Journal of Communications Vol. 15, No. 6, June 2020

A Comparative Performance Analysis of Manet Routing Protocols in Various Propagation Loss Models Using NS3 Simulator

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Abstract—The standard design for efficient routing protocols that could provide the optimum value of performance for various network scenarios, particularly affecting the radio propagation is a great challenge. The aim of the paper is to investigate the impact of simulating MANET routing protocols with using various propagation model. It is because typical MANET studies assume the effect of radio propagation is negligible, therefore leading to insignificance simulation results. The choice of routing protocols are Ad-hoc On-Demand Distance Vector (AODV) and Distance Sequenced Distance Vector (DSDV), which has reactive and proactive mechanism respectively. The performance of routing protocols are quantified with three different radio propagation model i.e. Friis, Two-ray ground and Nakagami. Each model replicate the condition of open space, sub-urban and urban area. Typical performance metrics are used, which are packet delivery ratio, end-to-end delay and throughput using NS-3 simulator. Result indicates that various propagation loss models may substantially impact performance routing protocols. The AODV routing protocol shown higher throughput as compared to DSDV regardless of propagation model. The AODV also generates higher PDR when Friis and Two-ray Ground are employed. On the other hand, DSDV routing protocol shows lower delay, lower throughput and higher PDR only when Nakagami model is used. In general, specific path loss condition can affect the MANET routing protocol performance. This study provides a comparative result using NS3 of two extreme routing protocol approach, i.e. pro-active and reactive which can be used as a reference point for further development of routing protocol in various ad hoc network applications and scenarios.

Index Terms—Mobile ad-hoc network, propagation loss models, AODV, DSDV, NS3 simulator.

I. INTRODUCTION

In emergencies or natural disasters such as tsunami or earthquakes, military-strategic operations, exhibitions, large gatherings that lead the existing infrastructure to be destroyed, inoperable or the demand for infrastructure-less, communications are high. In such circumstances, a convenient approach to initiate communication is to set up distributed communication nodes, decentralized administration, dynamic network topology and low bandwidth.

MANET was first introduced in the 1970s as a project known as Packet Radio Network (PRNet), sponsored by US Defense Advanced Research Projects Agency (DARPA). It was initially known as packet-radio networks used by the military field.

Subsequently, the PRNet project was extended to Survivable Radio Network (SURAN) to overcome the problem related to radio resource management and security. It includes the Single Channel Ground-Airborne Radio System (SINCGARS), Strategic Command and Control Communication (C3) and Intra-Task Force System (ITF) [1]. The invention and extensive usage of wireless network interface IEEE802.11 in personal computers started in the 1990s. It leads to the development of the wireless ad hoc network [2].

Before Access Points (APs) technology, data are transmitted through nodes with simple communication protocol, unable to dynamically search for a route. The need for developing routing protocols that combine the IEEE802.11 ad hoc networks into mobile devices was developed to provide efficiency, dynamic and survivable communication for impromptu communication. According to Koccher *et al.* [3], MANET is defined as a collection of communication devices which are known as nodes, able to communicate with each other in the absence of permanently located infrastructure. The inherent attributes of MANET include highly dynamic network topology, operating in a hostile environment using unstable connectivity. The growing utilization has led to the evolvement of various types of MANET including Vehicular Ad Hoc Networks (VANETs), Smartphone Ad Hoc Networks (SPANs), Internet-based Mobile Ad Hoc Networks (iMANETs) and military or tactical MANETs [6].

On the other hand, the absence of fixed infrastructure and the existence of dynamic topology cause frequent changes in the network topology. The variety of condition is challenging, and as such, the choice of routing protocol employed must accommodate the network service level. Since then, many studies have been conducted to evaluate the performance of these protocols in order to identify the

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Manuscript received November 1, 2019; revised May 7, 2020.
This work was supported by the Universiti Kuala Lumpur under Short Term Research Grant UniKL/Cori/str17023
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doi:10.12720/jcm.15.6.537-544

optimal routing protocol that can establish route in MANET environment [3]-[7].

To that end, there is no ideal design for an efficient routing protocol that could provide optimum values of performance for various network scenarios. Although plenty of research works has been conducted. However, the current approach does not offer the best outcome on selecting an effective routing protocol that may work in most network scenarios. It is because such research works being conducted to quantify the network performance using typical path loss models to see the impact on routing protocols. Also, much of the research work only considers the number of nodes which have less significance on the performance of routing protocols.

