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Failure History-based Routing Protocol for Mobile Ad Hoc Networks.

بروتوكول التوجيه القائم على الأحداث الفاشلة السابقة للشبكات المخصصة المتنقلة

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Dedication

To my mother (my heart) and my father, May Allah give them more health and wellness.

To my brothers and sisters, my beloved husband, who stood beside me. To my princess “Aram and Mayyar” and my colleagues & friends who helped and supported me.

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Failure History-based Routing Protocol for Mobile Ad Hoc Networks

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Abstract

Mobile Ad-hoc NETworks (MANETs) are defined as a collection of mobile nodes that cooperate in order to operate. Nodes in MANETs should build and maintain routes in order to communicate. A routing algorithm is used to manage these routes. MANETs have dynamic topology because of node mobility. The probability of route failure increases when intermediate nodes have higher mobility.

In this study we propose a Failure History-Based Routing (FHBR) protocol that depends on the failure history of the nodes from which the route will constructed. The proposed protocol will be implemented over the existing Ad hoc On-Demand Distance Vector (AODV) routing protocol.

FHBR selects the best route by building a path constructed from number of nodes that have a better history of forwarding packets than other nodes. To estimate the history of a node we use a metric called Failure History Factor (FHF) which represents the ratio between successfully

forwarded packets and the total received packets in the node. We modified the route request phase and route reply phase in the original AODV protocol to use our factor in selecting best route between nodes

The proposed protocol was implemented using NS2.35 simulator, and we conduct many simulation scenarios to compare the performance between our protocol and AODV protocol. The scenarios were built to measure the performance over small networks against large ones and heavy-loaded networks against light-loaded ones.

The results show that FHBR outperforms AODV in terms of packet delivery ratio and average end-to-end delay. The improvement was significantly appeared in a heavy loaded networks more than lightly loaded networks. FHBR do not selects

the shortest path between source and destination. It always search for a stable nodes to construct the route.

The results also show that when we increase queue length in the nodes the packet delivery ratio increases and average end-to-end delay decreases. A higher queue length size gives a less number of dropped packets and then a higher packet delivery ratio and lower average end-to-end delay.

Key Words: MANET, Routing, AODV.

بروتوكول التوجيه القائم على الأحداث الفاشلة السابقة للشبكات المخصصة المتنقلة

رسالة ماجستير قُدمت من قبل
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ملخص

تعرف الشبكات المخصصة المتنقلة على أنها شبكات لاسلكية تتكون من مجموعة من العقد المتحركة التي تتعاون في ما بينها لتشغيل الشبكة. ولكي تتواصل هذه العقد مع بعضها البعض فلا بد من أن تقوم ببناء مسارات تراسل في ما بين المرسل والمستقبل. تتميز الشبكات المخصصة المتنقلة في أن توزيع العقد غير ثابت بسبب الحركة الدائمة للعقد. تزداد احتمالية فشل التراسل بازدياد حركة العقد الوسطية.

في البحث تم اقتراح بروتوكول توجيه تقوم على اختيار المسارات اعتماداً على الأحداث الفاشلة السابقة للعقد الوسطية. تم تمثيل البروتوكول المقترحة بتعديل بعض الخصائص في خوارزمية AODV.

يقوم البروتوكول المقترح ببناء المسارات بين العقد من مجموعة العقد الوسطية التي لها تاريخ أفضل بناءاً على الأحداث الفاشلة السابقة في تمرير الحزم. لكل عقدة في الشبكة معامل يمثل النسبة بين الحزم التي تم تمريرها بنجاح ومجموع الحزم التي تم استلامها في العقدة.

لقياس الأداء تم إجراء محاكاة مكثفة للبروتوكول باستخدام محاكي الشبكة NS2.35 ومقارنة الأداء بناءاً على نسبة تسليم الرزم ومعدل زمن التأخير. تم بناء التجارب لقياس الأداء في الشبكات الصغيرة والكبيرة وبأحمال خفيفة وثقيلة. أظهرت النتائج أن البروتوكول المقترح قدم تحسين في نسبة تسليم الحزم وزمن التأخير مقارنة مع أداء خوارزمية AODV.

Chapter 1 Introduction

1.1 MANET limitations

The main property of a MANET is that it does not need any type of infrastructure to operate (Bamrah, 2016), (Bouhorma, 2009). There are many limitations on MANET operations. The following are the main limitations (Toh, 2002):

1. Transmission Range

Each node has a limited transmission range. Nodes can directly send and receive messages to and from other nodes that lie within the transmission node. If the destination node lies outside the transmission range, then the message should be sent through one or more intermediate nodes.

2. Physical Topology

Nodes in a MANET are free to move in any direction, so that this causes continuous changes in network topology (Kumar, 2015).

3. Energy

The nodes are powered using batteries. Energy should be taken in account when designing a MANET because it can be consumed rapidly.

4. Infrastructure

A MANET has no infrastructure, and there is no central administration. Each node in a MANET should be able to operate as a host and as a router.

1.2 MANET Routing

Messages exchanged between far away nodes are sent using a routing algorithm that is used by each intermediate node to determine the path that the message should take to reach the destination node. The routing algorithm has one or more metrics to select the best routing path. There are mainly two types of routing protocol used in MANETs (Jadeja, 2013).

1. Proactive Routing

In this type of routing, each node has routing information stored in a routing table (Toh, 2002). Each node selects the next hop according to what is stored in the history table. This type of routing is used in may protocols such as Sequence Distance-Vector Routing (DSDV) (Perkins, 1994).

2. Reactive Routing

In this type of routing, there is no need to store any routing information a priori, because the routes between nodes are discovered only when needed (Murthy, 1996). Any node that needs to send a message to another node first sends a request message to discover a route to the destination node. When a reply is received, the source uses the discovered route and starts sending messages. Reactive routing is used in many routing protocols, such as the Ad hoc On-Demand Distance Vector (AODV) routing protocol (Perkins, 1999).

1.3 Ad-hoc On-demand Distance Vector (AODV) Routing Protocol

AODV is the most known reactive routing protocol that uses the shortest path between source and destination. Its consists of the following phases:

1. Route Discovery Phase

In this phase any node can find a valid route to any other node by broadcasting a route request (RREQ) to all of its neighbors. Each RREQ has a unique sequence number to prevent dealing with duplicate requests. Other important information was included in RREQ packet such as: destination ID, source ID, and time to live (TTL).

Any intermediate node receives RREQ checks sequence number field to prevent forwarding duplicate. Then it checks if there is a valid route to the destination to send a Route Reply (RREP) packet to the source, or to rebroadcast the RREQ packet to all of its neighbors. The RREQ will keep traveling until it reaches the destination itself or a node that has a valid route. In both cases RREP will travel back to the source telling that a valid route was discovered. Each time RREQ was forwarded the TTL is decremented by one to prevent RREQ from being travel in a loop (Liu, 2017).

2. Route Maintenance Phase

This phase of AODV is responsible of detecting any link failure by listening a periodic hello messages from neighbors. When a link failure detected, a route error (RERR) packet should be sent to notify all node that a failure was detected and a new RREQ should sent again.

1.4 Motivation

Most of existing routing algorithms in MANET concentrate on finding the shortest path between source and destination, without giving an importance to the routing reliability. Our proposed protocol uses history information to select the best route rather than the distance between source and destination.

Our contribution will be introducing a reliable routing protocol to address the routing problem in MANETs and improve the packet delivery ratio. We will implement our protocol by modifying exciting AODV protocol and compare their performance using many simulation scenarios according to different mobility patterns. We will design and run our simulation using NS2.35 simulator.

1.5 Objectives

The purpose of this study is to propose a new routing protocol for MANETs that selects the route between nodes according to failure history and achieves the following objectives:

- Reduce the congestion in the network.
- Increase the packet delivery ratio in the network.
- Reduce average end to end delay.

Chapter 2 Related Work

Many protocols were proposed to address routing process between nodes in MANETs Most of these algorithms use some metric to select best roué such as shortest path and least congested nodes. We will discuss some of these protocols

2.1 Associativity-Based Routing Protocol. (Toh, 2002)

The Associativity-Based Routing (ABR) protocol uses node stability as the main metric in selecting the best path. ABR is a reactive protocol that searches for a route only when a source needs to find a route to a destination. ABR uses an associativity-based scheme in which a route is constructed from nodes that have an associativity state with their neighbors that guarantees stability. Thus, ABR selects routes that are likely to be long-lived. ABR measures node stability by the node's association with its

neighbors. ABR finds all the possible routes from source to destination, and then selects the best path according to the selection criteria. The disadvantage of ABR is that it does not consider node congestion in the route selecting process; this may lead to using a route with congested nodes.

2.2 Signal Stability-Based Adaptive Routing Protocol. (Dube, 1997)

The Signal Stability-Based Adaptive (SSA) routing protocol is another on-demand protocol that proposed to perform route discovery by selecting the longest-lived path between source and destination. SSA selects the best route by including signal strength and node location stability. This protocol ranks the channels as strong and weak according to their average signal strength between the two ends of the channel. The node location stability is used by SSA so as to choose the longest-lived route. By considering these two criteria, SSA always chooses strong channels that have existed for a period of time that is greater than some threshold value identified by the protocol. In SSA, the source broadcasts the RREQ packet to all of its neighbors. When any intermediate node receives the request packet, it rebroadcasts it only if it was received over a strong channel. The destination chooses the route of the first arriving request because it is probably shorter and less congested, and sends a reply message that contains the best route. The main disadvantage of SSA is that it works fine only when there are a significant number of strong routes between source and destination.

2.3 Stable Weight-based On-demand Routing Protocol (SWORP) (Wang, 2007)

SWORP is another reactive protocol that searches for the most stable route between the source and destination. It uses a weight parameter to measure the stability level of a node. The weight factor depends on three factors. The first one is route expiration time, the second factor is the number of dropped packets, and the third one is number of hops.

2.4 History Based Routing Protocol for Opportunistic Networks (HIBOP) (Boldrini, 2007)

HIBOP is used for managing and using context-based routing framework for opportunistic networks for taking forwarding decisions. This model completely breaks the main assumptions on which MANET routing protocols are built.

Routing in opportunistic networks is usually based on some form of controlled flooding. But, often this results in very high resource consumption and network congestion. HIBOP is able to dramatically reduce resource consumption and reduce the message loss rate, and preserve the performance in terms of end to end delay.

