Investigation of the Effect of Mobility Models on Proactive and Reactive Routing Protocols in Mobile Ad Hoc Networks

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ABSTRACT

Mobile ad hoc networks are made up of wireless mobile nodes. In this mobile ad hoc network, wireless mobile nodes convey messages to each other without any pre-established infrastructure or centralized control. Wireless ad hoc networks eradicate the complications which may arise while setting up the infrastructure.

The mobility model is crucial when evaluating routing protocols performance in ad hoc mobile networks. Two parameters are very important when dealing with the mobility behavior of mobile nodes, these parameters are pause time and maximum speed.

The aim of this study is to investigate the effect of mobility models on proactive and reactive routing protocols for mobile ad hoc networks. Ad Hoc on Demand Distance Vector and Destination Sequenced Distance Vector are used in our simulation as the proactive and reactive routing protocols respectively. Reference Point Group Mobility model and Random Way Point Mobility model are the group and entity mobility model used in our simulation to compare and analyze the performance of the routing protocols.

In this study, the behavior analysis and comparison of the routing protocols under different mobility scenarios are evaluated using Network Simulator 2 and results of the simulations are presented. The results presented depend on four important performance metrics of ad hoc networks, which are average end-to-end delay, packet delivery ratio, normalized routing load or overhead and average number of hops.

Keywords: Mobile ad hoc networks (MANETs), Routing protocols, Mobility models, Simulation, Performance evaluation, and Network simulator (NS-2).

ÖZ

Gezgin özel amaca yönelik ağlar kablosuz gezgin düğümlerden oluşmaktadır. Bu ağlarda gezgin noktalar birbirleriyle önceden kurulmuş herhangi bir yapı ya da merkezi kontrol olmaksızın mesajlaşabilmektedirler. Kablosuz gezgin ağlar altyapı kurulumlarında ortaya çıkan sorunları kaldırmaktadır.

Devingenlik modelleri gezgin özel amaca yönelik ağlarda yönlendirme protokollerinin performansını ölçmede çok önemlidir. Gezgin düğümlerin devingenlik durumlarının üstesinden gelirken azami hız ve duraklama zamanı iki önemli parametredir.

Bu tezin amacı devingenlik modellerinin gezgin özel amaca yönelik ağlarda kullanılan önceden etkin (proactive) ve tepkin (reactive) protokollerine olan etkisini incelemektedir. Simulasyonlarda, önceden etkin protokollerinden Birbirini İzleyen Hedef Uzaklık Vektörü (DSDV) protokolü, Özel Amaca Yönelik Talepli Uzaklık Vektörü (AODV) protokolü kullanılmıştır. Yönlendirme, protokollerinin performanslarını karşılaştırmak ve analiz etmek için Dayanak Noktası Grup Devingenlik (RPGM) modeli ve Rasgele yol Noktası Devingenlik (RWPM) modeli kullanılmıştır.

Bu çalışmada yönlendirme protokollerinin performanslarını farklı devingenlik senaryolarında analiz etmek, karşılatırmak ve ölçmek için Ağ Simulatorü 2 (NS-2) kullanılmış ve simulasyon sonuçları sunulmuştur. Sonuçlar özel amaca yönelik ağlarda kullanılan dört önemli performans ölçütüyle verilmiştir. Kullanılan performans ölçütleri paket dağıtım oranı, normalize edilmiş yönlendirme yükü, ortalama sekme sayısı ve ortalama uçtan uca gecikmedir.

Anahtar Kelimeler: Gezgin özel amaca yönelik kablosuz ağlar (MANETS), Yönlendirme protokolleri (AODV ve DSDV), Devingenlik modelleri (RWPM ve RPGM), Performans değerlendirme, Ağ simulatörü 2 (NS-2).

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LIST OF ABBREVIATIONS

Abbreviation	**Meaning**
RWPM	Random Way Point Mobility Model
RPGM	Reference Point Group Mobility Model
AODV	Ad Hoc on Demand Distance Vector
DSDV	Destination Sequenced Distance Vector
MANETs	Mobile Ad hoc Networks
TORA	Temporally Ordered Routing Algorithm
DSR	Dynamic Source Routing
PUMA	Protocol for Unified Multicasting
NS-2	Network Simulator 2
CBR	Constant Bit Rate
OTCL	Object Oriented Version of Tool Command Language

Chapter 1

INTRODUCTION

Ad hoc mobile networks are among the types of wireless networks which communicate through electromagnetic waves. They comprise of wireless nodes which are mobile. These wireless nodes convey messages to each other without any pre-established infrastructure or centralized control. The wireless ad hoc networks eradicate the complications which may arise while setting up the infrastructure. They receive and transmit messages over the air. When a mobile node which is available in the network broadcasts information, the entire nodes within the network will receive the message.

Ad hoc mobile networks communication has been through node to node communication for nodes that are close to each other [1] or by one node serving as a router or host to aid communication for nodes that are not close to each other [2]. An ad hoc mobile network has a dynamic environment in the sense that the mobile nodes can easily leave the network anytime they want and as well to join whenever it pleases them.

In the design and analysis of routing schemes for mobile ad hoc networks, it has been of a great importance to fully understand the mobility characteristics. Different routing protocols can be compared and as well evaluated using simulation; this is the principal means researchers always use to compare and take measure in the way the routing protocols perform. Some routing protocols from previous studies exhibit different behavior with different mobility patterns.

The mobility model is crucial when evaluating the performance and study of ad hoc mobile networks (MANETs); it creates a realistic moving behavior for mobile nodes. Mobility behavior of each mobile node in mobile ad hoc networks and how the directions and speeds of each individual node change with time is always represented in the mobility models. There are two parameters which are very important when dealing with mobility behavior of mobile nodes, these parameters are maximum speed and pause time [3]. In a situation where maximum speed is small and pause time is large, the stability of network topology is assured, while in the reverse case there is always a dynamic network topology. The way mobile nodes move is very essential in mobile wireless networks. Mobility models help in mobile wireless networks performance analysis.

In wireless mobile ad hoc networks, routing protocol development has gained a significant role and the design of a good and dependable routing strategy has been a challenging problem. Ad hoc mobile networks have limited resources, so efficient routing is highly needed in order to manage the limited resources and in order to adapt to different network conditions [4]. Researchers have proposed a lot of routing protocols which are categorized or classified into groups. In this study, we focused on two of the routing protocol categories, reactive and proactive routing protocols. In MANET, routing from one node to another may be done by the use of reactive routing protocols. Reactive routing protocols is known with its “on demand basis” [5]. In many recent researches, on-demand routing protocols are used. These protocols generate routing information whenever interested stations initiate transmission. On the other hand, proactive routing protocols keep routes to all nodes, both the routes needed and the ones that are not needed. Topology changes easily affect proactive routing protocols whether network traffic is affected by the change or not [6].

1.2 Objectives

Our work mainly focuses on investigating the effect of mobility model on proactive and reactive routing protocol for ad hoc mobile networks. In most related work, researchers have compared Temporally Ordered Routing Algorithm (TORA) [10], Destination Sequenced Distance Vector (DSDV) [8], Ad Hoc on Demand Distance Vector (AODV) [7] and Dynamic Source Routing (DSR) [9] with Random Way Point Mobility Model (RWPM) while varying pause time, mobility speed and maximum connection. Some studies used two or three of these parameters in their performance metrics to compare the performance of their protocol(s).

In this thesis, both entity mobility model and group mobility model [11] are used with varied number of nodes to examine the behavior of the routing protocols used. The pause time, mobility speed and maximum connection are all kept constant.

DSDV and AODV are used in our simulation as the proactive and reactive routing protocols respectively. We choose DSDV over other proactive routing protocols because DSDV is among the protocols that come with NS-2. Also DSDV is a loop free proactive routing protocol. We choose AODV over other reactive routing protocol because it is adaptable to highly dynamic topologies. It uses some functions of DSDV routing protocol such as periodic beaconing and sequence numbering procedure. Also we chose it because it has less routing overhead than DSR though it uses DSR route discovery procedure.

Reference Point Group Mobility (RPGM) Model and RWPM represent the group and non-group mobility models used in our simulations to compare and study the behavior of the selected routing protocols. The non-group model is also known as entity mobility model. RWPM has been the mobility model most frequently used by most experimenters in the simulation study of ad hoc mobile networks in order to examine in contrast and analyze the behavior of such networks. In RWPM when mobile nodes finally get to a point where each of them becomes stable, they are always revolving mostly around the center region with almost none around the boundaries. Also the mobile nodes always pause for a specific period called pause time, but in RPGM, the mobile nodes in the group pause at the same time. We choose RWPM and RPGM as our entity mobility model and group mobility model respectively because the authors in [11] recommended to researchers to use RWPM when clustering in the middle is not desired. They as well, advise researchers to use RPGM whenever group mobility model is desired.

In this study the behaviors of selected routing protocols are compared with the selected mobility models and evaluated using some performance metrics.

1.3 Layout of the thesis

The remainder of our thesis is prepared in the following ways; Chapter 2 provides the literature review of the related work. Routing protocols and mobility models are overviewed in Chapter 3. Chapter 4 describes the conduction of simulation experiments in NS-2. Chapter 5 is devoted to the analysis and comparison of a given protocol under different mobility models with different assumptions. Chapter 6 concludes the thesis with a summary of obtained results and the proposals of a further work.

Chapter 2

LITERATURE REVIEW

This chapter mainly focuses on the research because a lot of work and research has been done in ad hoc mobile networks. Researchers have put more interest over the years now in the study of ad hoc mobile networks. This networks work without existing infrastructure and it changes frequently, this means that it is dynamic. The nature of this ad hoc mobile network requires end-to-end communication that is efficient. Routing is really crucial in ad hoc mobile networks; this is challenging though it has been an area of interest for many researchers. There are a lot of routing protocols in ad hoc mobile networks and mobility models have been essential tools used to test the behavior of these routing protocols. Researchers in recent years have tried to evaluate routing protocols in order to decide which ones behave better using various network scenarios.

2.1 Review on mobility models

Various mobility models survey in multi-hop networks as well as cellular networks was provided in [12]. The authors introduced a new group mobility model which represents the relationship among mobile nodes. They also investigated mobility models contribution in exhibition study in a particular network. For this reason they used the mobility they proposed on these protocols, ad hoc on demand distance vector, destination sequenced distance vector and Hierarchical State Routing (HSR). They used the following metrics' performance to examine in contrast their behavior, control overhead, end-to-end delay and throughput while they used link up/down to evaluate the effect of mobility in dynamics of link up/down.

Parallel simulation language maisie was used to stimulate their protocols. Number of mobile nodes used is 100 with a topology area of 1000m x 1000m in 200seconds. In their graph, they drew each of their metric against mobility. They provided a graph that compared the models with each of the protocol used.

According to the author's results, various protocols are affected by various mobility models in various approaches. Choice of mobility affects the ranking of routing algorithm. When the random model is used, there is an increase in the rate at which connectivity changes than when group model is used. The throughput of AODV and HSR performs well when communication is restricted using group mobility. While with group mobility DSDV performance in throughput is just normal, it shows little sensitivity with group mobility.

In [11] mobility models survey was provided by the authors. Both group and non-group mobility model was described. They show how the results gotten from the behavior of MANET protocol rapidly change due to the mobility model used in the simulation.

Overview of seven different entity mobility models and 5 different group mobility models was provided in the paper.

NS-2 is used to examine in contrast the behavior of random way point mobility model, reference point group mobility model, random walk mobility model and random direction mobility model with DSR routing protocol. In their simulation, they choose the parameters of the four mobility model such that path movements that were similarly related will be stimulated. The performance metrics used include end-to-end delay, data packet delivery ratio, average hop count and overhead of protocol. They drew the graph of each of the performance metrics used over average speed (m/s).

The authors conclude from their simulation results that, the mobility model used has effect on the behavior of ad hoc mobile network. The behavior of ad hoc mobile networks varies according to the mobility model used. Also the behaviors of ad hoc mobile networks have significant change when different parameters are applied on the same model. Moreover the authors emphasized that in order for researchers to choose mobility model for any protocol they want to simulate, a data traffic pattern which influences the protocol performance is needed. In addition, mobility model that is close to the scenario in the actual world more than the other mobility models should always be used. The authors finally recommended to researchers to use RPGM with parameters that are appropriate whenever they want to use group mobility model in their work. But they recommended RWPM and random walk mobility model if the researcher wants mobile nodes to cluster in the middle when simulating or gauss-markov mobility model whenever they don’t want group mobility model.

In [13] the effect of different mobility models on the behavior of ad hoc mobile was evaluated. Various independent protocol metrics was proposed in order to understand mobility characteristics. This characteristic includes spatial, temporal dependence and geographical restrictions. The effect mobility models have on the building blocks with influence of it on protocols generally was investigated.

RWPM, RPGM, freeway and manhattan models are the mobility models used in their simulation, while Dynamic Source Routing (DSR), DSDV and AODV are the routing protocols used. The authors used different metrics to evaluate the performance generally; both protocol performance metrics and protocol independent metrics were used. The later is used to bring forth graph connectivity within the mobile nodes and characteristics of mobility nodes. Finally this metrics were used to explain the mobility impact on the protocols performance metrics. Mobility metrics which include the degree of temporal dependence, relative speed and geographical restrictions, degree of spatial dependence was used to test the behavior of the models used. Graph connectivity metrics which include path duration, number of link changes, link duration and path availability was used to examine the mobility models effect on the graph connectivity within mobile nodes. Protocol performance metrics used include throughput, Packet delivery fraction and normalized routing load.

The various mobility patterns used in comparing the protocol was generated using network simulator 2. The same number of nodes was used in the entire pattern generated with a topology area of 1000m x 1000m and 900 seconds simulation time. They applied different maximum speeds in the patterns. The graph of each metric they used was provided and they drew it against maximum speed.

The authors concluded that no protocol out performs others in all areas. This is because various mobility patterns give various performances ranking of the protocols. With the mobility metrics and connectivity graph metrics they observed that mobility pattern has influence over the connectivity graph and as well connectivity graph has influence over the protocol performance.

2.2 Review on routing protocols

In [6] the authors evaluated the performance of non-demand based routing protocols, DSDV and demand based protocol, AODV with CBR (continuous bit rate) traffic. They used RWPM to figure out the behavior of these protocols. Metrics for performance such as routing efficiency, packet delivery fraction, throughput, normalized routing load, average end-to-end delay was used in their work to examine in contrast the behavior of the protocols.

Network simulator 2 was used to simulate these protocols. The authors used two different pause times to evaluate the performance metrics; Pause time zero is used to evaluate throughput, routing efficiency and average-end-to-end delay while pause time 0 to 600 is used to evaluate normalized routing load and packet delivery fraction. Their simulation was performed in the topology area of 1000m * 500m and the simulation time was 600s. They presented four different types of graph with different pause times and different sources. From their simulation result, the authors found out that the protocols they used in their simulation have distance vector characteristics in common but their performance differs with mobility because of the way each protocol works.

They concluded that AODV result shows that it gives less fluctuation and it performs better than DSDV in routing overhead, throughput and average end-to-end delay performance metrics. The authors put in their best in their research work but there are a lot of errors in the paper with respect to pause time and their labeling. The pause time is not well numbered and they made a mistake in some of their labeling for AODV and DSDV.

In [14] the authors evaluated and compared the CBR performance in different mobile scenarios which they generated using random way point mobility model. They discussed the result of AODV and DSDV routing protocols when it comes to constant bit rate delay and performance of drop rate. In their performance analysis, they used only two performance metrics drop ratio and end-to-end delay.