This research aims to perform network simulation of AODV and DSDV routing protocols using several propagation-loss models. It includes Friis propagation loss model, Two-ray ground propagation loss model and Nakagami propagation loss model with varying number of nodes. After that, the simulation experiments explore the performance of each routing protocol using performance metrics, i.e. throughput, packet delivery ratio and end-to-end delay. The simulation experiment is to analyze conditions of network load, which enable routing protocol to perform optimally in MANET. The outcome of this study may be used to enhance the existing mechanism. The comparison also serves as a benchmark that can be used by other researchers as a foundation to select the appropriate routing protocol for specific application and scenario.

II. OVERVIEW OF ROUTING PROTOCOLS

MANET routing protocols can be generally classified into three classes, as shown by Fig. 1. The study [4]-[7] categorises MANET routing protocols into proactive or table-driven, reactive or on-demand and hybrid.

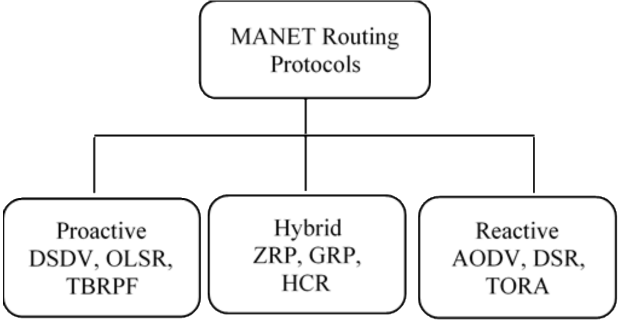

Fig. 1. MANET routing protocols classification

The proactive routing protocols periodically update routing table information by exchanging routing tables between nodes in order to maintain consistent and up-to-date routing information. Examples of these protocols include Destination Sequenced Distance Vector (DSDV), Optimized Link State Routing (OLSR) and Topology Dissemination Based on Reverse-Path Forwarding (TBRPF). In reactive or on-demand approach, the routing protocols only initiate path discovery when demanded rather than periodically broadcast routing control packets. The typical reactive routing protocols include Ad hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR) and Temporary Ordered Routing Algorithm (TORA). Hybrid, the protocols under this category combine the best features of proactive and reactive protocols. The routing protocol which is classified in this category includes Zone Routing Protocol (ZRP), Hybrid Cluster Routing (HCR), Ant Hoc Net and Geographical Routing Protocols (GRP).

A. AODV

Daas *et al*. [7] explain that AODV follows hop-by-hop algorithms to discover the routes to the destination. The algorithm begins when the source node initiates route discovery by broadcasting the Route Request (RREQ) to all neighbour nodes if there is no destination information available in the routing table. On receiving the RREQ packet, the intermediate nodes will check their routing table for the valid path to the destination. If the path is found, the Route Reply (RREP) message will be sent to the source; otherwise, the process of broadcasting the RREQ will continue until the valid path is found or RREQ reaches the destination node itself. However, when the route between source and destination is established, and suddenly the route is no longer accessible, or one of the intermediate nodes discovers a break in the path, the Route Error (RERR) message will be set.

B. DSDV

According to Sharma *et al*., [6], the protocol use Bellman-Ford routing algorithm to transmit packets from source to destination. In the routing protocol, each node stores the information of the neighbour nodes until each node has the information of all nodes in the entire networks. Daas *et al*. [7] explain that in DSDV, the entire mobile nodes exchanges hello messages to advertise their routing updates to the entire network. Upon receiving the hello messages, the neighbour nodes store the information in their routing tables, which enables all nodes to identify their neighbours. Later each neighbour will update the entire routing table to other nodes. Any node which sends the hello packet will update its position in the routing table, in this way each node will have a path to each node in the network.