2.5 A Centrality-Based History Prediction Routing Protocol for Opportunistic Networks (CHBPR) (Bamrah, 2016)

Due to high mobility, short radio range, intermittent links, unstable topology and sparse connectivity, routing in opportunistic networks is a very challenging task since it relies on cooperation between the nodes, using the concept of central nodes that are more likely to act as communication hubs to facilitate message forwarding and thereby routing, A node with the highest centrality value (so-called central node) is a node that has the capability to connect more often to other nodes in the network, and thereby is more likely to be a part of the constructed routing paths.

CHBPR inherits the same data structures and initialization settings utilized in HBPR, In addition, each node maintains a new data structure, called the centrality table, which records its home location, the number of neighbor nodes it has, and the centrality values of all nodes it has encountered so far. The CHBPR scheme is meant to reinforce the message forwarding part of HBPR.

CHBPR significantly outperforms HBPR and C-Epidemic (Epidemic protocol with the same centrality concept used in HBPR embedded in it) in terms of message delivered and overhead ratio under varying numbers of nodes, and time-to-live (TTL).

2.6 Dynamic Load-Aware Routing protocol (Lee, 2001)

Lee and Gerla proposed the Dynamic Load-Aware Routing (DLAR) protocol in 2001. DLAR is a reactive protocol that uses the routing loads of nodes as the main metric to select the best path. In this protocol, the highly loaded nodes are prevented from participating in the routes. The load of a node is measured by the number of packets buffered in its interface queue. This protocol selects always the more stable path, and reduces end-to-end delay. DLAR also controls the congestion states of the active routes and reconstructs them when any node in the path reaches its maximum queue capacity. In DLAR, the source broadcasts a request packet to find a route to the destination, and each intermediate node appends its load and broadcasts the packet again. The receiver can select the best path according to the loads of the intermediate nodes. It selects the path with the lowest aggregate load. The main disadvantage of DLAR is that it has a large overhead caused by the request flooding process in which each intermediate node appends extra information before rebroadcasting the request.

2.7 Congestion Adaptive Routing Protocol (Tran, 2006)

The Congestion adaptive Routing Protocol (CRP) is an adaptive routing protocol that tries to avoid congestion rather than dealing with it reactively. The main idea in CRP is that each node in any route should notify its previous node when it is about to be congested. To prevent congestion, CRP introduces a secondary route called the bypass route. CRP uses the bypass route to bypass the congestion area to the first non-congested node on the primary route. The traffic is split over these two routes. CRP has a significant overhead when there is a bypass route for each primary one. Another disadvantage of CRP is that there is a small loss rate because of dividing the traffic into two routes.

Chapter 3 Failure History-Based Routing Algorithm

Failure History-based routing protocol (FHBR) uses failure history as the main factor for selecting the best route between source and destination. When constructing routes, the protocol uses the intermediate nodes with the least failure history to achieve higher network reliability. The idea of this protocol comes from the fact that a node has periodic link failures will increase the probability of dropping packets if it participates in a route.

3.1 Motivation

Most of existing routing algorithms in MANET concentrate on finding the shortest path between source and destination, without giving an importance to the routing reliability. FHBR uses history information to select the best route rather than the distance between source and destination.

The main task of this study is introducing a reliable reactive routing protocol to address the routing problem in MANETs and improve the packet delivery ratio. FHBR protocol was implemented by modifying exciting AODV route request and route reply phases.

3.2 Protocol Design

Each node in the network has a table called “Failure History Table” (FHT). Initially, FHT will be empty and start growing during operation. FHT contains four fields: Route Identification Number (RID), number of forwarded packet, number of dropped packets, and Failure History Factor (FHF).

Each valid route discovered in the network has a unique number (RID). A node that participates in a route will save RID for the route in its FHT. Each record in FHT will maintain two counters: the number of successful packets that were forwarded using this route through this node, and the number of packets that were dropped by this node. Using these two counters, the FHF will be calculated using equation3-1.

$$FHF = \frac{Forwarded\ Pckets}{Forwarded\ Packets + Dropped\ Packets} \quad \ldots\ldots\ldots\ldots\ldots (3\text{-}1)$$

FHF is between 0 and 1. A higher value of FHF indicates a more stable node. The proposed protocol aims to use intermediate nodes with high values of FHF to construct a route from source to destination.

3.3 Protocol Phases

FHBR consists of three phases: the route discovery phase, the route reply phase, and the route maintenance phase. The first two phases are responsible of finding valid route between nodes. The sender broadcasts a Route Request (RREQ) packet to find a valid route to the destination. A Route Reply (RREP) packet is sent back to the source to tell the sender that a valid route was discovered. The third phase is responsible for sending a

Route Error (RERR) packet when a route becomes invalid for any reason. This phase remains as it in AODV without any modification because it lies out of the scope of this study.

3.3.1 Route Discovery Phase.

The route discovery phase is responsible for discovering a valid route between source and destination by broadcasting RREQ packet. RREQ contains the main fields listed in Table3-1 (Glabbeek, 2015).

Table 3-1: RREQ Main Fields

Field	Description
Source Identification (SID)	The address of the source node from which the route need to be established.
Destination Identification (DID)	The address of the destination node, to which a packet or more are to be sent.
Sequence Number (SEQ)	A number that uniquely identifies each packet sent from a source. This number is used to detect duplicate RREQ packets.
Number of Hops (HOP)	Number of hops traversed by the RREQ.

Time To Live (TTL)	The maximum number of hops that the RREQ can traverse before its lifetime expires. This value is used to prevent looping of packets. It is decremented by one at each node receiving the RREQ.
FHF	This value calculated as in equation 3-1.

In this phase if the source node does not have a valid route to the destination, it broadcasts a RREQ to all neighbor nodes. when any intermediate node receives the request, it checks if TTL is 0 or SEQ has been received previously then it discards RREQ. Then it checks if itself is

the required destination by comparing DID field to the node DID, if so it replies with RREP packet. Otherwise, if the intermediate node is not the destination it does the following: calculates it FHF value as in equation 3-1, updates FHF value in the RREQ, and broadcasts RREQ to all neighbors. The RREQ will continue travelling until it reach the destination.

3.3.2 Route Reply Phase.

This phase starts in one of two cases: if an intermediate node has a valid route to the destination or the RREQ has arrived to the destination. In both case a node should reply to the request with RREP packet. RREP contains the main fields listed in Table3-2 (Glabbeek, 2015).

Table 3-2: RREP Main Fields

Field	Description
Source Identification (SID)	The address of the destination of the RREQ.
Destination Identification (DID)	The address of the source node that initiated the RREQ.
Sequence Number (SEQ)	A number that uniquely identifies each packet. This number is used to detect duplicate RREQ packets.
Number of Hops (HOP)	Number of hops traversed by the RREP.
FHF	This value calculated as in equation 3-1.

When an intermediate or destination node wants to send a RREP packet, It calculates FHF as in equation3-1. If there is a previous RREP was sent to the source, the node compares the calculated FHF with the last sent FHF value. If the current one is smaller than the last one, then it discards the packet, otherwise it prepares RREP and sends it back to the source. The RREP message travels back to the source node that initiated the RREQ via all the nodes that previously rebroadcasted the RREQ packet.

Chapter 4 The Simulation

Many network simulators were used to compare performance between routing protocols in MANETs such as NS, GloMoSim, and QualNet. We used the NS-2 simulator to evaluate the performance of FHBR protocol against AODV because it considered accurate simulator and implements many existing routing protocols such as DSR and AODV (Jubair, 2016).

4.1 Simulator Environment

The first step in preparing simulation experiments is identifying the model of each layer in the simulator as shown in Table4-1.

Table 4-1: Models of Layers

Layer	Model
Application	CBR
Transport	UDP
Mac Layer	802.11n

There are many parameters used to design the scenarios. Table4-2 shows the simulation parameters used in our study, these parameters was recommended and used in many previous studies (Rais, 2014) (Saurin, 2014).

Table 4-2: The simulation Parameters

Parameter	Description	Value
Simulation time	Total simulation time in seconds.	600 seconds
Number of nodes	How many nodes were in the simulation area.	50, and 100 nodes
Simulation area	The dimensions of the simulation area.	1000 meters * 1000 meters
Transmission range	The distance within which a node can send direct packet.	250 meters
Buffer queue	Maximum number of packets a node can buffer	25, and 50 packets
Data flow type	The communication model used for transmitting packets.	CBR
Number of sending sources	How many source can send packets.	10, and 20 sources
Sending rate	How many packets were sent at a time.	2, 4, and 6 packets/second
Routing protocol	the routing protocols used in the simulation.	AODV, and FHBR
Packet Size		512 KB

4.2 Experiments Design

We conducted our experiments using NS2.35 simulator. Each nodes started at random coordination (x,y), and moved randomly using random way-point model. In this type of mobility, a node randomly chooses a destination in the simulation area, and moves toward this destination with a random velocity uniformly chosen between two values. When the node reaches its destination, it stays there for a period of time called Pause Time (PT). Then, it selects another destination and moves toward it (Tran, 2006). In this research we used random-waypoint style with PS values of: 0, 100, 300, and 600 seconds. Node velocity is generated uniformly between 0 and 10 meters/second (Jabeen, 2016).

To simulate the movement of nodes we generated node movement file for each scenario using random-waypoint mobility model. This file is generated using the command *"setdest"*. The general format of this command is as follows (Jubair, 2016):

setdest [-n num_of_nodes] [-p pausetime] [-m maxspeed] [-t simtime] [-x maxx] [-y maxy]

Where *n* specifies the number of nodes in the simulation, *p* specifies the pause time, *m* specifies the maximum speed, *t* specifies the simulation time, and *x* and *y* specify the dimension of the simulation area.

As example, the following command creates the node movement file for 100 nodes that move in an area of 1000 meters* 1000 meters, and follow the random waypoint style with a pause time=0 and a velocity generated randomly between 0 and 10 meters/second. The simulation time is 600 seconds (Jubair, 2016).

setdest -n 100 -p 0.0 -m 10.0 -t 600 -x 1000 -y 1000

Constant Bit Rate (CBR) model was used to generate traffic in form of 512 bytes packets. For each scenario there is a certain number of sources that send packets in a certain rate. We use 10, and 15 sources, with sending rates of 2, 4, and 6 packets/second.

To generate traffic for each scenario, a traffic connection file is prepared that contains both number of sources and sending rate. This file is generated in NS using a command called "ns cbrgen.tcl". The following is the syntax of this command.

ns cbrgen.tcl. [-type cbr] [-nn nodes] [-seed seed] [-mc connections] [-rate rate]

Where *type* specifies the traffic type, *nn* specifies the number of nodes in the simulation, *mc* specifies the number of traffic connections, and *rat*e specifies the sending rate (packets/second).

