Faulhaber's Formula Based Multipath Load Balancing Routing Protocol for Mobile Ad hoc Networks

موازنة أحمال المسارات المتعددة في الشبكات المتنقلة الخاصة باستخدام صيغة " "

Faulhaber's

BY

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Authorization

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DEDICATION

To My Family

Who Have Supported

Me

Through It All…

ACKNOWLEDGEMENTS

"In the name of Allah, most gracious, most merciful"

First of all, we would like to express our thanks to our Unique Almighty God, the most kind and generous who has blessed us by granting us this opportunity to have our project done. As well as, to our beloved prophet Mohammed (peace be upon him).

Secondly, I would like to sincerely acknowledge the one who has inspired, urged, guided and helped me in a way that I became able to carry out this project as perfect as I can by granting me "HOPE" that "I can and I will" fulfill this research; though I faced a lot of difficulties, my supervisor Dr. Yahya Tashtoush, who has worked with me step by step to accomplish this research. As we know, no one walks alone in the journey of life, I would like to thank those who joined me, stood beside me and helped me along the way, giving me the motivation to succeed, and they were my friends and my family, inspired and helped me with motivation to obtain success. Special thanks for Nour Al-Mukhtar for helping me to accomplish this thesis

Ali

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Abstract

Ad hoc networks become more popular in recent years due to the services that produce all users or nodes freely without any interruption. Allowing the nodes to change their location and the nodes constituents are free to move, join or leave the network. A mobile Ad hoc network (MANETs) has an infrastructure-less network and does not contain a central device to organize the operation and the functionality, so all nodes must perform both router and client job to serve the functions of the network.

Routing protocols are concerned with finding the optimal path between source and destination nodes. Reactive routing protocols initiate a route discovery process by broadcasting the network with a rout request packet and then find the shortest path between source and destination to send the data packet through it. This causes network congest and more dropped packet when the link fails or broken, so the need for finding alternative path is urgent to continue packet sending.

In this thesis, Faulhaber's Multipath Load Balancing Routing Protocol (FFMLB) which is a new approach for reactivating routing protocols is proposed based on AODV routing protocol to reduce the load on shortest path by discovering alternative paths to maximize the throughput and decrease delay. FFMLB saves multipath in routing table and sorts them in decreasing order according to the number of hops and distributes the data packet by using Faulhaber's formula. The shortest path has the highest weight and the longest path has the lowest weight. To decrease the percentage of the congestion problem and achieve better load balance. The simulation results prove that FFMLB outperforms the Ad hoc On-demand Distance Vector (AODV), Ad hoc On-demand Multiple-path Distance Vector (AOMDV), Fibonacci Multipath Load Balancing (FMLB), and Geometric Multipath Load Balancing (GMLB) routing protocols in terms of two performance metrics decreased the average end -to- end delay and increased packet delivery ratio.

موازنة أحمال المسارات المتعددة في الشبكات المتنقلة الخاصة باستخدام صيغة"Faulhaber's"

إعداد

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المشرف

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الملخص

الشبكات الخاصة هي مجموعة من العقد (أو الأجهزة المتنقلة) الموزعة عشوائياً في منطقة جغرافية معينة. أهم ما يميز هذه الشبكات أنْ ليس لها هيكلية أو بنية تحتية ثابتة. لأن العقد لها القدرة على الحركة والانضمام او ترك الشبكة بحرية من دون قيود..

التوجيه التفاعلي (عند الطلب) هو أحد أنواع بروتوكولات التوجيه المستخدمة في الشبكات الخاصة، يقوم باكتشاف الطريق عند الحاجة لها فقط بإغراق الشبكة بحزمة بيانات خاصة تسمى حزمة طلب اكتشاف الطريق. تقوم العقدة المصدرية بإرسال طلب التوجيه لجميع جيرانها ضمن مدى الإرسال الخاص بها، ثم تقوم كل عقدة تستلم هذه الحزمة بإرسالها لجميع جيرانها أيضا عند استلامها للمرة الأولى، وتستمر هذه العملية إلى حين وصول الطلب للعقدة الهدف او العقدة التي تمتلك طريقا حديثا للوصول إلى العقدة الهدف. وتختار معظم الشبكات الخاصة بالمسار الأقصر لنقل البيانات، واختيار المسار الأقصر غالباً ما يحتوي على مجموعة من الأجهزة الواقعة في وسط الشبكة، واستخدام تلك الأجهزة بعدة مسارات يولد كمية كبيرة من الضغط على الشبكة ويشكل الازدحام في تلك الأجهزة، وبالتالي فقدان البيانات. ويؤثر فقدان البيانات سلباً على عمر الشبكة إذْ إنّ البيانات المفقودة غالباً ما يتم اعادة ارسالها مما يؤدي إلى استنزاف مصادر الشبكة بشكل غير فعال.

تمّ في هذه الأطروحة اقتراح نموذج جديد يهدف إلى الحد من مشكلة الإزدحام في بروتوكلات التوجيه التفاعلي، ويقلل من تأثيراته السلبية على أداء الشبكة. يقوم مبدأ هذا النموذج على توزيع البيانات المرسلة على عدد من المسارات لتخفيف الحمل على الأجهزة الواقعة وسط الشبكة باستخدام معادلة Faulhaber's formula (FFMLB) مع التركيز على منح الطرق القصيرة قابلية ارسال عدد أكبر من البيانات. لدراسة أداء وسلوك النموذج الجديد، قورن مع نظام التوجيه أُحادي المسار (AODV) ونظام التوجيه المتعدد المسارات (AOMDV) و نظام التوجيه باستخدام متسلسلة Geometric (GMLB) و نظام التوجيه باستخدام معادلة Fibonacci (FMLB) واختبر باستخدام المحاكي GloMoSim. وأظهرت النتائج أن النموذج المقترح أعطى نتائج تفوقُ نظامَ ال AODV في جميع الاختبارات التي أجريت. نظام التوجيه الذي يعتمد على عدد من المسارات باستخدام معادلة Faulhaber's formula قلل من الوقت اللازم لإيصال حزم البيانات للعقد الهدف. وأنجز النموذج المقترح تحسيناً طفيفاً من ناحية نسبة تسليم الحزم مقارنة مع نظام التوجيه باستخدام معادلة Geometric ونظام التوجيه باستخدام معادلة Fibonacci ونظام AOMDV ونظام AODV.

Chapter One

Introduction

1.1 Introduction to Wireless Networks

There are two types of networks; wireless and wired networks. Wireless networks have recently become more popular, and they grew rapidly due to some features: easy to set up, cheaper, can be used without cables so any device can have access to the network easily while moving. Mobile Ad hoc Networks (MANETs) is an example to wireless networks. It consists of various types of devices like Mobile, Laptop and Smart phones etc. the connection in MANETs can be done anytime and anywhere in any direction. Wireless networks are divided into two categories depend on its infrastructure:

Infrastructure network: it is a central network containing Access Point (AP) to manage the connections between nodes and all the functionality of the network such as routing, switching, and addressing as in figure 1.1 (a) (Maurya and Prashant Kumar, 2012).

Infrastructure-less network (Ad hoc network): this network has no central router shown in figure 1.1 (b). All the devices can be able to move and connect dynamically. Accordingly, connecting, managing, and organizing relay on the devices themselves (Dahiyaet al., 2014; Sharma et al., 2016). If a node wants to connect another node, which is not within the range of connection, it will rely on nodes within the range of source and destination at the same time. These nodes are called hops. Communication has been done by using radio or infrared channel. Hop-by-hop strategy needs routing protocols to manage the communication between nodes. Routing protocol can be divided into two categories including: wire routing protocol and wireless routing protocol based on IPv4, so wired routing protocol is easy to implement by IPv4, which is not supported in wireless network because the nodes change their location randomly which needs to evaluate the optimization of ad hoc network (Singh, et al ,2014).

Ad hoc networks can connect to fixed network like internet. Bluetooth, VANET and MANET are examples of Ad hoc networks. MANET consists of a group of mobile nodes (devices). These nodes connect to each other without any fixed infrastructure. Each node in this network can perform as host and like a router too (Safdar and et al. 2016). Due to some features like unstable links, limited energy capacity, dynamic topology and specific bandwidth, MANET differs from wired networks. Therefore, it is used in military places and places with no network infrastructure, as well as damaged places resulting from an earthquake (Sharma & Singh, 2013).

1.2 Overview of Mobile Ad Hoc Networks

In Latin Ad hoc means “for this purpose”. Ad hoc network doesn't need infrastructure as a wired network, which means it doesn’t have central devices and it is also easy and doesn’t take much time to be installed (Jabeen and et al, 2016). Each node in network has a unique IP address which other nodes can communicate by this IP address. The most important feature in MANETs is that it is easy to configure. There is no stable and structured network topology so it changes dynamically, and that leads to changes in route. When a node tends to send data packet to other nodes, it should be sure that there is an available route to specific destination through number of intermediate nodes; this procedure that is called routing (Safdar and et al. 2016; Zou and et al, 2002).

A simple example of ad hoc network shows below in figure 1 with four nodes X, Y, Z and W. when node X needs to communicate with node W, firstly it needs to send the data packet to node Y, because node Y is within the transmission range of node X. then we notice that both of node X and Z are within the transmission range of node Y, but node W is out of its transmission range, so that node Y relays the data packet to the intermediate node Z, then node Z forwards the messages to W.

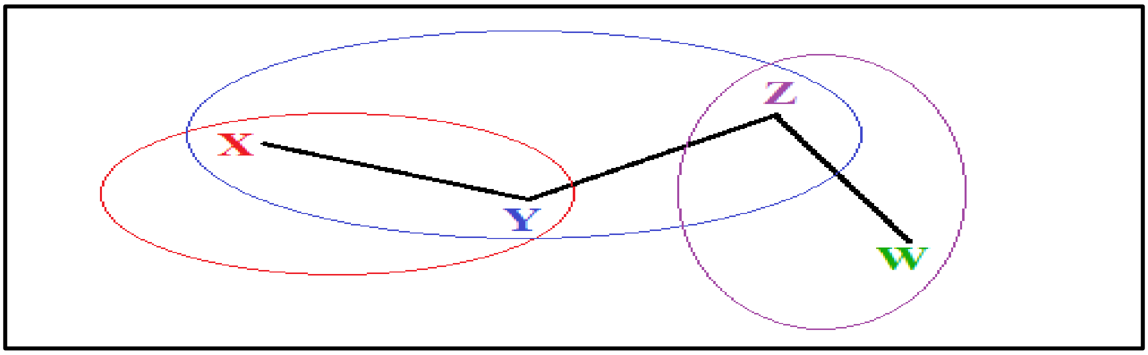


Figure 1: Simple ad hoc network with four nodes

So wireless network communication can be classified into two typical categories:

A single hop communication (cellular network): occurs when a node connects directly with other node, meaning that both nodes are within the transmission range to each other (Zou and et al, 2002).

A multi-hop communication (wireless ad hoc network): occurs when it depends on one or more intermediate nodes to forward a data packet (Zou and et al, 2002).

Transmission between nodes can be unicast, multicast and broadcast.

Unicast: one node transmits to only one neighbor node (one-to-one) (Kant and et al, 2010; Chitkara and et al, 2014).

Multicast: one node transmits to group of neighbor nodes (Kant and et al, 2010; Debnath and et al, 2010;Chitkara and et al,2014).

Broadcast: one node transmits to all nodes in the network (Debnath and et al, 2010).

1.3 Characteristics and Challenges of MANET

MANET has some properties differ from infrastructure networks:

Dynamic topology: nodes in MANET change its locations dynamically, nodes are free to move may cause disconnection or breaking the path of routing results increasing in packets drop (Safdar and et al. 2016).

No fixed infrastructure (infrastructure less): MANETs is a group of mobile devices that connect with each other without the need for central device to control the connection between them so MANET could be unsecure and vulnerable (Paul, 2016, P12;Aarti, 2013).

Self-Organization: nodes act like a host and like a router too, so addressing, routing, energy and security is all done by the node itself because there is no central device to do all the functionality (Narayana and etal,2017; Salem and et al, 2016)

Security: because of some features in MANET like Dynamic topology and open wireless medium may cause some security problems and make the network vulnerable to attack (Wei and et al, 2014). Attacks that are related to some issues such as integrity, authenticity, availability and confidentiality, Attacks could be passive or Active Attacks (Nazir and et al, 2016). MANETs can connect to other network such as the internet. Any node can easily be connected to network without requiring an authentication process (Goyal and et al, 2017). Some factors must be taken into account when building routing protocol to void the security problems (Nazir and et al, 2016).

Scalability: MANETs can handle thousands of nodes involved in communication (Raza and et al, 2016; Chitkara and et al, 2014).

Bandwidth constrained: The infrastructure network has a bandwidth up to Gbps when wireless network has about 2-10 Mbps. The throughput of wireless network is lower than the radio transmission rate, especially if it meets one or more of these factors such as fading, multiple access, interference condition and noise. Congestion problem can be increased with limited bandwidth (Aarti,2013).

Multi-hopping: If one node wants to send packet to another node outside its transmission range, then it needs to forward the packet to one or more intermediate node (hop) to reach the specific destination (Salem and et al, 2016,Aarti, 2013)

Battery power: Each Mobile node has its batteries which consumed in every transmission or receive packets, so it is hardly to recharge or replace batteries, that affect the whole network, when forwarding and receiving packets through the node (Aarti, 2013).

Variation in link and node capabilities: node in network may have one or more radio channel (interface), that have different transmission and receiving capabilities and different frequencies, that cause asymmetric links between nodes, also may the nodes operate a different hardware or software(Chitkara and et al,2014; Raza and et al, 2016).

1.4 Applications of MANET:

MANET is used in many situations due to infrastructure-less and mobility services based characteristics:

Military field: in the battlefield it is too hard to deploy an infrastructure network so that military uses Ad hoc network create a communication between soldiers (Chitkara and et al, 2014; Raza and et al, 2016; Paul, 2016, P13).

Automotive application: in recent years cars can connect to other cars through the road, making Ad hoc networks in different sizes, that helps the driver with congestion, accidents warning and helping to improve traffic flow (Paul, 2016, P 14).

Sensor networks: sensors can connect with each other as ad hoc network that used in measurements like temperature, pollution and earthquake (Raja and et al, 2014;Paul, 2016, P 14).

Personal area network and Bluetooth: is a short range network, usually the nodes are either laptop or mobile; it is possible to use Bluetooth to create these networks (Raja and et al, 2014). Like gaming network.

Education: is used to facilitate the connection between computers in labs, conference room or classroom (Raza and et al, 2016).

Emergency operations: in the case of earthquake, flood, fire or any other emergency situation and existing infrastructure network has been damaged, it is impossible to build an infrastructure network, so building an Ad hoc network would be much easier (Raja and et al, 2014;Paul, 2016, P 14;Raza and et al, 2016).

Collaborative and Distributed computing: MANETs used to share the research and lecture notes between group of researchers outside the business environment in a fast way to do specific project by using a high processing power devices like laptops, mobile phone and personal digital assistants (PDAs) (Raja and et al, 2014).

1.5 Routing concept in MANETs

Due to the possibility to leave and join the network, the availability to move and change the location of nodes, routing is considered as one of the most important challenges in Ad hoc network. The objective of routing is to lead the packets to proper destination. Finding the suitable path that leads to destination is the aim of routing (Saeed and et al,2012). Optimal path between source and destination may be the one that has the shortest path (less count of hops) and available. Forwarding the data packet from one node to another depends on routing tables in each node which has valid path or information about the next hop reachable destination (Yassein and et al, 2014). If one node needs to send data packet to another one and both of them are connected directly means that they are connected in case of single hop communication, while if the receiver node is not in the transmission range of the sender node which means that sender node needs one or more intermediate node, in this case multi-hop communication is required. Routing protocols use routing table to store the information of the next-hop to desert destination.

Classification of routing in MANETs

There are three major types of routing in MANETs depending on topological information are:

Flat routing: each node in network has the same features which means that every node can send data to all available nodes because each node has a unique global address. This type of protocols is efficient with small size networks sending less volume of information to remote nodes (Hong and et al, 2002). Each routing algorithm differs in link utilization (Devika and et al, 2013). Proactive, reactive and hybrid are types of flat routing depending on the way of saving information in routing table.

Hierarchal routing: this type of all the nodes is divided into groups called clusters, each cluster has a head node, and this head node is like a leader of this group. This leader collects the information from the group of nodes, this information enhances the power consumption (Devika and et al, 2013).If network is organized into a cluster, it becomes a more stable environment and all nodes within the cluster have full routing information about the network topology (Hong and et al, 2002). The suitable protocol is used within the cluster is proactive routing protocol. Inter-cluster routing is a reactive routing protocol, sometimes it is a combination of reactive and proactive routing that must be used in case when the destination node is in other cluster. Cluster head gateway switch routing protocol (CGSR) is an example of hierarchal routing.