III. RELATED STUDIES

Suleiman *et al*., [8] analyses the effect of two types of propagation models which is Two-ray ground model and Shadowing model for the DSDV and OLSR protocols using throughput, end-to-end delay, packet delivery ratio, and the number of dropped packets, evaluated for different node densities. The simulation experiment was conducted using the NS2 simulator. Results show that, In OLSR, as the number of nodes increases, the Two-ray model performs better than the Shadowing model in term of throughput, a similar result in DSDV. As the number of nodes increases the delay also increases, OLSR shows lower delay when Two-ray ground model is used as compared to using the Shadowing model. On the contrary, DSDV shows higher delay when the Two-ray model is employed. As the number of nodes increases, both OLSR and DSDV shows PDR performance was better when the Shadowing model used than the Two-ray model. As the number of nodes increases, the dropped packet decreases and vice versa. However, the number of the dropped packet is lower when Two-ray ground model used compared to shadowing model, both OLSR and DSDV protocol shows similar results. It was concluded that Shadowing model has a less significant impact on both routing protocols in terms of packet delivery ratio and end-to-end (E2E) delay. However, the Two-ray ground model performs better in terms of the number of dropped packets and throughput.

Das, A *et al*., [9] analyses the impact of propagation models on distance vector routing Protocols. The routing protocols, which are AODV and DSDV in MANET, is evaluated using end-to-end delay, packet delivery ratio, and energy consumption. Both routing protocols are evaluated with different node densities in both static and mobile scenarios. Also, the models used are two-ray ground, free-space and shadowing. The result shows that, in term of PDR, as the number of nodes decreases, the Shadowing model is not as severe as the two-ray ground model.

Nonetheless, with an increased number of nodes, the Two-ray ground outperforms the shadowing model. Likewise, as nodes move in high mobility and the number of nodes increases, the PDR decreases gradually. In terms of end-to-end delay, as the number of nodes increases the delay also increases. In the research work, it is deemed that different propagation models may affect routing protocols in regards to end-to-end delay, packet delivery ratio and energy consumption.

Sharma [10] discusses the performance of MANET routing protocols which are AODV, AOMDV (Ad-hoc On-demand Multi-path Distance Vector) and DSR, under different propagation models using packet delivery fraction and throughput, evaluated for different node densities. The models used are Two-ray ground, Nakagami and Shadowing. The simulation experiment conducted using NS2.35 simulator. Results show that Nakagami and Two-ray propagations performed well than shadowing model in all of the scenarios.

Bisoy, *et al*., [11] investigated the effect of propagation models and mobility on the performance of AODV, Dynamic Manet On-Demand (DYMO) and DSR using end-to-end delay, packet delivery ratio, and routing overhead and evaluated for different node speed (mobility) and several connections. The models used is two-ray ground, free-space, shadowing, Nakagami and Rayleigh Model. NS-2.34 simulator used during the simulation experiment.

The results of [11] are divided into two scenarios. In the experiment, the effect of propagation models was investigated for various node velocity. In term of PDR, Two-ray ground and Free space model offers higher PDR as compared to Shadowing, Rayleigh and Nakagami model over all the selected routing protocol. Also, the performance of DSR routing protocol is lower than AODV and DYMO for all propagation model. Based on the (E2E) delay, the DSR protocol shows a higher delay than AODV and DYMO for node velocity.

IV. METHODOLOGY

The methodology of this study involves various steps, including the setting of MANET routing protocols, designing simulation experiment, simulation experiment executions, performance metrics quantifications and calculation of confidence interval with independent replication.

A. Parameter Setting for MANET Routing Protocol

The routing protocol for a simulation experiment is chosen to be simulated using NS3 Simulator. The working principles of selected routing protocols are similar to the previous version of NS2, however with a few improvements for efficiency.

B. Design of Simulation Experiment

Designing a simulation experiment involves changing propagation loss models and the number of nodes and run numbers. Other parameters such as packet size, number of sinks, propagation delay, simulation time, node speed, pause time are not changed.

1) Propagation loss models

Wireless Channel 802.11b in NS3 is defined by the class YansWifiChannel, which works together with WifiPhy class and helper class YansWifiChannelHelper [12]. The Wireless channel is configured using propagation delay models and propagation loss models. The default NS3 predefined models are constant speed propagation delay model and the log-distance propagation loss model.

