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Original Article

Design, Simulation, and Performance Evaluation of Reactive and Proactive Ad-Hoc Routing Protocols

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Abstract
The primary goal of this study is to investigate and evaluate the performance of wireless Ad-Hoc routing protocols using the OPNET simulation tool, as well as to recommend the most effective routing strategies for the wireless mesh environment. Investigations have been testified to analyze the performance of the reactive and proactive Ad-Hoc routing protocols in different scenarios. Application and wireless metrics were configured that were used to test and evaluate the performance of routing protocols. The application metric includes web browsing metrics such as HTTP page response time, voice and video metrics such as end-to-end delay, and delay variation. The wireless network metrics include wireless media access delay, data dropped, wireless load, wireless retransmission attempts, and Packet Delivery Ratio. The simulations results show that the AODV overcome DSR and OLSR in terms of PDR (76%), wireless load (22.692 Mbps), voice delay variation (102.685 ms), HTTP page response time (15.317 sec), voice and video packet end-to-end delay (206.527 and 25.294 ms), wireless media access delay (90.150 ms), data dropped (10.003 Mbps), wireless load (22.692 Mbps), and wireless retransmission attempts (0.392 packets).

Keywords
Wireless Mesh Network, Ad-Hoc, AODV, DSR, OLSR, Routing Protocols.

I. Introduction

The majority of the required components, including Ad-Hoc network routing protocols, wireless security protocols, and IEEE 802.11 MAC protocol, are already widely available, making it simple to put Wireless Mesh Networks (WMNs) into use [1]. Wireless Mesh Networks (WMN) present an advanced architecture of wireless broadband Internet access by offering high data rate service, flexibility, and self-healing capabilities at a lower cost. WMNs are developing with associated services and applications. Digital homes, broadband Internet connectivity, building automation, health systems, networking for emergencies and disasters are just a few of the new uses for WMNs [2].

WMNs, which is a subset of mobile ad hoc networks (MANET), is an infrastructure network based on IEEE 802.11 in which stations and access points can transmit data on behalf of other access points in an ad hoc attempt to produce a self-configuring system that expands the service area and increases the bandwidth that is available. WMNs, which are made up of end clients and mesh routers, connect wirelessly in a multi-hop method. Ad-Hoc networks are made up of wireless mobile nodes that build a temporary network without the need for any existing network infrastructure or centralized administration. WMNs have nowadays attained significance because of their quick communication capabilities and ease of deployment.

To recommend the appropriate routing protocol, numerous experiments with various scenarios were undertaken. A comprehensive performance evaluation is still necessary, though, as differences in the protocol's mechanism can have a significant impact on performance. An active area of research is choosing the best routing protocols for WMNs. To find scalable, reliable, and efficient WMNs that satisfy the requirements for various usages, it is necessary to compare the routing protocols [3], [4]. Finding the best routing metric has been the main focus of recent research on routing protocols for WMNs.

In this paper, three algorithms of two types of routing protocols (reactive and proactive) in the WMNs topology are configured and simulated in various scenarios which the Mosul University campus considers as the case study. AODV and DSR were selected as the reactive routing protocols and the OLSR as the proactive routing protocol. The main objective and driving force behind this study are to evaluate the network performance of three algorithms of the two previously mentioned types of routing protocols using a variety of performance metrics, using two different scenarios, and assuming that the router fails using the OPNET simulator. This will allow us to decide which routing protocols are the best effective, suitable, and acceptable.

Our contribution in this paper is to propose a wireless mesh network for the University of Mosul campus, in addition, to evaluating and investigating the network performance, using several metrics that contain, including HTTP page response time, voice and video end-to-end delay, delay variation, wireless media access delay, data dropped, wireless load, wireless retransmission attempts, and packet delivery ratio. The originality of this research, based on the knowledge of the authors, is considered the first that several metrics were taken to estimate the performance of DSR, AODV, and OLSR routing protocols. Applying several criteria, it was found that AODV is the most effective routing protocol.

The remainder of the paper is structured as follows. Section II reviews the related research. The simulation design parameters and the proposed network design are shown in Section III. The simulation results analysis is presented in Section IV. The paper is concluded in Section V.

II. RELATED WORK

Some of the previous works that are related to the topic of this research will be mentioned in this section. In [5], the Temporary Ordered Routing Algorithm (TORA), Ad hoc on Demand Distance Vector (AODV), Optimized Link State Routing (OLSR), and Dynamic Source Routing (DSR) routing protocols were evaluated using Http Image Browsing traffic. Delay and throughput are the metrics used for the evaluation. The authors in [6] present the performance of OLSR, AODV, Dynamic MANET On-demand (DYMO), DSR, and Zone Routing Protocol (ZRP) routing protocols for the MANET network. Average jitter, average end-to-end delay, and average throughput are the metrics that use to test the performance.

In [7], the authors simulate the OLSR, DSR, AODV, and Geographic Routing Protocol (GRP) routing protocols for a vehicular ad hoc network using OPNET Modeler. Other work [8] evaluated the performance of the Destination Sequenced Distance Vector (DSDV), AODV, and DSR routing protocols. Applying the speed packet delivery function, delay, and routing load, the performance is examined and compared. The authors in [9] used the OPNET simulation to test the performance of DSR and AODV protocols under an Ad-Hoc wireless network. The evaluation and compression of OLSD and AODV in the MANET environment using the NS2 simulator are done [10]. The authors implement two test scenarios. The first test scenario examines how a change in the number of nodes and the second test scenario examines how changes in the network's size affect the performance of the protocols. The metrics of end-to-end delay, packet delivery ratio (PDR), and throughput are used to measure performance. A performance evaluation of the AODV, DSDV, and DSR protocols for Ad-Hoc applications is provided in [11]. Utilizing the NS2 application for simulation, research findings, and network evaluation is based on the size of the network, mobility, and changing network load. The efficiency of GRP, DSR, AODV, and OLSR routing protocols for MANET is compared in [12]. OPNET, a simulation tool, was used for tests to examine the protocols under various conditions and scenarios. Delay and throughput are the two performance metrics used to evaluate the effectiveness of these routing protocols. According to the simulation results, OLSR generally outperformed the other three protocols (ADOV, GRP, and DSR) in terms of delay and throughput while dealing with high FTP traffic.

The performance of the DSR and AODV routing protocols under the conditions of the data broadcast storm problem was examined by the authors in [13]. According to the simulation results, AODV performed better than DSR in terms of data throughput and data transmitting delay. As for packet loss analysis, both routing protocols provide results that are extremely similar throughout all simulation experiments. In [14], the authors present a comparison between DSR, OLSR, AODV, and DSDV routing protocols. They analyze and evaluate their performance based on the Average end-to-end delay, Throughput, and Packet Delivery Ratio. They have used the NS3 simulator. According to the simulation results, OLSR and DSDV operate most effectively in networks with stationary and heavily populated nodes. For networks with more nodes, AODV was acceptable. In networks with lower traffic densities and mobility rates, DSR performed effectively.