As example, the command creates 10 CBR traffic connections, each connection sends 6 packets/second.

ns cbrgen.tcl. -type cbr -nn 50 -seed 1 -mc 10 -rate 6

In our study we have 10, and 20 sources, and three sending rated, then we create six connection files.

We design our scenarios to measure the performance under different conditions. We conduct simulations for small networks that have fifty nodes, and big networks that have one hundred and fifty nodes.

To study the effect on buffer size on the performance we use two sizes: twenty-five which is the default value, and fifty packets to address the expected effect of increasing the buffer size on enhancing the performance of the network.

Another important condition that we design the scenarios to address is the congestion of the traffic (Shrivastava, 2011). We change both the number of sources and sending rates to make different congestion levels and study the behavior of FHBR under these different congestion levels.

4.3 Performance Comparison Metrics

We compare the performance of FHBR protocol against AODV using packet delivery ratio metric. Packet delivery ratio could be expressed as in equation4-1.

$$PDR = \frac{RP.}{TP.} * 100\% \quad \ldots\ldots\ldots\ldots\ldots \text{(4-1)}$$

Where *RP* is number of received data packets, and TP is number of total sent data packets.

Also we add another comparison metrics which is average end to end delay that can be expressed in equation4-2

$$\text{Average end} - \text{to} - \text{end delay} = \frac{\sum_{i=1}^{P}(\text{RTi} - \text{STi})}{\text{P}} \ldots\ldots\ldots\ldots\ldots\ldots \text{(4-2)}$$

Where, *P* is the total number of data packets received in the network, *RTi* is the time at which packet *Pi* was received, and *STi* is the time at which packet *Pi* was sent.

Chapter 5 Results and Discussion

In this chapter, we analyze the results of the simulation scenarios and compare the performance of FHBR against AODV. We conduct twenty-four different scenarios. Each experiment was ran ten times, and the average value of these runs was considered. We study the behavior of small, and large number of nodes to find how is number of nodes affects packet delivery ratio.

To address the effect of network congestion on packet delivery ratio we study different scenarios in which different congestion levels were considered by changing number of sources and packet sending rate. These different were compared and analyzed to capture the effect of congestion on packet delivery ratio.

Buffer size of the nodes was increased in half of the scenarios to study its effect on enhancing packet delivery ratio. The performance of each two scenarios were compared to address this effect.

Figures from 5-1 to 5-4 show the packet delivery ratio for the case when ten communications sources send two packets per second with different number of nodes and different buffer sizes. The results show FHBR protocol outperforms AODV in terms of packet delivery ratio for all pause times. Table5-1 shows the packet delivery ratio that figured in figures from 5-1 to 5-4.

Table 5-1: Packet Delivery Ratio of 10 sources each one sends 2 packets/s

Number of Nodes	Queue Length					
50	25			50		
	Pause Time	FHBR	AODV	Pause Time	FHBR	AODV
	0	86.61	76.84	0	88.23	78.55
	100	91.92	81.65	100	93.63	82.20
	300	93.48	86.12	300	95.45	88.20
	600	95.59	88.73	600	97.70	90.33
100	25			50		
	Pause Time	FHBR	AODV	Pause Time	FHBR	AODV
	0	85.40	74.70	0	87.19	79.23
	100	88.30	76.33	100	95.36	83.36
	300	91.35	84.47	300	96.65	89.54
	600	94.46	86.36	600	98.88	91.54

The results show that FHBR outperforms AODV more substantially in the high mobility networks, and outperforms less when networks are more static. As example, figure5-1 shows that FHBR outperforms AODV by 12.71 percent when pause time is 0 (high mobility network), while it outperforms AODV by 7.74 percent when pause time is 600 seconds (low mobility network). FHBR protocol reach a high performance in high mobile networks because it considers a higher stable nodes rather lower stable nodes when constructing route between sender and receiver, the effect of this behavior appears more in dynamic networks rather than static networks. The reason is that dynamic networks change their topology rapidly and FHBR adapts with this change more effectively than AODV which always choose the shortest path rather than any other factors.

Figure5-1 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 12.71 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 12.57 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 8.55 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 7.74 percent. Figure5-1 shows that FHBR works more effective when the mobility of nodes is increased when compared with AODV performance in terms of packet delivery ratio.

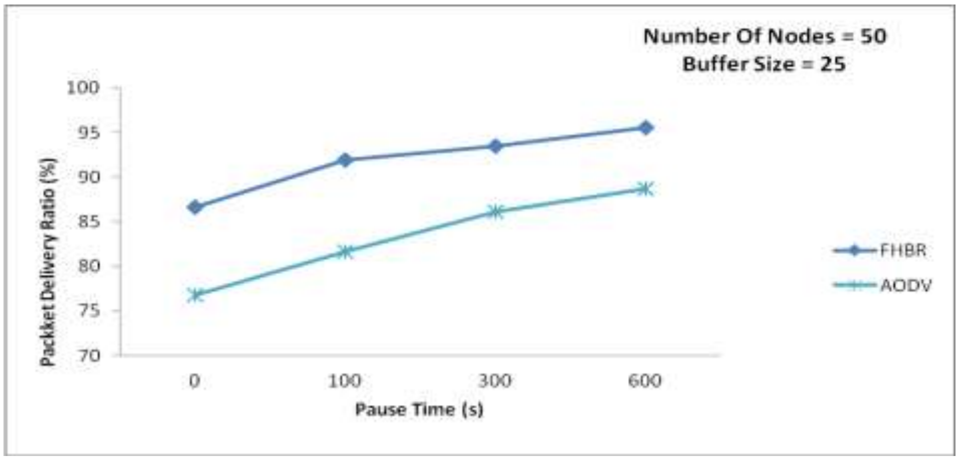

Figure 5-1: Packet Delivery Ratio of 10 sources each one sends 2 packets/s, with 50 nodes each has 25 packets buffer

Figure5-2 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 12.32 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 13.91 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 8.22 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 8.16 percent.

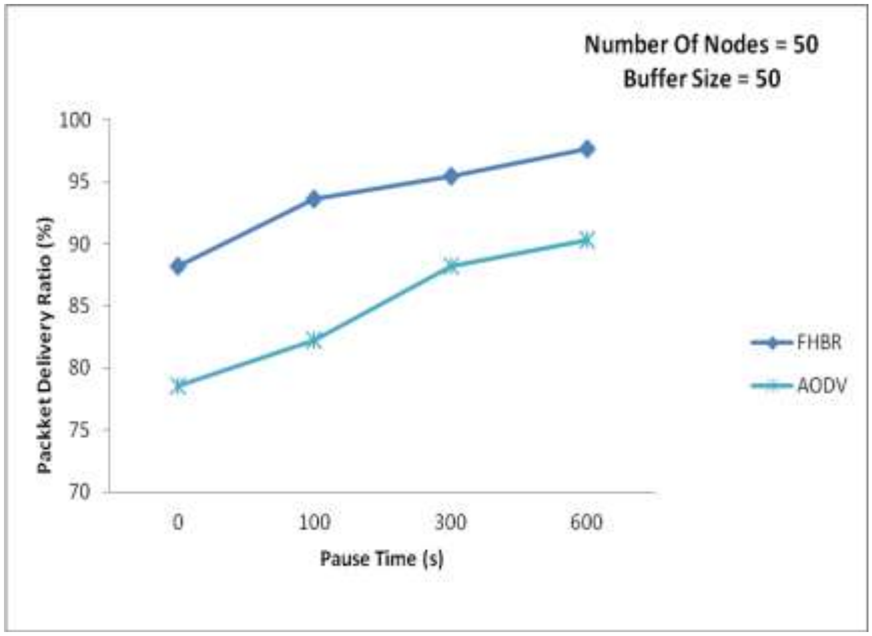

Figure 5-2: Packet Delivery Ratio of 10 sources each one sends 2 packets/s, with 50 nodes each has 50 packets buffer

Figures5-1 and 5-2 show that FHBR works more effective when the mobility of nodes is increased when compared with AODV performance in terms of packet delivery ratio. This is because FHBR protocol adapts with dynamic topology changes in better manner rather than AODV.

When we compare the packet delivery ratio between figure5-1 and figure5-2, we notice that the packet delivery ratio in figure5-2 is better than the packet delivery ratio in figure5-1 for both FHBR and AODV and for all pause times. Figure 5-1 shows the results when buffer size is 25 packets while figure5-2 shows the packet delivery ration when buffer size is 50 packets when buffer size is 50 packets. The reason of this difference in performance is that when we increase the buffer size of the nodes then the history failure factor will be increased and the route built from these nodes will be more effective and consequently the packet delivery ratio will be increased also.

Figure5-3 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 14.32 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 15.68 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 8.14 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 9.38 percent.

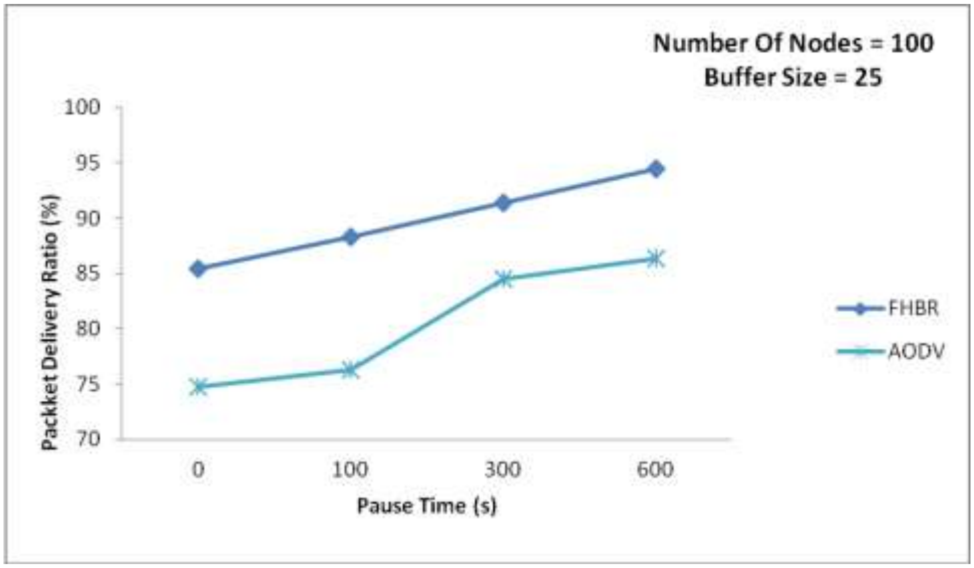

Figure 5-3: Packet Delivery Ratio of 10 sources each one sends 2 packets/s, with 100 nodes each has 25 packets buffer

Figure5-4 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 10.05 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 14.40 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 7.94 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 8.02 percent.