Network simulator 2 was used in their simulation with topology of 500m * 500m and simulation time of 200s. They applied different speeds, pause time and traffic pattern in their simulation. In their graph, they drew it with each performance metric they used against different pause times and as well against different CBR connections with different speeds.

They concluded by saying that DSDV with lower number of connections lost small percentage of the data which was generated, while the number of drop ratio increases as the number of connections are increased and also with increase in speed. Also as the number of connection is increased, end-to-end delay increases in DSDV as well. In their paper they said that CBR performed better on AODV than on DSDV and it's more stable when mobility is low than when it is high though they didn't provide the performance analysis of AODV.

In their simulation, they only evaluated the performance of DSDV but not AODV with the performance metrics they used though they presented the graph that contains both protocols. They mainly focused on DSDV in their analysis and didn’t explain the performance of AODV in the graphs they presented.

In [15] the authors modified path optimality metric and called their own weighted path optimality. They used their modified metric among others to examine in contrast the behavior of four routing protocols using random way mobility models. The protocols they used in their performance comparison are AODV, dynamic source routing, Temporally Ordered Routing Algorithm (TORA) and DSDV. The performance metrics used in their performance comparison includes average end-to-end delay, network load deviation, jitter in terms of average, weighted path optimality, maximum and deviation of jitter.

The simulation is done in NS-2 with topology area of 700m by 700m with 100s simulation time. In the simulation they varied their pause time and kept other parameters constant. In their graphs they plotted their performance metrics against pause time.

The paper concludes that in weighted path optimality they proposed that DSDV performed best while TORA’s performance was the worst. DSDV and AODV performed best in delay, while in load balancing DSDV out performed others. In average jitter, maximum and deviation of jitter DSDV came out best, followed by AODV, then TORA and DSR.

In [16] the authors compared Random Walk Mobility Model (RWMM) and RWPM over two demand based protocols dynamic source routing and one proactive routing protocol DSDV. They applied the following performance metrics in their study packet delivery ratio, normalized routing road and throughput.

In order to compare their protocols behavior with the mobility models they selected, in their simulation, they applied different number of nodes, different speeds and different number of maximum connections. Network simulator 2 was used to simulate the protocols in a topology area of 670m x 670m with 200seconds simulation time. Different pause times were applied in each mobility model; in random walk mobility model, they used pause time zero while in RWPM, pause time was 25s. In their graphs, they plotted the performance metrics they used against speed in all their graphs with different pause time and different maximum connections.

The authors concluded that though RWMM (random walk mobility model) and RWPM have the same motion, different pause times applied differ the mobility models motion differs. When the same pause time was applied in the mobility models, the protocols behave the same way. But with increase in pause time in the RWPM, it was noted that the pause time is inversely proportional to the motion and to the path linkage break. This increase in pause time provides difference as regards to the protocols behavior.

In [17], research on various parameters and comparison which is based on simulation was provided. The protocols used in their simulation are two demand based protocol DSR, AODV and one non-demand based DSDV with RWPM. They applied the following performance metrics in their performance analysis, packet loss, average end-to-end delay, routing overhead, and packet delivery fraction.

Network simulator 2 was used to simulate their protocols with the mobility model. Topology area of 800m x 1200m was used with different times of simulation. Four different groups of scenario files were generated; in the first one, number of nodes is varied while pause time and other parameters are kept constant with 1200 seconds time of simulation. In the second scenario file, speed was varied with other parameters being constant with simulation time of 1200 seconds. In the third, they varied pause time and kept other parameters constant as usual with simulation time of 1200 seconds. In the last scenario file, simulation time was varied while other parameters were kept constant.

The authors concluded that AODV performance is good in environment that is dense but not with packet loss performance metrics. From their result, AODV and DSR performed very well better than DSDV though no protocol will be chosen as the best for all the scenario file generated, each of the protocols involved in the simulation have their own advantages and disadvantages.

In their paper, they didn’t provide the graph of their work though they commented on it. They didn’t provide the graphs they used in their comparison, so it was very difficult to understand how they analyzed the performance metrics and how the graph was plotted.

In [18] two protocols were simulated using network simulator 2 and analyzed using some performance metrics. AODV and DSDV are the routing protocols used in simulation with RWPM. The metrics for performance used are packet loss, end-to-end delay, throughput, and packet delivery fraction.

In the simulation environment using NS-2 simulator, topology area of 500m x 500m was used with 500seconds simulation time. During the simulation varying number of nodes, speed and time were applied. They provided the graph of their throughput against variable pause time though the graphs provided was not so good and clear.

They concluded that AODV has less routing overhead when compared with DSDV. During high mobility simulation the authors argued that AODV out performs DSDV because in AODV routes are only created when they are needed unlike in DSDV. DSDV performs better in a smaller network.

The authors didn’t provide sufficient results; they only provided one graph of throughput against pause time without taking into consideration the graph of the other performance metrics they used.

In [4], routing protocol wide range overview was provided. The performance comparison of the routing protocols is presented. They classified routing protocol into 3 various groups namely;

- Global or proactive
- On demand or reactive
- Hybrid

The authors emphasized that during the start up; global routing protocols usually generate entire path to terminal or station and maintain them by updating the routes periodically while reactive determine routes to destination whenever route is needed. Routing protocol hybrid combines the characteristics of demand and non-demand based.

At the end of each group review, they provided a summary of the groups of routing protocols discussed. A table which provides the basic characteristics of each member in the group of routing protocols discussed and a table that compares their complexity was provided as well.

The paper concluded that flat addressing may be simple to implement when it comes to global routing though it may not scale well when applied in large network. Routing overhead which is presented in the networks has to be minimized so as to make flat addressing efficient enough. This can be done by using conditional update instead of periodic ones and by using GPS device. In routing protocols which are on-demand based such as DSR and AODV, the flooding based they use may have scalability problem. In order to avoid this, the way route is discovered and the way it is maintained will be controlled.

In [5] the authors provided survey of ad hoc routing protocols and as well compared each class of the protocols provided. They reviewed the technology collections that have been introduced for ad hoc networks. They organized protocols that are used for routing into 9 groups according to each group's structural foundation. This includes:

- Source-initiated which are also known as on-demand or reactive routing protocols: These are routing protocols which discover routes just whenever a source node requests route to destination. The source node can do that through a procedure known as route discovery procedure.
- Table –driven or proactive routing protocols: The protocols in this group always keep current news of all the routes to the entire nodes in the network.

- Hybrid protocols: The protocols that belong to this group, share features of both demand and global routing protocols.
- Location-aware or geographical protocols: The protocols that belong to this group presume that the individual mobile nodes involved know the place of the whole node in the network.
- Multipath protocols: The protocols in this group create several paths from originator node to target node, unlike other protocols that discover conventional single route from originator to target.
- Hierarchical Protocols: Protocols involved in this group build a hierarchy of nodes using a technique known as clustering because of the network size which cause control packet overhead.
- Multicast protocols: Multicasting can be defined as the concurrent broadcast of information from one sender to many receivers. A good number of these protocols depend on the beneficiary registering to the transmission of a particular transmitter. Most of the protocols involved in this group focused on building a multicast tree.
- Geographical multicast protocol: The protocols involved in this category usually direct the packets that come from the originator to target node positioned in a particular geographical area.
- Power aware protocols: The decision of routes for protocols involved in this category is based on power consumption characteristics. They take into consideration the nature of data flows, the irregular energy utilization due to the topology of the network and the heterogeneity of the energy resource of the nodes.

They provided a list and the survey of all the routing protocols which fall under each of the categories provided. For proactive routing protocol, the comparison was done with respect to multiple route, route metrics, route repository, route rebuilding and communication overhead. Reactive routing protocol comparison table compares the protocol according to number of table, update interval, critical node, routing metrics and communication overhead. The comparison of hybrid routing protocol was based on multiple routes, route metrics, route rebuilding, communication complexity and route repository. Geographical routing protocols comparison was done with respect to communication overhead, route metric, robustness, scalability, forwarding strategy, and loop-free. In multicast and geo-multicast theirs are according to protocol, core/broadcast, route metrics, route repository, and forwarding strategy. Finally they compared power aware routing protocols which are based on type, robustness, path strategy, scalability, and routing metric.

The authors concluded that though various protocols classes always function in different scenarios, they have aim which includes packet overhead reduction, reduction in delay and maximize throughput. The protocols differ from each other according to the way the route between source-destination is maintained and as well the way they discover their routes. All routing protocols out-perform others in a different way; this is based on the performance metrics combination used, as well as the scenario file. No routing protocol performed better than all other routing protocols.

In this work however a complete simulation is executed in order to study the effect of mobility models on proactive and reactive routing protocols for ad hoc mobile networks by changing the number of nodes while other parameters are kept constant. Four main protocol performance metrics were used in the analysis. Graphs of the performance of each of the protocols on mobility models used with each performance metric are presented. Also the graphs that show the performance of the protocols used with each mobility model on each performance metric are presented.

Chapter 3

ROUTING PROTOCOLS AND MOBILITY MODELS USED IN OUR WORK

In this chapter mobility models and routing protocols used in our investigation are presented in detail. Different routing protocols can be compared and as well evaluated with mobility models using simulation. For a researcher to weigh mobility models effect on mobile ad hoc networks, routing protocols are always involved and as well very necessary. Some routing protocols from previous studies exhibit differently with different mobility patterns. The way mobile nodes move is very essential in mobile wireless networks because it helps in mobile wireless network performance analysis.

3.1 Routing protocols

Routing protocols can be compared and as well evaluated using simulation; this is the principal means researchers always use to compare and weigh the behavior of routing protocols. In wireless ad hoc mobile networks, routing protocols development has really gained a huge significant advancement because the design of a good and dependable routing strategy has been a problem which is challenging. Ad hoc mobile network has limited resources, so efficient routing is highly needed in order to manage the limited resources and in order to adapt to different network conditions [4]. Experimenters have come up with a lot of routing protocols; these routing protocols are categorized or classified into groups. Their classification typically rests on their network structure and routing strategy [18]. In [4] the authors categorized routing protocols into three, while in [5] the authors categorized the routing protocols into nine categories as shown in chapter 2 of this work. Routing protocols in accordance with their routing decisions can stabilize the power consumption at nodes [2].

In our work we focused on two categories, proactive and reactive routing protocols. We tested the performance of one reactive and one proactive routing protocol, ad hoc on demand distance vector and destination sequenced distance vector respectively.

3.1.1 Destination Sequenced Distance Vector (DSDV)

DSDV [8] is classified as a table driven routing or proactive routing protocol which is based on hop-by-hop routing. Table driven protocols keep paths to all nodes, both the routes needed and the ones that are not needed. In DSDV routes are not created in demand based way, as a result all the routes to the entire destination are created at set up. These routes are controlled by using route update process periodically. Topology changes easily affect them, whether traffic is affected by the change or not [6]. This proactive protocol is a Bellman-Ford algorithm that is modified [19]. DSDV uses tables to store path news for all the nodes, though maintaining the routing table is not an easy task in DSDV. This is because of huge information which packets usually carry as a result of a large number of nodes. In the routing table, each node has an entry which is identified with a Destination-Specific Sequence Number (DSSN), subsequent hop and hop count to the terminal. Routing table information is distributed between nodes in either of the following ways, fully or partially. Nodes can exchange routing table information whenever a change in topology occurs, or unevenly, either fully with its neighbor or partially with its neighbor. When a node receives new information it will compare the information received with the previous information it has either through incremental or full dumped method [17]. These are two ways packets can be updated in DSDV. Full dumped or incremental is used to minimize the number of overhead that is being transmitted over the network. All available routing information is carried in full dumped, while the last updated full dumped information is carried in incremental. Usually in DSDV, routes with newest sequence numbers are used while the ones that have old sequence numbers are always discarded. In DSDV each mobile station constantly advertises its routing table information to nodes around it in order to help every node to get at its neighbor in the network and this updates the routing table. The flowchart of DSDV routing protocol is provided in Figure 1.

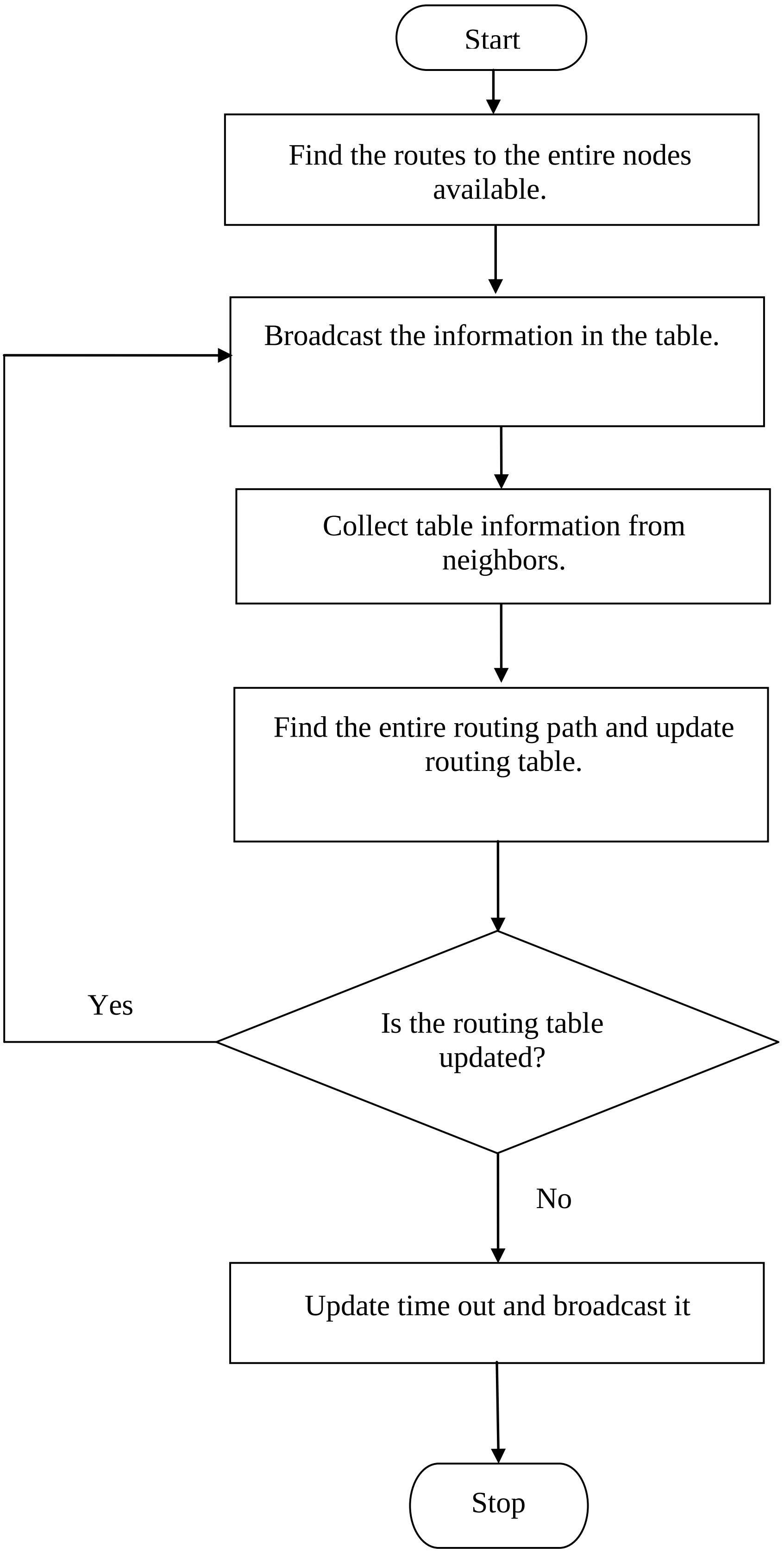


Figure 1: Flowchart of destination sequenced distance vector

3.1.2 Ad Hoc on Demand Distance Vector (AODV)

AODV [7] protocol is widely used protocol in ad hoc mobile networks. It is one of the reactive routing protocols which initiate routing when a route is needed. This means that it is an on demand based protocol that maintains information for paths that are active [4].