To add other models, the wifiChannel. AddPropagationLoss is added prior to calling the specific model. Since Friis, Two-ray ground and Nakagami propagation loss models are used in this study, the formulation of each model in NS3 is explained below:

The equation (1) is used to build the Friis propagation loss model.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi \times d)^2} L \qquad (1)$$

where, P_t is the transmission power (Watts), P_r is the reception power (Watts), G_t is the transmission gain, G_r is the reception gain, λ is the wavelength, d and distance, L is the system loss.

In the simulation scenario, the Friis propagation model is invoked using the command ns3:: FriisPropagationLossModel and the attribute is assigned. Frequency is parsed using command Frequency, DoubleValue (5.15e9), system loss using command SystemLoss", DoubleValue (1) and the minimum loss is modified using the command MinLoss", DoubleValue(0).

Equation (2) shows the Two-ray ground propagation loss model.

$$P_r = \frac{P_t G_t G_r (H_t^2 \times H_r^2)}{d^4 \times L} \qquad (2)$$

where H_t is the Height of transmission antenna (meter) and H_r is the Height of receiving antenna (meter). In order to utilise Two-ray ground model in simulation, the model is invoked using the command *ns3:: TwoRayGroundPropagationLossModel* and assign the attribute. It includes frequency using command *Frequency, Double Value (58.25),* height above z using command *Height Above Z, Double Value(1)* and the minimum distance command *MinDistance, DoubleValue (0.5).*

The Nakagami Propagation loss is built using Nakagami-m distribution and defined using equation (3).

$$p(x, m, \omega) = \frac{2m^m}{\Gamma(m)\omega^m} x^{2m-1} \exp\left(-\frac{m}{\omega}\right) x^2 \qquad (3)$$

whereas, m is the fading depth parameter and ω is the average received power. The model is invoked using the command *ns3::NakagamiPropagationLossModel* and assign the attribute including fading depth parameters. For (m0) command *m0*, the *DoubleValue(1)*, for (m1) command "*m1*", the *DoubleValue(1)* and for (m2) command "*m2*", the *DoubleValue(1)* was used [13]-[15].

2) *Number of nodes*

A various number of nodes are used during the simulation experiment for both AODV and DSDV routing protocols. The number of nodes used is set to 5 categories, which is 20, 30, 40, 50 and 60 number of nodes. Each variation of the node is simulated in 10 iterations against each protocol and the propagation loss models.

3) *Seeding and independent replications*

By default, the NS3 simulator employs a fixed, deterministic seed with the same run number, i.e. result is identical each time simulation is run, except if the seed or the run number is changed. The randomness over multiple simulation runs is obtained by varying the run number. It is a common scenario of running simulation as a series of independent tests in order to calculate statistics on a significant amount of independent runs. The only way to ensure that the streams (random variables) do not overlap, is to use the Random Number Generator (RNG) implementation's substream capability, which is also called an increment in run number.

Using a fixed seed and advancing the run number is the more statistically accurate way to configure different independent replications [16]. To configure run number with the same seed, the line ns3::RngSeedManager::Setrun() is added before random variables are created. The simulation experiment was done with 10 independent replications for each number of node chosen in the simulation. In other words, there are 10 iterations for each number of the node during the simulation run.

4) *Defaults parameters*

The number of nodes, propagation loss models, and set independent replications are parameters that were continuously changed during the simulation experiment. Other parameters remain constant throughout the simulation experiment. Those parameters are the number of sinks, propagation delay models, pause time, and node speed. The general parameters used during the simulation process are shown in Table I.

TABLE I: SIMULATION PARAMETERS

Parameters	Value
Operating System	Ubuntu 16.04
Simulator	NS3(v-3.29)
Channel Type	Wireless Channel
Number of Nodes	20, 30, 40, 50 & 60
Number of sinks	10
Wi-Fi Operation Mode	Ad Hoc
Mac Standard	802.11B
Node Speed	20 m/s
Pause Time	0
Mobility Model	Random Way Point
Position Allocator	Random Rectangular
Propagation Delay Model	Constant Speed
Propagation Loss Models	Friis, Two-ray Ground and Nakagami
Simulation Time	100 seconds
Simulation Area	300m x 1500m
Data Rate	2.048 kbps
Size of Data Packets	64 Bytes
Routing protocols	AODV and DSDV

C. *Simulation Experiment Execution*

Fig. 2 shows the flow of the simulation experiment conducted to measure performance comparison between AODV and DSDV routing protocols.