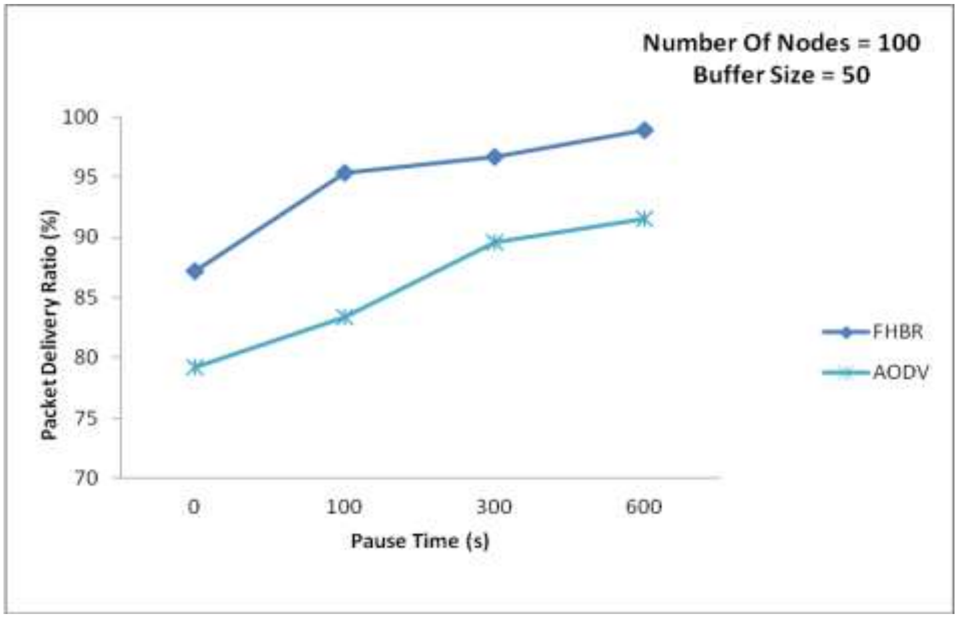

Figure 5-4: Packet Delivery Ratio of 10 sources each one sends 2 packets/s, with 100 nodes each has 50 packets buffer

Figures from 5-5 to 5-8 show the packet delivery ratio for the case when ten communications sources send four packets per second. We change both number of nodes and buffer size.

The performance for both protocol decreased when compared with the scenarios displayed in figures from 5-1 to 5-4. The reason is that the congestion level in the network is increased because we increased the packet transmission rate from two to four packets per second.

We note that FHBR outperforms AODV in these case as in the previous case but in higher factor. As example in figure 5-1 FHBR outperforms AODV by 12.71 percent when pause time is zero, while figure5-5 shows that FHBR outperforms AODV by 14.95 percent for the same pause time value.

The results show that FHBR outperforms AODV more substantially in the high mobility networks, and outperforms less when networks are more static. As example, figure5-5 shows that FHBR outperforms AODV by 14.95 percent when pause time is 0 (high mobility network), while it outperforms AODV by 9.56 percent when pause time is 600 seconds (low mobility network).

Figure5-5 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 14.95 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 14.56 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 10.14 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 9.65 percent.

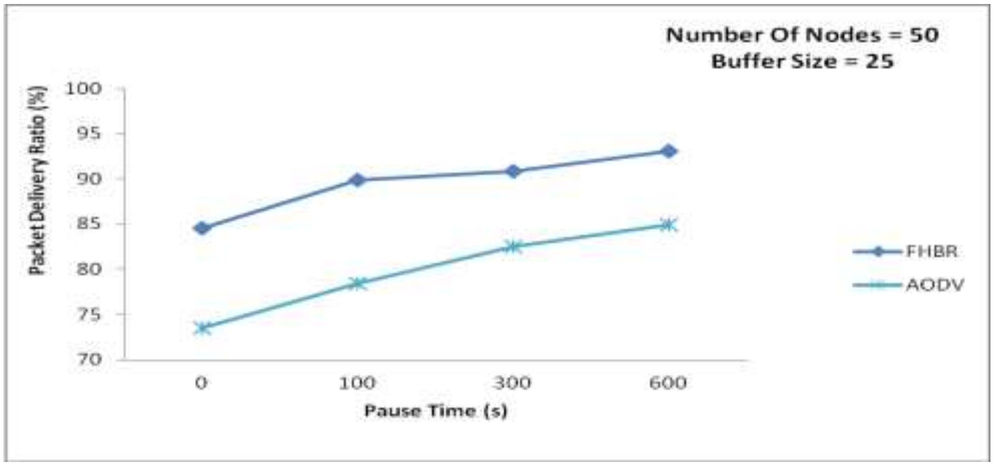

Figure 5-5: Packet Delivery Ratio of 10 sources each one sends 4 packets/s, with 50 nodes each has 25 packets buffer

Figure5-6 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 14.64 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 16.63 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 10.69 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 9.72 percent.

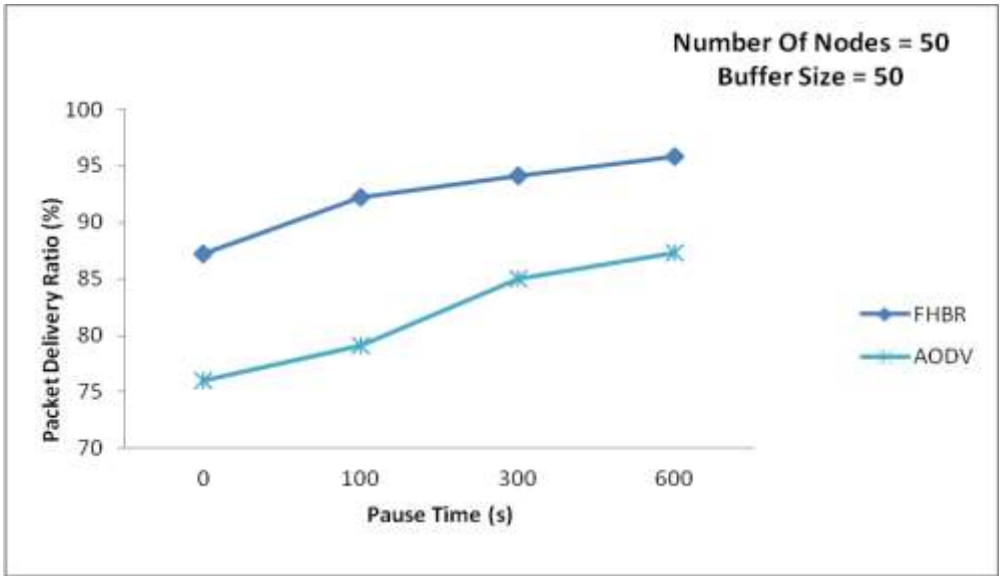

Figure 5-6: Packet Delivery Ratio of 10 sources each one sends 4 packets/s, with 50 nodes each has 50 packets buffer

Figures5-5 and 5-6 show that FHBR works more effective when the mobility of nodes is increased when compared with AODV performance in terms of packet delivery ratio. This is because FHBR protocol adapts with dynamic topology changes in better manner rather than AODV.

Figure5-7 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 16.22 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 14.37

percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 10.61 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 11.20 percent.

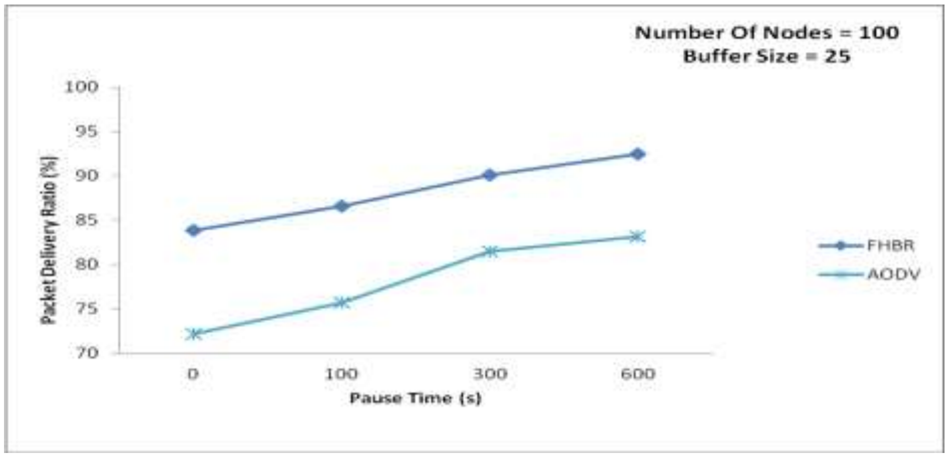

Figure 5-7: Packet Delivery Ratio of 10 sources each one sends 4 packets/s, with 100 nodes each has 25 packets buffer

Figure5-8 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 12.58 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 16.54 percent. When the pause time is equal to 300 seconds FHBR outperforms

AODV by 9.63 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 10.05 percent.

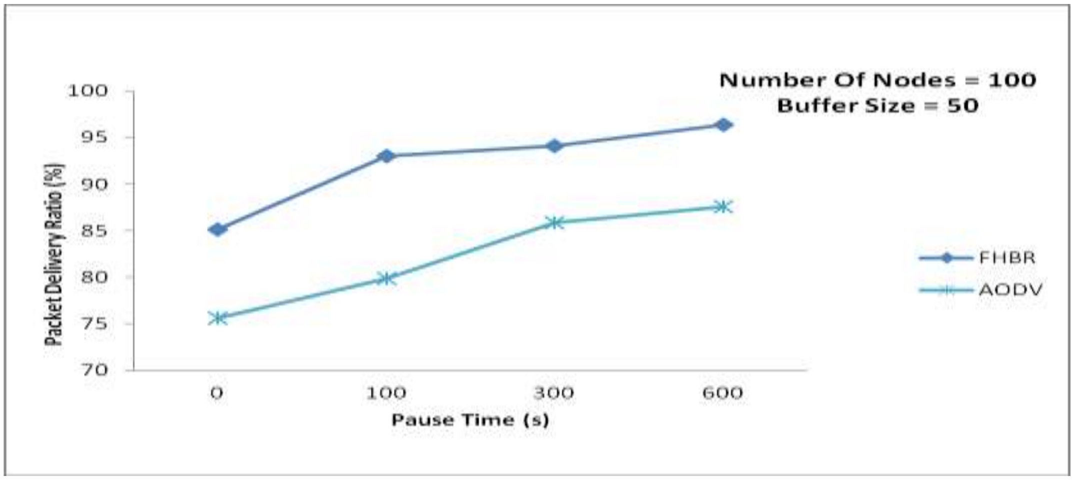

Figure 5-8: Packet Delivery Ratio of 10 sources each one sends 4 packets/s, with 100 nodes each has 50 packets buffer

When we compare the packet delivery ratio in figure 5-5 against figure 5-6 and the packet delivery ratio in figure5-7 against figure5-8 we find that when we increase the buffer size the packet delivery ratio also increased for both protocols. The reason is that increasing buffer size will increase the accuracy of node in delivering packets successfully.