Location based routing: before every transmission the sending node must know the position of receiving node. This type also called directional routing (Devika and et al, 2013).

1.5.2 Classification of routing protocols in MANETs

Routing in MANET can be classified into three types based on routing information update mechanism (as shown in figure 2):-

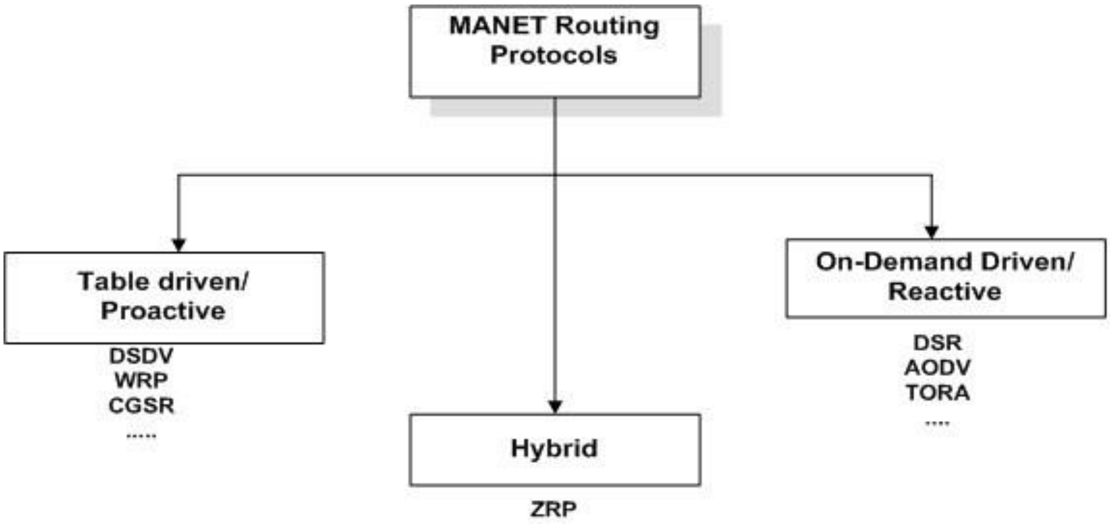


Figure 2: MANETs Routing Protocol

(Jagtap, and etal, 2014)

Proactive routing protocols (Table Driven Routing Protocol): they can be used to gain correct route information, and to get information about each node in the network. Practically speaking, the node must send a control message frequently. However, these control messages may waste the power and the bandwidth if they are sent when there is no data transmission or traffic (Jaiswal& Prakash, 2014; Hindset al., 2013). Any time nodes need to transmit a packet, it selects a route that is immediately used and predefined. From here comes the name of proactive. Nodes in proactive protocol may have one or more routing table to store complete information about the network, which is different from other routing protocols. Global State Routing (GSR) is an example of this type.

Reactive Routing Protocols (On Demand Routing Protocol): if a node tends to transmit data to another node, it sends request messages to the entire network nodes to gain the route depending on the sequence packet number to avoid loops and make the route up to date. The highest sequence packet number indicates that the route is fresh (Sharma, and et al 2016). Ad hoc On Demand Distance Vector (AODV) is an example of this type. AODV uses traditional table containing one entry per destination. Accordingly, it preserves time based on the status of the routes; they can easily choose a route used recently and not expired (Talwar and et al, 2014). Ultimately, AODV supports unicast, multicast, and broadcast (Jaiswal& Prakash, 2014).

Hybrid routing protocols: they have the benefits of reactive and proactive routing protocols. First, it acts as the proactive routing protocol because its nodes have tables. Second, it acts as the reactive routing protocol when it starts to discover the paths. Zone-Based Hierarchical Link-State Routing Protocol (ZRP) is an example of this type (Sharma and et al., 2016).

1.6 Faulhaber Formula

In mathematics, Faulhaber's formula, named after Johann Faulhaber, expresses the sum of the p-th powers of the first n positive integers

$$\sum_{k=1}^{n} kp = 1^p + 2^p + 3^p + \ldots + n^p \quad ;\ldots\ldots\ldots\ldots\ldots\ldots(1.1)$$

In this thesis, the Faulhaber's formula is used because it produces large numbers as a sequence.

1.7 Thesis Scope and Objectives

This research attempts to investigate the case when a node trying to send data to a destination. AODV protocol uses the minimum number of hops to reach the destination as the primary path. It forwards the data packets towards the neighbors through the shortest path (A-B-F) as shown in figure 1.4. The congestions through the shortest path can be high (Aleksandr, 2004). This makes the overhead of these hops is high. In addition, the delivery ratio is low and the number of packet drops is high. The delay of delivering a packet from the source to the destination is high as well.

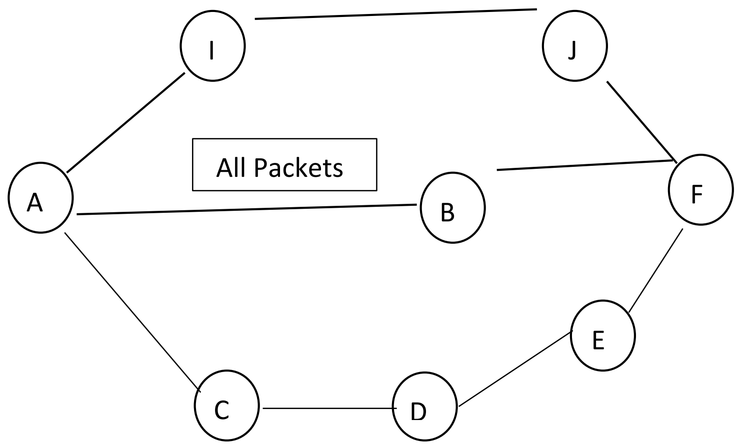


Figure 3: Routing in AODV protocol

The significance of this study lies in designing, implementing, and evaluating a new approach for routing protocols. This approach will be based on AODV routing protocol, unlike AODV. At the same time, it reduces the packet congestion in the network through finding alternative paths and distributes the packets among them. The data packets will be distributed over the multiple paths using Faulhaber formula for packet distribution. The packets sent by the sender will be distributed over the available paths using the Faulhaber's formula approach. The shortest path is taking the highest number of the data packets while the longest path is taking the least number of data packets.

Accordingly, it can be assumed that n is the number of the available paths between source and destination. Distribute the packets over n paths in Faulhaber's formula with different bases while p is the power number:

Therefore, the sequence is:

$$\sum_{k=1}^{n} kp = 1^{p} + 2^{p} + 3^{p} + \ldots + n^{p} \quad ;\ldots\ldots\ldots\ldots\ldots\ldots(1.1)$$

Where (n) is a positive integer and (p) is a positive constant

The longest path is the first entry path in the routing table and takes a low weight according to these series the shortest path is the last one in the routing table and takes the height weight. Which means the most number of data packets will be sent across the shortest path. In this scheme we distribute the load of packets along multiple paths and avoid congestion problem and decrease the delay especially in the case of link failure. Quality of services and scalability are taken into consideration. The main objectives of the new routing algorithm are to maximize the percentage of delivery data and reducing the load on the shortest path.

1.8 Thesis Organization

Chapter 1 describes an overview of MANET and provides various applications of ad hoc networks and routing in MANETs and the objective of this thesis. Chapter 2 summarizes some related work in the scope of my thesis. Chapter 3 concludes the main idea and mechanisms of the proposed scheme. Chapter 4 explains the FFMLB design and its algorithm. Chapter 6 explains some works of MANET routing protocols and compared among the FFMLB, GMLB, GMLB, AOMDV and standard AODV protocol. Chapter 6 concludes the thesis and provides future work.

Chapter Two

Literature Review

This section represents the literature review of this study.

(Tashtoush et al., 2016) and (Tashtoush et al., 2014) produced new approaches for multipath routing protocol based on AODV routing protocol using Geometric sequence and Fibonacci sequence to distribute the traffic over multiple available paths. The Geometric sequence shows a better result than the original AODV. For the Fibonacci approach, it shows a good result in packet delivery ratio and end-to-end delay. They have used Fibonacci and Geometric sequences in their approach while our research approach will use Faulhaber's formula. Therefore, the proposed approach is different in the way of distributing packets. In Geometric, Multiple-Path Load Balancing (GMLB) and Fibonacci Multiple-Path Load Balancing (FMLB) uses two sequences to distribute packets on multiple paths, the shortest path takes higher number of data packets and longer path take the minimum. GMLB uses equation (2.1):

$a = 2, \; r = 2$

$Xn = a * r (n-1)$

$\{a, ar, ar2, ar3, ar4, ar5, \ldots\}$ …………………………………… (2.1)

And FMLB uses equation (2.2):

$f0 = 0$

$f1 = 1$

$fn = fn-2 + fn-1; \; n \geq 2$:…………………………………………………..(2.2)

(Zangeneh and Mohammadi, 2012) proposed a new multipath routing protocol based on AODV routing protocol. The protocol initiates an alternative path called a backup path. In addition, the primary path between source and destination is the shortest path in AODV. This protocol is called "Multipath node-disjoint with back up list AODV (MNL-AODV)" which means that there are no joint nodes in the two paths. When the primary path is unavailable, the backup path is used. This work is somehow similar to the current study project since they used the AODV multipath. However, it differs from my study since they used only two paths. Accordingly, undefined number of paths was used in my study.

In addition, (Alghamdi, 2016) proposed a new approach called Load Balancing Maximal Minimal nodal Residual Energy Ad hoc On-demand Multipath Distance Vector routing protocol (LBMMRE-AOMDV). This approach computes the maximum residual energy that node can use to transmit a number of packets over a specific path and send the data without consuming all the node energy. This approach can enhance the packet delivery ratio and decrease the number of death nodes. This work uses AOMDV routing protocol, which is similar to the proposed approach that the (LBMMRE-AOMDV) related with node energy to distribute the packets among them. A higher energy node has the highest number of packets.

Likewise, (Mallapur and et al, 2016) proposed a new approach based on a candidate node to be the backbone of data transmission called Stable Backbone based on demand Multipath Routing Protocol (SBMRP). The protocol initiates the node with highest residual bandwidth, highest residual power, highest link quality, and lowest mobility. The communication is done through the candidate nodes. When the candidate node fails other node (candidate) with less performance begins. This approach results in a higher packet delivery ratio than AODV and AOMDV. On the other hand, SBMRP depends on the primary node in transmission.

Moreover, Tao and Lin (2016) proposed a new schema for loading balance; it deals with multi path routing network and considers the way of distribution packets among these paths. When each node receives the RREQ message, the schema calculates the interface queue occupancy and response of the sender. The threshold value is calculated by each node. The threshold value determines which path will be used and how much data will flows through. The dynamic value can be changed during communication. This schema produces a good result to end the delay and packet delivery ratio.

However, (Salem and Yadav, 2016) presented a new method for loading balance on AODV protocol and a multipath called EELAR (Energy Efficient Load Aware Routing). Before the source node transmits the data to destination node, routing protocol sets all the source node neighbors off (sleep), but it puts all the nodes in active mode and starts transmission on multi-path when it is ready. If a node has a lower energy level than the threshold value, the source node finds another node with higher threshold energy to forward packets. The schema shows an improved result than the AODV in throughput, end-to-end delay and packet delivery ratio.

Furthermore, (Ali and et al, 2015) proposed a new approach in loading balance and energy aware of multipath MANET. They used a schema to determine the congestion on the node and the residual node energy. They used a fuzzy engine, which accepts input and determines in which paths the data are distributed. The forwarding delay, bandwidth, residual energy, and average load are the inputs of fuzzy engine. The result illustrates a shortage in end-to-end delay, energy consuming, and packet drop, as well as it illustrates an enhancement on packet delivery ratio.

Besides, (Bai and et al, 2015) presented an enhancement on AOMDV routing protocol to select a path. The approach concerns about choosing a path from many available paths. The selected path needs to have low traffic rather than the shortest path. In order to load balance in transmission and reduce delays, this approach is only simple enchantment on an existed routing protocol. Therefore, it is not a new approach.

Chapter Three
The proposed scheme

3.1 Overview

This chapter presents the idea of multi-path routing protocol for ad hoc networks. The purpose of multi-path is to reduce the congestion problem which occurs when network becomes heavily loaded and achieves load balance that tries to separate the traffic along multiple paths. To maintain Multi-path routing must choose an efficient routing protocol. AODV is a reactive routing protocol that is classified as distance vector and it initiates a route on demand fashion, so it decreases the number of request packet that broadcasts and provides fast recovery when router failure occurs which means it is more attractive to the idea of maintaining the multiple path routing (Shaheen and et al, 2016). AODV is used to evaluate and implement the performance of the proposed Faulhabour formula sequence based multipath load balancing approach for MANETs.

3.2 Ad hoc On-demand Distance Vector Protocol (AODV)

AODV uses traditional table containing one entry per destination. Accordingly, it preserves time based on the status of the routes,they can easily choose a route used recently and not expired. AODV uses intermediate node between source and destination to store specific information in their routing table for specific time that called hop-by-hop routing. One important feature in AODV is that it supports unicast, multicast, and broadcast (Jaiswal& Prakash, 2014). AODV is free loop protocol, because it uses sequence number technique which means it avoids the count to infinity problem, all the routing packets carry that sequence number (Talwar, &Benakappa, 2014).

AODV has two procedures: route discovery process and route maintenance process.

The route discovery process begins when the source node send Route Request (RREQ) packets to the whole network to reach the destination node, after that the destination node reverse a Route Reply (RREP) packet to the source node, after that the source node determine which is the shortest path to the destination, and make it a primary path. The route maintenance process begins after the link primary path fails or breaks, if the intermediate nodes find an alternative path to the destination, the process will be done otherwise, the source node broadcasts a Route Error (RREQ) packet to the whole network and begins a new route discovery process.

3.2.1 Route Discovery Phase

When the source node attempts to transmit a message to another node it checks the routing table if there is a route to that destination node, if it exists it starts transmission directly otherwise, if it cannot find a route in its routing table, the source node starts the path finding (discovery) process by sending a Route Request (RREQ) packets to all its neighbor nodes.The RREQ packet contains <source-address, source-sequence number, destination-address, destination-sequence number, broadcast-id, hop-count> as shown in figure 4 below, the source node S Begins the route discovery process to find the path to the destination node, broadcasting a RREQ message from source to its neighbors with 0 hop count, then neighbor nodes store the information about the reverse path in its own routing table as shown in figure 4 that uses it to unicast back the Route Reply(RREP) packet, after that both nodes C and B rebroadcast the RREQ packet to its neighbor nodes after incrementing the hop count by 1 and so on . This process continues until RREQ packet reaches to the specific destination D which unicasts back the route reply (RREP) packet to the same source (Sharma and et al, 2013; Tayal and et al, 2013).

Each packet in AODV RREQ has a time-to live (TTL) value at node IP address that guarantees the node to avoid redundant RREQ packets, after a period of time if no RREP message received by the source; it retransmits the RREQ packet again. Source node set TTL with high value to guarantee RREQ reach to every node in the network (Sethi and Udgata, 2010).

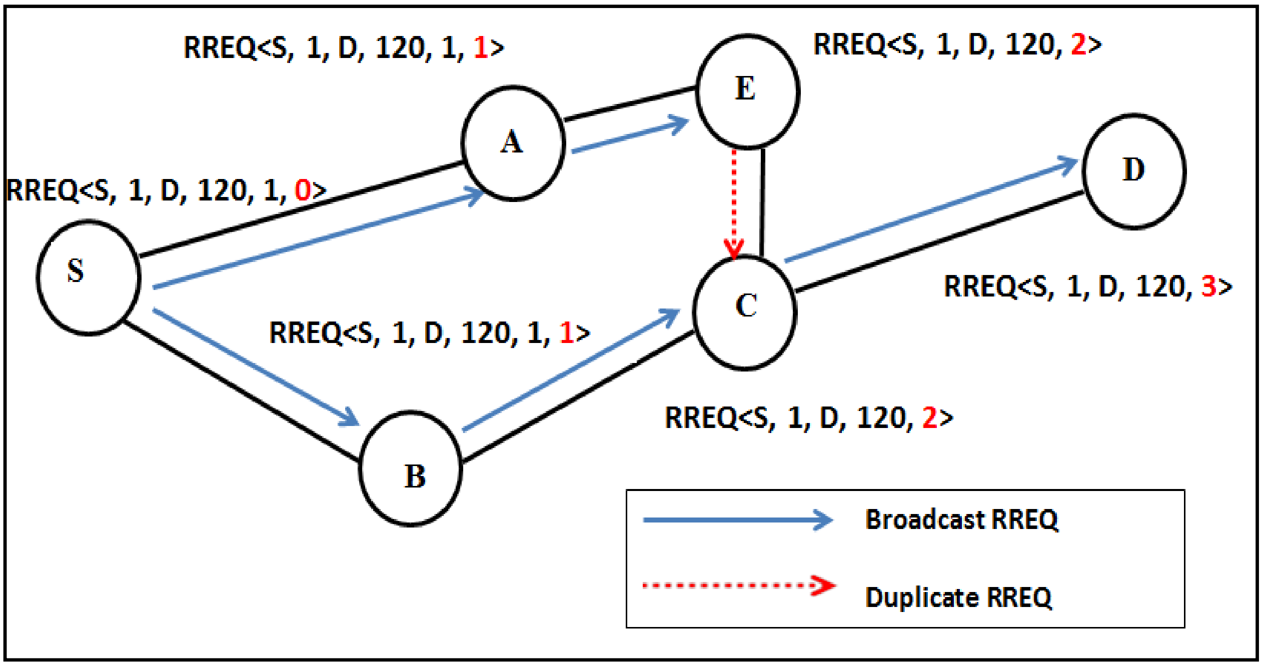


Figure 4: Request packet propagation process in AODV and example of duplicate RREQ in node C

The intermediate node determines if the RREQ packet is duplicated or not using the unique identifier (IP source address and broadcast ID). That means any node receives duplicate RREQ packets, it will drop the recent one as shown in previous figure 4.

