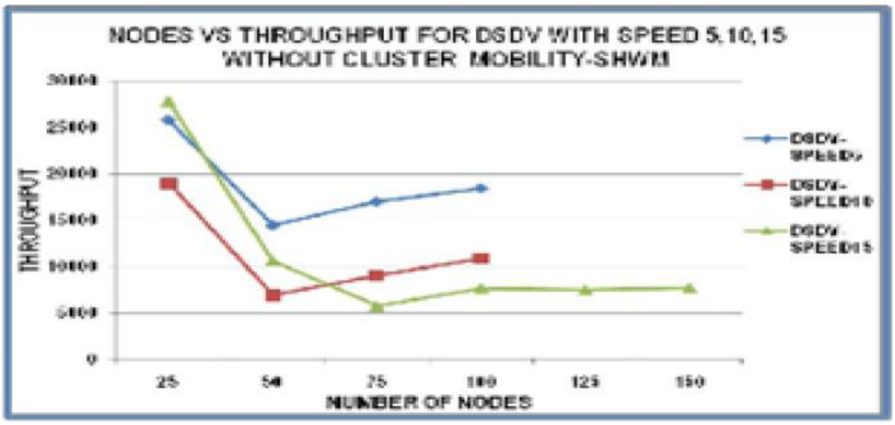


Fig. 3: The average latency performance results

Fig 4 presents the comparative end-to- end throughput performance results obtained by the three protocols. We observe unsteady but higher throughput performance results for xWCETT as compared to the two routing counterparts. This unsteady behaviour is attributable to the presence of PUs and multiple traffic flows in the network. The channel switching and route re -establishment process appear to affect the steady throughput performance of all the three routing protocols as indicated in Fig 4.



The average end-to-end throughput results are presented in Fig 5.

Fig. 4: The end-to-end throughput performance results

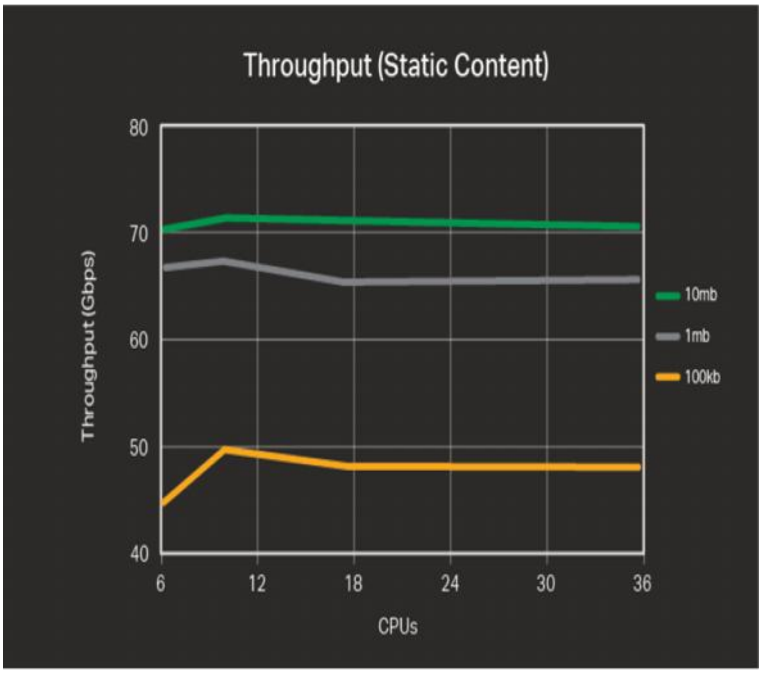


Fig. 5: The average throughput performance results

From Fig 5, we observe that the average delay results obtained by each protocol have a direct bearing on the throughput rate and ultimately, the bandwidth utilization. The shorter the time packets traverse from source to destination node, the higher the number of packets transmitted, providing higher network throughput. The xWCETT was able to obtain a much higher throughput rate when compared to the two routing counterparts.

The next two figures present the average jitter and packet delivery ratio (PDR) respectively.