The main object of [15] is to investigate the performance matrices including PDR, packet loss, jitter, and end-to-end delay of OLSR, DSDV, and AODV using NS3 Simulator. In large and dense networks, the authors discovered that the OLSR routing protocol performs better than AODV and

DSDV. The authors in [16] present the performance evaluation of OLSR, DSR, AODV, DSDV, and AOMDV in a MANET domain based on the NS2 simulator. Implemented evaluation metrics include PDR, end-to-end delay, and throughput. According to the evaluation results, the AODV outperforms comparable protocols in most of the simulated scenarios.

In [17], the authors have presented the performance of Temporally-Ordered Routing Algorithm (TORA), OLSR, and AODV routing protocols using the OPNET simulator using a variety of system designs with various protocols under loads of various probability distributions. Jitter, PDR, and throughput are three metrics used in [18] to evaluate the performance of three routing protocols: AODV, DSDV, and DSR using the NS2 simulator. The results showed that when network topology (nodes) increased, the average jitter, PDR, and throughput of the protocols also increased. When the network has more than 35 nodes, the AODV protocol performed better than the other two protocols overall, however, the DSR protocol performs better in smaller networks.

The authors in [19] compare the performance of two routing protocols AODV and OLSR for MANET using FTP and HTTP traffics. Throughput, retransmission, and data dropped are the metrics that are used to evaluate the performance using the OPNET simulator. The results show that the OLSR performs remarkably better than AODV on prevailing nodes increasing in the network. In [20], the OMNET++ simulation program was used to estimate the MANET performance for the DSR, AODV, and DYMO routing protocols. The analysis of the network use the PDR, throughput, transmission count, and routing overhead. Using network simulator 3, the authors of [21] evaluate the performance of the AODV, DSDV, and OLSR routing protocols for VANET applications. The comparison parameters for evaluation were throughput, PLR, and packet overhead. In [22], network simulator 3 (NS3) was used to simulate the OLSR, DSDV, and AODV routing protocols using a performance-compared scenario based on the network size. While other factors remained constant, the investigation concentrated on the network size increase. Simulated networks with different node counts of 30, 60, and 100 were used. The simulation's results on the efficiency of the AODV demonstrated the protocol's scalability. The authors in [23] demonstrate the effectiveness of OLSR, DSDV, and AOMDV using NS3 and various node counts. Average end-to-end delay, average throughput, and average energy consumption are applied as test metrics.

The authors in [24], a comparison of MANET protocols based on throughput, packet delivery ratio, end-to-end delay, and normalized routing load is presented by the authors. The NS-2 simulator is used to run the simulation. In [25], the authors used NS2 simulation for a comprehensive evaluation of the performance of the TORA and AODV routing protocols using end-to-end delay and packet delivery fraction. Based on different data rates, the authors in [26] examine and assess how well AODV, AOMDV, and MDART work. Latency, PDR, throughput, PDF, and delay are used as the evaluation criteria. Network Simulator 2.35 has been used to replicate implementation research work. In [27] the authors present the performance of AODV, DSR, and DSDV routing protocols. Average jitter, average end-to-end delay, number of dropped packets, forwarding overhead, node mobility, and the increasing number of nodes. In [28], the authors used the NS-3 simulator to test the performance of AODV, DSDV, and OLSR. The performance parameters used throughput, packet delivery ratio, and number of packets missed. The authors in [29] used the OPNET version 4.5 simulator to evaluate the performance of DSR, AODV, and TORA routing protocols. In [30], the authors used the NS2 simulator to investigate the performance improvement of the AODV routing protocol in terms of total delay, routing overhead, throughput, and packet delivery ratio. The authors in [31] investigate the effectiveness of reactive and proactive routing protocols as well as the effects of security attacks on those performances. In [32], a survey of simulation analysis based on the reactive and proactive MANET algorithms OLSR, DSDV, and AODV respectively, is presented in this article. These routing algorithms have been put to the test through the evaluation of packet loss rate, packet delivery ratio, and throughput using the NS3 simulator.

Through this work, the performance of Ad-Hoc routing protocols was evaluated efficiently and differently from the previous works on this subject. Where the evaluation was done by some contributions that the researchers did not address in advance, evaluation improvements include the following:

- The performance of the Ad-Hoc routing protocols was evaluated using different types of metrics. The evaluation was done using application metrics (such as browsing response time, and real-time communication delay) and wireless network metrics (such as wireless delay, data dropped, wireless load, and packet delivery ratio)
- All conditions that the network may go through while working are taken into account in the evaluation of the performance of Ad-Hoc routing protocols, the performance of these protocols was evaluated in the case when some of the wireless routers failed to work, in addition to the evaluation when all the wireless routers were operating normally with no fail.

III. Proposed Network Design

The goal of this study is to investigate the efficiency of wireless mesh networks (WMNs), the proposed investigation method evaluates the performance of reactive and proactive ad-hoc routing protocols using different performance metrics in the campus environments. The proposed network is designed and evaluated using a network simulation tool, network simulation tool provides the capabilities to evaluate the performance easily and economically and also save time. We use OPNET software to simulate our proposed network, this software supports a Graphical User Interface (GUI) for designing the networks and analyzing the results to simplify the tasks of the simulation process [33]. In our proposed work we design and simulate a wireless mesh network for the University of Mosul campus, Figure 1 shows the network simulation procedure.

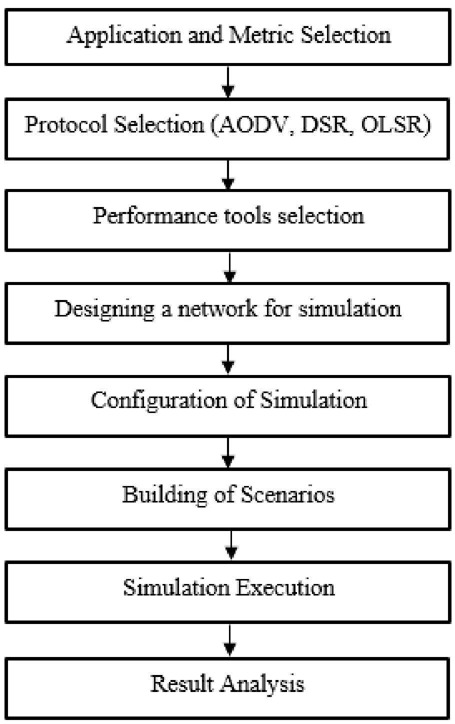


Fig. 1. Network simulation procedure

The network is designed by projecting the map of the University of Mosul in the simulated scenarios. Wireless routers are distributed over the University campus after a survey of the geographical area is conducted and a focus is made on the most densely populated areas. The distance between wireless routers has been considered so that it does not exceed 125 meters, which is the distance that can be covered by the wireless router operated using IEEE 802.11a standard [34], [35]. Figure 2(a) shows the proposed network structure in Google Maps. Figure 2(b) shows the Proposed network structure in the OPNET simulator.