In figure 5 shows that both intermediate nodes sets a reverse path from which they are achieve RREQ that means source node with nodes that has 1 hop count information in their routing tables, and nodes with hop count equal 2 set a reverse path to nodes that have 1 hop count and so on.

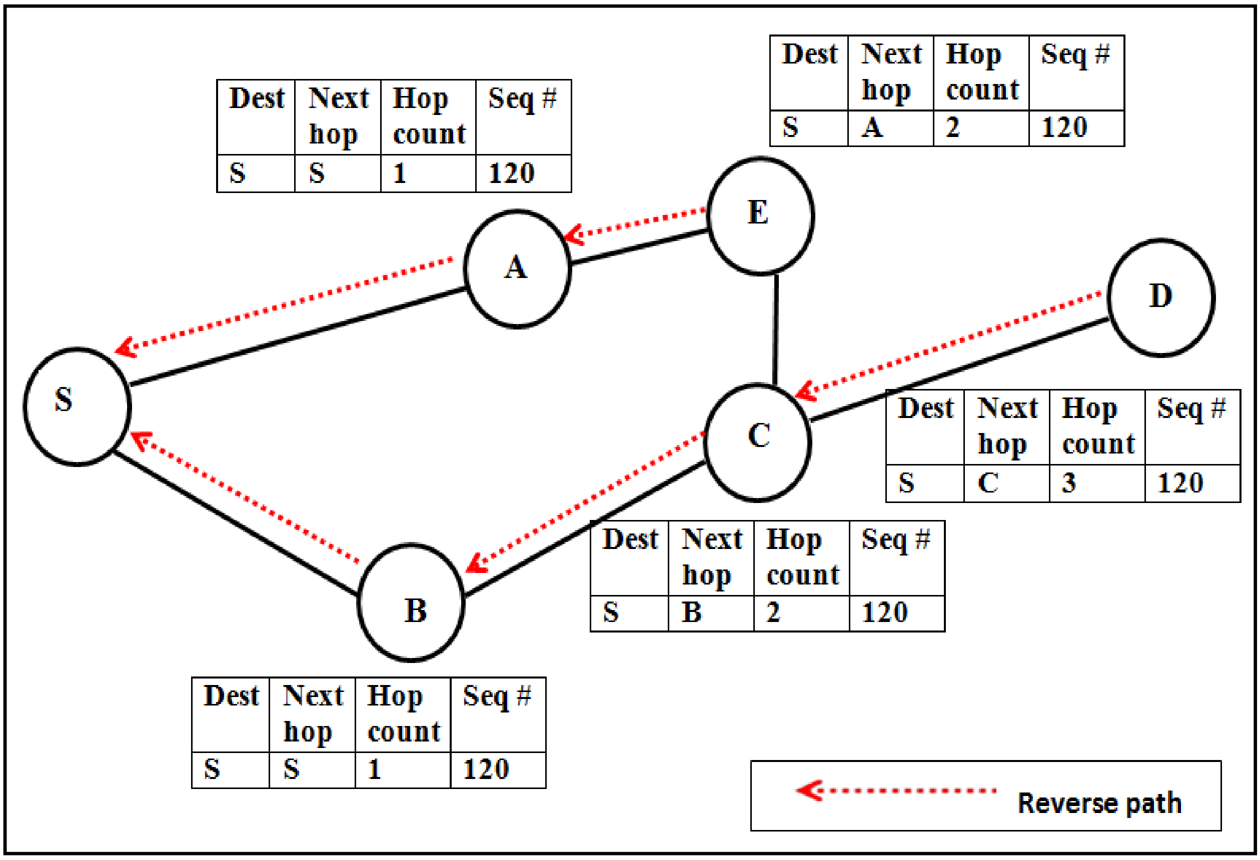


Figure 5: Initiate Reverse path after sending RREQ in AODV

The sequence number of source node increases with each RREP message received, and it used destination sequence number to avoid the old or broken route. When the RREP arrives to any node, the receiving node checks the destination sequence number with the current sequence number that stored in routing table, the greater value considers as more freshness path also to prevent routing loops. After destination node received the RREQ message it sends RREP to pervious node with a higher sequence number and the pervious node store all the information in its routing table and so on, when RREP arrives to source node transmission begins through the path as shown in figure 6.

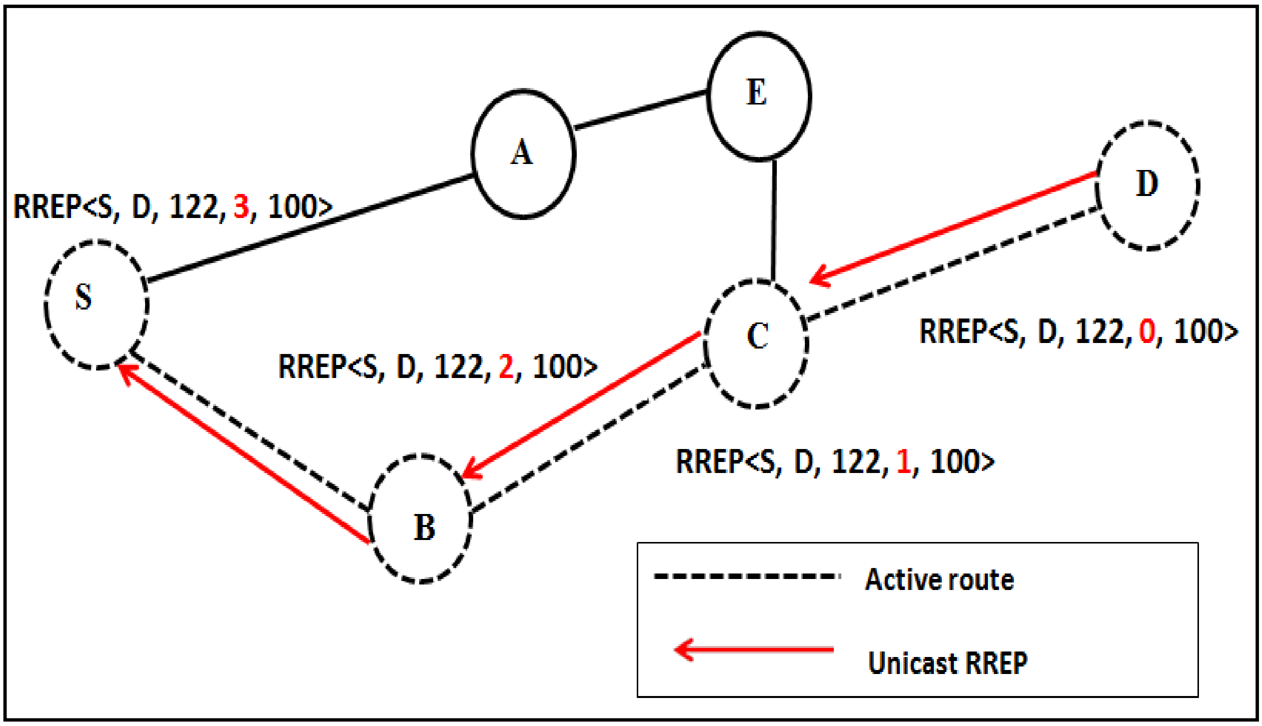


Figure 6: Reply process in AODV

As shown in figure 7 each RREP packet contains < source-address, destination-address, destination-sequence number, hop-count, lifetime>, hop count also known as cost to reach destination, it is equal to the number of intermediate nodes between source and destination pair. Minimum number of hops means the best path. The lifetime is defined as expiration time of the routing information, which means after how much time route entry is going to be expired. It is refreshed to a higher value at the first transmission and if no replies are received it will be incremented at a retransmission.

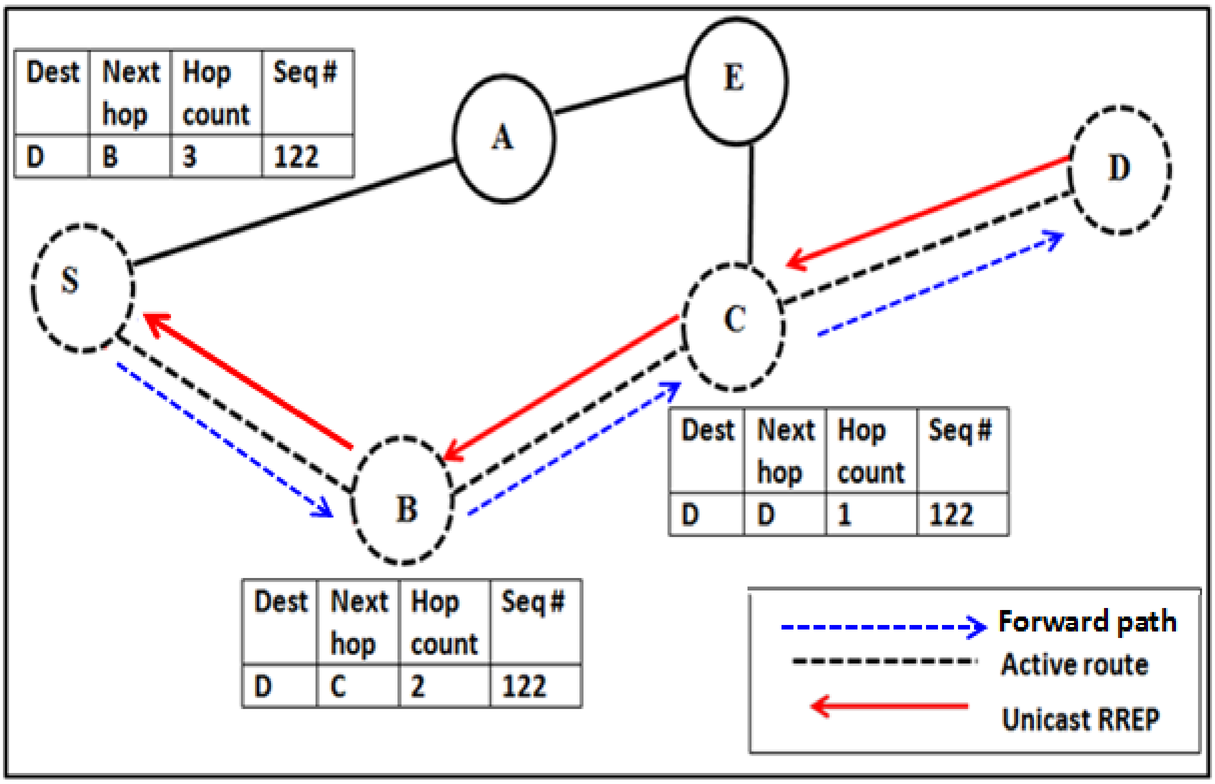


Figure 7: Initiate Forward path after sending RREP in AODV

3.2.2 Route Maintenance Phase

After the route discovery process if any link along the path breaks, the active nodes belong to this link, the node tries to find any alternative route to the same destination, if there is no other route to the destination, the node broadcasts a Route Error message (RERR) to the whole network, when the source node receives the RRER message it has begun a new discovery process (Sharma and et al, 2013).

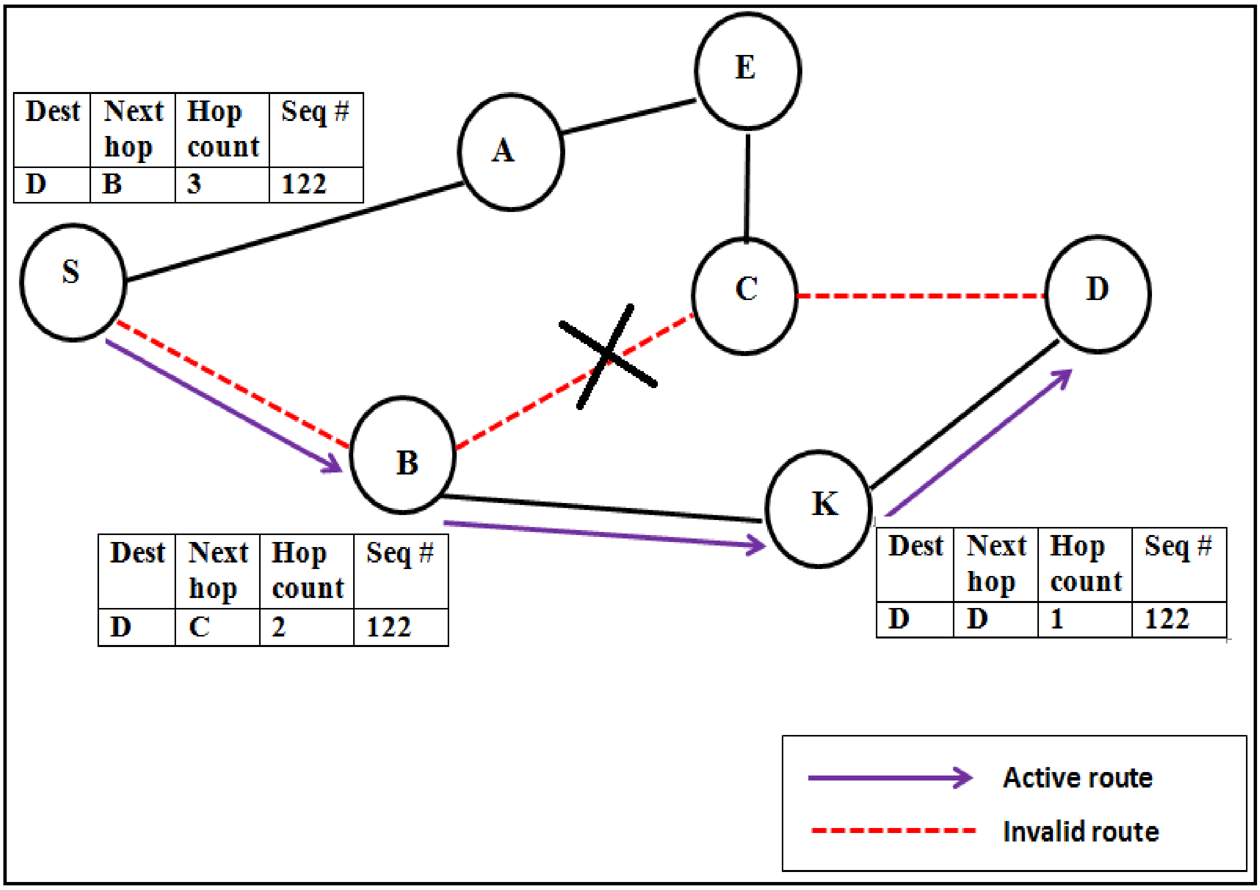


Figure 8: Local repair procedure

Nodes frequently change their location, so link failure may happen as shown in figure 8, the link connects between two intermediate nodes, becomes failure, trying to find another active neighbor node to repair the path is done by the active node (node B in figure 8) to reach the destination, node B updating its routing table with new information about the path. The active node doesn't need to flood a RRER message to the whole network in case it found another path that led to the destination.