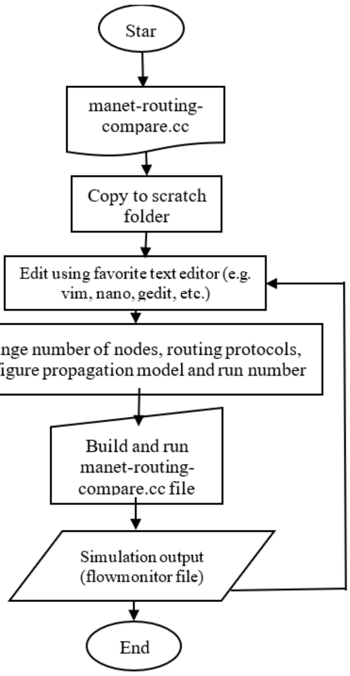

Fig. 2. Steps in the simulation experiment

D. *Performance Metric for Quantification of Network*

The computation of throughput, PDR, and E2E delay are shown subsequently:

Throughput is calculated using the equation (4)

$$Throughput = \frac{rxBytes \times 8}{1024 \times Simulation\,Time} \quad (4)$$

The $rxBytes$ is referred as total received bytes converted to bits by multiplying with 8 since 1bytes equals to 8 bits. It is because the throughput is commonly measured in kilobits per seconds(kbps).

The PDR is calculated using equation (5)

$$PDR = \frac{rxPackets}{txPackets} \times 100 \quad (5)$$

where $rxPackets$ are total received packets and $txPackets$ are the total transmission packets.

The E2E delay is computed using equation (6)

$$E2E = \frac{DelaySum}{rxPackets} \quad (6)$$

where $DelaySum$ is referred as sum of all end-to-end delay for all received packets of the flow[17]-[19].

E. Calculation of Confidence Interval for the Independent Replications

To ensure credibility of the result, the average throughput, PDR and E2E computed for each node of each model in 10 independent replications, a confidence interval are calculated. Table II shows the steps used to calculate the confidence interval. Since 10 replications conducted were independent with the number of nodes, the average throughput, PDR and E2E were assumed to be normally distributed. There may be slight variations between iterations of each node that is captured by computing the standard error and marginalized using t-distribution. The margin of errors that were computed by multiplying the critical value of t-distribution (d=9, 97.5%) with standard errors was added to average values of throughput, PDR and E2E to get confidence interval.

TABLE II: CALCULATION OF CONFIDENCE INTERVAL

Step	Description	Equation
1	Computation of mean of each node for all iterations	$\bar{x}_i = \frac{1}{n}\sum_{j=1}^{n} x_{i,j}$ $\bar{x}_i = \frac{1}{n}\sum_{j=1}^{n} x_{i,j}$ **For j = 1, 2, 3, … n**
2	Computation of Variance	$Var(\bar{x}_i) = \frac{1}{n-1}\sum_{j=1}^{n}(x_{i,j} - \bar{x})^2$ $Var(\bar{x}_i) = \frac{1}{n-1}\sum_{j=1}^{n}(x_{i,j} - \bar{x})^2$
3	Computation of Standard error of the mean	$SEM = \sqrt{\frac{Var(\bar{x}_i)}{n}}$
4	Computation of Confidence Interval	$C = \bar{x}_i \pm t(SEM)$ $C = \bar{x}_i \pm t(SEM)$

V. RESULTS AND DISCUSSION

The comparison between the two routing protocols AODV and DSDV against each propagation loss model with the selected performance metrics, E2E, throughput and PDE are discussed in this section.

A. E2E Delay

The E2E delay performance comparison between AODV and DSDV routing protocols against Friis, Two-ray ground and Nakagami propagation loss models are illustrated in Fig. 3 through Fig. 5.