For the purpose of testing network performance and showing simulation results, fixed and mobile workstations have been included in our design. Voice, video, and web browsing services are supported and configured using an application server. Reactive and Proactive Ad-Hoc routing protocols such as AODV, DSR, and OLSR are designed and evaluated in our simulated scenarios. In Table I, we collect the parameter values for our proposed network.

TABLE I.
CONFIGURATION DETAILS FOR THE PROPOSED NETWORK

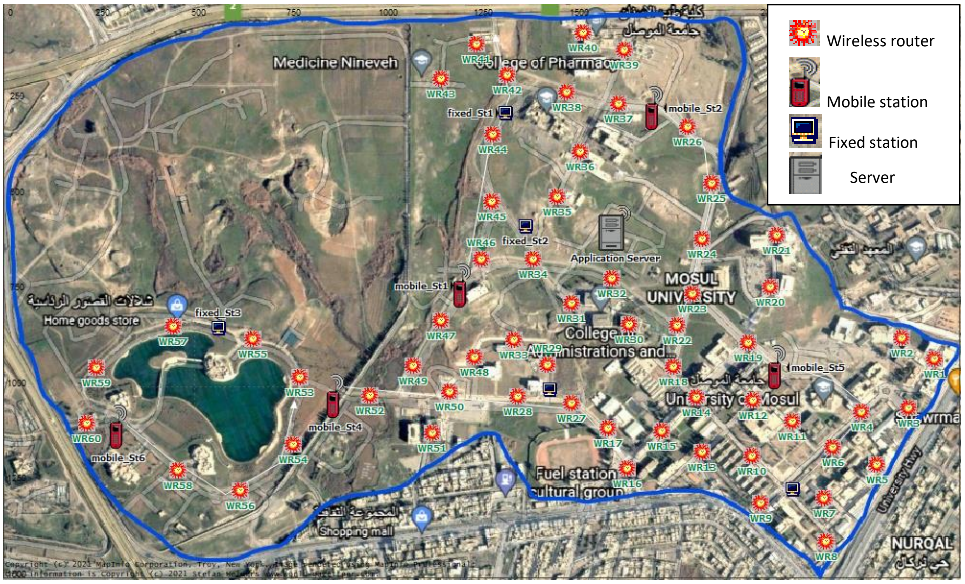
Parameter	Value
Simulator	OPNET (Modeler 14.5)
Topology	Wireless Mesh Network
No. of Wireless Routers	60
No. of Workstations	10 (Fixed and mobile)
Simulation Time	10 minutes
No. of Scenarios	2
Physical Layer Technology	OFDM (802.11a)
Wireless Data Rate	54 Mbps
Frequency Band	50 GHz
Router Model	Wireless Ad-Hoc
Transmission Power	0.1 W
Network Coverage Area	University of Mosul Campus
Network Addressing	IPv4
Routing Protocols	AODV, DSR, and OLSR
Supported Applications	Web Browsing, Voice and Video Conferencing

To apply and implement the proposed network practically, we need a budget that supports the purchase of one server and a group of wireless mesh routers distributed within the network. We also need to provide continuous power for these routers, it is possible to use solar energy. TP-Link EAP225-Outdoor can be used as a wireless mesh router, the estimated price for this product is 60 USD.

Figure 3 Shows some settings for the simulated network, three applications (Http browsing, voice, and video conferencing) are configured to be supported in the simulated network as shown in Fig. 3(a). Figure 3(b) represents the configured profiles to support the above applications to network users. Wireless LAN parameters for fixed and mobile end stations are explained in Fig. 3(c). Figure 3(d) shows the server setting used to support network applications.

IV. SIMULATION RESULTS ANALYSIS

To evaluate the performance of the wireless Ad-Hoc routing protocols, several metrics are tested in our simulation. We consider different metric categories in our simulation to evaluate the performance more accurately. Simulated metrics include application metrics that test the application performance and wireless metrics that test the performance of the wireless network. Simulated application metrics include web browsing metrics such as HTTP page response time, delay variation, voice, and video end-to-end delay. Considered wireless network metrics include wireless media access delay, data dropped, wireless load, wireless retransmission attempts, and packet delivery ratio.



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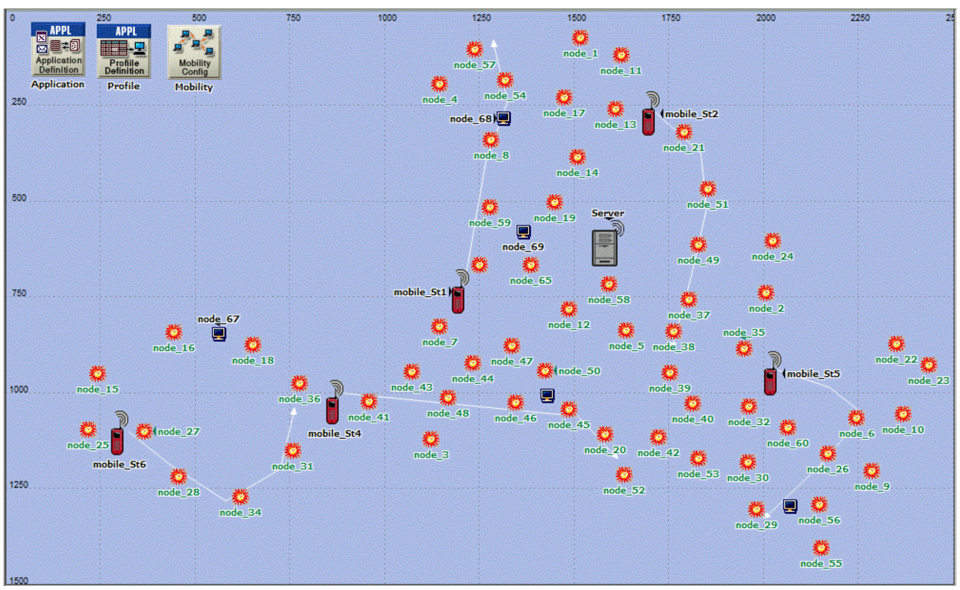


(b)

Fig. 2. (a) Proposed network structure in Google map for Mosul University, (b) Proposed network structure in OPNET simulator

AODV, DSR, and OLSR are evaluated using testing tools by simulating two scenarios using OPNET software. The first scenario evaluates the network performance when all wireless mesh routers are working normally without fail. The second scenario investigates the performance in case there is a malfunction of some wireless routers for the proposed network. To show the behavior of the network when failure in wireless routers occurs, a Ping request is configured in our work. The proposed network is designed and simulated using OPNET software (Modeler 14.5) installed on a laptop with specifications presented in Table II. In the following sections, we present and discuss simulated results.