We increase the sending rate to six packets per second and change both number of nodes and buffer size as shown in figures from 5-9 to 5-12. The congestion level in these case was increased because of increasing the number of packets sent in a second. The congestion causes the packet delivery ratio to be decreased because of increasing dropped packet

through transmission. Both FHBR and AODV performance was effected by the congestion but FHBR was more adaptive and outperforms AODV more significantly than other cases in which a light load was generated.

Figure5-9 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 16.41 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 15.17 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 9.45 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 10.93 percent.

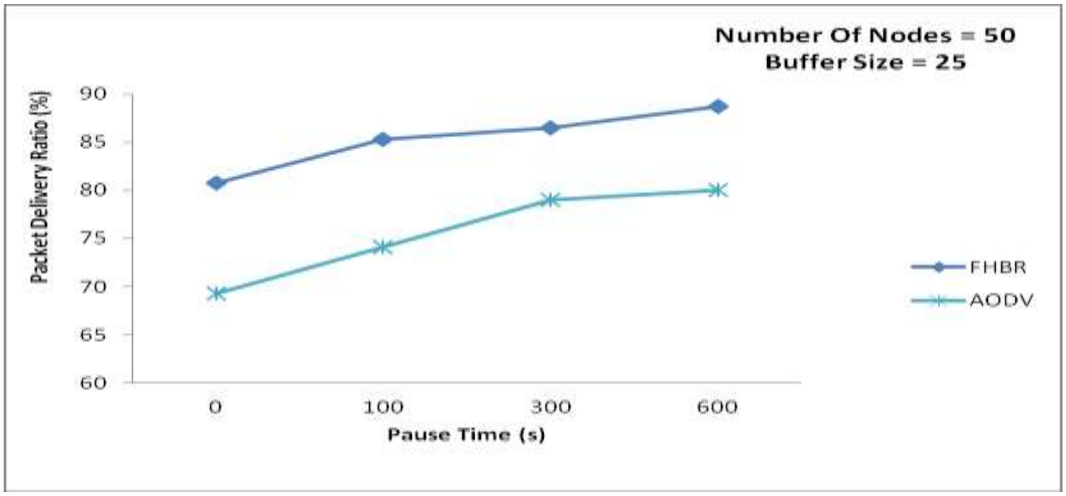

Figure 5-9: Packet Delivery Ratio of 10 sources each one sends 6 packets/s, with 50 nodes each has 25 packets buffer

Figure5-10 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 14.64 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 17.20 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 11.04 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 10.42 percent.

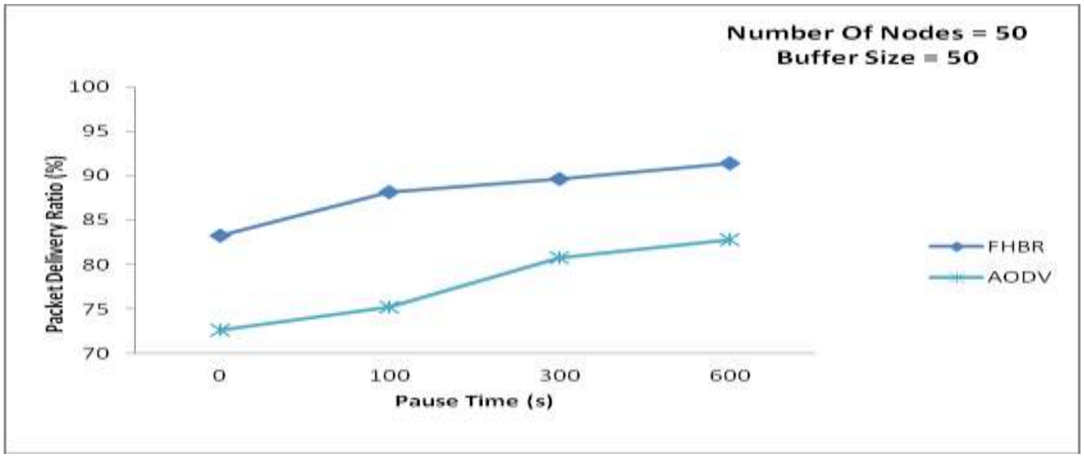

Figure 5-10: Packet Delivery Ratio of 10 sources each one sends 6 packets/s, with 50 nodes each has 50 packets buffer.

The difference between the scenario in figure 5-9 and figure 5-10 is that we increase the buffer size. the results show that increasing the buffer size makes the network more adaptive to the high congestion level caused by the increased traffic connections. As example when buffer size is twenty-five as shown in figure 5-9 the FHBR packet delivery ratio for high mobility network is 80.72, while it was increased to 83.25 percent when the buffer size was doubled as shown in figure 5-10.

Figure5-11 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 16.46 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by

15.94 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 10.73 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 11.49 percent.

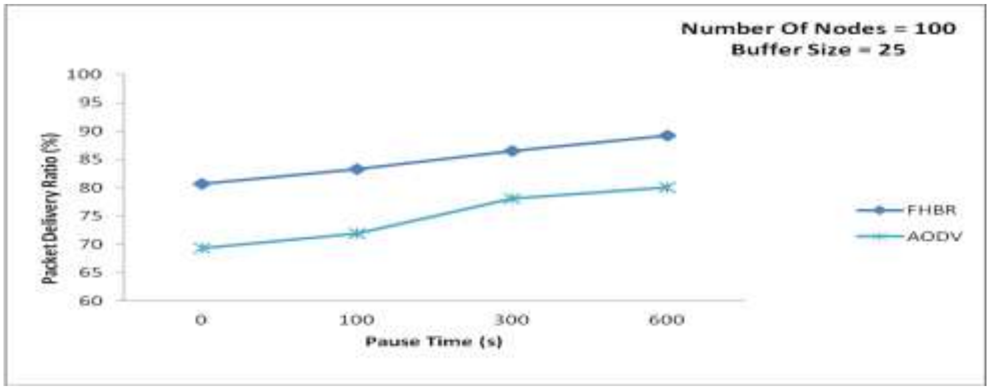

Figure 5-11: Packet Delivery Ratio of 10 sources each one sends 6 packets/s, with 100 nodes each has 25 packets buffer

Figure5-12 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 14.00 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 17.40 percent. When the pause time is equal to 300 seconds FHBR outperforms

AODV by 9.86 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 10.28 percent.

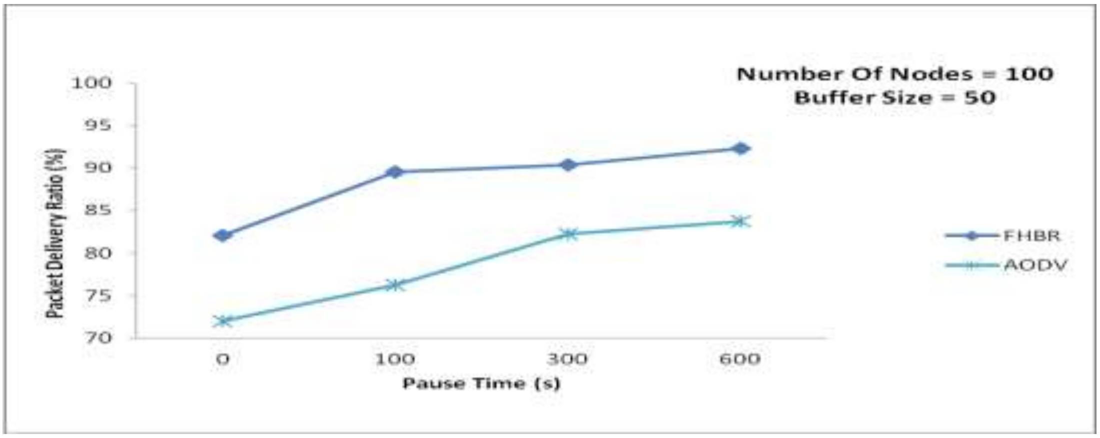

Figure 5-12: Packet Delivery Ratio of 10 sources each one sends 6 packets/s, with 100 nodes each has 50 packets buffer

In figures from 5-13 to 5-24 we increase number of sources from ten sources to twenty sources to increase congestion level by loading more traffic from more sources. We also try three sending rate: two, four, and six packets per second. We change number of nodes between fifty and one hundred and change buffer size between twenty five and fifty packets.

The results show that the packet delivery ratio was dropped for FHBR and AODV as we increase the congestion level. As example figure5-1 shows that the packet delivery ratio was up to 98.88 and 91.54 for FHBR and AODV respectively with low level of congestion, while figure 5-22 shows that the packet delivery ratio was up to 88.13 and 73.48

for FHBR and AODV respectively with high level of congestion.

The results also show that FHBR was more adaptive to increasing congestion than AODV. The enhancement was increased dramatically when we increase the number of sources from ten to twenty sources. As example, in figure5-1 FHBR outperforms AODV by 12.17 percent but in figure 5-13 the enhancement was 27.55 percent for high mobility networks. The difference between these two figures is that we increase the congestion level. FHBR takes the failure history as a main metric in constructing routes between nodes without any care about how long is the distance between source and destination. FHBR is constructing more stable routes than AODV which always choose the shortest path between source and destination.

Figure5-13 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 27.55 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 20.82 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 16.18 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 15.45 percent.