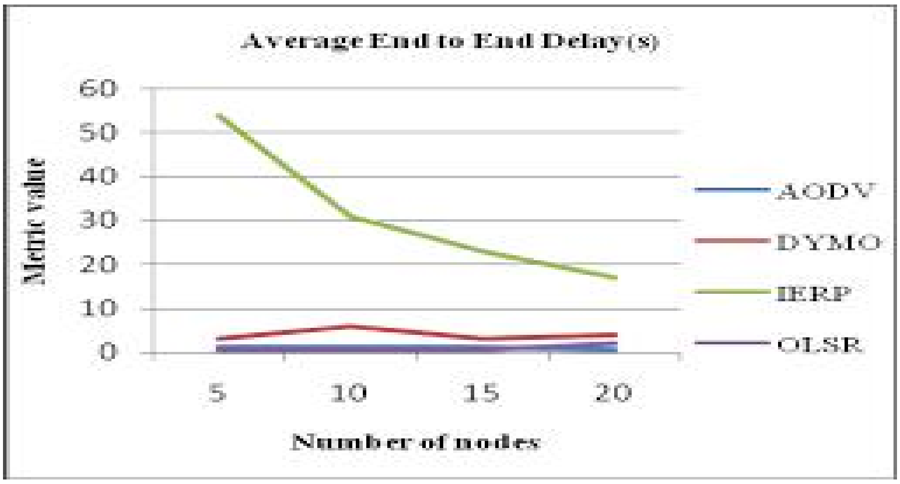


Fig. 6: The average end-to-end jitter performance results

The average jitter results obtained indicate that the IERP protocol suffers in terms of delay variations per packet delivery and so far we can only attribute such behaviour to the multiple dynamics inherent in multi-hop CRN environment.

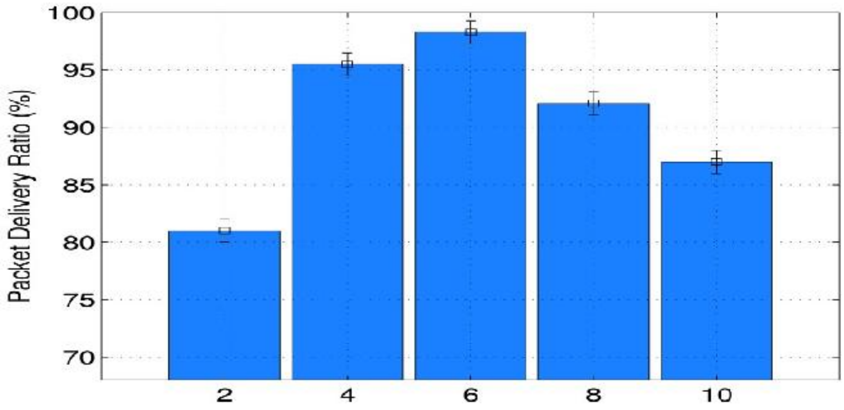


Fig. 7: The packet delivery ratio results

The performance in terms of the PDR (as observed from Fig 7) also favours the IERP due to its flexibility in discovering available channel set and its ability to recover from route failures. The higher throughput obtained by IERP indicates that fewer packets are lost as compared to the congestion prone AODV and inflexible IERP in the CRN environment.

FIGURE7 presents the total and average number of hops traversed by each of the three routing protocols. We observe from the table that AODV has traversed less number of hops and has a lower average hop count mainly because it uses the shortest path Dijkstra's algorithm. However, it degrades performance due to the dynamic nature of the cognitive radio environment. On the other hand, OLSR and IERP packets traverse longer paths with improved performance primarily because they are adapted to cognitive radio environment in terms of channel diversity and the mechanisms employed to establish the best path.

As it can be seen the normalized load generated by IERP is less in comparison to AODV and OLSR. This shows good performance and utilization of network resources as minimal routing packets transmitted utilizes bandwidth efficiently for data transmission. Higher routing load generated by the AODV and IERP results in increased end-to-end average delay and reduced average throughput rate as observed in Fig 3 and 5.

VI. CONCLUSION

This paper presented the comparative performance results of three routing protocols, AODV, IERP and OLSR . Simulation results show that the proposed IERP protocol performed better that the AODV and OLSR in terms of end-to-end latency, throughput, packet delivery ratio and routing overhead. The OLSR protocol obtained results close to the IERP and outperformed its successor IERP protocol in terms of steady end- to-end delay variations (jitter). On the other hand, the AODV protocol was unstable in cognitive radio environment as it suffered high end-to-end latency, low throughput rate and low packet delivery ratio. The IERP protocol was able to maintain stable and robust performance.

The future work will involve extensive experimental simulations and analysis to validate the performance and effectiveness of the IERP routing protocol under more complex and dynamic cognitive radio environment.

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