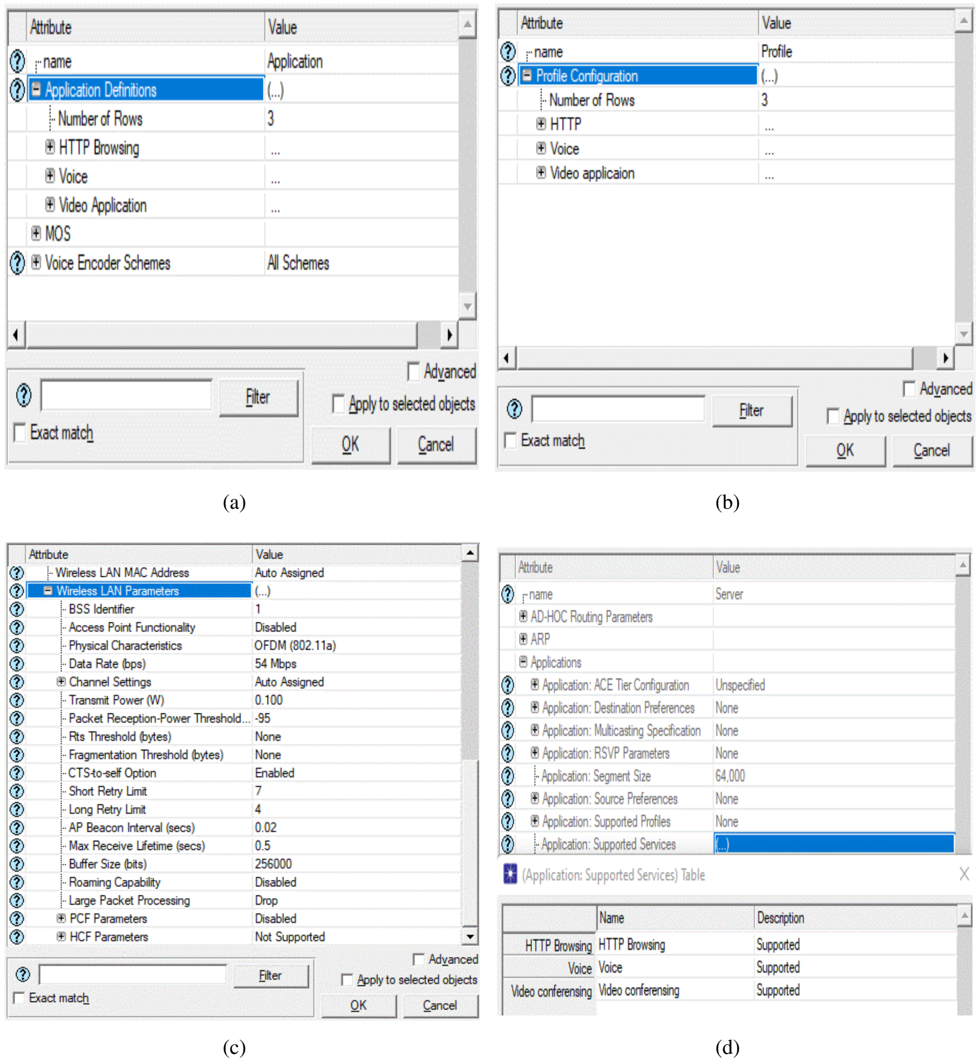


Fig. 3. Simulated network settings of (a) Application configuration, (b) Profile configuration (c) Wireless LAN configuration, and (d) Server configuration.

TABLE II.
LAPTOP SPECIFICATIONS

Parameter	Specification
Operating System	Windows 11 Pro
Processor	Intel(R) Core(TM) i7-8550U CPU @ 1.80GHz, 1.99 GHz
Memory	16.0 GB
Hard Disk Drive	1 TB
Graphics	Intel(R) UHD Graphics 620

A. *The First Scenario (all wireless routers are worked without fail)*

This simulated scenario is configured and simulated to examine the effectiveness of Ad-Hoc routing protocols when all wireless routers are working normally without any failing. Simulation time is configured to 600 seconds (10 minutes) to show network behavior for this period. A summary of the results obtained for selected metrics during this period for different scenarios is discussed and compared below, the following section shows and discusses obtained results for application metrics:

1. **Browsing Response Time (sec)** The HTTP page response time metric is considered in our simulation to evaluate the web browsing application for each type of Ad-Hoc routing protocol. This metric measures the time required to respond to the requested HTTP page. Simulation results show that the AODV routing pro-

tocol gives better performance than other simulated protocols, it gives the fastest HTTP page response time (2.728 sec) as shown in Fig. 4(a).

2. **Video Packet End-to-End Delay (sec)** End-to-end delay of video packet statistic measures the average time elapsed to send a video packet from the transmitting node to the receiver node through the network. Simulation results show that AODV has the best video end-to-end delay which gives the minimum video delay (31.951 msec) concerning DSR and OLSR routing protocols. Figure 4(b) shows simulation results for this metric.

3. **Voice End-to-End Delay (sec)** The amount of time needed for a voice packet to travel across the network from source to destination is measured using the voice end-to-end delay metric. The minimum value of this metric defines the quality of service. Figure 4(c) shows the obtained results for the voice packet delay and demonstrates that the AODV routing protocol has the best performance compared with the other routing protocols, it gives the minimum voice end-to-end delay with respect to other protocols. The obtained voice delay for the AODV protocol is (227.411 msec).

4. **Voice Delay Variation (sec)** The variation in voice end-to-end delay is called voice delay variation. This metric is considered in our simulation to test voice quality. Figure 4(d) depicts obtained results for this metric and exposes that the AODV protocol gives the best performance relating to other simulated wireless protocols. AODV provides the best voice delay variation with a minimum value regarding other protocols (148.788 msec).

The above results show that AODV gives better performance in terms of application quality such as HTTP traffic, video and voice packet delay compared to DSR, and OLSR protocol. The reason for that is, AODV offers quick adaptation to mobile networks with low processing and low bandwidth utilization. The results for simulated wireless network metrics are presented and discussed as follows, these metrics include wireless media access delay, data dropped, wireless load, and wireless retransmission attempts.

1. **Wireless Media Access Delay (sec)** This metric calculates the total contention and queuing delays for all wireless nodes in the network. This delay is computed for each frame as the amount of time between when it is submitted to the transmission queue and when it is first sent to the physical layer. Figure 5(a) shows the wireless media access delay after simulating our simulated scenario. The results display that the AODV protocol works in a good performance with respect to other simulated protocols, it gives the minimum delay (115.824 msec).

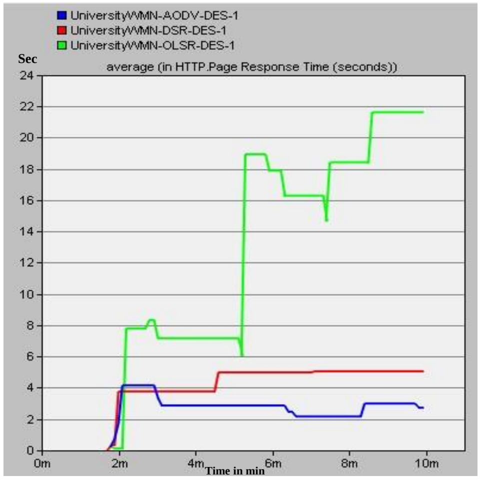
2. **Data Dropped (Buffer Overflow) (bps)** Traffic analysis metrics evaluate the performance of wireless networks, These metrics include data dropped, data sent and data received. Data dropped (buffer overview) calculates the total size of data packets dropped by all the WLAN MACs in the wireless network measured in bits per sec. After running the simulation, obtained results are demonstrated in Fig. 5(b). The results display that AODV gives the best performance with the minimum value (10.795 Mbps).