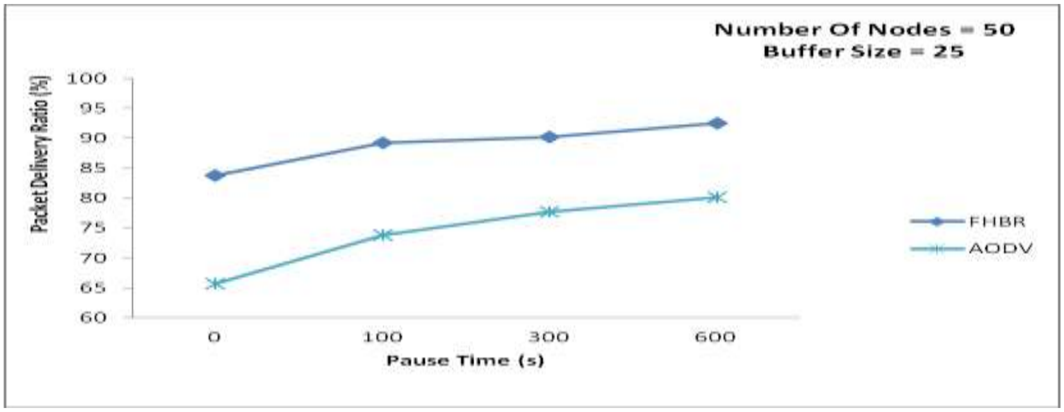

Figure 5-13: Packet Delivery Ratio of 20 sources each one sends 2 packets/s, with 50 nodes each has 25 packets buffer

Figure5-14 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 20.80 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 23.30 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 16.66 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 15.81 percent.

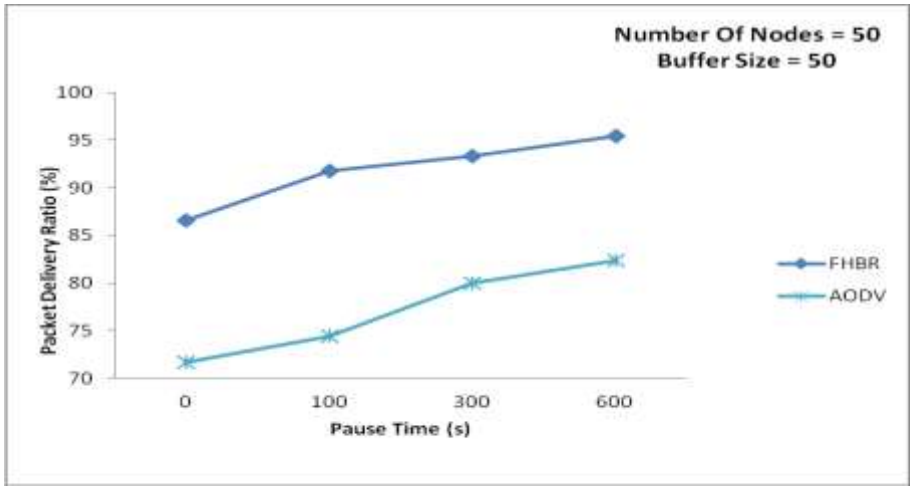

Figure 5-14: Packet Delivery Ratio of 20 sources each one sends 2 packets/s, with 50 nodes each has 50 packets buffer

Figure5-15 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 22.19 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 20.37 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 16.65 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 17.17 percent.

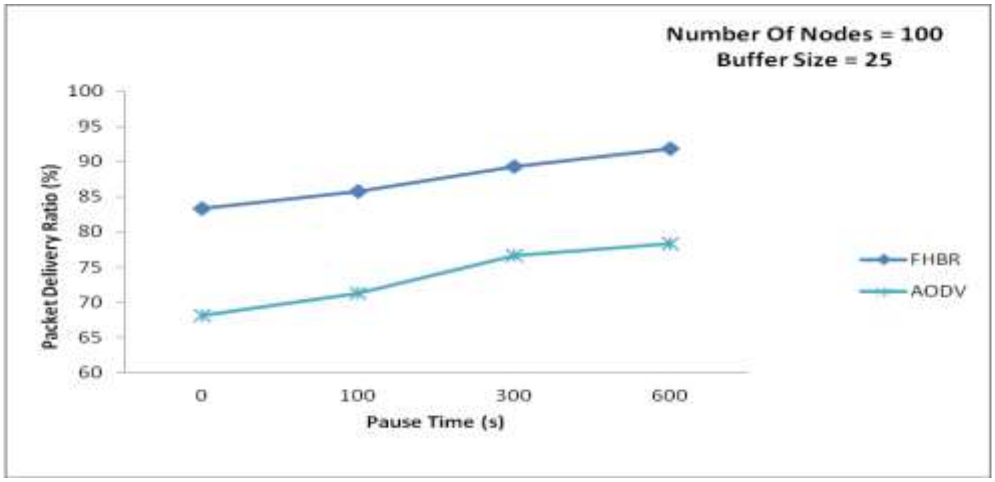

Figure 5-15: Packet Delivery Ratio of 20 sources each one sends 2 packets/s, with 100 nodes each has 25 packets buffer

Figure5-16 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 18.39 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 22.68 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 15.16 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 15.83 percent.

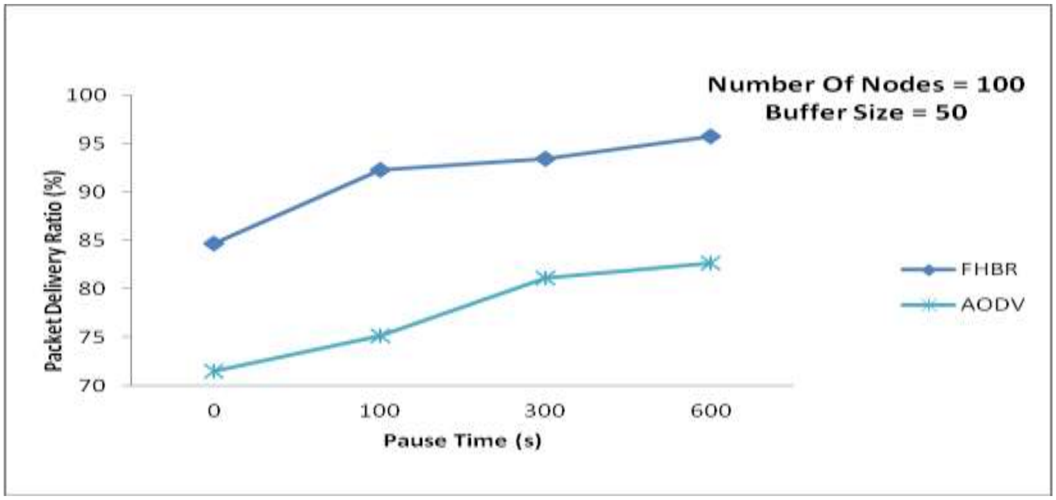

Figure 5-16: Packet Delivery Ratio of 20 sources each one sends 2 packets/s, with 100 nodes each has 50 packets buffer

Figure5-17 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 29.59 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 22.82 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 17.78 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 17.33 percent.

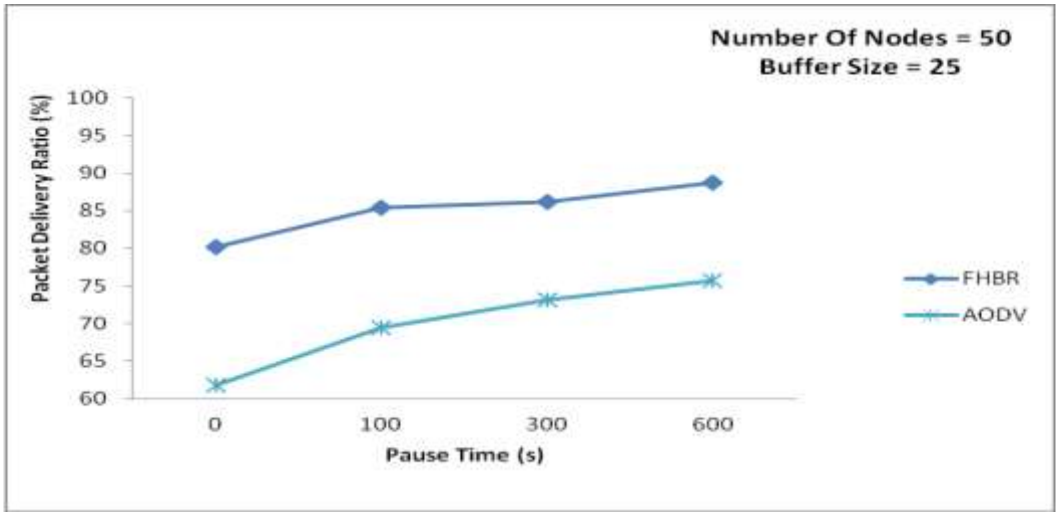

Figure 5-17: Packet Delivery Ratio of 20 sources each one sends 4 packets/s, with 50 nodes each has 25 packets buffer

Figure5-18 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 22.08 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 24.60 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 17.86 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 17.04 percent.

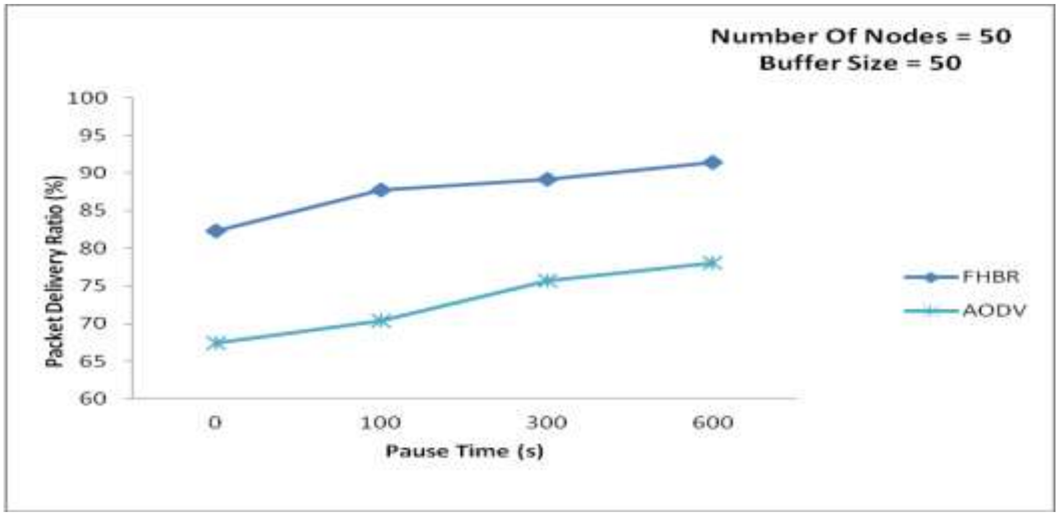

Figure 5-18: Packet Delivery Ratio of 20 sources each one sends 4 packets/s, with 50 nodes each has 50 packets buffer

Figure5-19 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 24.33 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 22.63 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 18.01 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 17.73 percent.