AODV make use of sequence numbers. This protocol uses a route table and always stores destination nodes routing information in it [6], but if no source makes use of a route for a specific period of time, nodes can remove it from their table because they may not know if it still exists.

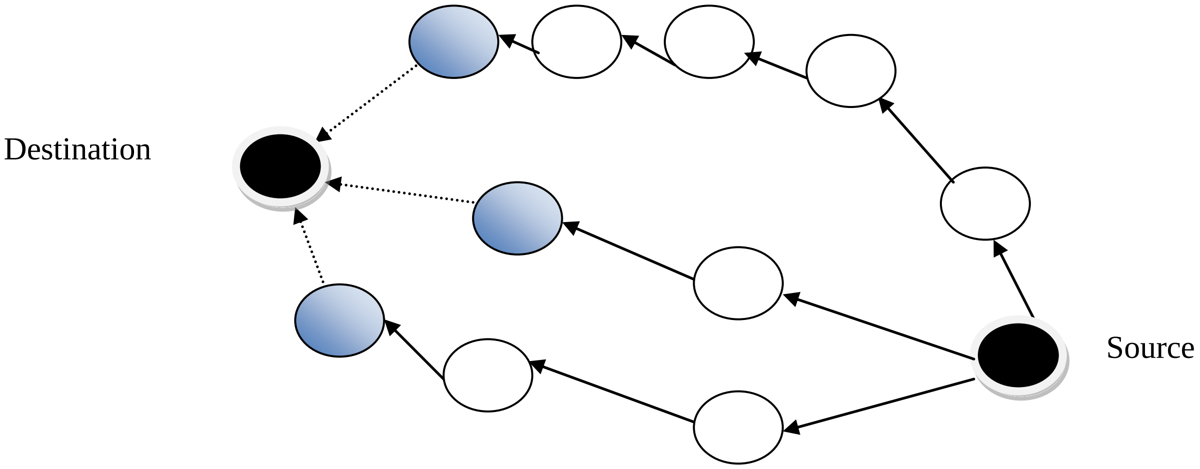
AODV is developed from DSDV and DSR. It works well by using the DSR and DSDV functions such as route maintenance and on-demand mechanism of routing discovery of DSR, sequence numbers and hop-by-hop routing of DSDV. AODV protocol makes use of sequence numbers and this helps to avoid some problems, such as count-to-infinity problem. For AODV to aid in route discovery, it makes use of a request-reply mechanism.

When the initiator node has a packet it wants to transmit without knowing the path to its terminal that is when the source node is in need of a path, it simply broadcasts (sends) a Route Request (RREQ) message all over the network as illustrated in Figure 2a. In the figure, the black dots represent destination node and source node. The gray dots represent nodes that have route to destination. White dots represent mobile nodes without the destination route. These route request packets are always identified using its unique parameters such as source address and request id fields.

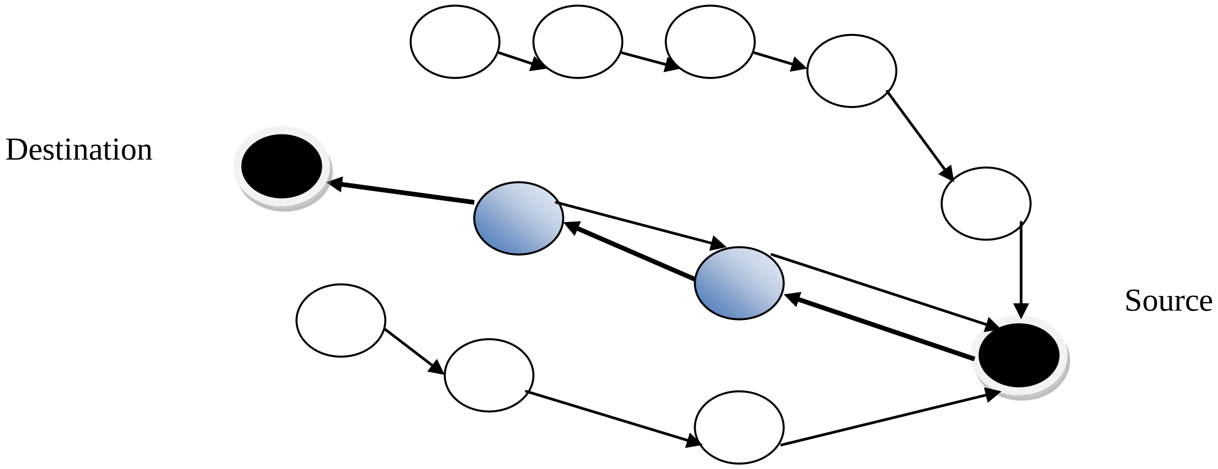
These parameters enable nodes to easily identify duplicates and discard them. There are some parameters which help in keeping track of data's number of hops which it has traveled, such as sequence number of source, the value which is the most recent among all the values in the destination sequence number which has been seen by the source, and the field which is responsible for the hop count. Nodes that are between source and destination node always keep the sequence number of the source that is most recent.

Whenever a source sends a route request, any of its neighbors or any node that knows a destination route the source wants including the destination itself will let the source know about it by informing the source using a Route Reply (RREP). By so doing AODV automatically provides a communication known as unicast. But if the neighbor who receives the route request doesn't know the route the source wants, it will simply send the RREQ across to other nodes and as well increase the hop count. If path to destination which originator is looking for exist, it will be found because any node that receives the RREQ will keep rebroadcasting it if it doesn't have the path to terminal.

As soon as a path is found, route reply is sent to node that is the originator. As a RREP is sent, each intermediate node that is between the initiator and the terminal establishes a path to the terminal. As soon as the source gets the RREP, if the RREP it receives is more than one, it will select the route which has the shortest hop count and start immediately to send the packets to the destination. Figure 2b illustrates the route reply mechanism. The source node is always notified when a link is broken through a route error (RERR) message, as soon as initiator gets RERR if it is still in need of the path, it will send the route discovery again.



(a) Route request broadcast



(b) Route to destination and how route reply is propagated

Figure 2: Route discovery cycle

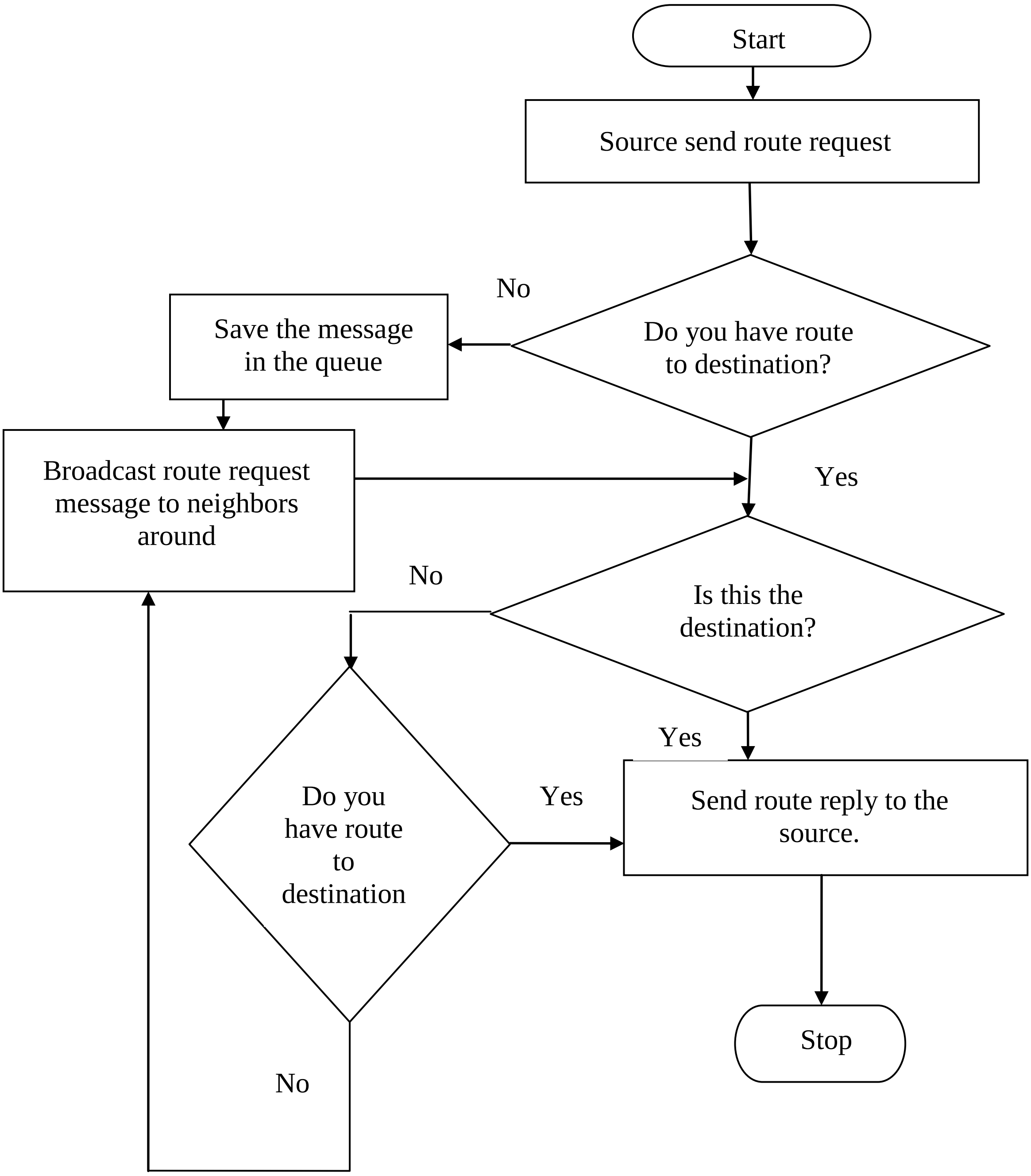


Figure 3: Flowchart showing process of route request in AODV

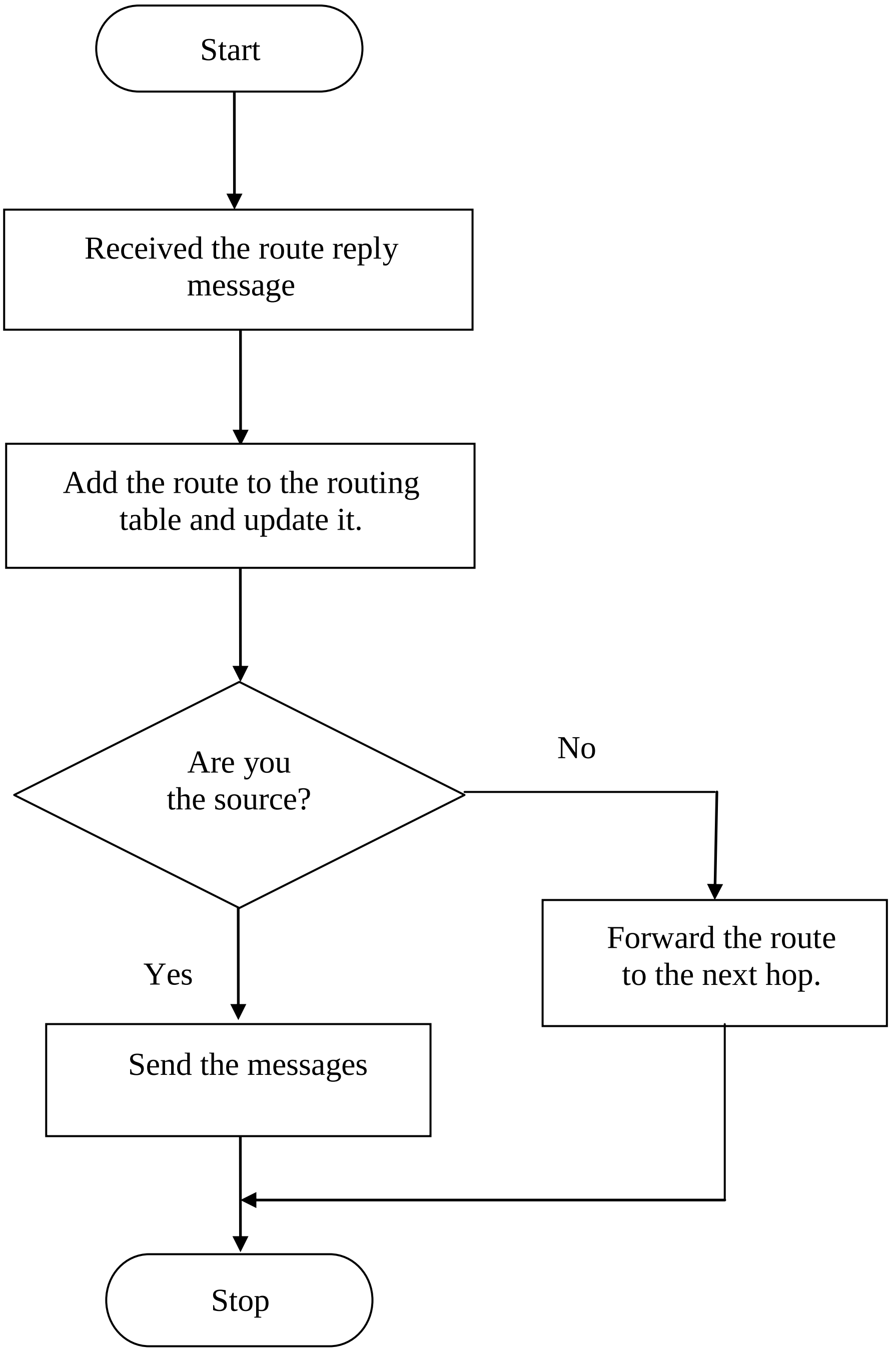


Figure 4: Flowchart showing process of route reply in AODV

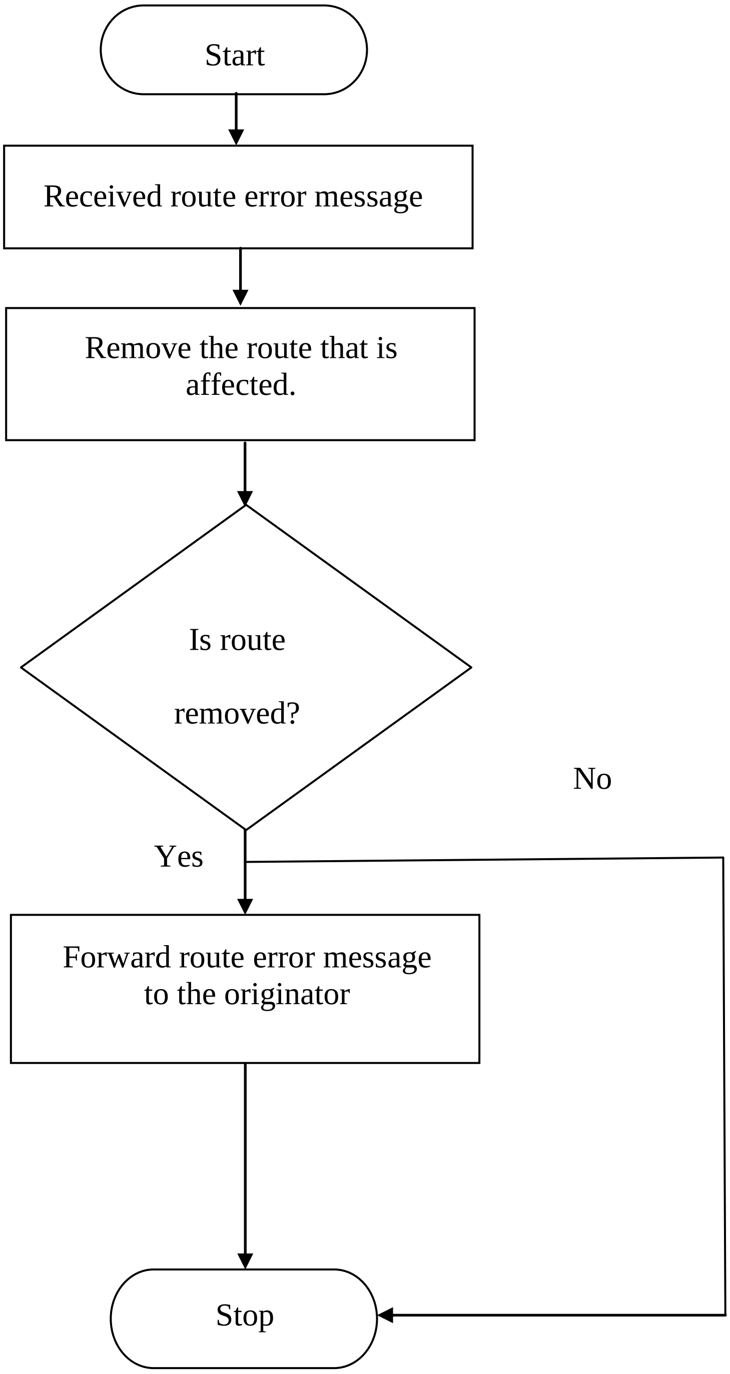


Figure 5: Flowchart showing process of route error in AODV

Table 1: Differences between DSDV and AODV

DSDV	**AODV**
It is a proactive routing protocol or table driven.	It is known as a reactive routing protocol or on demand routing protocol.
Paths are created at start up.	Paths are created whenever needed.
Loop free path is one of its advantages.	It's adaptable to highly dynamic topology, this is one of its advantages.
DSDV has the problem of high overhead	AODV has scalability and large delay problem