3. **Wireless Load (bps)** The wireless load is the overall load that all upper layers in all wireless nodes of the network have sent data to the wireless LAN layers. Figure 5(c) presents obtained wireless load results after running the simulation. Obtained results expose that the AODV protocol provides good performance with the minimum load (24.458 Mbps).

4. **Wireless Retransmission Attempts (packets)** The total number of retransmission attempts made by all WLAN MACs in the network up until a packet is successfully transmitted or is deleted because it has exceeded the short or long retry limit is represented by the wireless retransmission attempts metric. The higher number of retransmission attempts generates higher network latency. Figure 5(d) shows the simulated results for the wireless retransmission attempts metric after simulating for 10 minutes. The results show that AODV gives the best results concerning other protocols, which gives the minimum wireless retransmission attempts (0.415 packets).

Obtained wireless results displayed in Fig. 5 show that compared with DSR and OLSR protocols, the AODV protocol has better wireless performance in terms of wireless media access delay, data dropped, wireless load, and wireless retransmission attempts. Obtained results are presented in Table III.

The results obtained in this scenario exhibit that the AODV routing protocol performs best in the case when all network routers are operating without any failure. We can conclude that concerning other simulated protocols, AODV can be considered the best Ad-Hoc routing protocol for campus networks in the case when no failures in network routers, in the next section we evaluate the performance when a failure occurs in some network routers.



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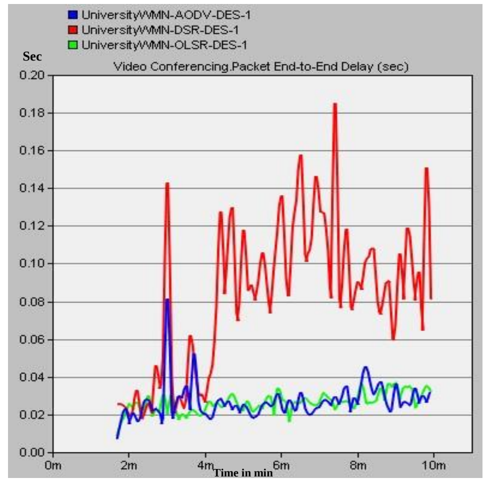

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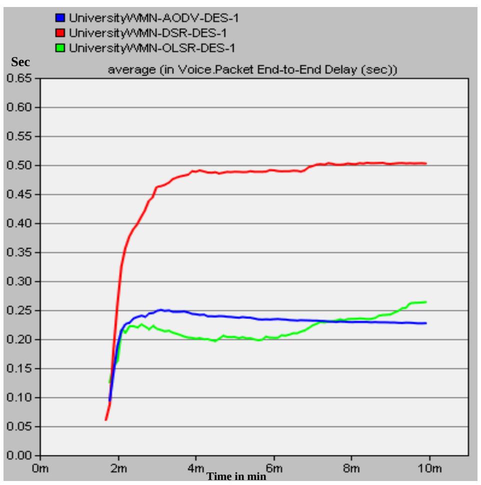

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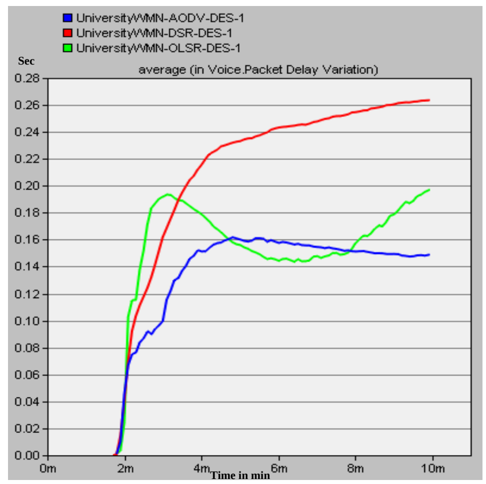

(d)

Fig. 4. First scenario results for application metrics of (a) Browsing response time, (b) Video end-to-end delay (c) Voice end-to-end delay, and (d) Voice delay variation

TABLE III.
SIMULATION RESULTS SUMMARY FOR THE FIRST SCENARIO

Metric	Routing Protocol		
	AODV	**DSR**	**OLSR**
HTTP Page Response Time (sec)	2.728	5.056	21.631
Video Packet End-to-End Delay (msec)	31.951	81.362	32.212
Voice End-to-End Delay (msec)	227.411	502.626	263.686
Voice Delay Variation (msec)	148.788	263.496	196.778
Wireless Media Access Delay (msec)	115.824	278.903	151.293
Data Dropped (Buffer Overflow) (Mbit/sec)	10.795	18.520	16.747
Wireless Load (Mbit/sec)	24.458	27.340	30.609
Wireless Retransmission Attempts (packets)	0.415	0.445	0.458

B. The Second Scenario (five wireless routers are failing)

This simulated scenario is configured and simulated to test the performance of Ad-Hoc routing protocols when some wireless routers are stopped to work. This scenario is built and simulated to evaluate the performance of Ad-Hoc routing protocols if the failure occurs to network routers. Among the capabilities available in the OPNET software is that it is possible to fail some routers during the simulation time. Five routers are selected to stop working at 100 seconds of simulation time, these routers were chosen randomly in a distributed manner throughout the network to ensure the impact of this failure on the network, and Fig. 6 shows the simulated failure configuration.