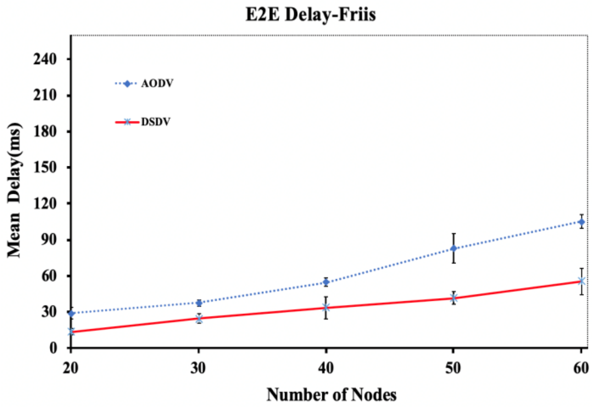

Fig. 3. Friis E2E delay for AODV and DSDV

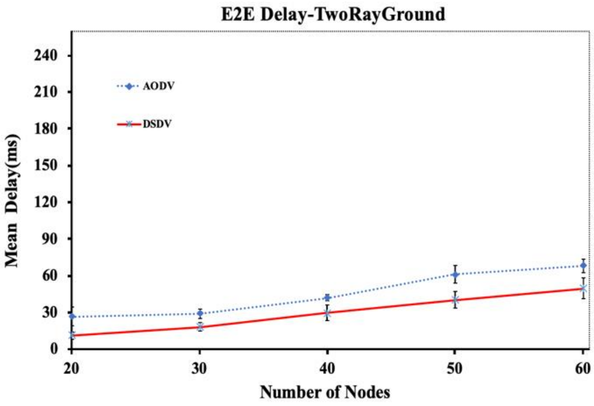

Fig. 4. Two-ray Ground E2E delay for AODV and DSDV

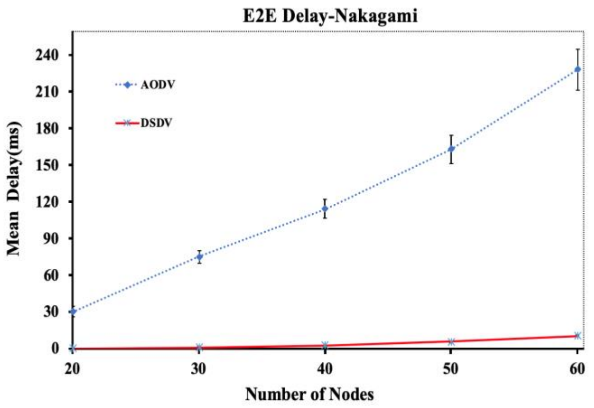

Fig. 5. Nakagami E2E delay for AODV and DSDV

By comparing the E2E delay of the two routing protocols AODV and DSDV when all propagation loss models are used against the varied number of nodes, AODV shows the highest delay compared to DSDV for all propagation models.

Due to its reactive nature, AODV initiates the routes only when demanded. Therefore, when the source node needs to send information to the destination node, it requires more time to discover the path to the destination. Subsequently, it results in higher delay, the presence of advance routing information contributes to a lower end-to-end delay on DSDV routing protocol. Although DSDV protocol shows the lower delay than AODV, when Nakagami model is used, it offers the lowest delay as compared when Friis and Two-ray ground model was used. It is because the Nakagami fading can affect DSDV protocol, while it does increase the mean delay of AODV. The AODVrouting protocol is a reactive protocol that uses the multi-route, and with a combination of Nakagami model, which also uses the multiple paths will lead to more interference that results in more delay.

Generally, the end-to-end delay measure the ability of a routing protocol adapts to the various network limitations and reflects the routing protocol's reliability. The reliability of routing protocol is optimal when it shows minimum delay; in this case, DSDV outperforms AODV in all propagation models.

B. Throughput

Throughput performance comparison between AODV and DSDV routing protocols against Friis, Two-ray ground and Nakagami propagation loss models are illustrated in Fig. 6 through Fig. 8, respectively.