3.2 Mobility models

Mobility models are very important in evaluating the behavior of routing protocols in ad hoc mobile networks. These models help researchers to understand the behavior of each mobile node and how the directions and speeds of each mobile node change with time. In ad hoc mobile network simulation study, two types of mobility models are involved. Traces based model which is still in its early stage and synthetic based model [20] which is used by most researchers. There are two parameters which are very important when dealing with mobility behavior of mobile nodes, these parameters are maximum speed (V_{max}) and Pause time (T_{pause}) [3]. Maximum speed is the highest speed each mobile node will attain; the mobile nodes usually choose its speed randomly between maximum speed and minimum speed. Pause time is the time a mobile node can wait when it gets to its destination before it chooses another direction of its choice. In a situation where pause time is large and maximum speed is small, the stability of network topology is assured while in the reverse case there is always network topology that is dynamic.

There are two different synthetic mobility models used by experimenters to simulate the performance of ad hoc protocols. The first one is entity mobility models [11] where the motion of mobile nodes does not depend on one another. The second group of synthetic mobility models is called group mobility models [11] where the movement of mobile nodes depends on one another.

In this work, we used one entity mobility model, RWPM and one group mobility model, RPGM.

3.2.1 Random Way Point Mobility Model (RWPM)

In this type of mobility model, mobile nodes are at first spread indiscriminately all over the simulation range and this has nothing to do with the way the mobile nodes choose to distribute when moving. Random way point mobility model is a very easy mobility model which relies on random speeds and direction and each mobile node generates its speed and direction. This mobility model makes use of pause time [25]; pause time is a specified period of time mobile node must stay in some location when it arrives before starting the process again. In RWPM when a mobile node gets to its maximum speed it becomes stationary for a while according to the pause time specified. After this precise period of time, the mobile node will randomly choose its speed again. It will also choose its destination area which it will move towards to at the specified speed randomly but it must be from the simulation area. The mobile nodes will keep repeating this process until the end of simulation time. Problems experienced when using random way point mobility model include sudden stop and sharp turn of mobile nodes.

3.2.2 Reference Point Group Mobility (RPGM)

RPGM is a group mobility model in which mobile hosts are arranged in group, this group arrangement depends on their logical relationships. There is a logical centre in all the groups in the RPGM model. The movement of the entire group such as speed, acceleration, location and direction depends on the center's motion. RPGM was first defined in [12]. The model has to do with the way mobile nodes in the group moves irregularly according to the path travel by a logical centre to the group. Also it represents each distinctive mobile node random motion in their group with the help of their reference point [11]. In RPGM nodes are distributed uniformly within the area of the group. A path for the centre must be provided in order to determine the path for the group.

The entire node in the group possess a referral's trace (reference point), the motion of this referral's trace relies completely on the association motion. At each simulation step, a node is placed in a random manner around its referral's trace. The work of the referral's trace of individual node is to give the node access to independent random motion behavior, apart from the group motion. The referral's trace of a node always moves from RP_T to RP_{T+1} with the association movement vector know as $\overrightarrow{GM}$ [12],

T represent the tick time. In order to generate the position of the new node, the random motion vector $\overrightarrow{RM}$ is added to the reference point RP_{T+1}. The random

motion vector does not depend in the node's previous location, it has nothing to do with it. The lenght of the random motion vector is distributed uniformly within a certain radius which is centered at the reference point with its direction distributed evenly within 0 to 360 degree.

The motion of each group is determined by the RPGM model which defines a motion path each group must follow. To create a path each group has to follow, a sequence of check points, along the path the group will travel is defined which must correspond to the given time interval. The group continually travels from one check point to another as the time moves. New motion vector $\overrightarrow{Vg}$ is always computed from current check point location, next check point location and as well from time interval whenever a group gets to a new check point.

The movement of the logical canter for each group and as well the random motion of each individual mobile node within their group are all implemented in this manner with Random way point Mobility model [17]. There is one significant difference between RWPM and RPGM, this difference is that in RWPM each individual node makes use of pause time when they reach their maximum speed but in RPGM individual nodes has nothing to do with pause time, pause time is used by all the group members at the same time. Whenever the association referral’s trace reaches terminal the entire nodes in the association must pause at once.

Chapter 4

CONDUCTION OF SIMULATION EXPERIMENTS IN NETWORK SIMULATOR 2

Network simulator 2 (NS-2) [26] has been widely used by researchers to simulate protocols in ad hoc mobile networks. In NS-2 you can simulate the following five routing protocols TORA, DSR, Protocol for Unified Multicasting (PUMA) [27], DSDV, and AODV. These protocols come with the NS-2, in order to simulate the protocols with the simulator you need to write the tcl script for your protocol. NS-2 is implemented in C++ code and OTcl (an object oriented version of Tool Command Language used in version 1) script is used in running the simulation in NS-2. OTcl is used as the command and configuration interface. Version 2 also supports tcl script that is written for version 1. The traffic model, the random way point mobility model and RPGM used in simulating the protocols were generated using NS-2 simulation platform.

4.1 Simulation setup

In this work, network simulator 2 is used in simulating DSDV and AODV with RWPM [28] and RPGM. The motion of the nodes in our simulation relies on RWPM and RPGM. Traffic sources in our communication model are CBR. We generated different movement scenario files for both RWPM and RPGM. Random way point movement scenario file was generated using setdest tool in NS-2 [26] while scenario file for reference point group mobility model was generated using the code from [11] in NS-2. Different communication scenario files are also generated using cbrgen.tcl which is in NS-2 [26]. Movement scenario files and communication scenario files generated, all parameters are kept constant but the number of nodes varies. Seven communication scenario files were generated for different numbers of nodes. Forty-two different movement files for RWPM and RPGM were generated with different numbers of nodes. Three different movement files are generated for each number of nodes for both entity model and group mobility model used. In total 21 movement files were generated for each mobility model used. Each simulation run includes one communication scenario file, one movement scenario file, protocol to be simulated and tcl script. The same communication model is used for both group mobility model and non-group mobility model according to the number of nodes to be simulated. Trace file was generated for each simulation run and awk script [29] was used to get the results of the simulation. The protocol’s performance was evaluated and shown according to the average results of simulations.

Table 2: Communication model parameters

Traffic Source	CBR
Maximum connections	8
Data packet size	512 bytes
Sending rate	2 packets/seconds

Table 3: Simulation parameters

Methods	**Values**
Chanel type	Wireless channel
Radio propagation model	Two ray round
Network interface type	Wireless physical
Interface queue type	Priority queue
Link layer type	Link layer
Antenna	Omni Antenna
Maximum packet interface queue	50
X and Y coordinates	1000m x 1000m
Number of nodes	10 -70
Source type	TCP
Simulation time	1000 seconds
Routing protocols	AODV, DSDV
Mobility models	RWPM, RPGM

Table 4: Parameters for Random Way Point Mobility model (RWPM).

Maximum speed	1.5m/s
Pause time	60 seconds
X coordinate	1000m
Y coordinate	1000m

Table 5: Parameters for Reference Point Group Mobility model (RPGM)

Maximum speed	1.5m/s
Number of groups	5
Nodes per group	2 to 14, it varies according to the number of nodes being simulated.
Pause time	60 seconds
X coordinate	1000m
Nodes separation	3
Y coordinate	1000m

4.2 Performance metrics

In this work, four important performance metrics are used to figure out and examine in contrast the behavior of two routing protocols, AODV and DSDV. Metrics for performance used in our work includes:

- Average end to end delay
- Normalized routing
- Average number of hops
- Delivery ratio.

Delivery ratio

This particular performance metric is related with the throughput of the network. It shows the ratio of the data packets that are delivered to its destination to those that the initiator actually generated. The delivery ratio represents how successful the protocol being evaluated is while delivering the packets sent from source to destination. With packet delivery fraction, the performance increases with increase in the value. This simply means that the higher the value, the better its performance and as well the better the result. Its formula is as follows

$$\text{Packet delivery fraction } (\%) = \frac{Total\ number\ of\ received\ packets}{Total\ number\ of\ send\ packets} * 100 \text{ ...... } (4.1)$$

Average end-to-end delay

End-to-end delay is simply how long the packets the initiator generated take to reach their terminal. Average end-to-end delay is the overall end-to-end delay for all the packets received (n). It is calculated by subtracting the total time it takes to receive all the packets at the destination from the total time it takes to send all the packets from the source and dividing them with the overall time it takes to receive all the packets at the destination. The higher the end-to-end delay, the lower the behavior of the protocol while the reverse is the case when end-to-end delay is lower. Mathematically we can represent it as

$$\text{Average-end-to-end delay} = \frac{\sum_1^n (Packets\ received - packets\ send)}{\sum_1^n packets\ received} \text{ .... } (4.2)$$

Normalized routing load

This is the sum of routing packet per data packet that successfully reached its terminal. It is the fraction of the number of routing packets transferred to those that successfully reached its destination. The smaller the normalized routing load, the more excellent the behavior of the protocol being evaluated. Normalized routing load can be written as:

$$\text{Normalized routing load} = \frac{Total\ number\ of\ routing\ packets\ sent}{Total\ number\ of\ data\ Packets\ recived} \quad \ldots\ldots\ldots\ldots\ (4.3)$$

Average number of hops

This is number of hops a packet crosses to get to its terminal node. Average number of hops is the fraction of the sum of the total number of hops from all packets to the sum of the total number of received packets at the destination. Mathematically it can be represented as follows:

$$\text{Average number of hops} = \frac{\sum_1^n Total\ number\ of\ hops\ for\ each\ packet}{\sum_1^n Total\ number\ of\ received\ packets} \quad \ldots\ldots\ldots\ (4.4)$$

Chapter 5

SIMULATION RESULTS AND ANALYSIS

The results of our simulation are presented and analyzed in this chapter with respect to each performance metric we used considered. After simulating our routing protocols with two different mobility models in NS-2, a huge amount of results was gathered. From the result collected, we represent the performance of each routing protocol against each of the mobility models we considered.

5.1 Analysis and comparison of a given routing protocols under different mobility models with different assumption.

In this section the results of our simulation are presented in four different categories. The first and the second categories examine the behavior of each routing protocol used in our simulation against the mobility models used. The third and the fourth categories examine the behavior of our routing protocols with each mobility model we used.

5.1.1 Analysis of AODV with RWPM and RPGM

Here the performance and study of AODV with RWPM and RPGM is presented. The AODV performance with each performance metric is evaluated. Below are the results and the figures which present AODV performance with the mobility models on each performance metric.

Delivery ratio

Table 6: Delivery ratio result of AODV with RWPM and RPGM

Mobility Model	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
RPGM	74.46	71.46	79.48	86.72	94.28	93.79	92.32
RWPM	25.94	82.96	94.24	96.04	96.21	97.43	97.50

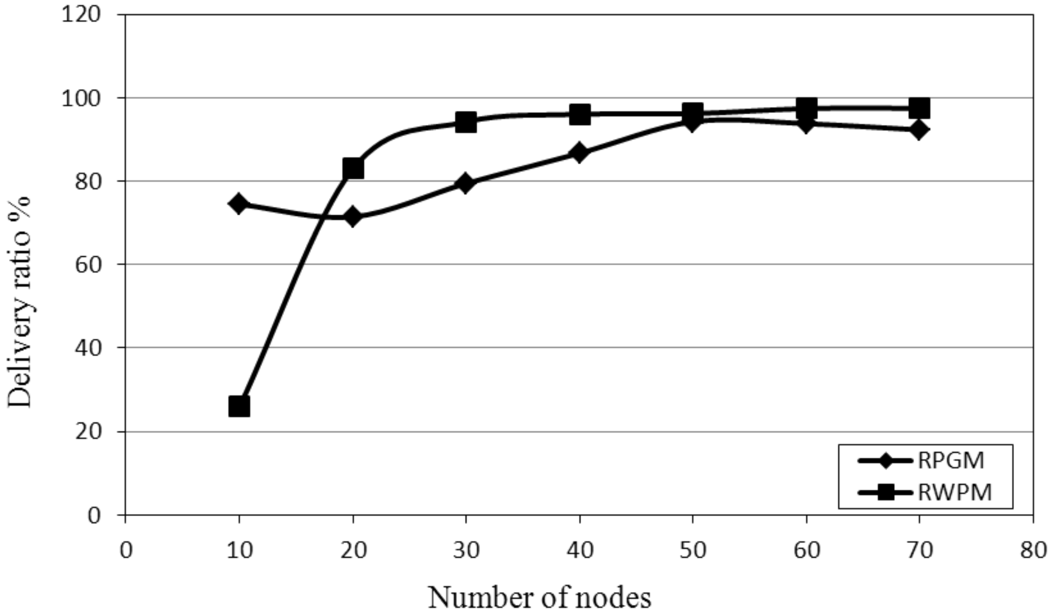


Figure 6: Delivery ratio against number of nodes for AODV protocol with RWPM and RPGM mobility models.

Table 6 presents the average result of delivery ratio performance metric of AODV with the mobility models used for each number of nodes. The result is the average of three simulation results with the same parameters for each number of nodes used. The Figure 6 presents the delivery ratio of AODV against number of nodes with RWPM and RPGM.

The results show that the delivery ratio of AODV with the two mobility models is similar. It only had the slight difference when the number of nodes was 20 to 70. The big difference when the number of nodes was 10 according to Figure 6. Both mobility moves in a similar way after that, the protocols gradually reach its maximum above 92% and 97% with RWPM and RPGM respectively. Delivery ratio of the two mobility models increases whenever there is increase in number of node, though the reverse was the case in RPGM when the number of nodes is 70.