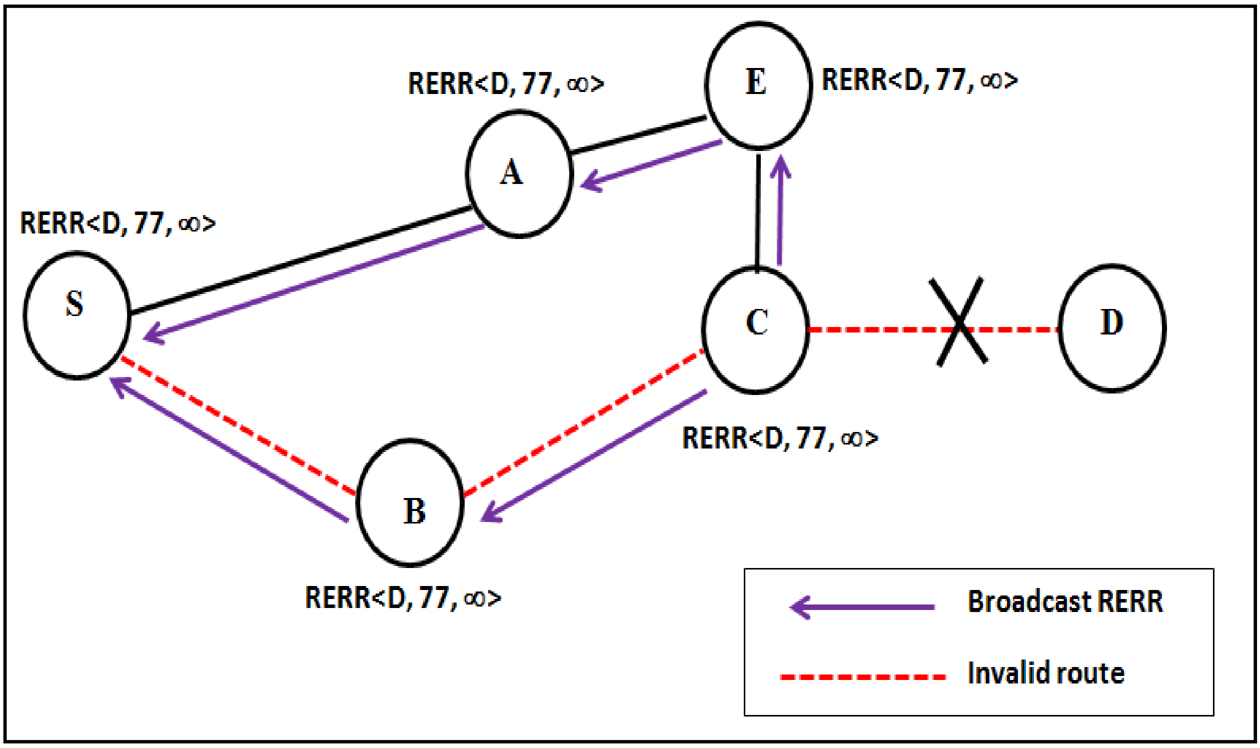


Figure 9: RERR message propagation

In figure 9 assumed link failure occurs between both nodes C and D means that path {S, B, C, D} becomes invalid route, and because there is no active neighbor connected to node C has a valid path to destination node D, which means it cannot use the local repair process; therefore node C flooding the route error packet to all its neighbor such as node E and B, with infinity hop count and generates a new destination sequence number equal to 77, both node E and B rebroadcast the RERR to its neighbor like A and S. when source node S receives RERR message and it still needs the route, it reinitiates the discovery process to find an optimal route to the destination node D.

3.3 Ad hoc On-Demand Multi-path Distance Vector (AOMDV)

Ad Hoc On-Demand Multipath Distance Vector Routing Protocol is one common Ad-Hoc routing protocol. Based on DSDV and it is a reactive routing protocol. AOMDV is designed for networks with large number of mobile nodes. The main idea in AOMDV is to determine multiple paths during route discovery process. It is designed primarily for highly dynamic ad hoc networks where route breaks and link failures occur frequently. In AOMDV a new route discovery is needed only when all paths to the destination break. A main feature of the AOMDV protocol is the use of routing information already available in the underlying AODV protocol as much as possible. Thus little additional overhead is required for the computation of multiple paths.

3.3 The Proposed Scheme

The aim of this study lies in designing, implementing, and evaluating a new approach for routing protocols (FFMLB). This approach is based on AODV routing protocol, unlike AODV. While the packet congestion in the shortest path, finding alternative paths and distributes the packets among them is one of most important issues in the proposed scheme (Tashtoush and et al, 2016). AODV uses the shortest path to destination for sending data packets (Periyasamy ant et al, 2015). That means it has one path to send data packets that make the network heavily loaded that causes more packets drop or invalid path. The data packets can be transmitted in a multiple path using Faulhaber's formula sequence concept, and the using of one path frequently consuming nodes power or breaking the link (Tashtoush and et al, 2016).

Load balancing, maximizing Packet delivery ratio and decreasing the delay are the main objective of this thesis. Using multiple path in AODV is possible. So the source node starts the path finding process by sending a route request packet (RREQ) to all its neighbor nodes. All the receiver nodes store their pieces of information in their own routing tables to initiate a path back to the source node, which is necessary to pass the route reply packet (RREP)(Tashtoush and et al, 2016).The RREQ packet still broadcasts until it reaches the destination node or a node that has a route to that destination. When the RREQ packet reaches the destination node, the destination node stores the information handled by this RREQ in its routing table and generates multiple RREP packets (one for each multiple available paths).Then it sends them back, each one to the same source node using the multiple reverse paths. After that, the source node saves all the information with each RREP in its local routing cable and sort the entries in this table based on the hop count in each path in a decreasing order. That means the first path in the routing table has the highest hop count, the proposed scheme distributes the data packets over these paths in Faulhaber's formula sequence. The shortest path takes the higher number of data packets and the longest path takes lower data packet (Tashtoush and et al, 2016).

3.3.1 Design FFMLB

To maintain multiple paths to destination in order to use one of them when the route fails. To reduce congestion and achieve load balancing multiple paths can help (Singh, et al, 2014). During RREP phase and after RREQ packets are sent, multiple routes are established. Multiple paths can be used simultaneously that means the possibility of sending data packets on multiple paths at the same interval of time. When a node needs to communicate with other node first it checks if the destination has an available route in source routing table (Tashtoush and et al, 2016). If not it initiates a route discovery process by broadcasting the RREQ. The intermediate nodes receive the RREQ message, they check if there is duplicate with other message depending on unique identifier <source address, broadcast- id> if there is no duplicate it checks if it has a fresh route in its routing table to the destination, then it saves the new information of RREQ message in its routing table. If intermediate nodes receive two copies of RREQ packet they compare the number of hop and save the information of the RREQ that have less hop count.

After RREQ message reaches the destination, check if the RREQ message duplicates using the value of <source address, broadcast-id, last address> if there is no duplicate then it creates the RREP packet and multicast it back forwarding it to each route that it receives RREQ from.

When RREP packet reaches the intermediate nodes, the intermediate node comparing the RREP packet with the existing destination sequence number to avoid duplicate, saving the information when the RREP largest destination sequence number to create the path used to forwarding data packets. Other copy of RREP with less destination sequence number will drop (Tashtoush and et al, 2016).

Source just node has an ability to save multiple path to the same destination. When it receives the RREP packet then it checks if it duplicates depending on the value of < destination -Address, last Hop> if it duplicates RREP then it drops, it otherwise stores the information that is carried with RREP in its routing table.

If link failure happened the detected node broadcasting a RRER message to the whole network, then the source node stops sending data packets at that route and sending it through remaining paths. When the route discovery process is done, the source node receives multiple RREP packets for different paths, saves it in its routing table in decreasing order of hop count. So assume there are three available paths between the sender A and the receiver F as shown in figure 10 also, assume P is 2.

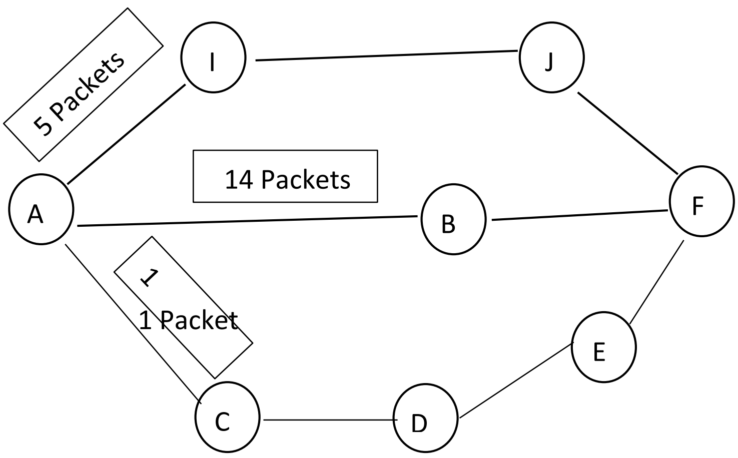


Figure 10: FFMLB Multipath

For example, by using our approach and based on Faulhaber's formula, the shortest path (A-B-F) will deal with highest number of packets (12+22+32) =14. The path (A-I-J-F) will deal with 5 packets. Finally, the longest path, (A-C-D-E-F) will deal with minimum number of packets.

3.3.3 FFLMB algorithm

Step 1: initiate Destination FaulHaber table to store the destination address in it. Each destination node address has multiple paths.

Step 2: initiate FaulHaber table to save multiple path in it. It is unlimited size. And work parallel with the routing table.

Step 3: Sort multiple paths in a decreasing order according to the number of hops.

Step 4: assign weight to each path according to the FaulHaber sequence.

Step 5: using update FaulHaber function at each time insert, change or delete node is required.

Step 6: Update Routing Table and Faulhaber's Table.

Step 7: delete the FaulHaber table and the Destination FaulHaber table.

Chapter Four
Simulation results

4.1 Overview

In this chapter, the proposed scheme will discuss and evaluate using GloMoSim (version 2.02). Comparison is done between FFLMB, GLMB, FLMB, AOMDV and AODV in Packet Delivery Ratio (PDR) and End-to-End (E2E) delay under performance metrics.

4.2 GloMoSim simulator

In order to study the performance of MANET network, there is a need for simulator program and environment. Global Mobile information system Simulator (GloMoSim), based on Prasc, is a discrete simulator written in C programming language dealing with thousands of nodes either wired or wireless networks (Kathirvel and Srinivasan, 2009). The simulator is used to study and simulate behavior of networks. GloMoSim deals with OSI 7 layers, each layer interacts with the above layer and works independently. GloMoSim has an Application Program Interface (API) so it can easily manage and change the features of OSI layers. The flexibility in GloMoSim makes it an appropriate tool to design and implement a new approach of routing protocol. This project has focused on network layer, because it is the only layer concerning routing packet. Additionally, GloMoSim saves the result of simulation in text file (glomo.stat). This result contains all layer statistics (optionally). Therefore, it can easily calculate the performance of protocol using the two metrics Average, End-to-End delay and packet delivery ratio. These two metrics are used to study the behavior and performance of the AODV routing protocol. Table 1 shows a type of protocol used for each layer.

Table 1: GloMoSim Library

Name of layer	Type of protocol
Application (traffic generator)	CBR(constant bit rate)
Transport layer	UDP
Network	AODV
Data Link - MAC	IEEE 802.11
Radio propagation	Free space
Mobility	Random waypoint

4.3 Performance Metrics

To study the performance of the proposed protocol (FFMLB) as compared with GLMB, FLMB, AOMDV and AODV. Packet delivery ratio and end-to-end delay have been used. Basically, any routing protocol studies the delivery of data between any user pair. Strong efforts are made to achieve high delivery of data with minimum delay to provide the user requirements that means that the end–to–end delay metrics is also taken into account. The following is two metrics used to study and assess the performance of the ad hoc routing protocol:

Packet Delivery Ratio (PDR): is used to measure the routing protocol efficiency. The packet delivery ratio is the ratio of packets successfully received by the receiver node to the number of packets sent by the sender node. Given that the sender sent 1000 packets and the receiver received only 700 packets; this means that the delivery ratio is 70%. Therefore, the data delivery ratio shows how many packets are dropped or lost mainly, because of one route congestion and they must be retransmitted.

Average end-to-end delay: it is the time that a sender needs to send a packet to its destination, including route discovery operation delay, packet processing delay, and propagation delay (Latency).

5.4 Simulation Environment Setup

The simulations were made by GloMoSim simulator version 2.03. The simulated network contains 30 nodes in random positions in area of 600 x 600 meters. Simulation time is 150 seconds, four runs were made to change the random simulator parameters and the presented data were averaged for each point. 250 meters are the transmission range of the nodes. Mobility model is used meaning nodes are freely moving in the network area. Random waypoint (RWP) model is set here. Each node has three values associated with RWP such as minimum speed, maximum speed and pause time. Each node moves with speed randomly changes between minimum and maximum speed also selects a random destination based on its speed. The time that nodes spend in their locations is called pause time, the pause time varies by 0, 50 and 100 seconds, pause time of 100 denotes low movement and pause time of 0 denotes high movement. The minimum speed is set to 0 m/s and the maximum speed is set to 10 m/s. To provide fair results, all protocols are implemented under the same traffic scenarios and mobility. The following table 2. Summarizes the simulation parameters.

Table 2: Simulation parameters

Parameter	Value
Simulator	GloMoSim (version 2.03)
Simulated protocols	FFLMB, GMLB ,FMLB, AOMDV and AODV
Simulation time	150 s
Transmission rate	10 packets/second (default)
Simulation area	600 m* 600 m (default)
Number of nodes	30 (default)
Node placement	Random
Radio propagation model	Two-ray
Transmission range	250 m (default)
Bandwidth	2Mbps
Mobility model	Random waypoint
Minimum speed	0 m/s

Maximum speed	10 m/s
Pause time	0, 50 , 100
Traffic type	CBR (Constant Bit Rate)
Data packet size	512 bytes

In the simulation the control parameters are dependency of packet transmission rate, a number of nodes, network dimensions, transmission range and the node pause time. The traffic load is varied by 1, 5, 10, 15, 20, 25 packet per second. All data packets have a fixed size equals to 512 bytes. The CBR traffic generator type is used in the application layer. A number of nodes is varied by 20, 25, 30, 35, 40 node. The network dimension is varied by (500 x 500), (750 x 750), (1000x 1000), (1250 x 1250), (1500 x 1500). And transmission range varied by 10, 15, 20, 25 and 30 meters and the pause time is varied by 0, 50, and 100 second.

4.5 Simulation Results and Analysis

In the delivery of data simulation the transmission rate is varying between 1 to 25 packet/second and the pause time is varied between 0, 50 and 100 second. The simulation result shows the performance of the routing protocols when packet rate increased. A number of nodes are set to 30. In order to measure the range of improvement of FFMLB protocol as compared with GMLB, FMLB, AOMDV and AODV.

Scenario #1 (PDR and E2E delay with varied transmission rate and pause time)

Varies PDR with implementing FFMLB, GMLB, FMLB, AOMDV and AODV routing protocol, with same simulation parameter that in table 2. Six scenarios for each routing protocol. Three mobility pause time implemented high, medium and low as shown in figures 11, 12 and 13.