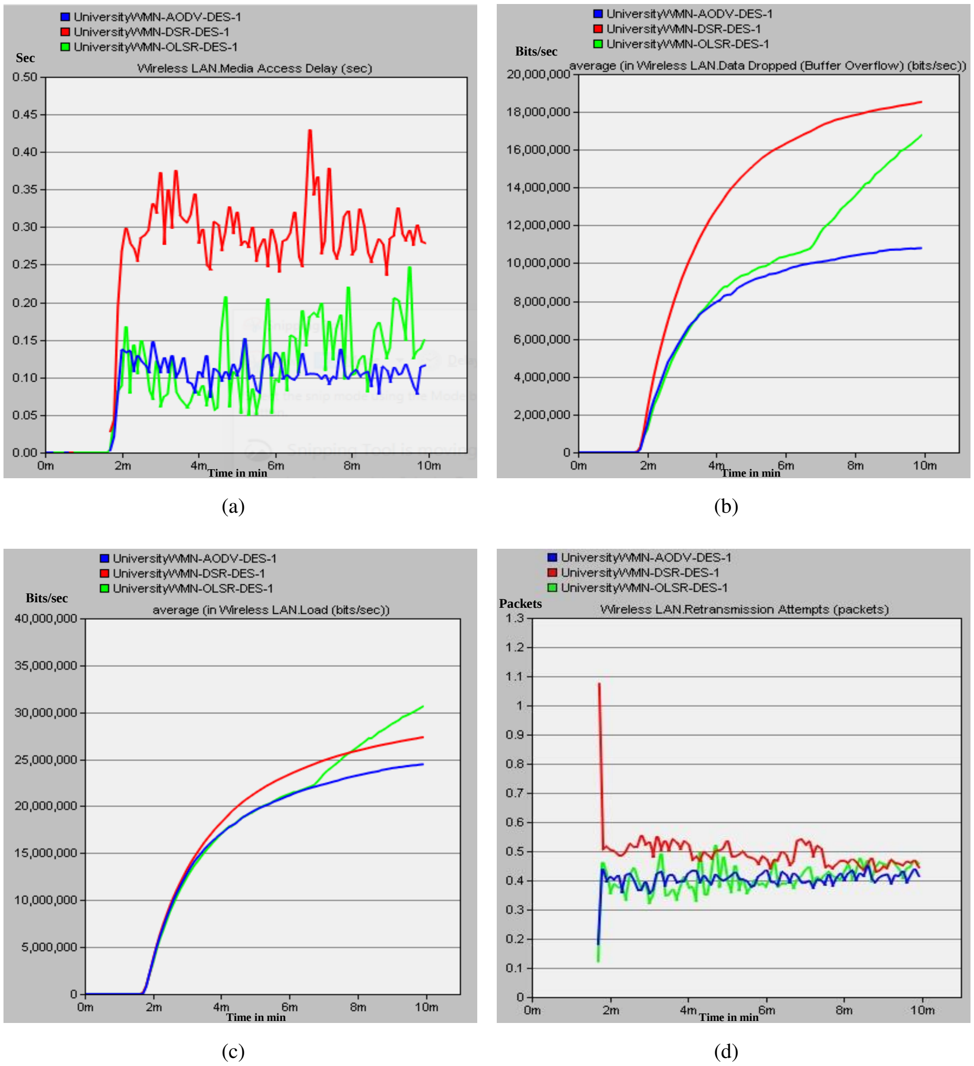

Fig. 5. First scenario results for wireless metrics of (a) wireless media access delay, (b) data dropped (c) wireless load, and (d) wireless retransmission attempts

After simulating the second scenario, obtained results for selected metrics are displayed and discussed. Figure 7 shows the simulation results for selected application metrics and in Fig. 8 we present the simulation results for wireless network metrics. Obtained results for the second scenario are presented in Table IV.

The results in Fig. 7 show that AODV gives better performance in terms of application quality compared to DSR, and OLSR protocols even if there is a failure in network routers. AODV is designed to be self-starting in an environment of mobile nodes, withstanding a variety of network behaviors such as node failures, mobility, and packet losses, each node maintains a time-based state: a routing entry not recently used is expired. In case of a route is broken the neighbors can be notified. Route discovery is based on query and reply cycles, and route information is stored in all intermediate nodes along the route in the form of route table entries so that AODV gives better performance even if there is a failure in network routers.

The results for simulated wireless network metrics for the second scenario are presented and discussed as follows, these metrics include wireless media access delay, data dropped, wireless load, and wireless retransmission attempts.

Obtained results displayed in Fig. 8 demonstrate that compared with DSR and OLSR protocols, the AODV protocol has better wireless performance in terms of wireless media access delay, data dropped, wireless load, and wireless retransmis-

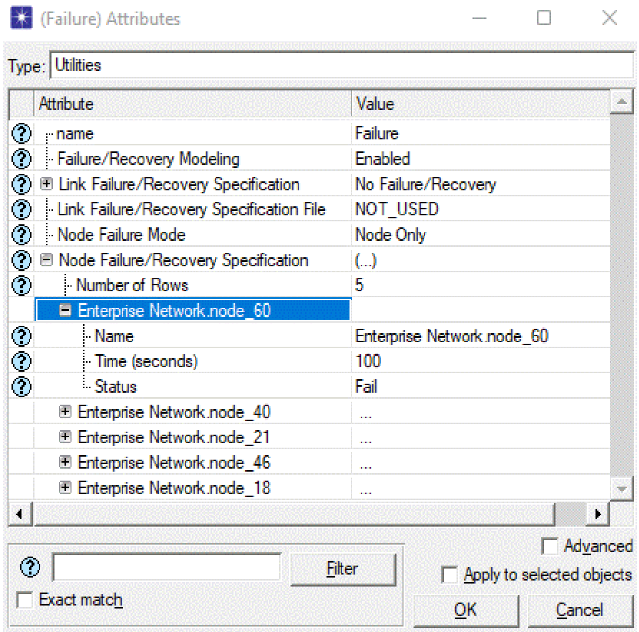

Fig. 6. Failure configuration setting

sion attempts. Captured results for this scenario are presented in Table IV.

TABLE IV.
SIMULATION RESULTS SUMMARY FOR THE SECOND SCENARIO

Metric	Routing Protocol		
	AODV	**DSR**	**OLSR**
HTTP Page Response Time (sec)	15.317	20.207	69.582
Video Packet End-to-End Delay (msec)	25.294	97.688	27.414
Voice End to End Delay (msec)	206.527	591.696	349.207
Voice Delay Variation (msec)	102.685	402.739	279.945
Wireless Media Access Delay (msec)	90.150	297.282	130.693
Data Dropped (Buffer Overflow) (Mbit/sec)	10.003	18.079	21.829
Wireless Load (Mbit/sec)	22.692	29.144	37.204
Wireless Retransmission Attempts (packets)	0.392	0.449	0.439

To investigate the performance of network connectivity when some wireless network routers fail, the Ping test is configured from the application server to mobile station 6. Obtained results are shown in Fig. 9.

Obtained results show that the network which operates using the AODV routing protocol gives the best performance with a minimum response time (322 msec). The results obtained in the second scenario show that the AODV routing protocol performs best in the case of failure in network routers. We can conclude that concerning other simulated protocols, AODV can be considered the best ad hoc routing protocol for campus wireless networks when failures in network routers occur.

After building and implementing the two scenarios for the proposed network and when making a comparison for the obtained results of each protocol separately, we notice that the AODV protocol gives good performance even if there is a failure in the network routers. While we notice that the network performance for DSR and OLSR protocols decreases a lot when a failure occurs in network routers.

To get a more accurate evaluation, another metric is tested in our scenarios to show the performance of the wireless Ad-Hoc routing protocols by comparing the traffic sent and traffic received through the network for each protocol using the packet delivery ratio (PDR), PDR is calculated using Eq. 1.

$$PDR = \frac{number of packet received}{number of packet send} \times 100 \tag{1}$$

To calculate the PDR, sent and received traffic for each simulated Ad-Hoc routing protocol is selected and captured. Obtained results for the simulated protocols are presented in Fig. 10.