Normalized routing load

Table 7: Normalized routing load results of AODV with RWPM and RPGM

Mobility model	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
RPGM	1.21	1.08	0.95	0.69	0.58	0.66	0.81
RWPM	4.14	1.43	1.14	1.31	1.42	1.63	1.94

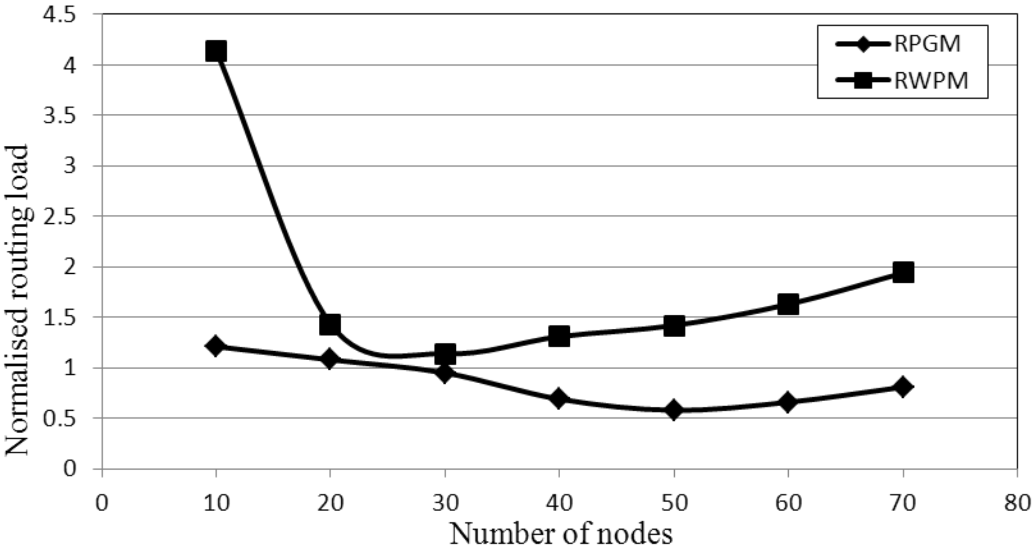


Figure 7: Normalized routing load against number of nodes for AODV protocol with RWPM and RPGM mobility models.

In Table 7, the result of normalized routing load of AODV with RWPM and RPGM under different number of nodes is presented. It is the average result of three different simulations with the same set of parameters for each number of nodes used in our simulation. Figure 7 presents the normalized routing load of AODV with different mobility models used against number of nodes.

From Table 7, when the number of nodes is 10, the normalized routing load of RWPM is too high when compared with that of RPGM. Figure 7 shows that, RWPM and RPGM's behaviors on normalized routing load for AODV protocol are clearly different. The values obtained with RPGM were low's compared with the result of RWPM. This is because in RPGM all the mobile nodes in the group pause at the same time when they reach their destination unlike RWPM where the mobile nodes in the network pause differently when they get to destination before they chose another speed and destination. This simply shows that AODV performs better with RPGM on normalized routing load than RWPM.

Average end-to-end delay

Table 8: Average end –to-end delay results of AODV with RWPM and RPGM

Mobility model	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
RPGM	77.14	18.9	21.54	21.24	25.13	11.3	17.91
RWPM	276.04	129.94	35.99	47.58	36.88	34.47	34.69

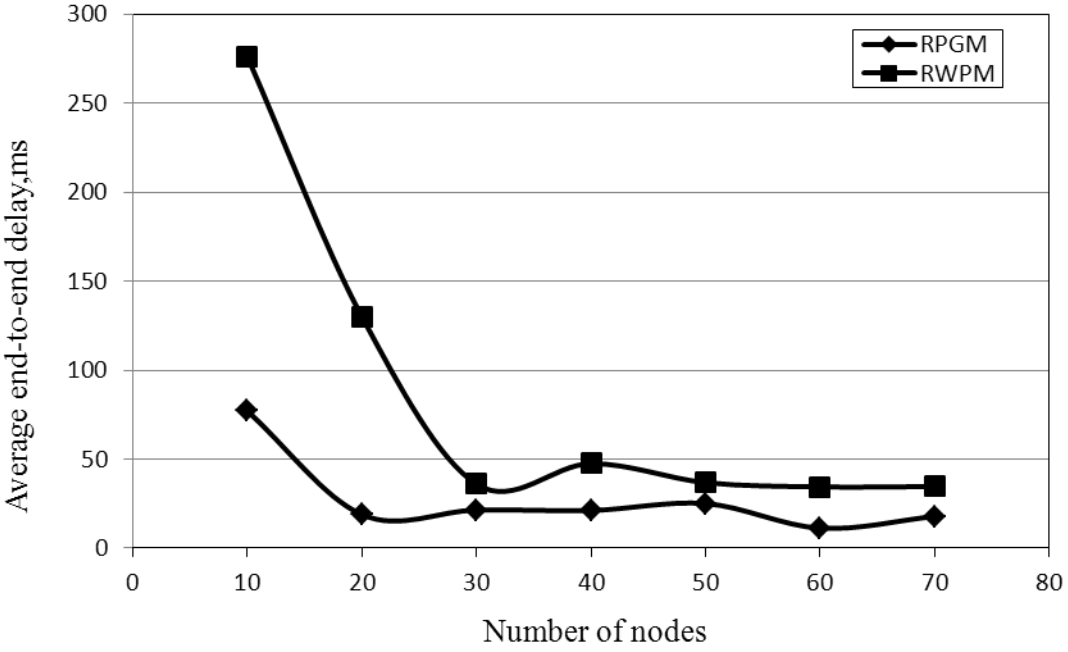


Figure 8: Average end-to-end delay against number of nodes for AODV protocol with RWPM and RPGM mobility models.

Table 8 shows the result of average end-to-end delay of AODV with RWPM and RPGM with variable number of nodes. The result is the average of three simulation results with the same set of parameters for each number of nodes used. Figure 8 represents the performance of AODV with average end-to-end delay performance metric when RWPM and RPGM are used.

From Figure 8 we can see the behavior of AODV on the two mobility models we used. RWPM experiences a higher delay when compared to RPGM. Both mobility models experience a higher delay when the number of nodes is 10. Though with RWPM the result of average-end-to-end delay are much higher when the number of nodes was 10 than when the number of nodes were 20 to 70.

Average number of hops

Table 9: Average number of hops results of AODV with RWPM and RPGM

Mobility Model	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
RPGM	0.97	0.84	0.88	0.84	0.99	0.98	0.93
RWPM	0.54	2.62	2.8	3.09	2.79	3.04	3.08

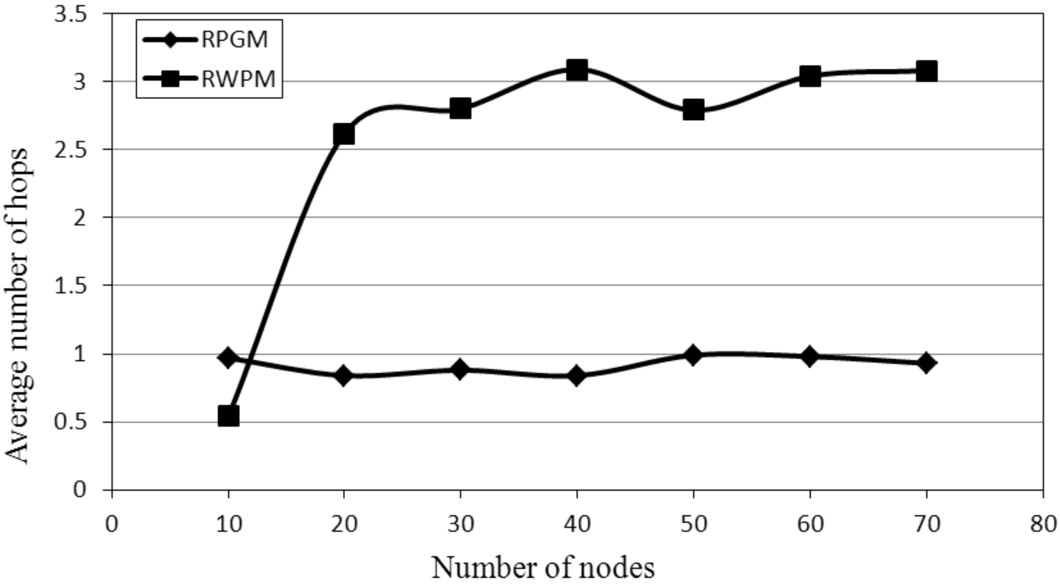


Figure 9: Average number of hops against number of nodes for AODV protocol with RWPM and RPGM mobility models

Table 9 presents the performance result of average number of hops of AODV with RWPM and RPGM with different number of nodes. The result presented is the average of three simulation results of each number of nodes with the same set of parameters. Figure 9 presents the graph of AODV with the two mobility models used.

From the figure and as well from the results in Table 9, we see that RWPM performs better when the number of nodes is 10 but RPGM considerably outperform RWPM with an increase in the number of nodes. The plots figure of the two mobility models on average hop count is so different; a lot of hop count was involved with RWPM. This is because the movement of mobile nodes in RPGM depends on its Reference point or motion centre, the nodes move in groups unlike RWPM where individual nodes move separately while they choose their speed and pause time differently. This increases the delay because they pause differently in RWPM. In RPGM, nodes in group move with the same speed and have the same pause time.

From our analysis and comparison in this section, AODV performs better with RPGM than RWPM in the end-to-end-delay, normalized routing load, and average number of hops. In delivery ratio AODV performs better with RWPM than RPGM. We conclude that RPGM generally performs better over RWPM when using them to test the performance of AODV protocol.

5.1.2 Analysis of DSDV with RWPM and RPGM

This section presents the performance results and their analysis for destination sequenced distance vector routing protocol with RWPM and RPGM. DSDV performance with each performance metrics is evaluated.

Delivery ratio

Table 10: Delivery ratio results of DSDV with RWPM and RPGM

Mobility Model	Number of nodes						
	10	**20**	**30**	**40**	**50**	**60**	**70**
RPGM	60.93	75.22	77.38	88.87	94.69	93.45	91.87
RWPM	30.03	68.81	81.87	82.73	83.61	84.87	91.21

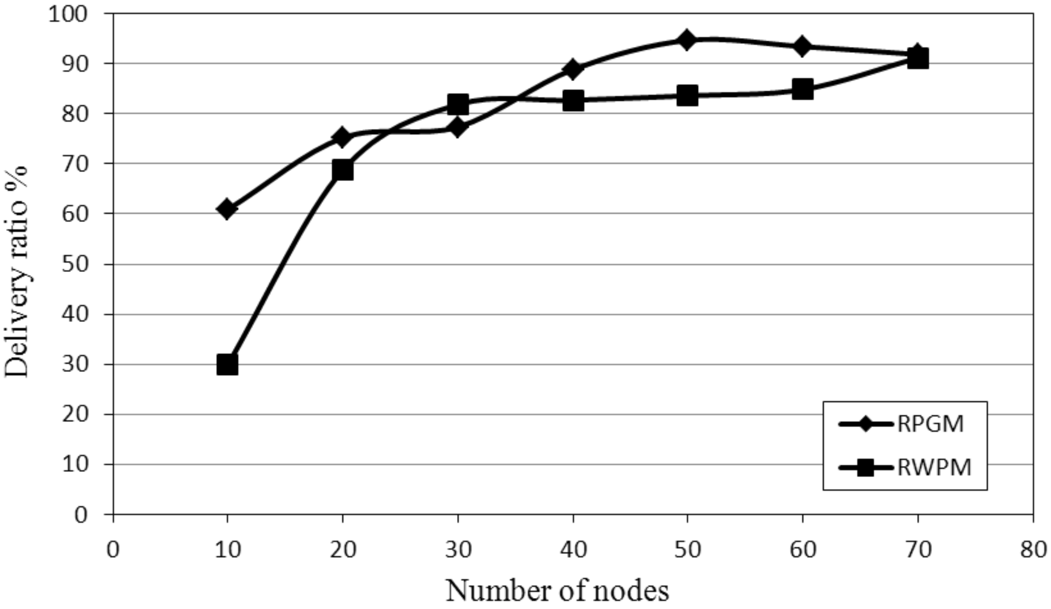


Figure 10: Delivery ratio against number of nodes for DSDV protocol with RWPM and RPGM mobility models.

Table 10 presents the average results of delivery ratio performance metrics of DSDV with the mobility models used for each number of nodes. The result is the average of three simulation results with the same parameters for each number of nodes used. The Figure 10 presents the delivery ratio of DSDV against number of nodes with RWPM and RPGM.

The results in the above table indicate that the delivery ratio of RWPM increases whenever the number of nodes increases. For RPGM, the delivery ratio increase with increase in number of nodes from 10 to 40, it starts fluctuating from 50 to 70. Delivery ratio of RWPM is very low when the number of node is 10, when compared to RPGM. This simply shows that, mobility model has an effect on the behavior of DSDV protocol. The pause time of mobile nodes when the number of nodes was 10 is too high in RWPM. RPGM performs better than DSDV when the number of nodes is 30 as shown in Figure 10 and Table 10. Generally from the graph in Figure 10, DSDV performs slightly better than RWPM than RPGM with respect to delivery ratio performance metric.

Normalized routing load

Table 11: Normalized routing load results of DSDV with RWPM and RPGM

Mobility model	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
RPGM	0.4	0.28	0.28	0.28	0.25	0.3	0.32
RWPM	0.8	0.35	0.41	0.59	0.8	1.61	2.28

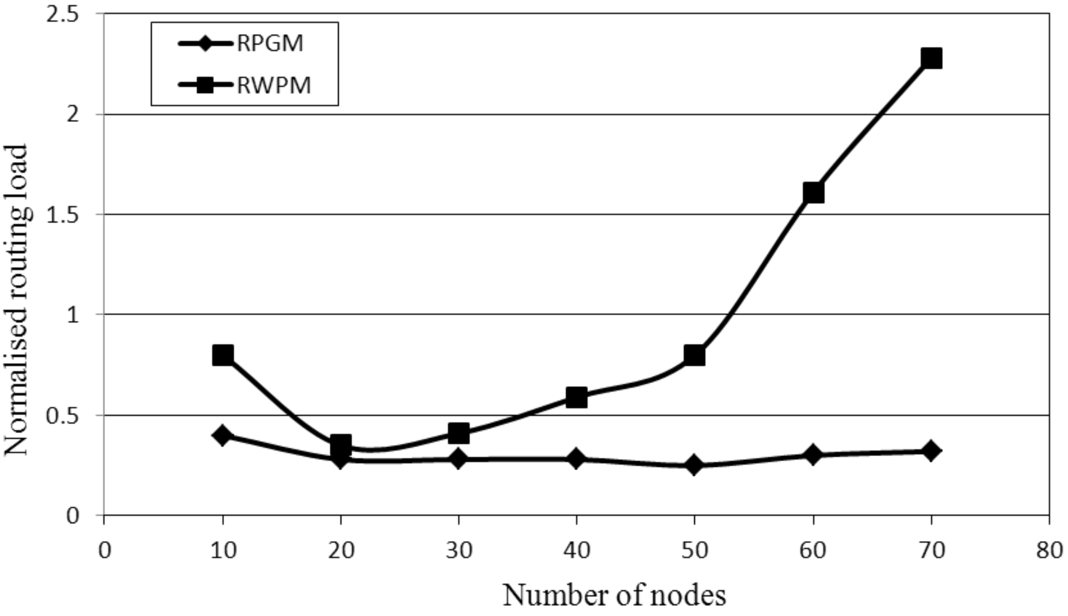


Figure 11: Normalized routing load against number of nodes for DSDV protocol with RWPM and RPGM mobility models.