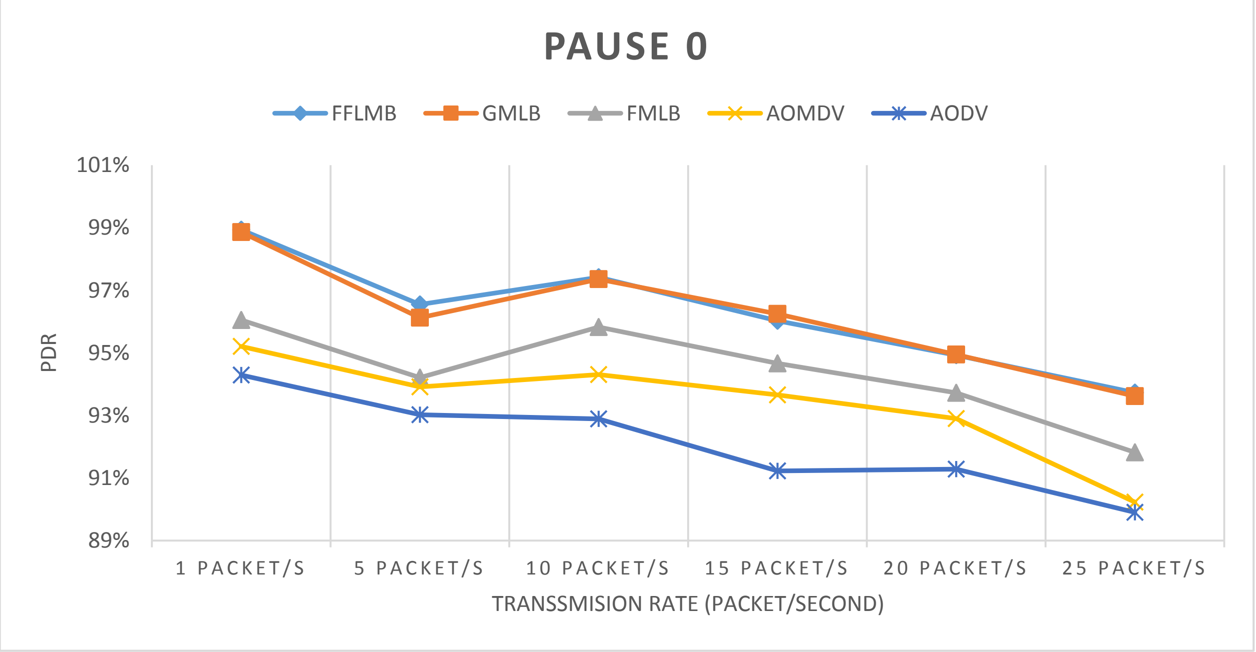


Figure 11: Packet Delivery Ratio vs. transmission rate with 0 second pause time

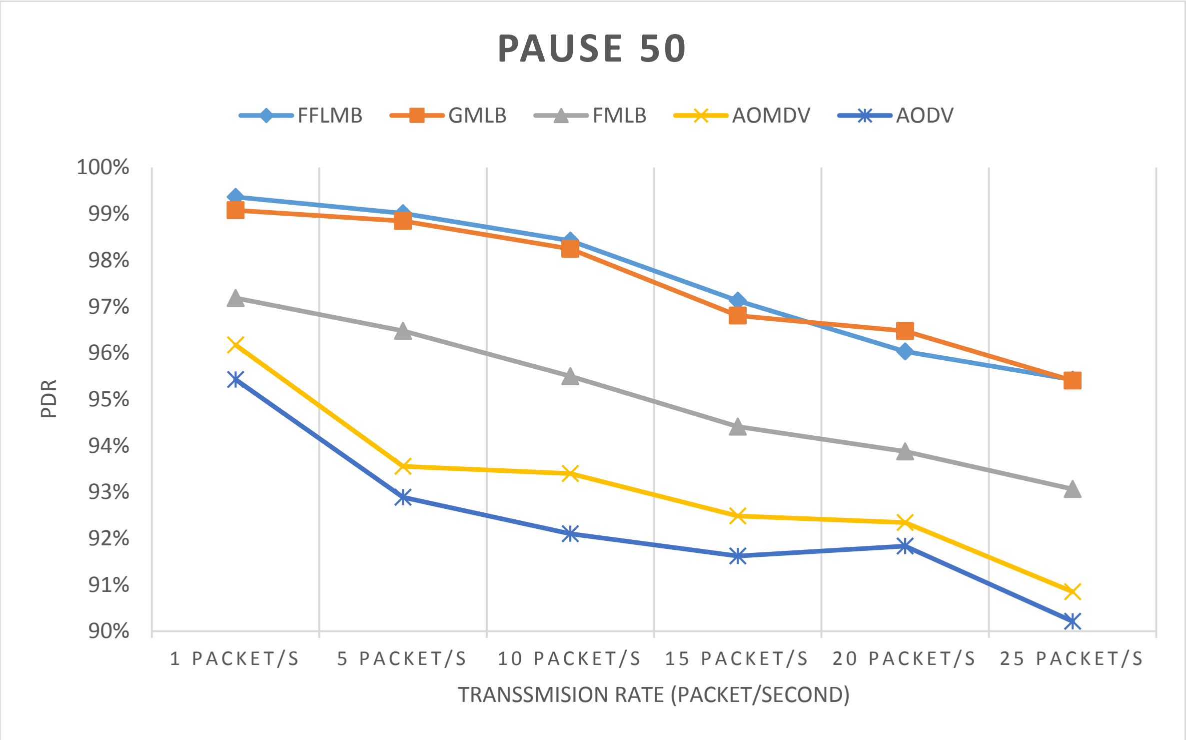

PAUSE 50
FFLMB
GMLB
FMLB
AOMDV
AODV
100%
99%
98%
97%
96%
95%
94%
93%
92%
91%
90%
PDR
1 PACKET/S
5 PACKET/S
10 PACKET/S
15 PACKET/S
20 PACKET/S
25 PACKET/S
TRANSSMISION RATE (PACKET/SECOND)

Figure 12: Packet Delivery Ratio vs. transmission rate with 50 second pause time

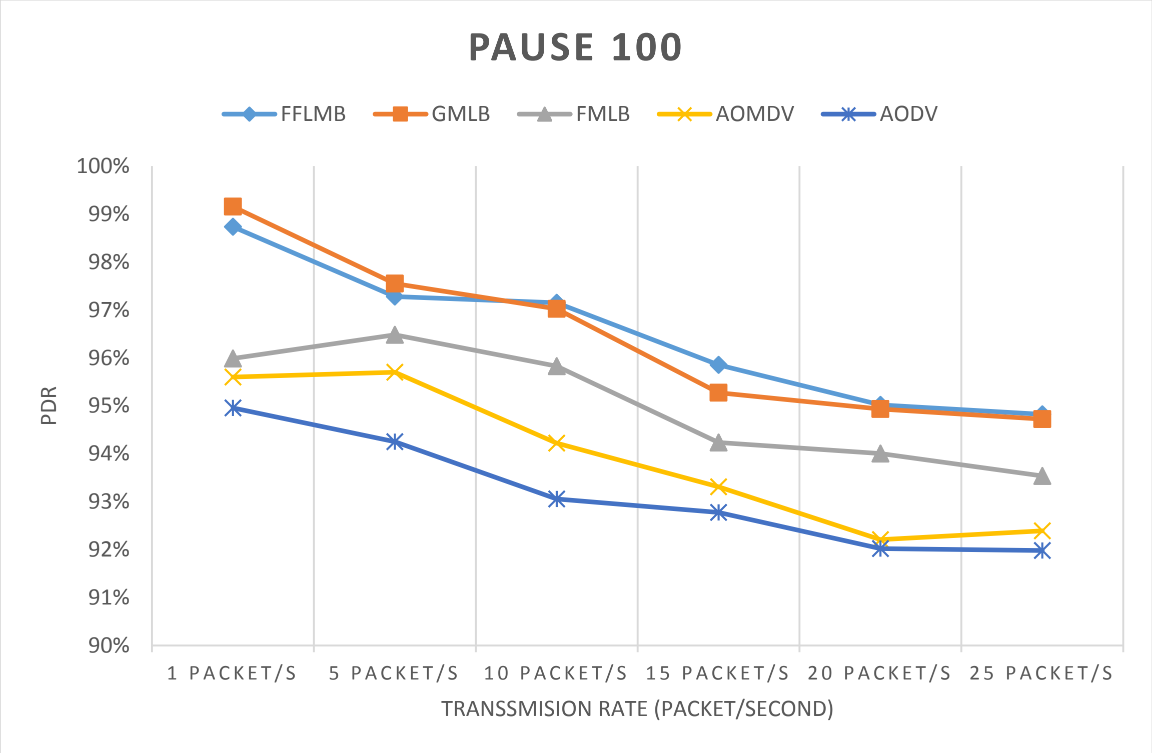
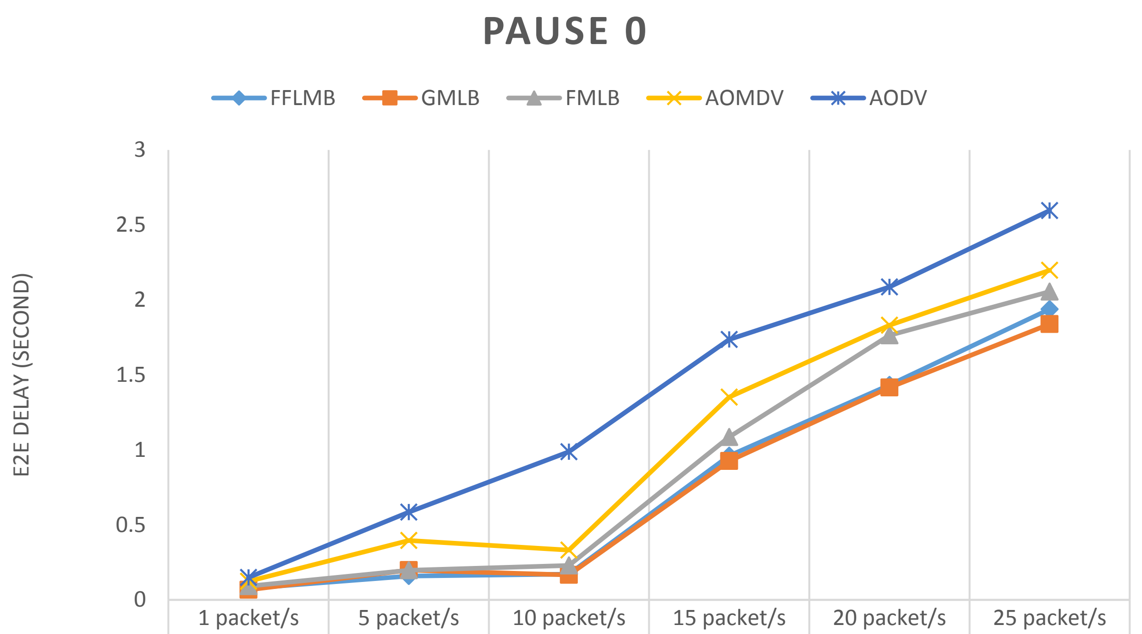


Figure 13: Packet Delivery Ratio vs. transmission rate with 100 second pause time

From figure 11 (mobility is high) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 0.7%, 1.9%, 3%, and 4.3% respectively, and from figure 12 (mobility is medium) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 0.8%, 2.5%, 4.5%, and 5.3% respectively, and from figure 13 (mobility is low) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 0.3%, 1.5%, 2.6%, and 3.4% respectively.

From figures 11, 12 and 13 observes that FFMLB outperforms (in total) GMLB, FMLB, AOMDV, and AODV with 0.6%, 2%, 3.4%, and 4.3% respectively. When the mobility is high the PDR in general is lower than other situation. And observe that the delivery ratio is decreasing when the transmission rate is increasing, because when the number of packets sent is increasing in each interval of time, it may cause congestion problem and may also increase the packet drop that means it decreases the ratio of data packet delivered by the destination. Also there researcher noticed that the FFMLB protocol outperforms the AODV protocol because, it uses multipath instead of single path, which means when one of these paths was broken, it converts to other one, which means it decrease the loss packet during an interval of time. Also FFMLB outperforms AOMDV because AOMDV packets handle larger header than other so it sends more than packets with the same size of data. Also FFMLB sends packets over each available path greater than GMLB, FMLB, AOMDV and AODV that's lead to more packets drop when transmission rate increase because that paths handles more packets which make the congestion is higher, sending more packets over each path may also cause more consuming batteries power which cause more link fail.

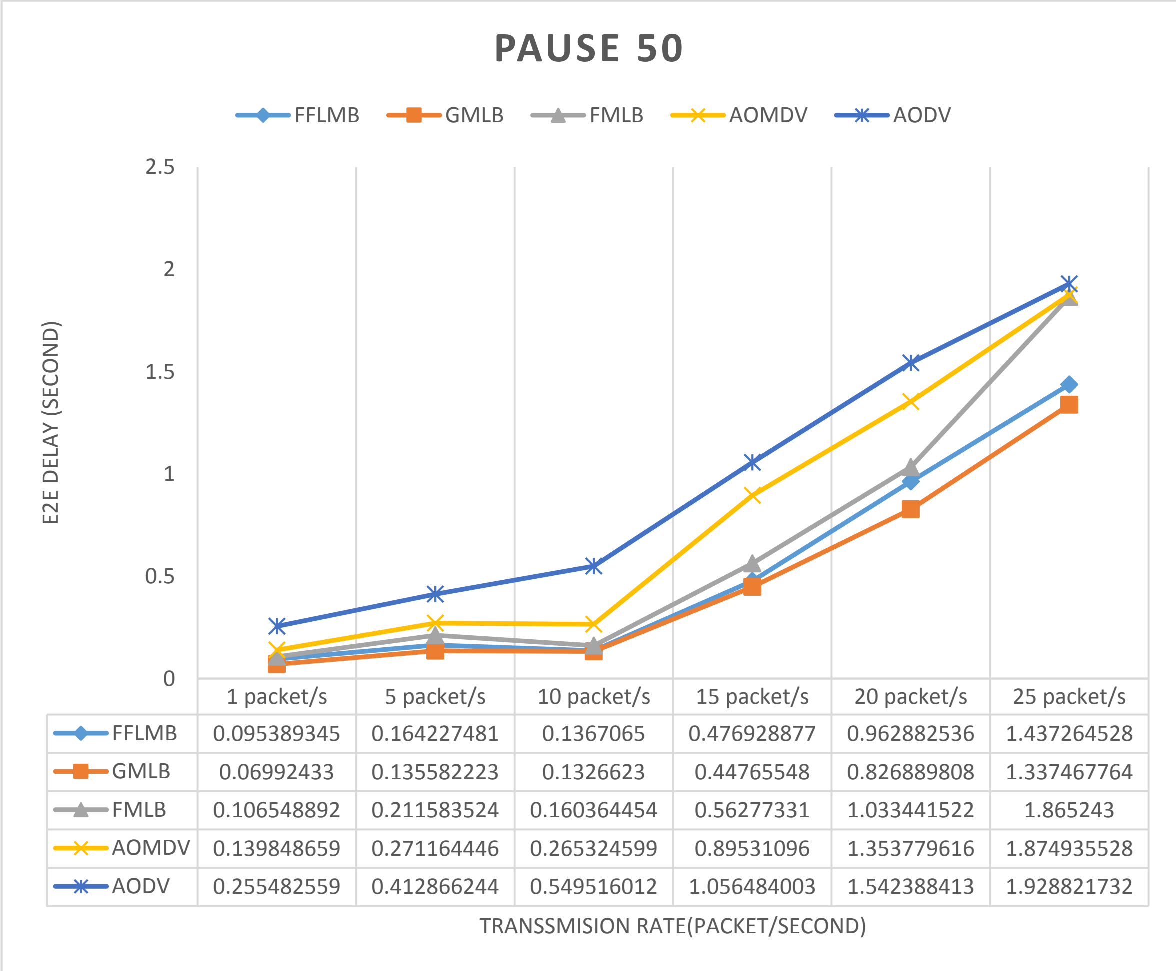
The other section in this scenario examining the End-to-End delay with varies Transmission rate with the same parameters in table 2, with different mobility, the results are shown in figures 14, 15 and 16:



	1 packet/s	5 packet/s	10 packet/s	15 packet/s	20 packet/s	25 packet/s
FFLMB	0.076237893	0.158336996	0.170937636	0.960238559	1.432762993	1.937264528
GMLB	0.066268735	0.197548325	0.16575903	0.925354535	1.41550047	1.838384524
FMLB	0.091245445	0.196758628	0.229083195	1.085181624	1.76352865	2.055235003
AOMDV	0.122537469	0.395096651	0.331518061	1.350709069	1.83100094	2.19676769
AODV	0.148839421	0.583876555	0.986715458	1.735586907	2.085535782	2.595271239

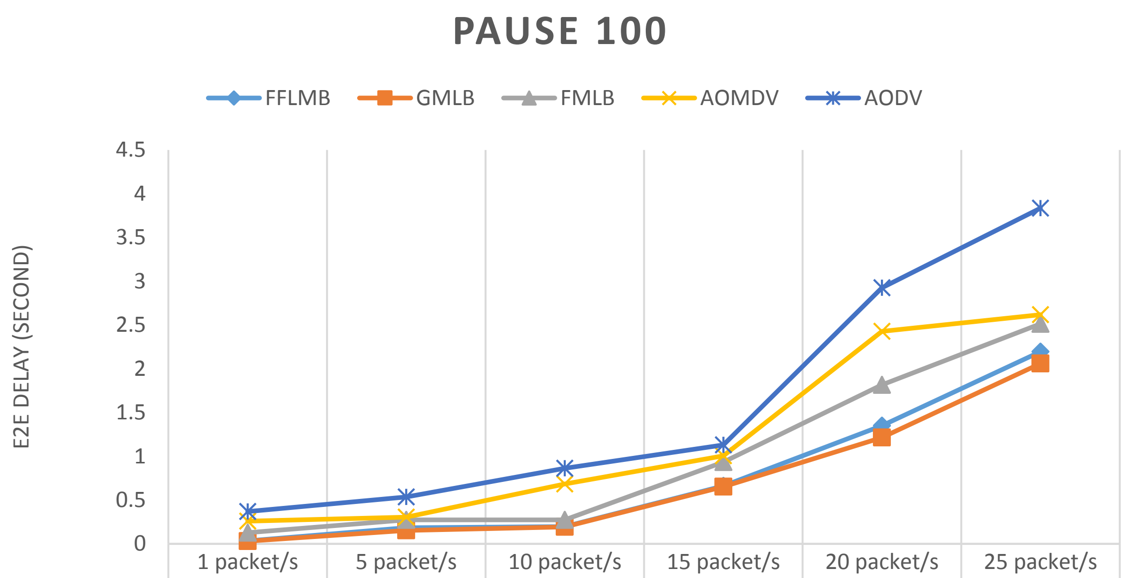
TRANSSMISION RATE(PACKET/SECOND)

Figure 14: End –to –end delay vs. transmission rate with 0 second pause time



	1 packet/s	5 packet/s	10 packet/s	15 packet/s	20 packet/s	25 packet/s
FFLMB	0.095389345	0.164227481	0.1367065	0.476928877	0.962882536	1.437264528
GMLB	0.06992433	0.135582223	0.1326623	0.44765548	0.826889808	1.337467764
FMLB	0.106548892	0.211583524	0.160364454	0.56277331	1.033441522	1.865243
AOMDV	0.139848659	0.271164446	0.265324599	0.89531096	1.353779616	1.874935528
AODV	0.255482559	0.412866244	0.549516012	1.056484003	1.542388413	1.928821732

Figure 15: End –to –end delay vs. transmission rate with 50 second pause time



	1 packet/s	5 packet/s	10 packet/s	15 packet/s	20 packet/s	25 packet/s
FFLMB	0.0329554	0.182353203	0.196176629	0.660255386	1.349264299	2.193726453
GMLB	0.0292318	0.152071138	0.19158864	0.652132817	1.212902642	2.058825625
FMLB	0.125559458	0.273369144	0.272287199	0.93356566	1.815280254	2.512982592
AOMDV	0.2584636	0.304142276	0.683177279	1.004265634	2.425805284	2.61765125
AODV	0.367304	0.533685347	0.861657251	1.128828718	2.923578151	3.833445741

Figure 16: End –to –end delay vs. transmission rate with 100 second pause time

From figure 14 (mobility is high) FFMLB outperforms FMLB, AOMDV, and AODV by 16%, 34%, and 50% respectively, but GLMB outperforms FFMLB by 1.5%, from figure 15 (mobility is medium) FFMLB outperforms FMLB, AOMDV, and AODV by 15%, 36%, and 52% respectively, but GLMB outperforms FFMLB by 3.1%, from figure 16 (mobility is low) FFMLB outperforms FMLB, AOMDV, and AODV by 33%, 48%, and 62% respectively, but GLMB outperforms FFMLB by 9%.