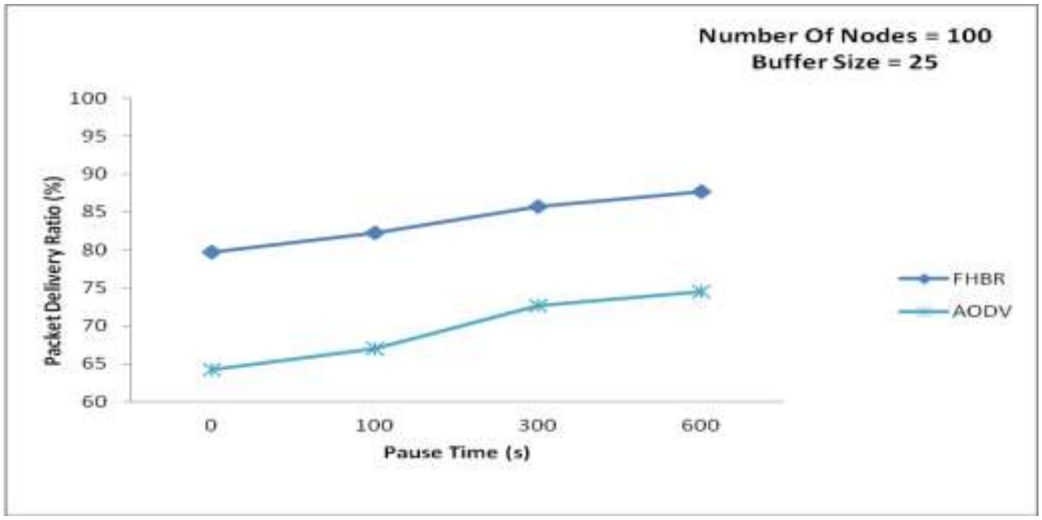

Figure 5-19: Packet Delivery Ratio of 20 sources each one sends 4 packets/s, with 100 nodes each has 25 packets buffer

Figure5-20 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 19.37 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 23.97 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 16.42 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 17.03 percent.

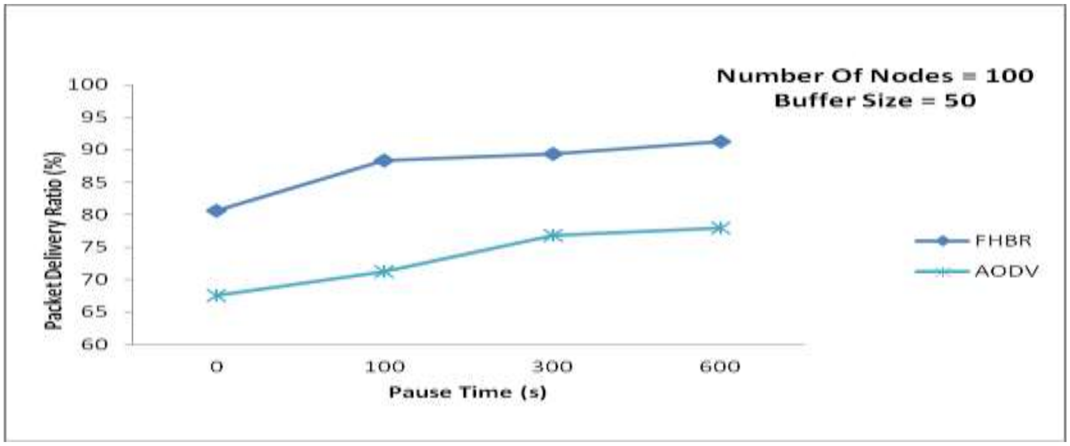

Figure 5-20: Packet Delivery Ratio of 20 sources each one sends 4 packets/s, with 100 nodes each has 50 packets buffer

Figure5-21 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 32.36 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 25.34 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 19.85 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 18.99 percent.

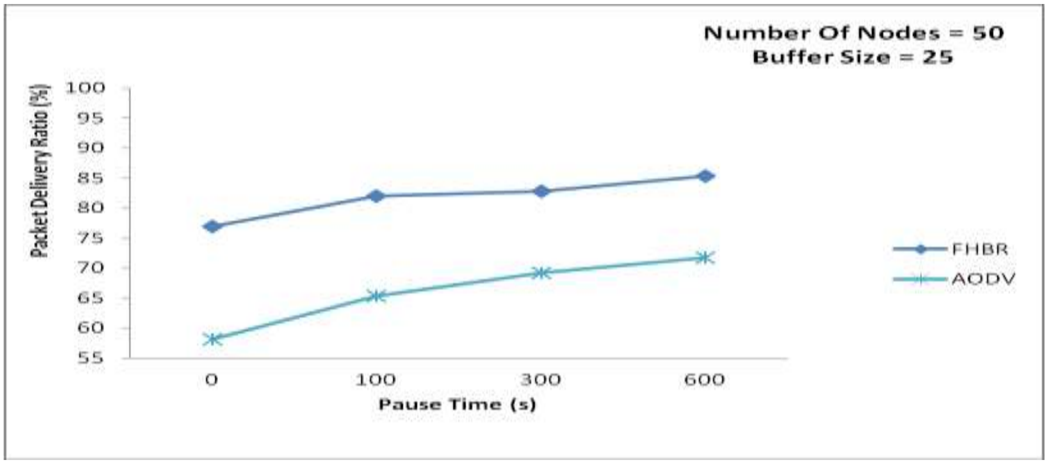

Figure 5-21: Packet Delivery Ratio of 20 sources each one sends 6 packets/s, with 50 nodes each has 25 packets buffer

Figure5-22 shows the packet delivery ratio for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 24.33 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 26.97 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 20.50 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 19.95 percent.

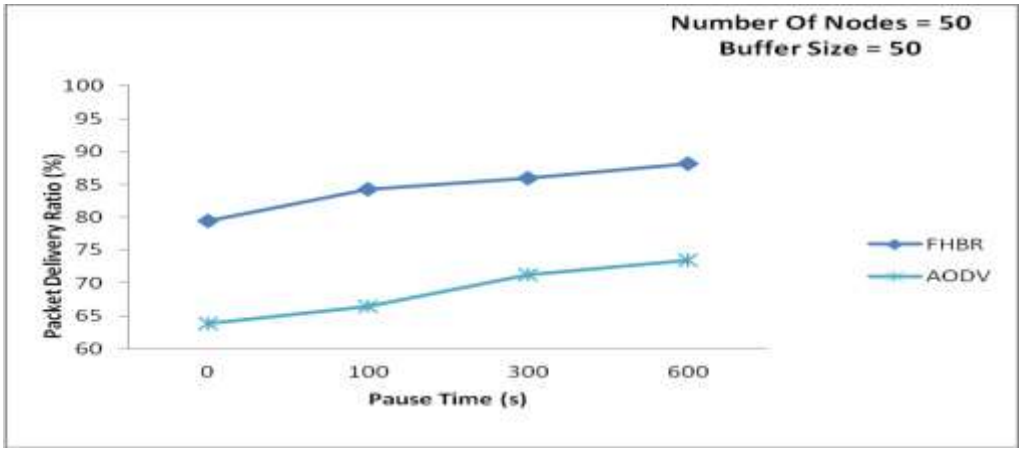

Figure 5-22: Packet Delivery Ratio of 20 sources each one sends 6 packets/s, with 50 nodes each has 50 packets buffer

Figure5-23 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 25.91 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 25.22 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 20.37 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 20.15 percent.

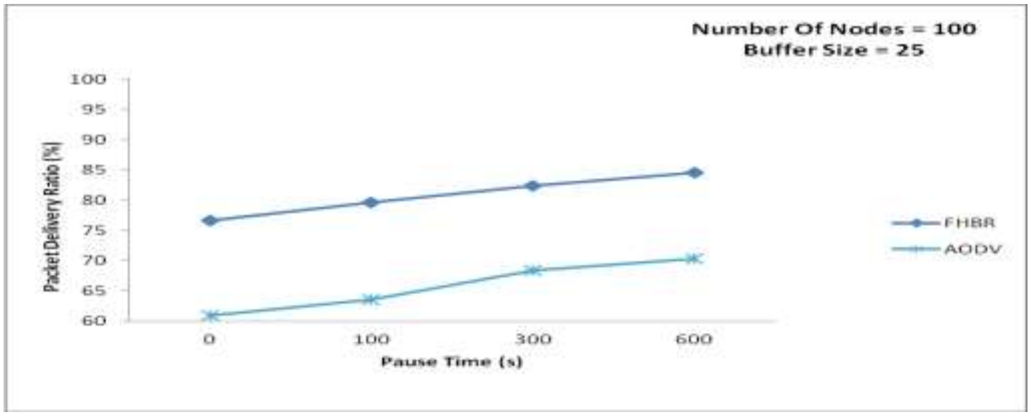

Figure 5-23: Packet Delivery Ratio of 20 sources each one sends 6 packets/s, with 100 nodes each has 25 packets buffer

Figure5-24 shows the packet delivery ratio for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 21.26 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 26.46 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 18.61 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 19.58 percent.

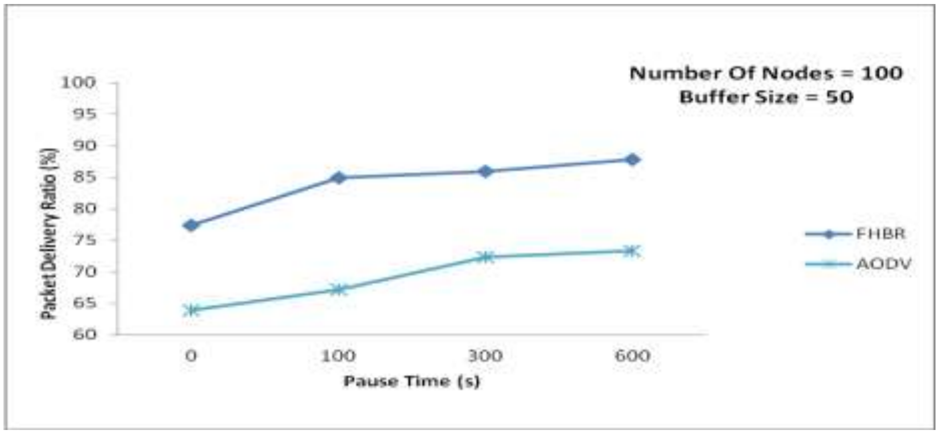

Figure 5-24: Packet Delivery Ratio of 20 sources each one sends 6 packets/s, with 100 nodes each has 50 packets buffer

Figures from 5-25 to 5-28 show the average end to end delay for the case when ten communications sources send two packets per second with different number of nodes and different buffer sizes. The results show FHBR protocol outperforms AODV in terms of average end to end delay for all pause times.