For the AODV routing protocol, simulated results show the traffic sent is (250 packets/sec) and the received traffic for this protocol is (190 packets/sec) as shown in Fig. 10(a). For the DSR routing protocol, simulated results show the traffic sent is (190 packets/sec) and the received traffic for this protocol is (100 packets/sec) as shown in Fig. 10(b). For the OLSR routing protocol, simulated results show the traffic sent is (300 packets/sec) and the received traffic for this protocol is (190 packets/sec) as shown in Fig. 10(c).

Using Eq. 1 and obtained results in Fig. 10, PDR is calculated for the simulated Ad-Hoc routing protocols as follows:
1- For AODV: PDR = (190 / 250)*100% PDR = 76 %
2- For DSR: PDR = (100 / 190)*100% PDR = 52.63%
3- For OLSR: PDR = (190 / 300)*100% PDR = 63.33%

After showing the PDR values for the above three Ad-Hoc routing protocols, we conclude that the AODV routing protocol gives the best performance concerning other protocols (DSR and OLSR).

V. CONCLUSIONS

In this paper, reactive and proactive Ad-Hoc routing protocols including AODV, DSR, and OLSR have been evaluated and investigated over the University of Mosul campus using OPNET software. Tested metrics in this work include HTTP browsing response time, voice and video delay, wireless media access delay, wireless data dropped, wireless load, wireless retransmission attempts, Ping response time, and the PDR. The results show that the AODV routing protocol gives

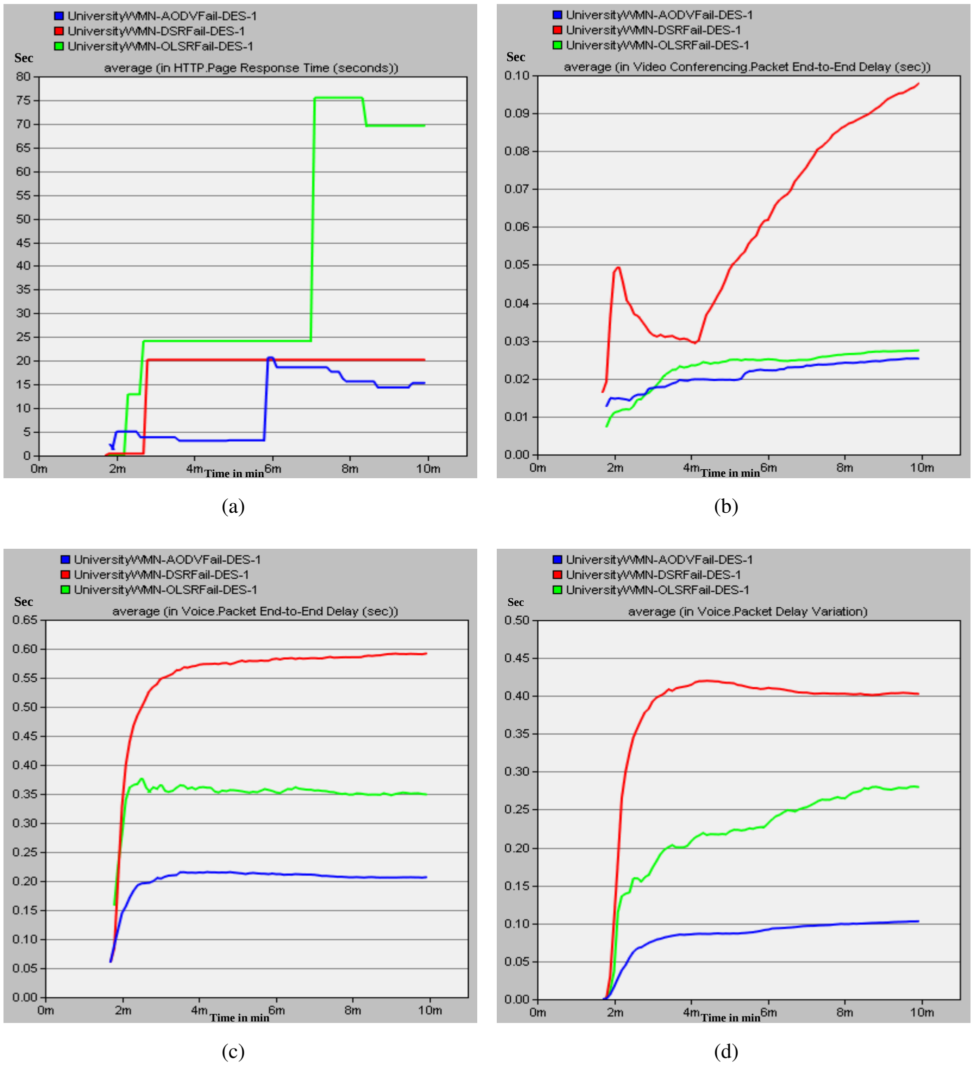

Fig. 7. Second scenario results for application metrics of (a) Browsing response time, (b) Video end to end delay (c) Voice end to end delay, and (d) Voice delay variation

better performance concerning DSR and OLSR routing protocols. The evaluation was done by testing the above metrics for these Ad-Hoc routing protocols in two cases. In the first case, we evaluate the performance in the case of all wireless routers are working without any failing, and in the second case we evaluate the performance when failing occurred to five wireless network routers, AODV gives the best performance in terms of HTTP browsing response time (15.317 sec), voice packet delay (206.527 msec), video delay (25.294 msec), wireless media access delay (90.150 msec) and satisfy (76%) packet delivery ratio. We observed that compared with the other Ad-Hoc routing protocols the reactive AODV is an efficient Ad-Hoc routing protocol to be implemented over the University of Mosul campus in the WMN environment.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