From figures 14, 15 and 16 observes that FFMLB outperforms (in total) FMLB, AOMDV, and AODV with 21%, 40%, and 55% respectively, but GLMB outperforms FFMLB by 8.5%.

From figures 14, 15 and 16 observing that the End –to –end delay increased when transmission rate increases. Because when the number of packet sent at an interval of time increases, it may cause congestion problem because there are more data injects on the network. It may also increase the broken link and the packet drop which means that need to reinitiate a discovery process to find a backup path instead of the recent one which increases the average End –to –end delay of the network. GLMB outperforms FFLMB because FFMLB sends more packets over each path which cause more link fail so increasing in delay. Also notice that FFLMB outperforms AODV and AOMDV because AODV depend on single path may fail and cause more packets drop, also AOMDV doesn't depend only of alternative paths when primary path fail, so it doesn't make a new discovery process until all link fail.

Scenario #2 (PDR and E2E delay with varied number of nodes and pause time)

In the delivery of data simulation number of nodes is varying between 20 - 40 nodes, the pause time is varied by to 0, 50 and 100 seconds and other parameter is stay default to show the performance of the routing protocols when the number of nodes is increased.

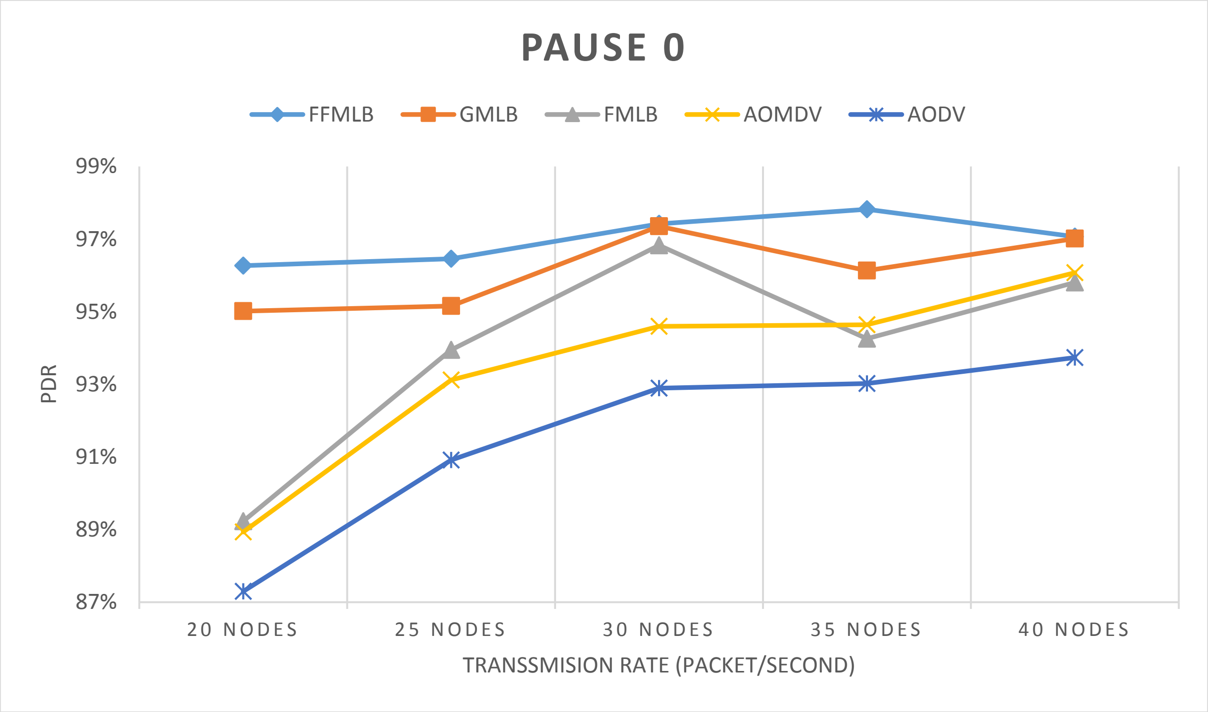


Figure 17: Delivery ratio vs. number of nodes with 0 second pause time

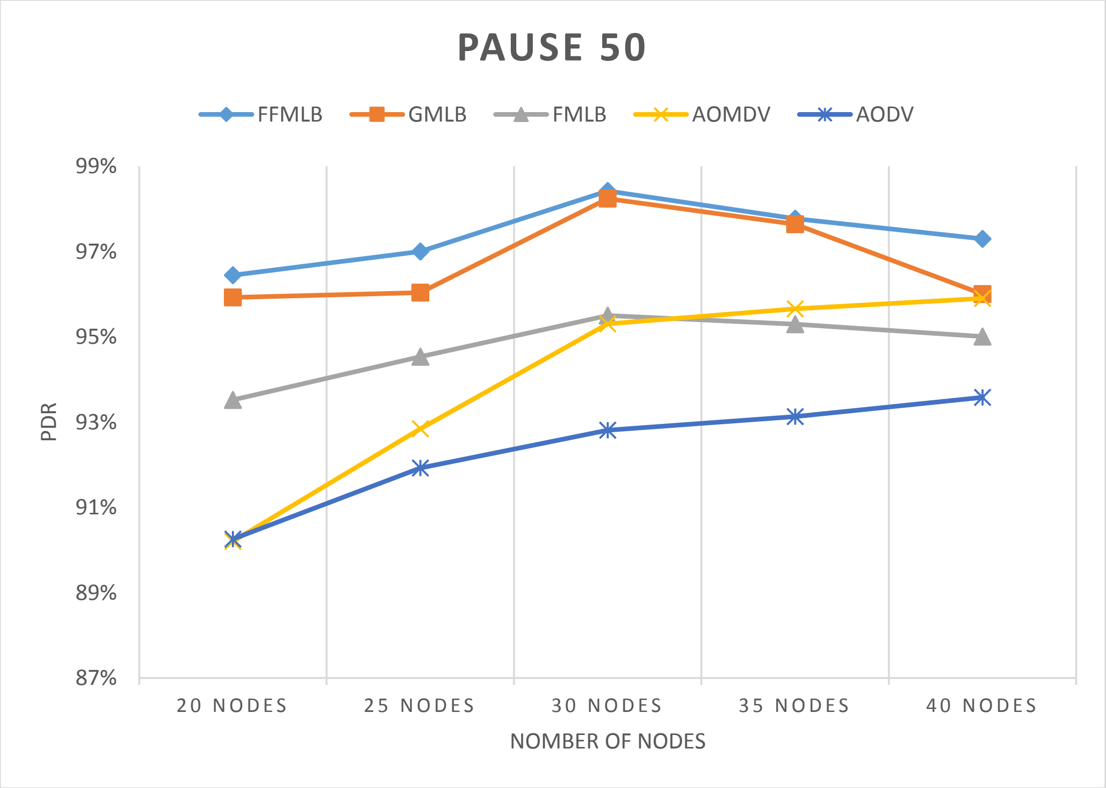


Figure 18: Delivery ratio vs. number of nodes with 50 seconds pause time

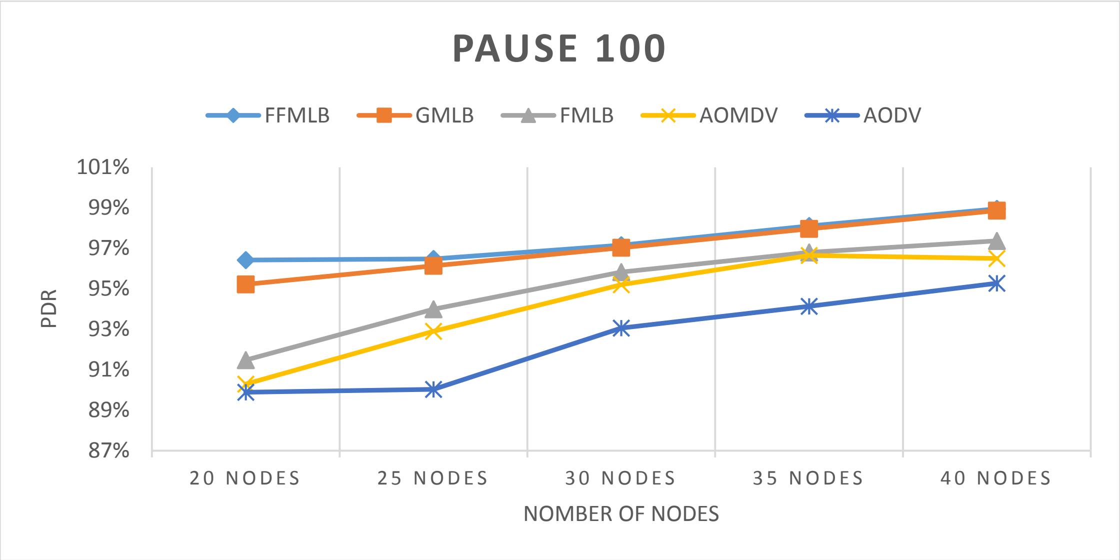


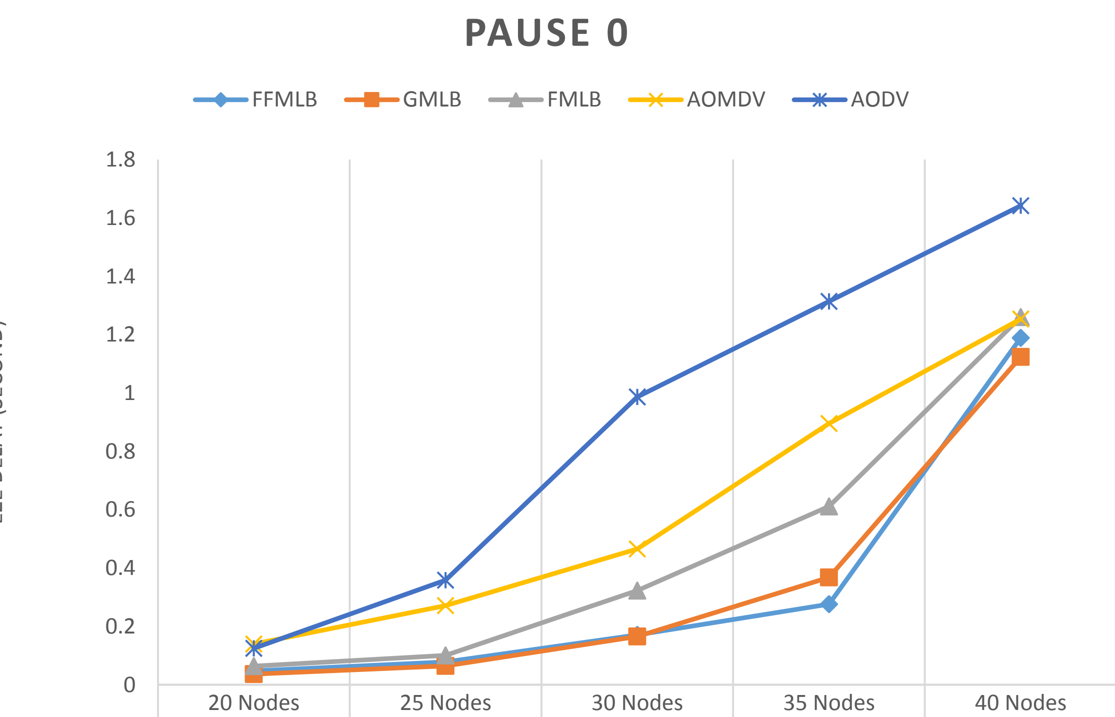
Figure 19: Delivery ratio vs. number of nodes with 100 second pause time

From figure 17 (mobility is high) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 0.9%, 3.0%, 3.6%, and 5.6% respectively, and from figure 18 (mobility is medium) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 0.6%, 2.6%, 3.5%, and 5.1% respectively, and from figure 19 (mobility is low) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 0.4%, 2.3%, 3.2%, and 5.0% respectively.

FFMLB outperforms (in total) GMLB, FMLB, AOMDV, and AODV with 0.7%, 2.8%, 3.5%, and 5.2% respectively.

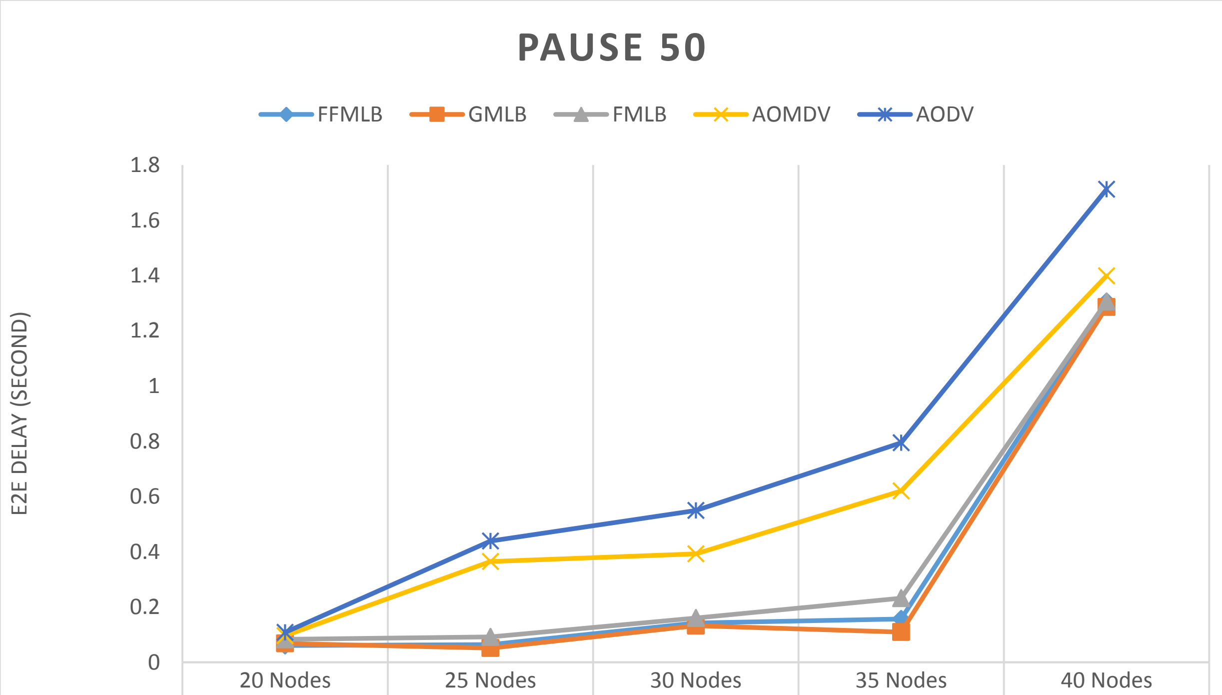
From figures 17, 18 and 19 observe that the delivery ratio is increasing when the number of nodes is increasing. Because when the number of nodes increases then it may find various short paths between large numbers of nodes, which means it sends many data packet easily with less of loss packets. FFLMB outperforms AODV because when number of nodes increase reliability of transmission increased too because increasing in multipath. AOMDV is designed for large scale networks so it is reliable for network with high number of nodes, notice that the performance of AOMDV are increasing due to increasing in nodes.