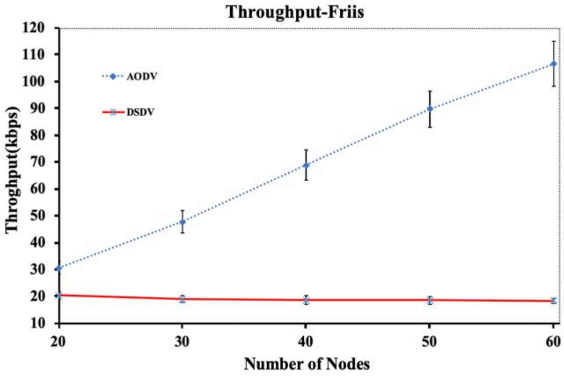

Fig. 6. Friis - Throughput for AODV and DSDV

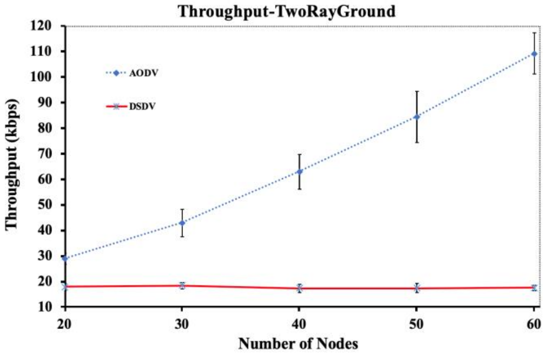

Fig. 7. Two-ray Ground - Throughput for AODV and DSDV

When comparing the throughput of AODV and DSDV routing protocols for each propagation loss models with various node numbers, the AODV generates higher throughput than DSDV. It is because AODV has rapid response mechanism in the event of a link failure and avoid rebroadcast routing information. In contrast, the DSDV performance decreases due to regular route updates of information. However, the throughput value varies for each propagation loss model, where Two-ray ground model shows the highest value among all others.

The throughput describes the ratio of the total amount of data from a sender to the time it takes for the receiver to get the last packet. Routing protocol performance is best when the throughput is higher; in this scenario, the AODV performs better than DSDV in all propagation models.

C. PDR

The performance comparison of the PDR between AODV and DSDV routing protocols against Friis, Two-ray ground and Nakagami loss propagation is shown in Fig. 9 through Fig. 11.

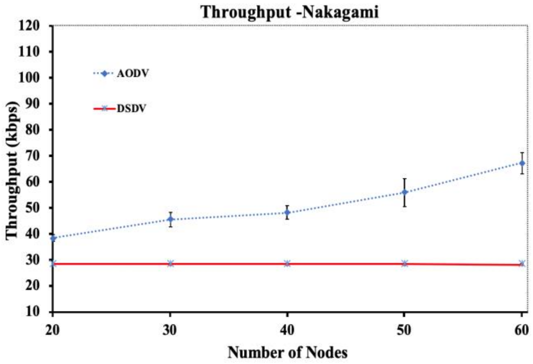

Fig. 8. Nakagami - Throughput for AODV and DSDV

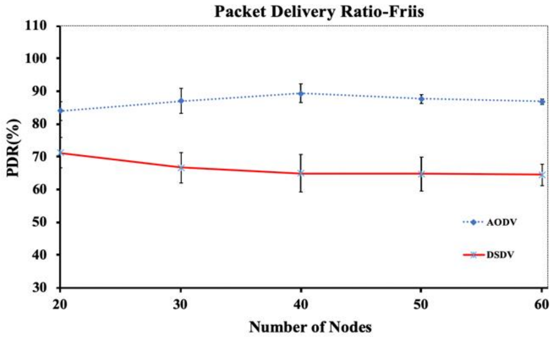

Fig. 9. Friis - PDR for AODV and DSDV

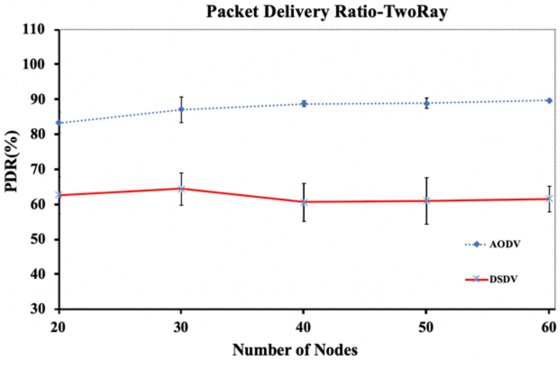

Fig. 10. Two-ray Ground - PDR for AODV and DSDV

The AODV and DSDV routing protocols are simulated with each propagation loss models and different numbers of nodes. When Friis and Two-ray ground models are employed, the AODV routing protocol shows higher PDR than DSDV. However, when the Nakagami propagation loss model is used, the DSDV shows higher PDR. The reason AODV routing protocol has higher PDR than DSDV is because of AODV changes topology rapidly and as such, performs better as compared to Friis and Two-ray ground model. Nonetheless, the DSDV routing protocol performances are less affected by Nakagami fading, which shows higher PDR than AODV. It is because the DSDV routing protocol utilizes the shortest path algorithm and models the fading as a random process.