Figure 11 presents the normalized routing load of DSDV with different mobility models used against number of nodes.

From the result in Table 11, the normalized routing load of DSDV with RPGM was generally low compared with that of RWPM. RWPM has a high normalized routing load with DSDV. In RWPM, individual nodes randomly select their speed and direction. Also they select their pause time randomly unlike in RPGM where nodes in the group move with common speed and have common pause time. From our results we can conclude that DSDV performs better in normalized routing load with RPGM.

Average end-to-end delay

Table 12: Average end-to-end delay results of DSDV with RWPM and RPGM

Mobility model	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
RPGM	7.49	6.29	6.15	11.59	7.09	6.98	7.13
RWPM	29.93	62.1	32.11	30.44	34.38	33.65	45.12

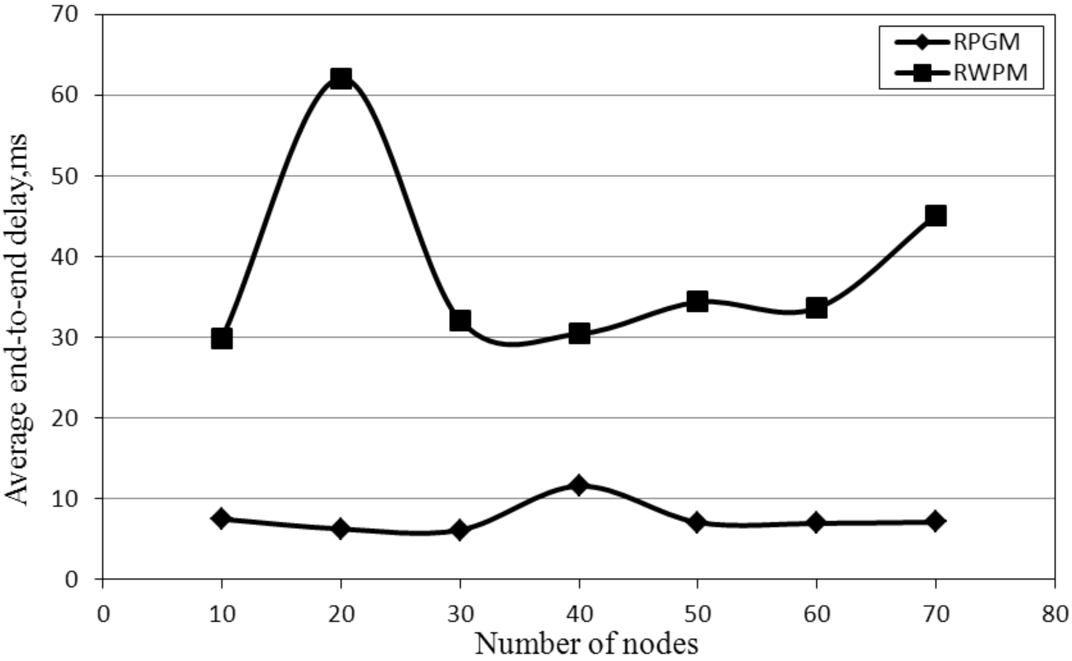


Figure 12: Average end-to-end delay against number of nodes for DSDV protocol with RWPM and RPGM mobility models.

Figure 12 represents the performance of DSDV with average end-to-end delay performance metrics when RWPM and RPGM are used. Figure 12 indicates that, RWPM has a high delay with DSDV compared RPGM. RWPM has the highest delay when number of nodes is 20. This is because in RWPM, the pause time involved when number of nodes is 20 is too high and this increases the delay as seen in the figure. From the graph presented above, there is a huge difference in the performance of DSDV with RWPM and RPGM. From our results, RPGM outperforms RWPM when variable number of nodes is used.

Average number of hops

Table 13: Average number of hops results of DSDV with RWPM and RPGM

Mobility Model	Number of nodes						
	10	**20**	**30**	**40**	**50**	**60**	**70**
RPGM	0.67	0.78	0.79	0.92	0.97	0.97	0.93
RWPM	0.5	1.5	2.56	2.45	2.46	2.54	2.78

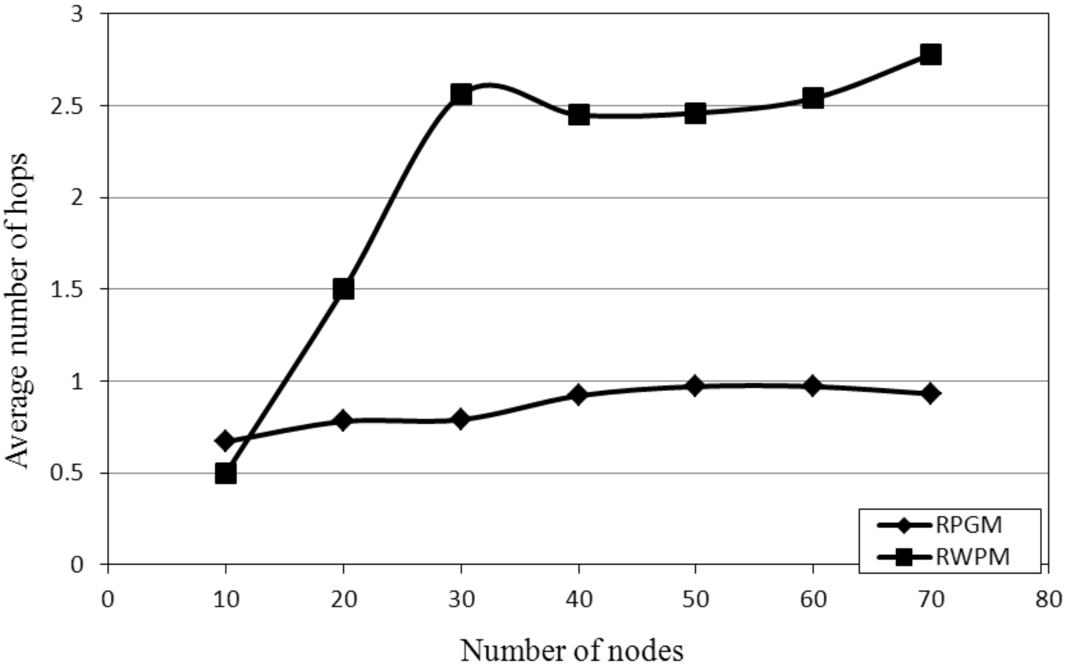


Figure 13: Average number of hops against number of nodes for DSDV protocol with RWPM and RPGM mobility models.

Table 13 presents the performance result of average number of hops of DSDV with RWPM and RPGM with different number of nodes. The result presented is the average of three simulation results of each number of nodes with similar values. Figure 13 presents the graph of DSDV with the two mobility models used.

The results in Table 13 indicate that, RWPM performs better when the number of nodes is 10 but RPGM performs better than RWPM with increase in the number of nodes. This is as a result of pause time which individual nodes in RWPM select randomly and pause differently at different times. The number of hops involved is much RWPM is much higher.

In this Section DSDV performance was compared using RWPM and RPGM. We found out from our results that RPGM in all the metrics of performance used performs better than RWPM.

5.1.3 Analysis of AODV and DSDV with RWPM

Delivery ratio

Table 14: Delivery ratio results of AODV and DSDV with RWPM

Routing protocol	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
DSDV	30.03	68.81	81.87	82.73	83.61	84.87	91.21
AODV	25.94	82.96	94.24	96.04	96.21	97.43	97.5

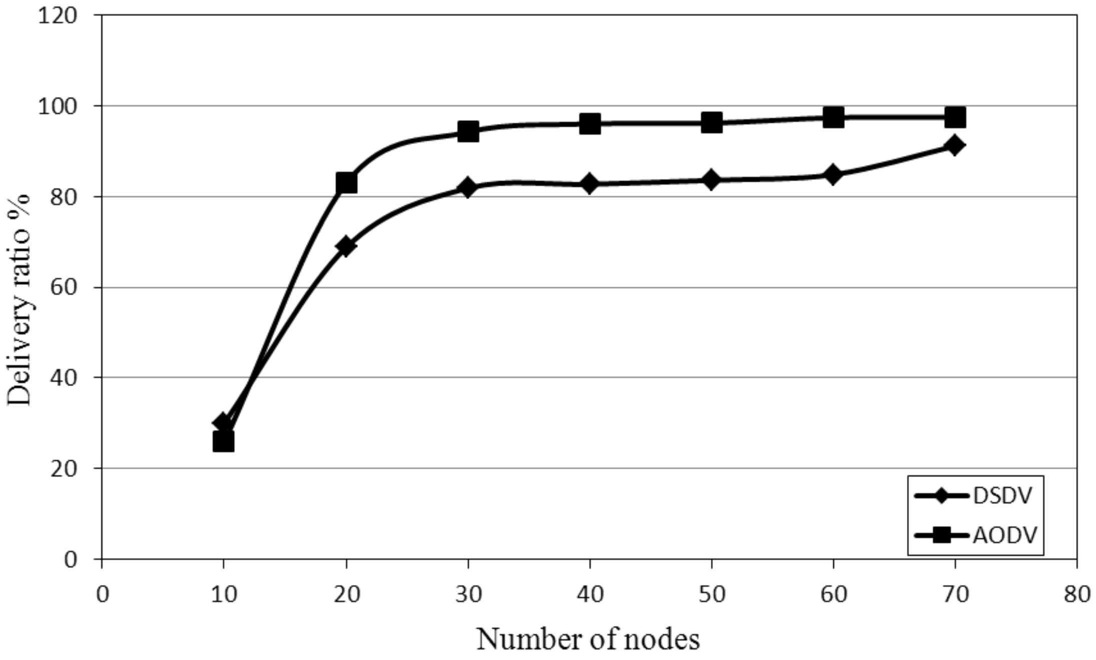


Figure 14: Delivery ratio against number of nodes for AODV and DSDV protocols with RWPM mobility model.

The Table 14 above presents the average result of delivery ratio performance metrics of AODV and DSDV with random way point mobility model for each number of nodes. Figure 14 presents the delivery ratio of AODV and DSDV against the number of nodes with random way point mobility model.

Figure 14 shows that, the delivery ratio of the protocols increases with increase in the number of nodes. As seen from the graph, AODV slightly performs better than DSDV in delivery ratio performance metric with RWPM. This is because, the two protocols involved performed differently with the mobility model.

Normalized routing load

Table 15: Normalized routing load results of AODV and DSDV with RWPM

Routing protocol	Number of nodes						
	10	**20**	**30**	**40**	**50**	**60**	**70**
DSDV	0.8	0.35	0.41	0.59	0.8	1.61	2.28
AODV	4.14	1.43	1.14	1.31	1.42	1.63	1.94

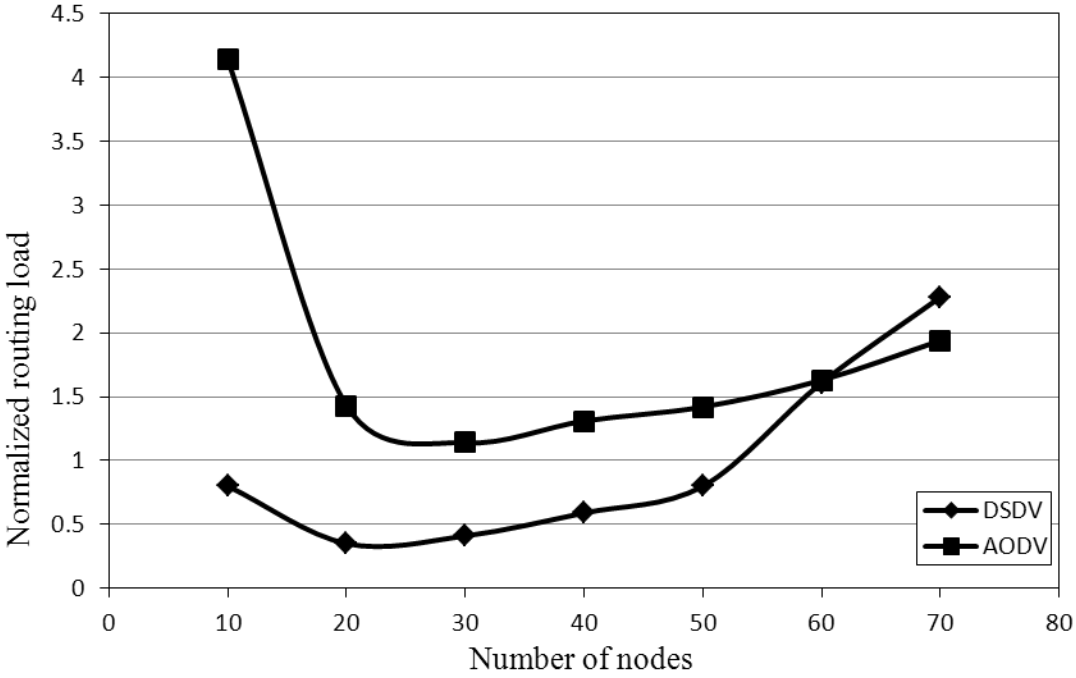


Figure 15: Normalized routing load against number of nodes for AODV and DSDV protocols with RWPM mobility model.

In Table 15 the result of normalized routing load of AODV and DSDV with RWPM under different number of nodes was presented. It is the average result of three different simulations with the same set of parameters for each number of nodes used in our simulation. Figure 15 presents the normalized routing load of AODV and DSDV with random way point mobility model against number of nodes.

From the result presented in Table 15, DSDV perform better than AODV. This is because, in DSDV the route to destination of all the nodes in the network are stored in the routing table before start up. This is unlike AODV which finds routes when needed.

Average end-to-end delay

Table 16: Average end-to-end delay results of AODV and DSDV with RWPM

Routing protocol	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
DSDV	29.93	62.1	32.11	30.44	34.38	33.65	45.12
AODV	276.04	129.94	35.99	47.58	36.88	34.47	34.69

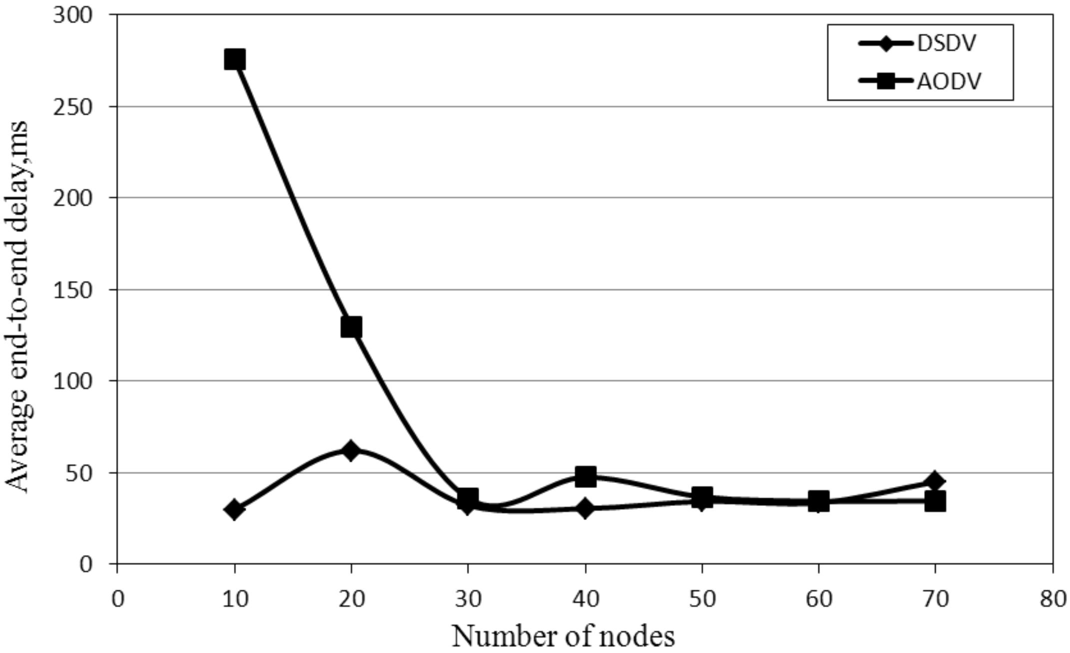


Figure 16: Average end-to-end delay against number of nodes for AODV and DSDV protocols with RWPM mobility model.