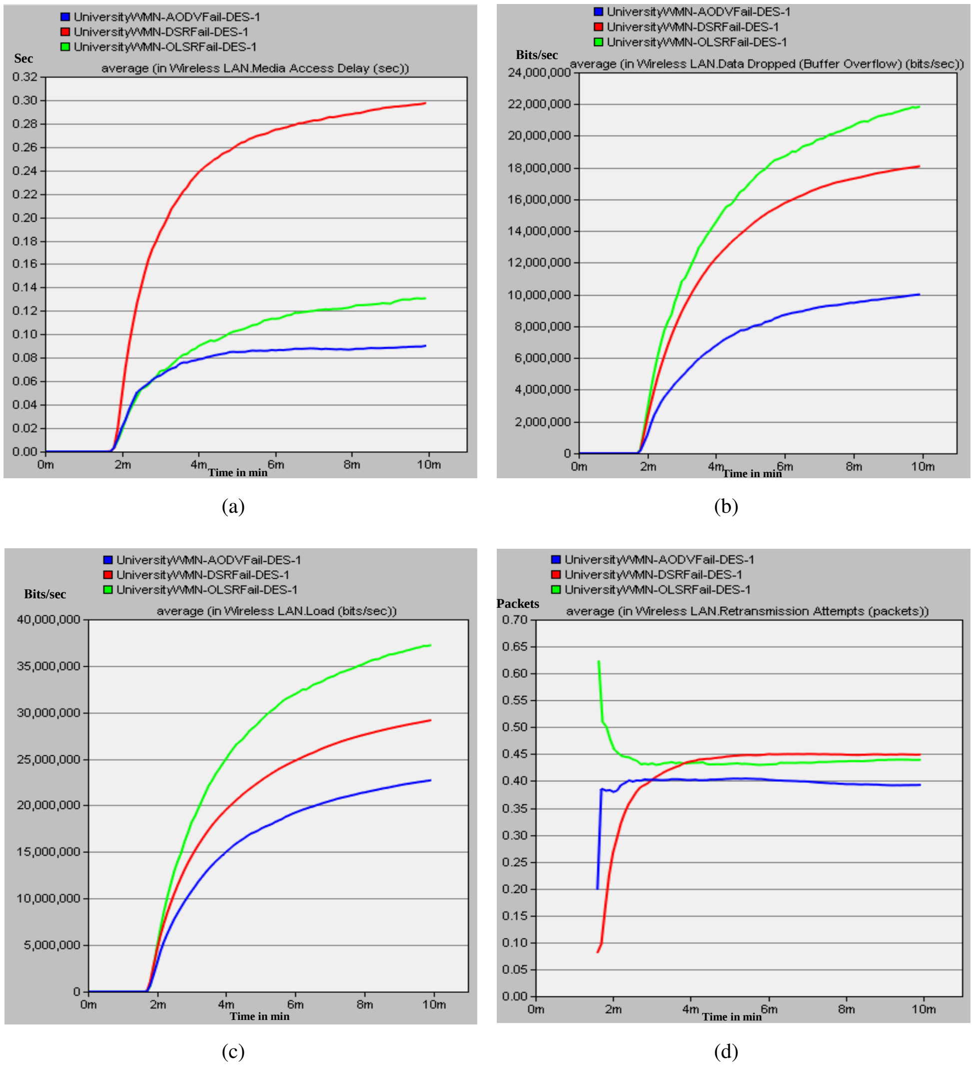

Fig. 8. Second scenario results for wireless metrics of (a) wireless media access delay, (b) data dropped (c) wireless load, and (d) wireless retransmission attempts

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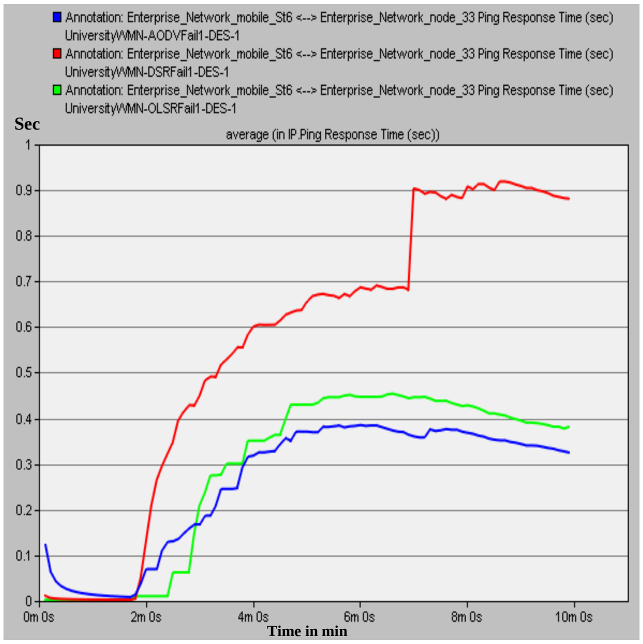

Fig. 9. Ping response time (sec)

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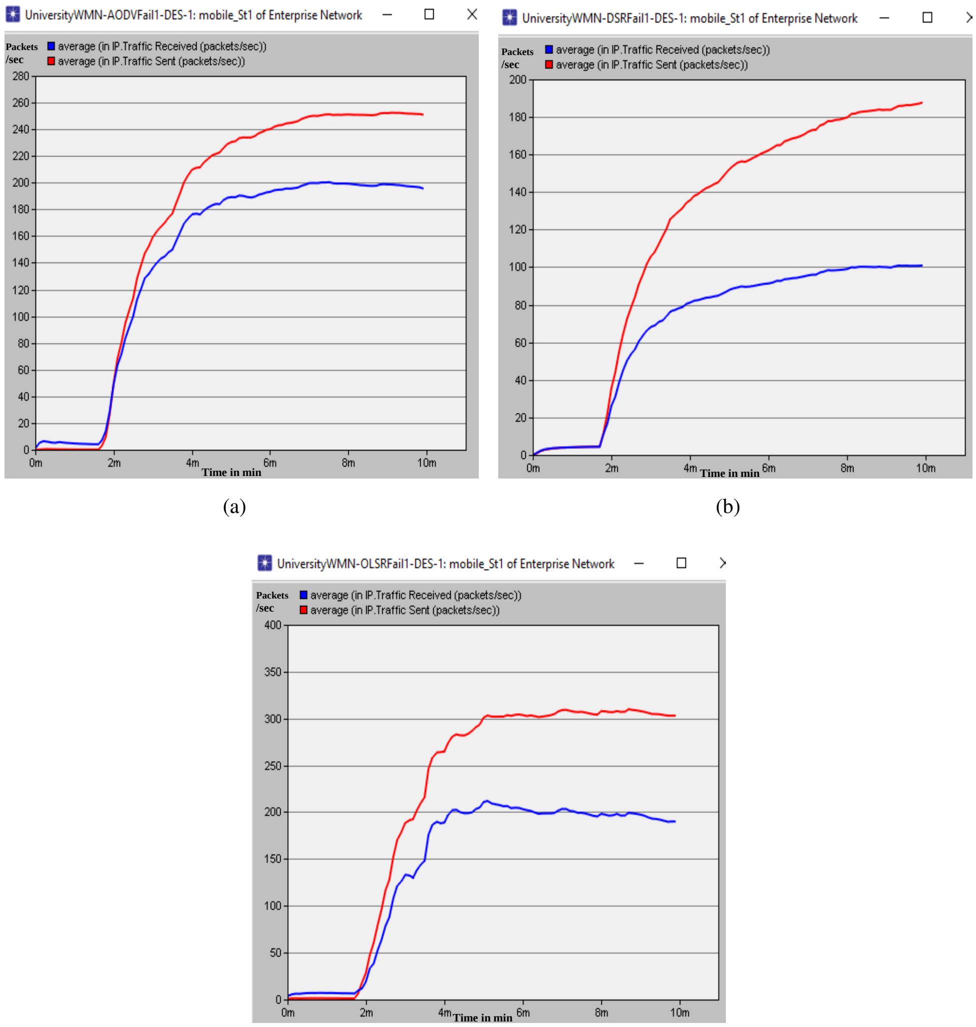

(a) (b)

(c)

Fig. 10. Sent and received traffic (Packets/sec) of (a) AODV traffic, (b) DSR traffic, and (c) OLSR traffic

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