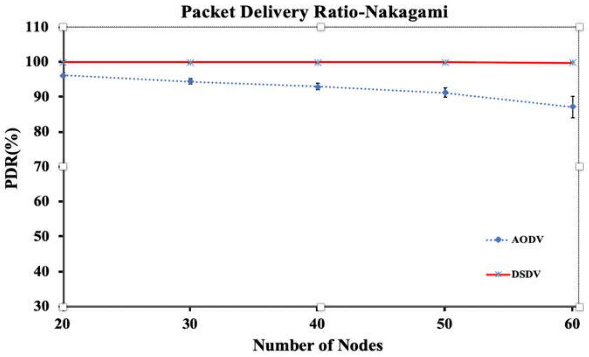

Fig. 11. Nakagami - PDR for AODV and DSDV

In general, the PDR defines the completeness, efficiency and accuracy of the routing protocol. The higher the PDR of a particular routing protocol, the more optimal the performance. The AODV routing protocol shows higher PDR as compared to DSDV when Friis and Two-ray ground model are used; however, quantified with using Nakagami model, DSDV routing protocol shows higher PDR than AODV. The AODV is best operated when Two-ray ground and Friis propagation model is in place. On the contrary, the DSDV outperforms AODV when Nakagami model is employed.

VI. CONCLUSION

In conclusion, the comparison between AODV and DSDV routing protocols provide valuable insight into both routing protocols capability. Typical routing protocol performance metrics exclude the effect of radio propagation, and in this paper, substantial impact due to variation of propagation model is observed. In light of the results, routing protocol such as DSDV shows improved PDR performance under Nakagami model but performs sub-optimal in other propagation models. It is shown in Table III. Therefore, this study presented that developing a routing protocol must be specific to the condition and application that the routing protocol will be applied. Hence the optimum performance of the network will be achieved.

AODV is the best protocol performed in term of throughput and PDR compare to DSDV as it produces maximum throughput regardless of the propagation model used, and generates higher PDR when used with Friis and Two-ray ground model. However, it generates a higher delay than DSDV, especially when measured against the Nakagami model.

Based on the results and conclusion drawn, this study recommends that the AODV routing protocol is most feasible to be used in an environment typical of Two-ray propagation loss model. The routing protocol may offer optimum performance, particularly in a scenario with a higher number of nodes. Although the AODV routing protocol generates higher delay than DSDV routing protocol, the delay is lower when experimented with Two-ray ground model. This work deems that Two-ray ground model is most suited with AODV routing protocol.

The DSDV routing protocol optimally performs when measured with Nakagami propagation loss model, as it produces lower delay and higher PDR. Although DSDV produces lower throughput than AODV routing protocol, the throughput is higher using Nakagami model compares when using other propagation loss models. It shows that Nakagami model is feasible to be used with DSDV routing protocol.

TABLE III: PERFORMANCE ANALYSIS COMPARISON BETWEEN AODV AND DSDV

Metrices	**Model**	**Routing Performance**		**Increasing node density**	
		AODV	DSDV	AODV	DSDV
Delay	Friis	High	Low	Increase	Increase
	Two- ray	High	Low	Increase	Increase
	Nakagami	High	Lowest	Increase	Increase
Throughput	Friis	High	Low	Increase	Decrease gradually
	Two-ray	High	Low	Increase	Decrease gradually
	Nakagami	High	Low	Increase	Decrease gradually
PDR	Friis	High	Low	Increase	Decrease
	Two-ray	High	Low	Increase	Decrease
	Nakagami	Low	High	Decrease	Constant

CONFLICT OF INTEREST

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article.

AUTHOR CONTRIBUTIONS

Megat F. Zuhairi conceived and planned the experiments. Sabra A. Saleh carried out the experiments the simulations. Megat F. Zuhairi and Hassan Dao contributed to sample preparation. Megat F. Zuhairi contributed to the interpretation of the results. Sabra A. Saleh took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript. All authors had approved the final version.

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