Table 16 present the result of average end-to-end delay of AODV and DSDV with random way point mobility model under variable number of nodes. The result collected is the average of three simulation results with the same set of parameters for each number of nodes used. Figure 16 represents the performance of AODV and DSDV with average end-to-end performance metrics when RWPM is used.

Figure 16 shows that, the end to end delay of AODV is much higher when the number of nodes is 10 and 20. For larger number of nodes the delay of the two protocols was almost the same. The delay of the protocols slightly differs with increase in the number of nodes.

Average number of hops

Table 17: Average number of hops results of AODV and DSDV with RWPM

Routing protocol	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
DSDV	0.5	1.5	2.56	2.45	2.46	2.54	2.78
AODV	0.54	2.62	2.8	3.09	2.79	3.04	3.08

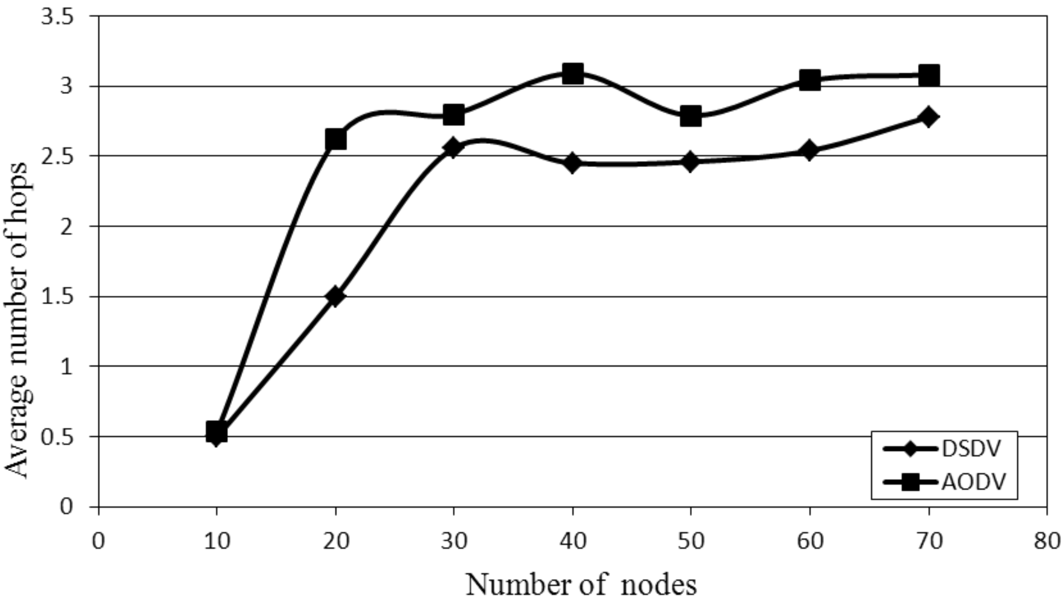


Figure 17: Average number of hops against number of nodes for AODV and DSDV protocols with RWPM mobility model.

Table 17 presents the performance result of average number of hops of AODV and DSDV with RWPM when different number of nodes is used. The result presented is the average of three simulation results of each number of nodes with similar values. Figure 17 presents the graph of AODV and DSDV with random way point mobility model.

From the graph in figure 17, DSDV perform better than AODV in average number of hops metric with RWPM.

From the simulation results we observed that the selected protocols AODV and DSDV have a performance metric where each of them is weak. From our analysis in this section we conclude that no protocol out performs the other. Each of the protocols performs well on some of the performance metrics.

5.1.4 Analysis of AODV and DSDV with RPGM

Delivery ratio

Table 18: Delivery ratio results of AODV and DSDV with RPGM

Routing protocols	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
DSDV	60.93	75.22	77.38	88.87	94.69	93.45	91.87
AODV	74.46	71.46	79.48	86.72	94.28	93.79	92.32

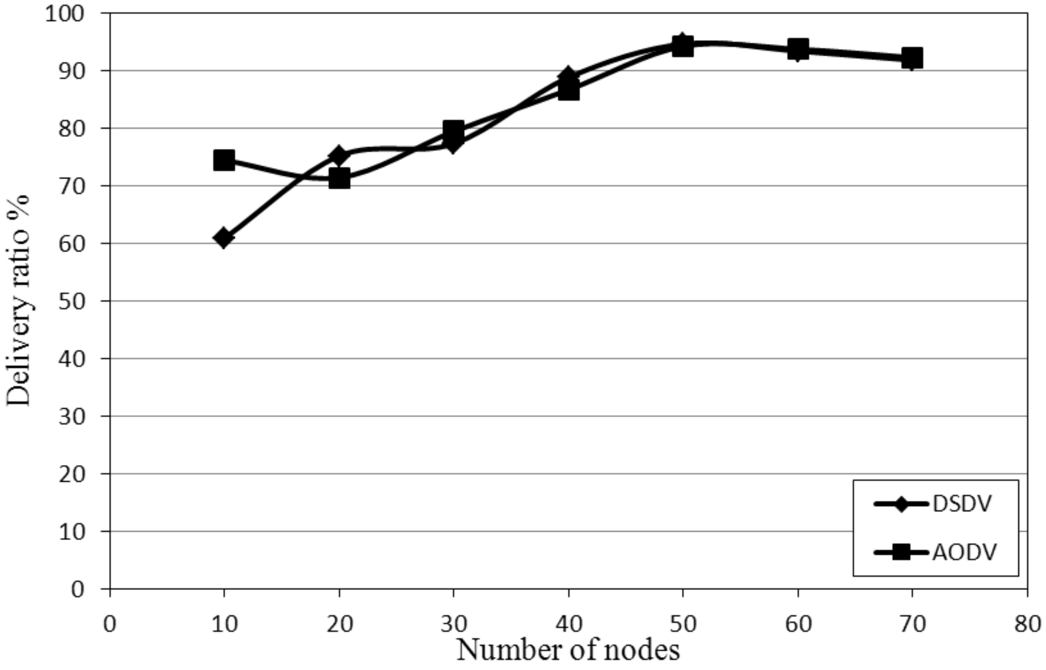


Figure 18: Delivery ratio against number of nodes for AODV and DSDV protocols with RPGM mobility model.

The Table 18 presents the average result of delivery ratio performance metric of AODV and DSDV with RPGM for each number of nodes. The result is the average of three simulation results with the same parameters for each number of nodes used. The Figure 18 above presents the delivery ratio of AODV and DSDV against number of nodes with reference point group mobility model.

From Table 18 and as well from Figure 18, the delivery ratios of the two protocols are very similar. AODV out performs DSDV in some cases while in some DSDV performs better.

Normalized routing load

Table 19: Normalized routing load results of AODV and DSDV with RPGM

Routing protocols	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
DSDV	0.4	0.28	0.28	0.28	0.25	0.3	0.32
AODV	1.21	1.08	0.95	0.69	0.58	0.66	0.81

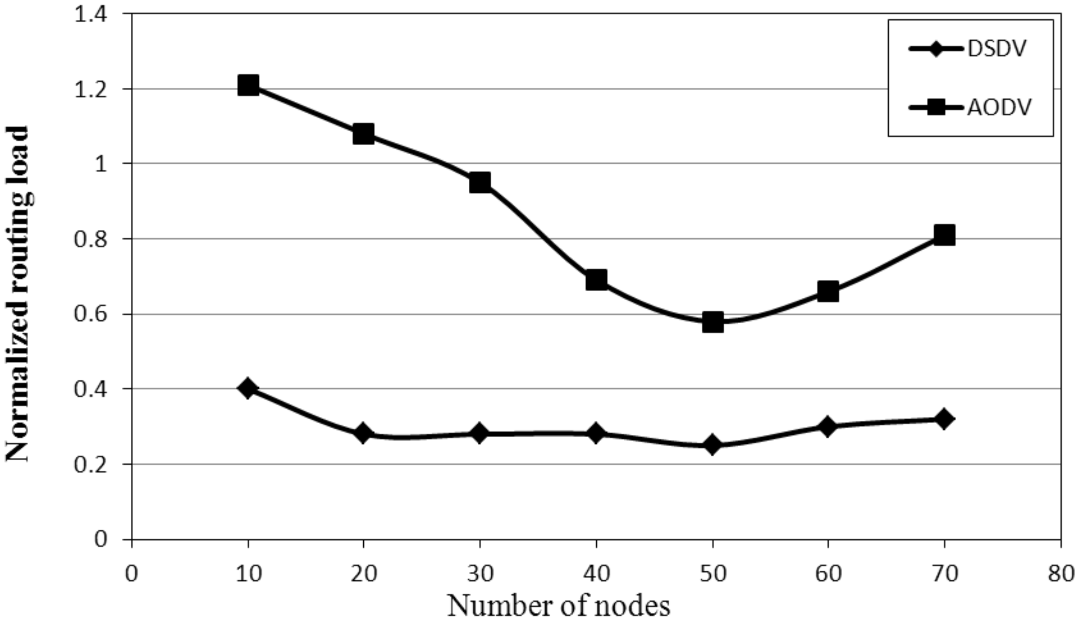


Figure 18: Normalized routing load against number of nodes for AODV and DSDV protocols with RPGM mobility model.

In Table 19 the result of normalized routing load of AODV and DSDV with RPGM under different number of nodes was presented. It is the average result of three different simulations with the same set of parameters for each number of nodes used in our simulation. Figure 19 presents the normalized routing load of AODV and DSDV with reference point group mobility model against number of nodes.

From Table 19, DSDV has lower normalized routing load than AODV. This is because in DSDV all routes are stored in the routing table before the start up. This makes it easy for the source node in the network that wants to send packet to destination node to easily retrieve the route to destination node and send their packets without much delay. This reduces the overhead encountered in finding the route to destination each time the initiator wants to transfer a packet as seen with AODV protocol. Our graph in Figure 19 shows that DSDV clearly out performs AODV in normalized routing load metric with RPGM.

Average end-to-end delay

Table 20: Average end-to-end delay results of AODV and DSDV with RPGM

Routing protocol	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
DSDV	7.49	6.29	6.15	11.59	7.09	6.98	7.13
AODV	77.14	18.9	21.54	21.24	25.13	11.3	17.91

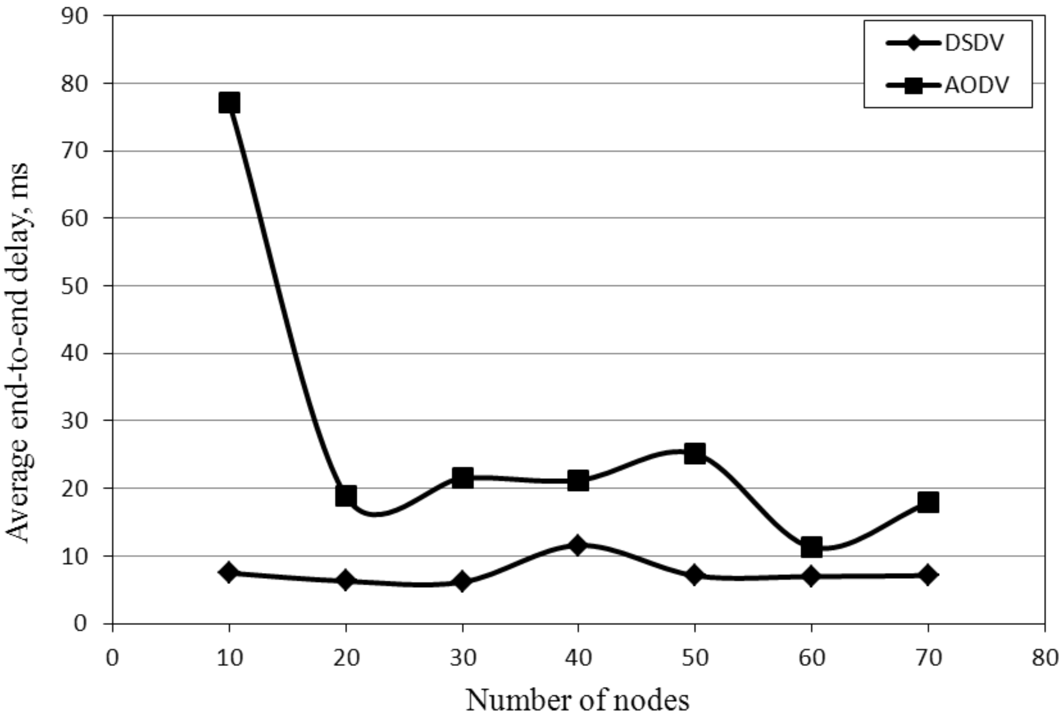


Figure 19: Average end-to-end delay against number of nodes for AODV and DSDV protocols with RPGM mobility model.

Table 20 presents average end to end delay of AODV and DSDV with reference point group mobility model under variable number of nodes. The result collected is the average of three simulation results with the same set of parameters for each number of nodes used. Figure 20 represents the performance of AODV and DSDV with average end-to-end performance metric when RPGM is used.

Our result in Table 20 shows that AODV has a very high delay when compared with the delay of DSDV. This is as a result of its on-demand basis. DSDV has a low delay in RPGM and thus, performs better than AODV.

Average number of hops

Table 21: Average number of hops results of AODV and DSDV with RPGM

Routing protocol	Number of nodes						
	10	**20**	**30**	**40**	**50**	**60**	**70**
DSDV	0.67	0.78	0.79	0.92	0.97	0.97	0.93
AODV	0.97	0.84	0.88	0.84	0.99	0.98	0.93

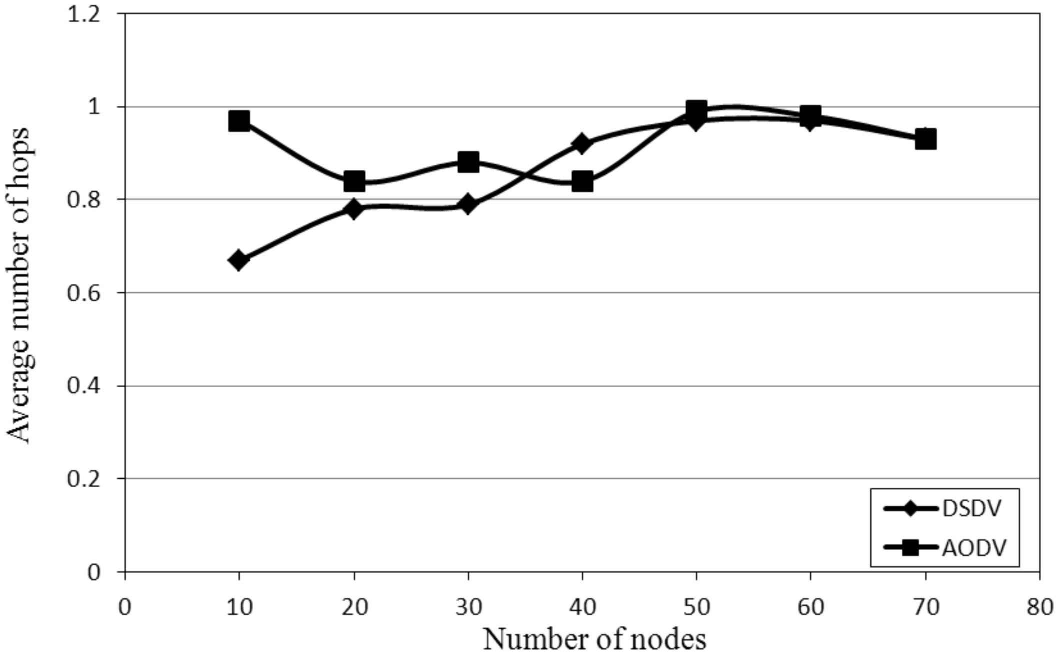


Figure 20: Average number of hops against number of nodes for AODV and DSDV protocols with RPGM mobility model.