The other section in this scenario examining the End-to-End delay with varies number of nodes with the same parameters in table 2, with different mobility, the results are shown in figures 20, 21 and 22:



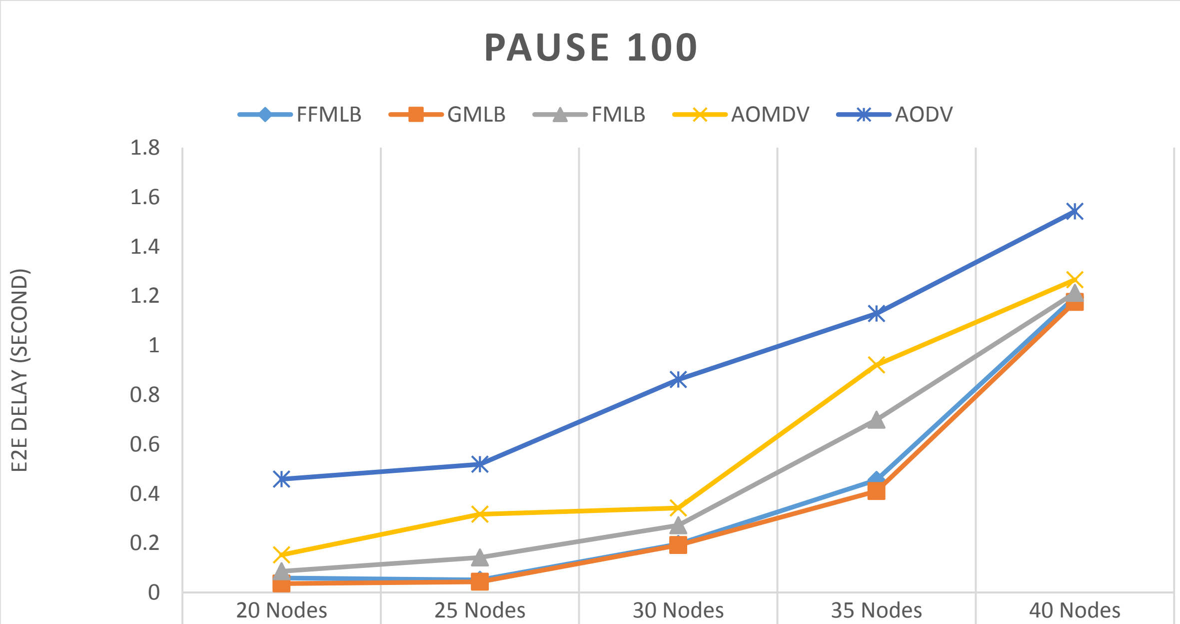
	20 Nodes	25 Nodes	30 Nodes	35 Nodes	40 Nodes
FFMLB	0.047411599	0.078466627	0.170937636	0.27635093	1.188712081
GMLB	0.0363818	0.064583508	0.16575903	0.367957605	1.123832718
FMLB	0.064183853	0.100712479	0.32290832	0.611605808	1.260318451
AOMDV	0.139848659	0.271164446	0.465324599	0.89531096	1.253779616
AODV	0.12467823	0.358452254	0.986715458	1.314077065	1.642258366

Figure 20: End –to –end delay vs. number of nodes with 0 second pause time



	20 Nodes	25 Nodes	30 Nodes	35 Nodes	40 Nodes
FFMLB	0.060619285	0.064198157	0.142095804	0.156785942	1.305693016
GMLB	0.068274	0.051403815	0.1326623	0.109273902	1.285846093
FMLB	0.083054198	0.092043534	0.160364454	0.232226634	1.30620603
AOMDV	0.0959108	0.364706406	0.392353257	0.620510771	1.398528599
AODV	0.107945236	0.43915435	0.549516012	0.794861713	1.712158903

Figure 21: End –to –end delay vs. number of nodes with 50 second pause time



	20 Nodes	25 Nodes	30 Nodes	35 Nodes	40 Nodes
FFMLB	0.058735911	0.050968034	0.196176629	0.455477278	1.195034137
GMLB	0.036076	0.043225311	0.19158864	0.410346859	1.175277324
FMLB	0.085998102	0.141664147	0.272287199	0.699168045	1.212307909
AOMDV	0.152475787	0.316673992	0.341875271	0.920477117	1.265525986
AODV	0.458455687	0.518951435	0.861657251	1.12888457	1.542358798

Figure 22: End –to –end delay vs. number of nodes with 100 second pause time

From figure 20 (mobility is high) FFMLB outperforms FMLB, AOMDV, and AODV by 31%, 55%, and 65% respectively, but GLMB outperforms FFMLB by 7%, from figure 21 (mobility is medium) FFMLB outperforms FMLB, AOMDV, and AODV by 20%, 53%, and 61% respectively, but GLMB outperforms FFMLB by 13%, from figure 22 (mobility is low) FFMLB outperforms FMLB, AOMDV, and AODV by 31%, 49%, and 67% respectively, but GLMB outperforms FFMLB by 19%.

From figures 20, 21 and 22 observes that FFMLB outperforms (in total) FMLB, AOMDV, and AODV with 27%, 52%, and 64% respectively, but GLMB outperforms FFMLB by 13.5%.

Observing that the End –to –end delay increased when the number of node increases. Because when the number of nodes increases, it increases the broken link while the node movement which needs to reinitiate new routs by discovery process that takes a lot of time. All of these reasons increase the average end – to – end delay of the network. Also observing that the FFMLB protocol outperforms the AODV protocol because it depends on multipath rather than a single path which means that all paths used to transmit the data packet simultaneously at an interval of time. GLMB outperforms FFLMB because FFLMB sends more packets over each available path that may causes more drop packets which need to retransmit so increasing end-to-end delay.

Scenario #3 (delivery ratio with varied network area and pause time)

Network area in this scenario are varied between 500*500 meters to 1500*1500 meters and other parameters are the same from table 2. Packet delivery ratio with network area simulation results shown in figures 23, 24 and 25.

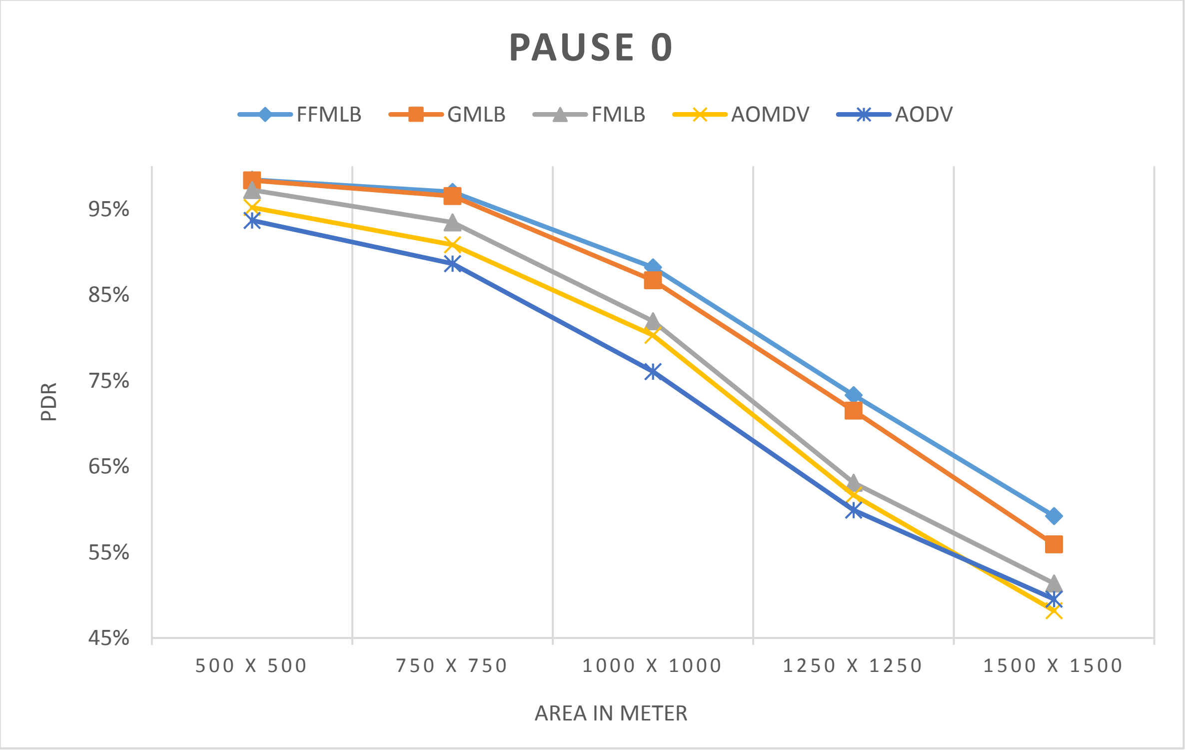


Figure 23: Delivery ratio vs. Area (in meter) with 0 second pause time

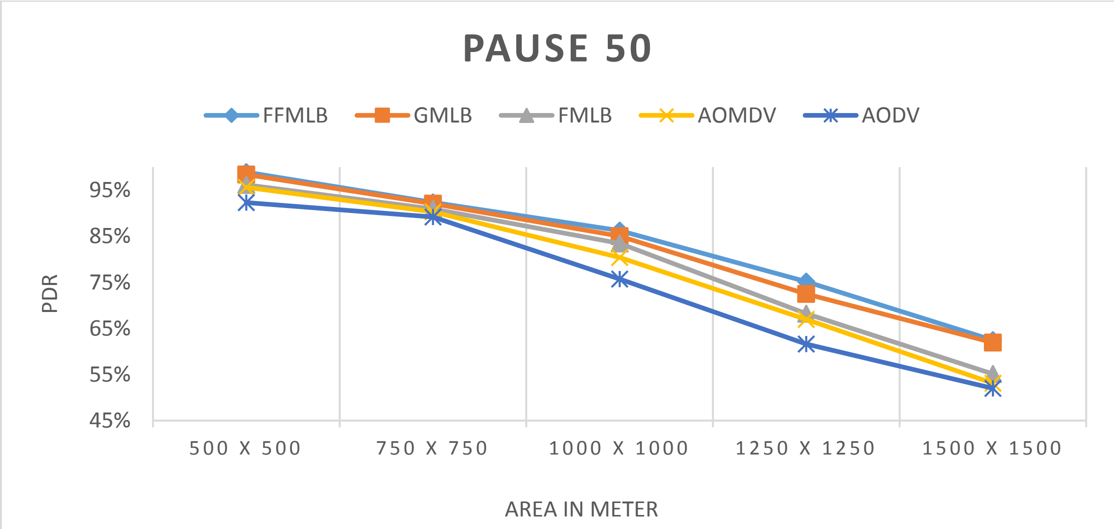


Figure 24: Delivery ratio vs. Area (in meter) with 50 seconds pause time

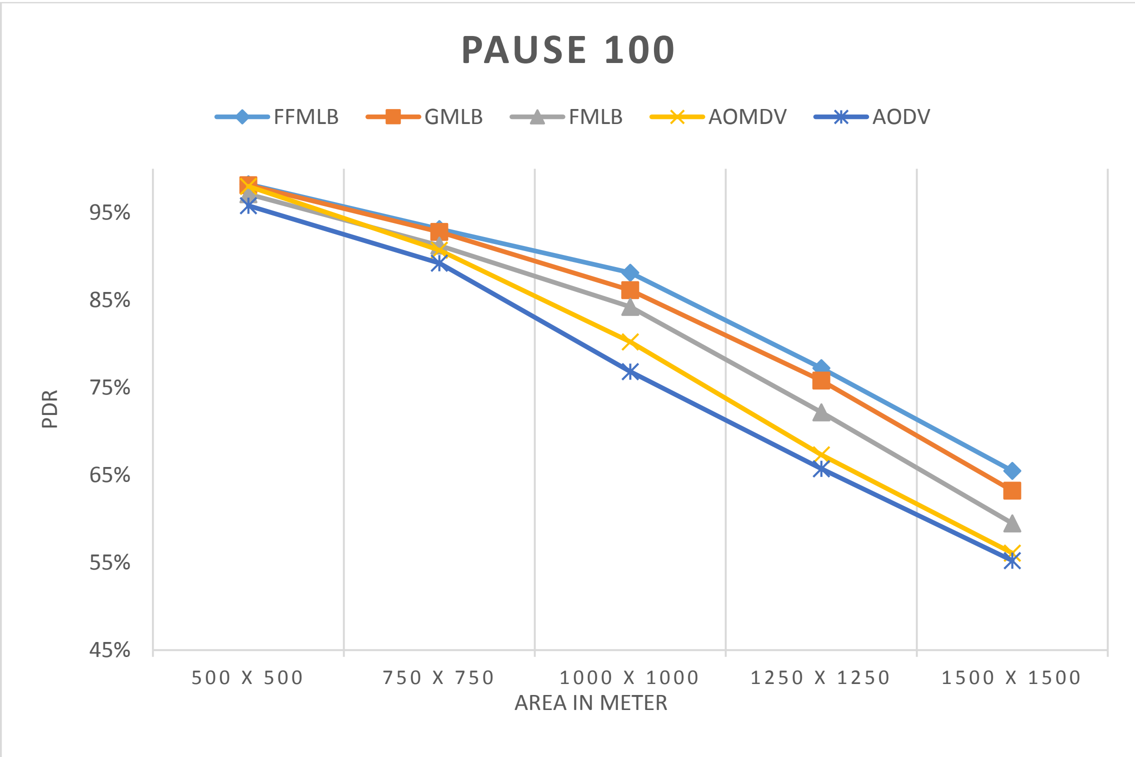


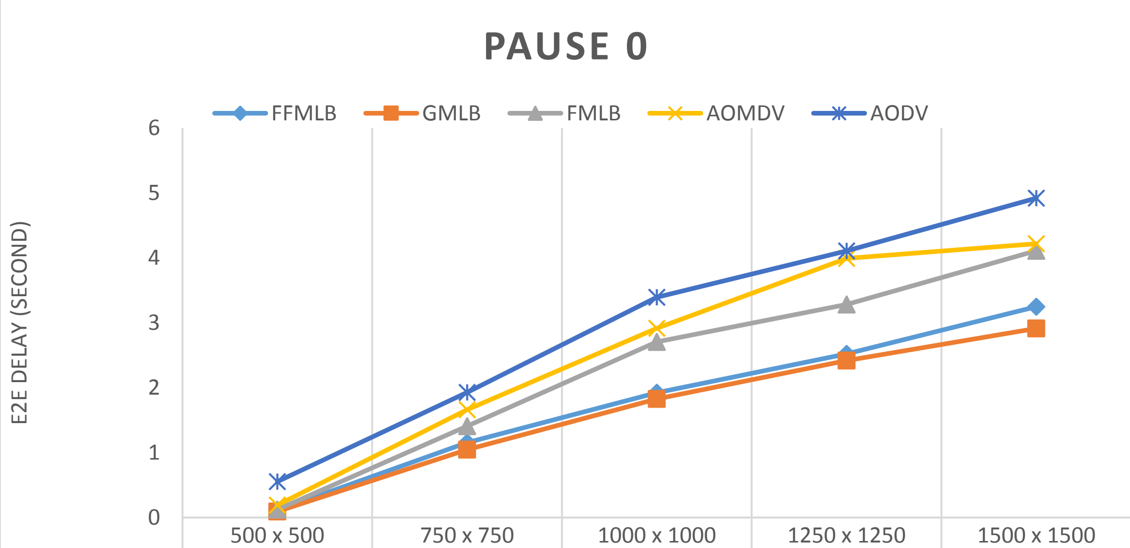
Figure 25: Delivery ratio vs. Area (in meter) with 100 seconds pause time

From figure 23 (mobility is high) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 2%, 8%, 12%, and 12.4% respectively, and from figure 24 (mobility is medium) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 1.3%, 5.6%, 7.5%, and 11.4% respectively, and from figure 25 (mobility is low) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 1.6%, 4.6%, 7.8%, and 10% respectively.

FFMLB outperforms (in total) GMLB, FMLB, AOMDV, and AODV with 1.7%, 6.0%, 9.1%, and 11.2% respectively.