Table 21 presents the performance results of average number of hops of AODV and DSDV with RPGM when different number of nodes is used. The result presented is the average of three simulation results of each number of nodes with similar values. Figure 21 presents the graph of AODV and DSDV with reference point group mobility model.

From our result in Table 21, none of the protocols out performs the other in average number of hops with RPGM. Both protocols perform better in some cases while in some their performance was low. AODV performs better than DSDV when the number of nodes is between 40 and 60 while DSDV out performs AODV when the number of nodes is between 10 and 30. The two protocols have the same number of hops when the number of nodes is 70.

In this Section AODV and DSDV did not out perform each other in deliver ratio and average number of hops, their performance was similar. DSDV performs better than AODV in normalized routing and end-to-end delay. We conclude that DSDV slightly out performs AODV in this section.

Researchers that tested the performance of proactive and reactive routing protocols with varying number of nodes, use RWPM as their mobility model. Also some of them vary their pause time and speed, while some vary speed and kept their pause time constant or vice versa. In their graphs, they plotted the graph of each performance metrics with respect to pause time or speed.

In this work however, we tested the performance of proactive and reactive routing protocols using RWPM and RPGM with varying number of nodes. We kept node speed and pause time constant. We plotted the graph of each performance metrics against number of nodes.

Chapter 6

CONCLUSION

In this research work, we have examined in contrast the behavior of one reactive and one proactive routing protocol with one group and one entity mobility model. We have simulated AODV and DSDV using RPGM and RWPM with network simulator 2 in order to show the impact of entity and group mobility models on behavior analysis of mobile ad hoc networks.

We choose DSDV over other proactive routing protocols because DSDV is among the protocols that come with NS-2. Also DSDV is a loop free proactive routing protocol.

We choose AODV over other reactive routing protocol because it is adaptable to highly dynamic topologies. It uses some functions of DSDV routing protocol such as periodic beaconing and sequence numbering procedure. Also we chose it because it has less routing overhead than DSR, although it uses DSR route discovery procedure.

We choose RWPM and RPGM as our entity mobility model and group mobility model respectively because the authors in [11] suggested to researchers to use RWPM when clustering in the middle is not desired. The authors as well, recommend researchers to use RPGM whenever group mobility model is desired.

We have tested the normalized routing load, delivery ratio, end-to-end-delay and average hop count of both protocols with the mobility models used.

From our study both protocols perform differently with the mobility models used. When AODV is compared with the mobility models, our results show that AODV performs differently in entity and group mobility models. Also results obtained from comparison of DSDV with the two mobility models show that, the entity and group mobility models have an effect on the protocol performance.

When AODV and DSDV performance are compared with each mobility models, we found out from our results that the protocols did not outperform each other totally. Reactive routing protocols have greater packet delivery ratio with RWPM compare to proactive protocol as also seen in [6]. Their performance was similar with RPGM.

Further research on effect of RWPM and RPGM on AODV and DSDV routing protocol for mobile ad hoc networks is needed.

- Researchers can examine the performance of these routing protocols using real world movement scenario files of RWPM and RPGM in order to evaluate the effect.
- We suggest that larger number of nodes should be used and as well nodes less than 10, in order to see the effect of increase in the number of nodes clearly.

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APPENDICES

Appendix A: Average simulation results of AODV protocol with RWPM for each performance metric used in our work for each number of nodes with identical parameters.

Delivery ratio %:

Run	Number of nodes						
	10	**20**	**30**	**40**	**50**	**60**	**70**
Run 1	24.95	82.17	94.43	95.63	98.60	98.52	98.11
Run 2	30.45	85.45	92.38	96.16	91.52	95.79	96.25
Run 3	22.43	81.26	95.92	96.33	98.51	97.98	98.14
Average	25.94	82.96	94.24	96.04	96.21	97.43	97.50

Normalized routing load:

Run	Number of nodes						
	10	**20**	**30**	**40**	**50**	**60**	**70**
Run 1	4.67	1.53	0.99	1.47	0.92	1.35	1.84
Run 2	3.33	1.43	1.25	1.27	2.01	1.76	2.17
Run 3	4.41	1.34	1.17	1.20	1.32	1.79	1.82
Average	4.14	1.43	1.14	1.31	1.42	1.63	1.94

Average end-to-end delay (ms):

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	288.55	117.88	45.84	41.51	23.18	30.09	33.80
Run 2	218.25	115.47	35.30	52.24	52.50	34.46	34.76
Run 3	321.32	156.48	26.83	48.98	34.95	38.87	35.50
Average	276.04	129.94	35.99	47.58	36.88	34.47	34.69

Average hop counts:

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	0.62	3.00	2.67	3.07	2.38	3.03	3.06
Run 2	0.54	2.18	2.62	2.97	2.87	2.87	3.10
Run 3	0.47	2.68	3.12	3.22	3.12	3.23	3.08
Average	0.54	2.62	2.80	3.09	2.79	3.04	3.08

Appendix B: Average simulation results of AODV protocol with RPGM for each performance metric used in our work for each number of nodes with identical parameters.

Delivery ratio %:

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	71.90	69.00	78.68	84.40	93.52	92.64	92.39
Run 2	74.71	66.59	79.18	89.31	95.36	95.66	91.38
Run 3	76.77	78.80	80.57	86.44	93.96	93.06	93.18
Average	74.46	71.46	79.48	86.72	94.28	93.79	92.32

Normalized routing load:

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	1.75	1.11	0.9	0.73	0.47	0.75	0.99
Run 2	0.96	0.85	0.84	0.79	0.58	0.55	0.82
Run 3	0.91	1.27	1.12	0.55	0.68	0.68	0.63
Average	1.21	1.08	0.95	0.69	0.58	0.66	0.81

Average end-to-end delay (ms):

Run	Number of nodes						
	10	**20**	**30**	**40**	**50**	**60**	**70**
Run 1	81.76	24.50	23.53	21.67	22.11	9.34	15.83
Run 2	70.11	15.10	23.06	20.18	27.58	11.33	18.77
Run 3	79.56	17.09	18.03	21.87	25.70	13.24	19.14
Average	77.14	18.90	21.54	21.24	25.13	11.30	17.91

Average hop counts:

Run	Number of nodes						
	10	**20**	**30**	**40**	**50**	**60**	**70**
Run 1	1.14	0.71	0.90	0.84	0.96	0.96	0.96
Run 2	0.96	0.85	0.84	0.79	0.94	1.01	0.89
Run 3	0.80	0.96	0.89	0.90	1.06	0.97	0.93
Average	0.97	0.84	0.88	0.84	0.99	0.98	0.93

Appendix C: Average simulation results of DSDV protocol with RWPM for each performance metric used in our work for each number of nodes with identical parameters.

Delivery ratio %:

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	28.24	67.49	78.48	87.35	80.24	86.55	89.06
Run 2	29.17	61.26	86.76	75.79	84.39	90.58	92.27
Run 3	32.68	77.67	80.36	85.06	86.19	77.49	92.31
Average	30.03	68.81	81.87	82.73	83.61	84.87	91.21

Normalized routing load:

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	0.85	0.35	0.45	0.54	0.71	1.54	2.36
Run 2	0.82	0.38	0.36	0.57	0.76	2.03	2.20
Run 3	0.73	0.33	0.42	0.66	0.92	1.25	2.27
Average	0.80	0.35	0.41	0.59	0.80	1.61	2.28

Average end-to-end delay (ms):

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	28.19	47.47	33.08	26.31	31.01	32.74	49.43
Run 2	38.15	63.19	32.06	30.24	32.80	32.42	50.06
Run 3	23.44	75.65	31.19	34.77	39.34	35.79	35.87
Average	29.93	62.10	32.11	30.44	34.38	33.65	45.12

Average hop counts:

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	0.47	1.51	2.41	2.55	2.60	2.55	2.66
Run 2	0.60	1.91	2.84	2.43	2.43	2.54	3.24
Run 3	0.43	1.08	2.42	2.37	2.36	2.52	2.45
Average	0.50	1.50	2.56	2.45	2.46	2.54	2.78

Appendix D: Average simulation results of DSDV protocol with RPGM for each performance metric used in our work for each number of nodes with identical parameters.

Delivery ratio %:

Run	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
Run 1	69.50	68.23	73.84	86.88	96.36	93.35	91.14
Run 2	63.22	83.28	78.53	90.26	95.44	93.89	91.93
Run 3	50.07	74.16	79.76	89.47	92.26	93.12	92.55
Average	60.93	75.22	77.38	88.87	94.69	93.45	91.87

Normalized routing load:

Run	**Number of nodes**						
	10	**20**	**30**	**40**	**50**	**60**	**70**
Run 1	0.35	0.30	0.30	0.29	0.24	0.28	0.33
Run 2	0.38	0.27	0.27	0.28	0.26	0.32	0.33
Run 3	0.48	0.28	0.28	0.27	0.24	0.30	0.31
Average	0.40	0.28	0.28	0.28	0.25	0.30	0.32

Average end-to-end delay (ms):

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	7.22	6.47	5.97	10.53	6.47	7.80	6.46
Run 2	7.75	6.09	6.57	11.81	8.53	6.61	8.68
Run 3	7.49	6.32	5.92	12.42	6.27	6.54	6.25
Average	7.49	6.29	6.15	11.59	7.09	6.98	7.13

Average hop counts:

Run	Number of nodes						
	10	20	30	40	50	60	70
Run 1	0.74	0.71	0.75	0.89	0.98	0.94	0.92
Run 2	0.73	0.86	0.82	0.95	1.01	0.96	0.93
Run 3	0.54	0.78	0.80	0.91	0.92	1.00	0.93
Average	0.67	0.78	0.79	0.92	0.97	0.97	0.93

Appendix E: Formulas used in calculating confidence interval

- Confidence Interval (CI) = $\bar{x} \pm t^{*} \frac{s}{\sqrt{n}}$

  $\bar{x}$ = mean

  S = standard deviation

  n = sample size

  t* = critical value.

- Standard deviation formula:
  S=

  $$\sqrt{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + (x_3 - \bar{x})^2 \ldots\ldots\ldots\ldots \ldots\ldots\ldots (x_n - \bar{x})^2}$$

- Mean calculation

  $$\bar{x} = \frac{x_1 + x_2 + x_3 + \ldots\ldots\ldots\ldots x_n}{n}$$

- t* is calculated using the formular TINV (1-level, n-1)

  n = Sample size

  level = Confidence interval or confidence level

  n-1= The degree of freedom

Appendix F: Average Values and Confidence Intervals of the Investigated Performance Metrics

In this appendix, average values and confidence intervals of the investigated performance metrics of the experiments are provided. The performance metrics that were used in these experiments are delivery ratio, normalized routing load, average end-to-end delay and average number of hops.

Average values and 95% confidence intervals of the performance metrics for AODV with RPGM

Metric	Number of Nodes						
	10	20	30	40	50	60	70
Delivery ratio	74.46 ± 6.07	71.46 ± 16.06	79.48 ± 2.43	86.72 ± 6.12	94.28 ± 2.39	93.79 ± 4.06	92.32 ± 2.24
Normalized routing load	1.21 ± 1.17	1.08 ± 0.53	0.95 ± 0.37	0.69 ± 0.31	0.58 ± 0.26	0.66 ± 0.25	0.81 ± 0.45
Average end-to-end delay	77.14 ± 15.37	18.90 ± 12.30	21.54 ± 7.57	21.24 ± 2.29	25.13 ± 6.90	11.30 ± 4.84	17.91 ± 4.50
Average number of hops	0.97 ± 0.42	0.84 ± 0.31	0.88 ± 0.08	0.84 ± 0.14	0.99 ± 0.16	0.98 ± 0.07	0.93 ± 0.09

Average values and 95% confidence intervals of the performance metrics for AODV with RWPM.

Metric	Number of Nodes						
	10	20	30	40	50	60	70
Delivery ratio	25.94 ± 10.18	82.96 ± 5.47	94.24 ± 4.41	96.04 ± 0,91	96.21 ± 10.08	97.43 ± 3.59	97.50 ± 2.69
Normalized routing load	4.14 ± 1.76	1.43 ± 0.24	1.14 ± 0.33	1.31 ± 0.35	1.42 ± 1.37	1.63 ± 0.61	1.94 ± 0.49
Average end-to-end delay	276.04 ± 130.74	129.94 ± 57.13	35.99 ± 23.64	47.58 ± 13.66	36.88 ± 36.63	34.47 ± 10.90	34.69 ± 2.12
Average number of hops	0.54 ± 0.19	2.62 ± 1.03	2.80 ± 0.68	3.09 ± 0.31	2.79 ± 0.93	3.04 ± 0.45	3.08 ± 0.05

Average values and 95% confidence intervals of the performance metrics for DSDV with RPGM.

Metric	Number of Nodes						
	10	20	30	40	50	60	70
Delivery ratio	60.93 ± 24.62	75.22 ± 18.82	77.38 ± 7.76	88.87 ± 4.39	94.69 ± 5.34	93.45 ± 0.98	91.87 ± 1.75
Normalized routing load	0.40 ± 0.17	0.28 ± 0.04	0.28 ± 0.04	0.28 ± 0.02	0.25 ± 0.03	0.30 ± 0.05	0.32 ± 0.03
Average end-to-end delay	7.49 ± 0.66	6.29 ± 0.48	6.15 ± 0.90	11.59 ± 2.39	7.09 ± 3.11	6.98 ± 1.76	7.13 ± 3.34
Average number of hops	0.67 ± 0.28	0.78 ± 0.19	0.79 ± 0.09	0.92 ± 0.08	0.97 ± 0.11	0.97 ± 0.08	0.93 ± 0.01

Average values and 95% confidence intervals of the performance metrics for DSDV with RWPM.

Metric	Number of Nodes						
	10	20	30	40	50	60	70
Delivery ratio	30.03 ± 5.81	68.81 ± 20.57	81.87 ± 10.78	82.73 ± 15.20	83.61 ± 7.58	84.87 ± 16.64	91.21 ± 4.63
Normalized routing load	0.80 ± 0.16	0.35 ± 0.06	0.41 ± 0.11	0.59 ± 0.16	0.80 ± 0.27	1.61 ± 0.98	2.28 ± 0.20
Average end-to-end delay	29.93 ± 18.64	62.10 ± 35.06	32.11 ± 2.35	30.44 ± 10.51	34.38 ± 10.89	33.65 ± 4.62	45.12 ± 19.90
Average number of hops	0.50 ± 0.22	1.50 ± 1.03	2.56 ± 0.61	2.45 ± 0.23	2.46 ± 0.31	2.54 ± 0.04	2.78 ± 1.02