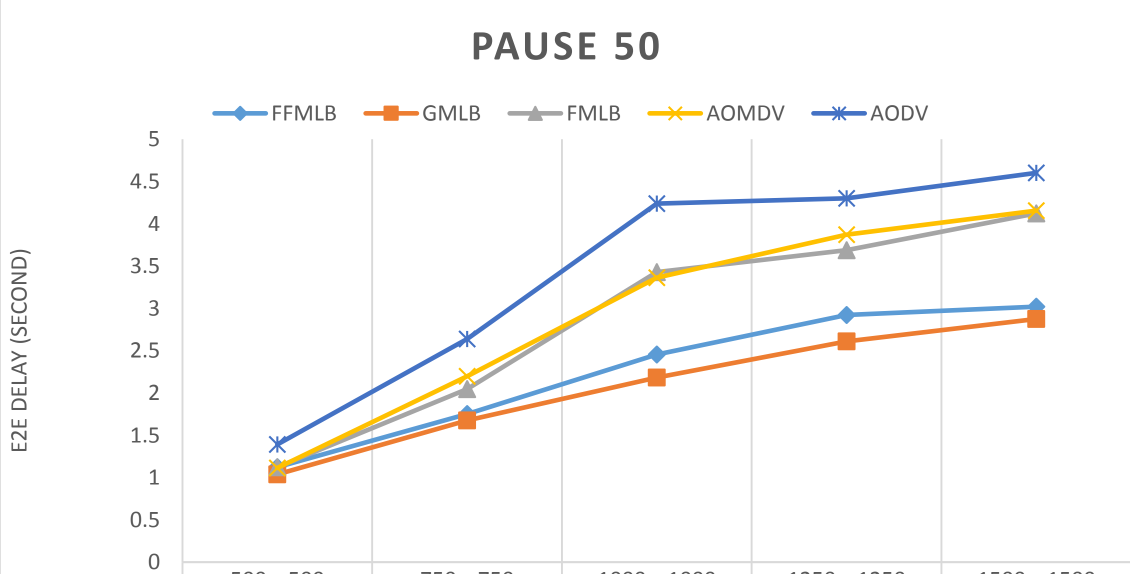
From figures 23, 24 and 25 notice that the delivery ratio decreases when the network area increases. Because of sparse network the numbers of neighbors nodes decrease due to the lack of overall connectivity at long routes which degrade the performance of the network. Also when the area increased the links become weaker and can easily fail. Also the possibility of direct connection between source and destination decrease.

The other section in this scenario examining the End-to-End delay with varies network area with the same parameters in table 2, with different mobility, the results are shown in figures 26, 27 and 28:



	500 x 500	750 x 750	1000 x 1000	1250 x 1250	1500 x 1500
FFMLB	0.109932756	1.154287392	1.922548832	2.5221832	3.2465822
GMLB	0.092242945	1.045794783	1.825361701	2.417245693	2.9124142
FMLB	0.121577312	1.408283491	2.70528525	3.282648202	4.109203572
AOMDV	0.191485472	1.660004395	2.915125163	3.991122863	4.219315592
AODV	0.5524059	1.926382459	3.394284259	4.108254263	4.9210065

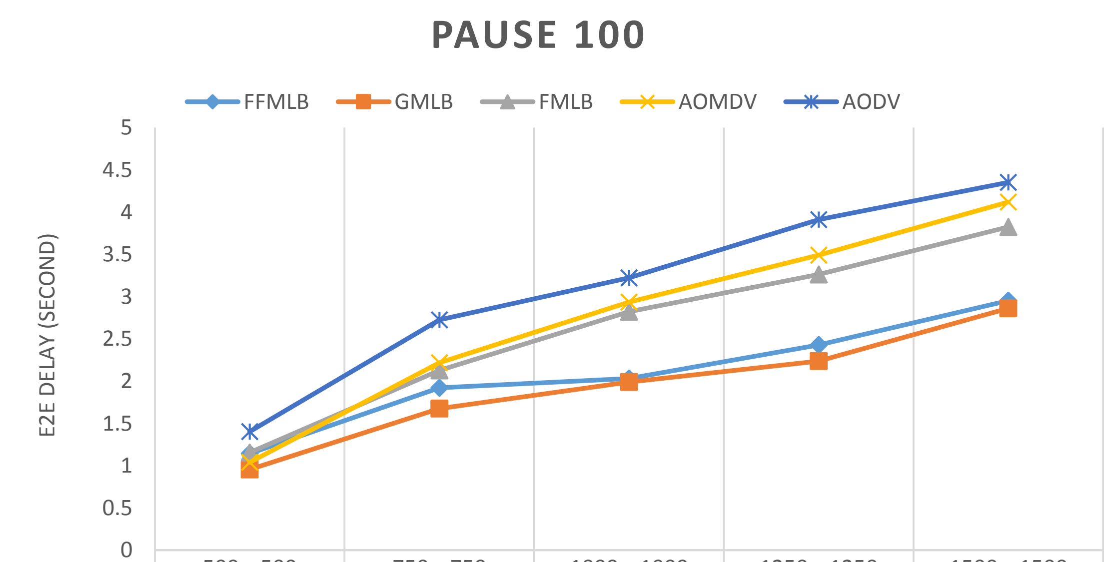
Figure 26: End –to –end delay vs. Area (in meter) with 0 second pause time



	500 x 500	750 x 750	1000 x 1000	1250 x 1250	1500 x 1500
FFMLB	1.12359953	1.75233526	2.45532365	2.921885222	3.02152872
GMLB	1.03902	1.676722087	2.182259173	2.61068965	2.8747261
FMLB	1.122513373	2.0459879	3.428702123	3.688232921	4.123425744
AOMDV	1.114467214	2.197072977	3.3640478	3.872314652	4.155459043
AODV	1.392548322	2.638809	4.238885763	4.302528276	4.60156535

AREA IN METER

Figure 27: End –to –end delay vs. Area (in meter) with 50 second pause time



	500 x 500	750 x 750	1000 x 1000	1250 x 1250	1500 x 1500
FFMLB	1.144522358	1.922546282	2.03123548	2.42862512	2.952878725
GMLB	0.955239857	1.67672132	1.990281243	2.238628907	2.86148259
FMLB	1.155520317	2.12864207	2.822557712	3.262594784	3.825642377
AOMDV	1.03954648	2.218823844	2.935411954	3.492306463	4.119117159
AODV	1.402739963	2.725428467	3.222593242	3.912652874	4.352877412

AREA IN METER

Figure 28: End –to –end delay vs. Area (in meter) with 100 second pause time

From figure 26 (mobility is high) FFMLB outperforms FMLB, AOMDV, and AODV by 20%, 33%, and 47% respectively, but GLMB outperforms FFMLB by 11%, from figure 27 (mobility is medium) FFMLB outperforms FMLB, AOMDV, and AODV by 18%, 19%, and 32% respectively, but GLMB outperforms FFMLB by 8%, from figure 28 (mobility is low) FFMLB outperforms FMLB, AOMDV, and AODV by 16%, 19%, and 30% respectively, but GLMB outperforms FFMLB by 9%.

From figures 26, 27 and 28 observes that FFMLB outperforms (in total) FMLB, AOMDV, and AODV with 18%, 23%, and 36% respectively, but GLMB outperforms FFMLB by 9.4%.

Notice that the End –to –end delay increased when the network area increases. Because of sparse network requires more time of the discovery process, propagation time and packet processing. GMLB has shortest end – to – end delay, because it sends data packet over each path less than FFLMB so the load on paths in GLMB are less than the load on paths in FFLMB. Also when the paths between source and destination become weak when the area increase because the distance between nodes so that's lead to more dropped packets which mean delay increased.

Scenario #4 (PDR and E2E delay with transmission range)

Transmission range is the area that the node can directly communicate with other node. The area here is 60X60 meters and transmission range are varies 10 to 25, other parameters are the same in table 2. The figure 29 shows PDR with different transmission range.

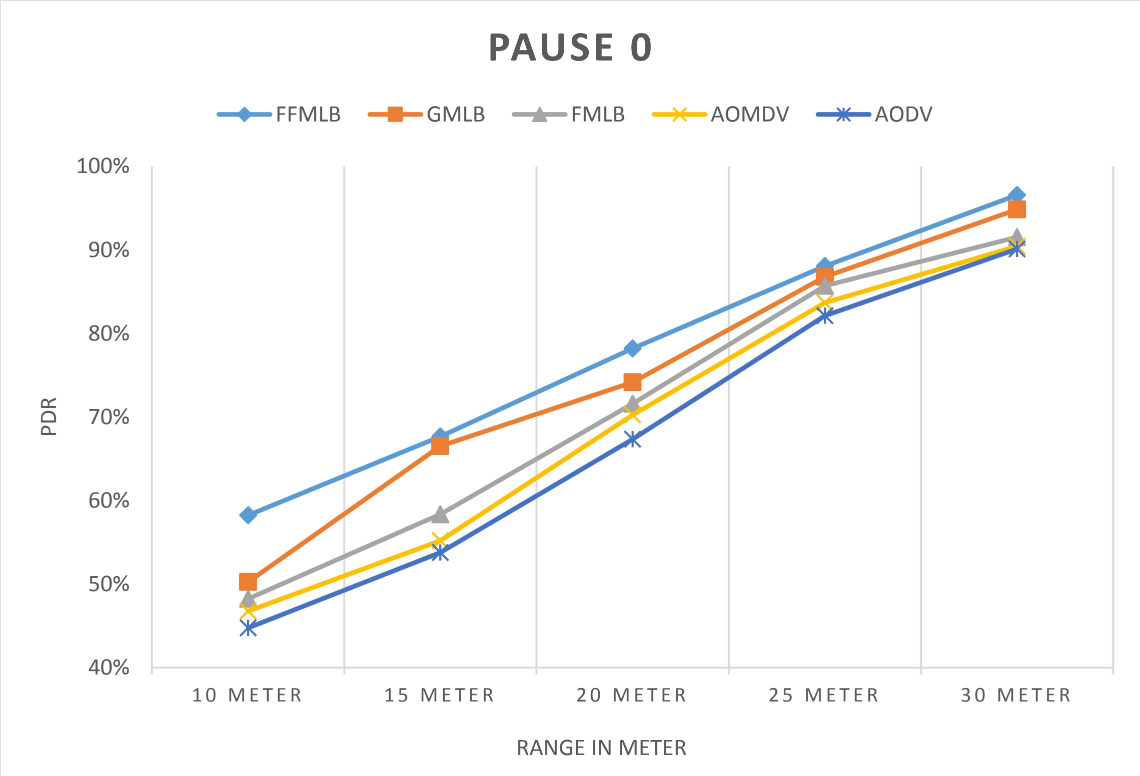
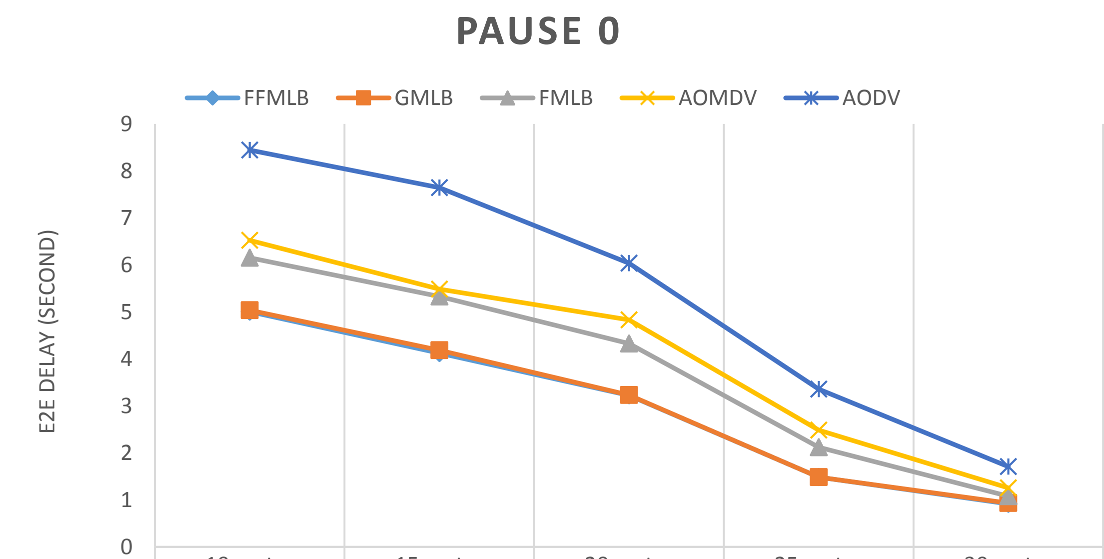


Figure 29: Delivery ratio vs. transmission rate with 0 second pause time

From figure 29 (mobility is high) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 4.7%, 9%, 12%, and 14% respectively.

Notice that the delivery ratio increased when the transmission range increases. Because of sparse network the numbers of neighbors nodes increase due to the high of overall connectivity at long routes which increase the performance of the network. Increasing transmission range mean more reliable network because the number of paths increase.



	10 meter	15 meter	20 meter	25 meter	30 meter
FFMLB	5.003954648	4.121882384	3.223541195	1.481923065	0.911911716
GMLB	5.03507816	4.182485365	3.229906367	1.482559381	0.928905548
FMLB	6.15067135	5.328042972	4.326744639	2.120278792	1.078336305
AOMDV	6.523320351	5.482485365	4.829906367	2.482559381	1.25548317
AODV	8.4407648	7.640422416	6.033988702	3.354594462	1.708293781

RANGE IN METER

Figure 30: End –to –end delay vs. Transmission range with 0 second pause time

From figure 30 (mobility is high) FFMLB outperforms GMLB, FMLB, AOMDV, and AODV with 0.7%, 1.9%, 3%, and 4.3% respectively.

Notice that the End –to –end delay decreased when the transmission range increases. Because of sparse network requires less time of the discovery process, propagation time and packet processing.

4.6 Summary

The results of simulation shows that when transmission rate increase PDR decreased because the number of dropped packet increased and that lead to increase delay as well. Increasing number of nodes in network make the network more reliable because the number of paths increased. When the area of the network is big, the PDR decreased because of weak paths between nodes. The result indicated that FFMLB outperforms the GMLB, FMLB, AOMDV and AODV protocols in a number of nodes, area, and transmission range and offered load balancing. It increased the packet delivery ratio. This is because of the distributed process of the data packets along multiple paths and these paths transmit the data packets simultaneously at a specific interval of time and FFMLB has higher packets delivery ratio. But GMLB outperforms FFLMB in minimizing the average end–to–end delay, because FFLMB sends higher number of packets over each available paths which lead to more drop packet than GMLB.

Chapter Five
Conclusion and Future Works

This chapter concluded the aim of thesis and some future works.

5.1 Conclusions

Routing is one of the most challenging issues in ad hoc networks. In this thesis, a new scheme is proposed for reactive routing protocol to decrease the effect of the congestion problem and to discover multiple paths between source and destination pair to maximize the throughput (delivery of data packet) of the network and minimize the average delay. Faulhaber's Formula Multipath Load Balance Routing protocol (FFMLB) allows saving multiple path in routing table of nodes in order to transmit the data packet along these paths at an interval of time. All paths sorted depend on the number of hops as a decreasing order and then each path assigns with weight according to the Faulhaber's formula series which means that the shortest path takes the high weight of data packet. In the other hand the longest path takes the low weight of data packet.

In our simulation, the researcher implemented our FFMLB protocol and compared with GMLB, FMLB, AOMDV and AODV protocols to measure the improvements. The result indicated that FFMLB outperforms the GMLB, FMLB, AOMDV and AODV protocols in a number of nodes, area and offered load balancing. It increased the packet delivery ratio. But GMLB out outperforms FFLMB in minimizing the average end–to–end delay. This is because of the distributed process of the data packets along multiple paths and these paths transmit the data packets simultaneously at a specific interval of time and FFMLB has higher packets delivery ratio. The congestion problem is reduced because the load is distributed along multiple paths rather than a single path. The results show that FFMLB is feasible and efficient to improve the reactive protocol for ad hoc network.

Future Work

This thesis depends on hop count as selection metric. However, the shortest path may be chosen depending on other metrics like the round trip time which means the time needed for the RREQ packet to leave the source until the RREP packet comes back to the same source from desired destination. Alternative paths may be selected based on node mobility. In this case, preference should be given to choosing slow moving nodes means the nodes which have a long pause time are more preferable to participate in the discovery process to find a more stable route. Not only the mobility but also another factor can be used to check if the node is in the congestion state or not, such as the wireless link quality, remaining power capacity and node's density. Studying the lifetime and the power consumption of the network in FFMLB scheme and comparing the result with the AODV protocol are also recommended.

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Appendix

Appendix A: List of Abbreviations

AODV	Ad hoc On demand Distance Vector
AP	Access Point
BS	Base Station
CBR	Constant Bit Rate
CW	Contention Window
DNB	Dynamic Neighbors Based
DSDV	Destination Sequenced Distance Vector Routing
DSR	Dynamic Source Routing
DV	Distance Vector
FMLB	Fibonacci Multiple Load Balance Protocol
Gbps	Giga bit per second
GloMoSim	Global Mobile information system Simulator
GMLB	Geometric Multiple Load Balance Protocol
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
LS	Link State
MAC	Medium Access Control
MANET	Mobile ad hoc NETwork

OSI	Open Systems Interconnection
PARSEC	Parallel Simulation Environment for Complex System
PDA	Personal Digital Assistant
PDR	Packet Delivery Ratio
PR	Packet Received
PS	Packet Sent
RERR	Route ERRor
RREP	Route REPly
RREQ	Route REQuest
RWP	Random WayPoint
TTL	Time-To-Live
UDP	User Datagram Protocol
VANET	Vehicular Ad hoc NETwork
ZRP	Zone Routing Protocol