The results show that FHBR outperforms AODV for all mobility levels. As example, figure 5-25 shows that FHBR outperforms AODV by 7.24 percent when pause time is 0 (high mobility network), while it outperforms AODV by 16.67 percent when pause time is 600 seconds (low mobility network). FHBR and AODV have a higher average end to end delay in high mobile networks than a low mobile networks. Because of high mobility of networks, the topology changes dynamically so that the route between nodes will be changed dramatically and consequently the average end to end delay will be increased.

Because of the behavior of FHBR protocol it always avoid to route packets through shortest but congested paths to make the delivery at minimum time. Shortest path may cause a packet to wait more in a buffer and delayed which increases the average end to end delay of packets.

Figure 5-25 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 7.24 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 13.36 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 6.13 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 16.67 percent.

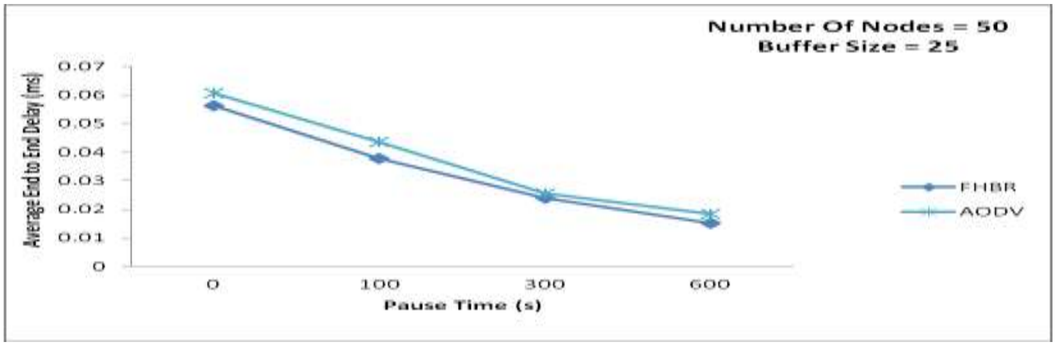

Figure 5-25: average end to end delay of 10 sources each one sends 2 packets/s, with 50 nodes each has 25 packets buffer

Figure 5-26 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 7.95 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 5.15 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 7.38 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 6.11 percent.

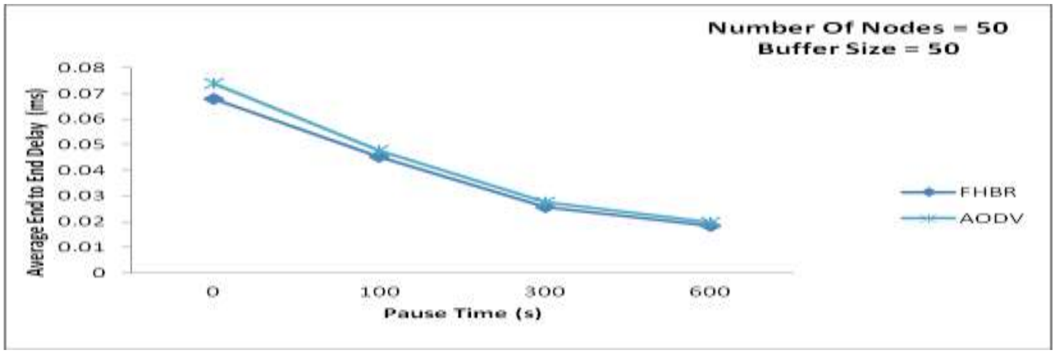

Figure 5-26: Average end to end delay of 10 sources each one sends 2 packets/s, with 50 nodes each has 50 packets buffer

Figures 5-25 and 5-26 show that FHBR works more effective when the mobility of nodes is increased when compared with AODV performance in terms of average end to end delay because of its high adaptively approach.

When comparing the effect of increasing buffer size between figure 5-25 and 5-26 we notice that the average end to end delay has been improved because that increasing buffer size will increase the ability of a node to handle more packets and so decrease the congestion in the network and decrease the average end to end delay of packets.

Figure 5-27 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 6.87 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 5.65 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 10.24 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 9.76 percent.

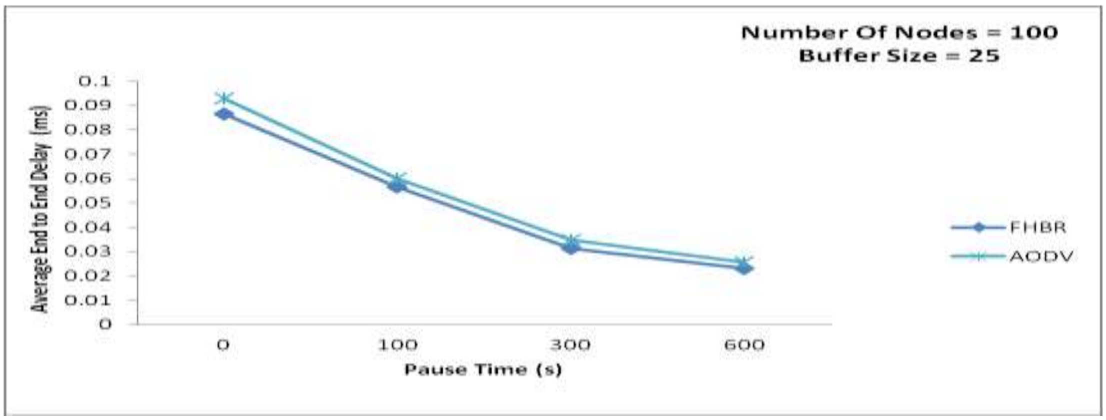

Figure 5-27: average end to end delay of 10 sources each one sends 2 packets/s, with 100 nodes each has 25 packets buffer

Figure 5-28 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 7.24 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by

12.96 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 5.63 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 10.07 percent.

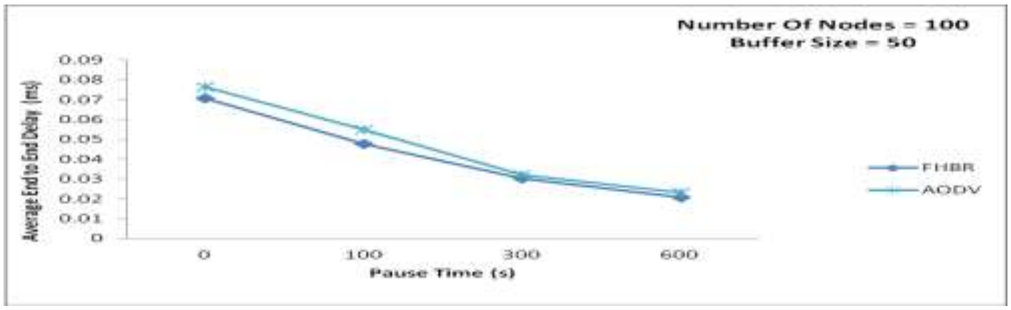

Figure 5-28: average end to end delay of 10 sources each one sends 2 packets/s, with 100 nodes each has 50 packets buffer

Figures 5-29 ~ 5-32 show the average end to end delay for the case when ten communications sources send four packets per second. We increase the congestion level by increasing the rate in which nodes send packets so that the average end to end delay was increased when compared with the results shown in figures 5-25 ~ 5-28.

The results show that FHBR outperforms AODV in all. As example, figure 5-29 shows that FHBR outperforms AODV by 7.11 percent when pause time is 0 (high mobility network), while it outperforms AODV by 5.79 percent when pause time is 600 seconds (low mobility network).

Figure 5-29 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 7.11 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 15.65 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 7.60 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 5.79 percent.

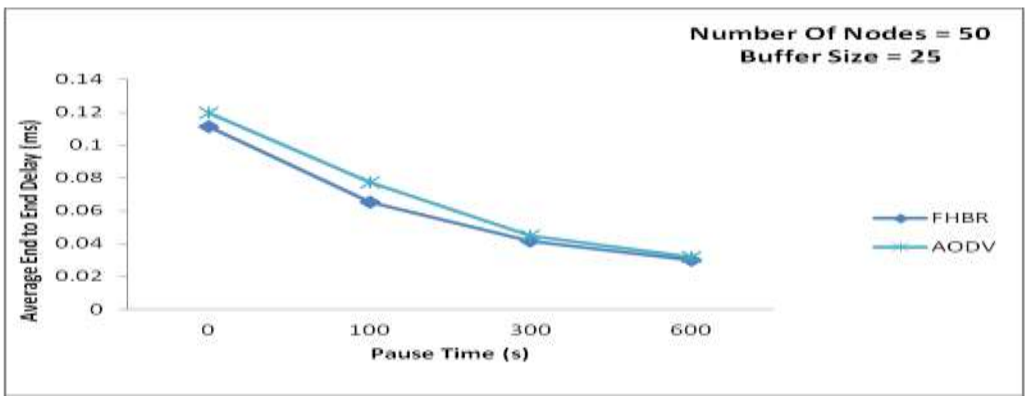

Figure 5-29: average end to end delay of 10 sources each one sends 4 packets/s, with 50 nodes each has 25 packets buffer

Figure 5-30 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 7.24 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 7.08 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 6.32 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 5.73 percent.

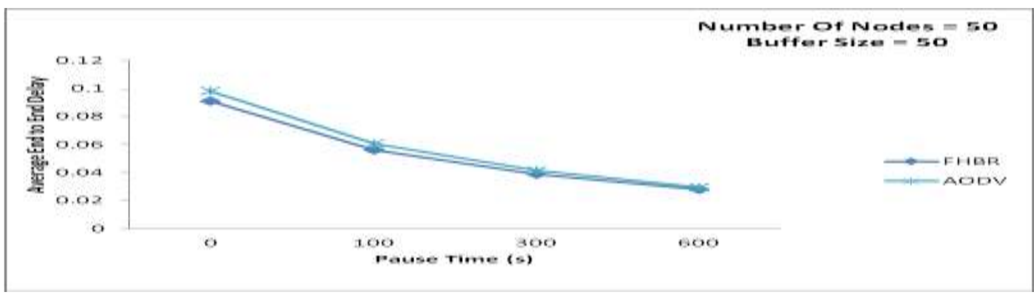

Figure 5-30: average end to end delay of 10 sources each one sends 4 packets/s, with 50 nodes each has 50 packets buffer

Figure 5-31 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 8.59 percent. When the pause time is equal to 100 seconds FHBR outperforms

AODV by 16.65 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 9.10 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 6.35 percent.

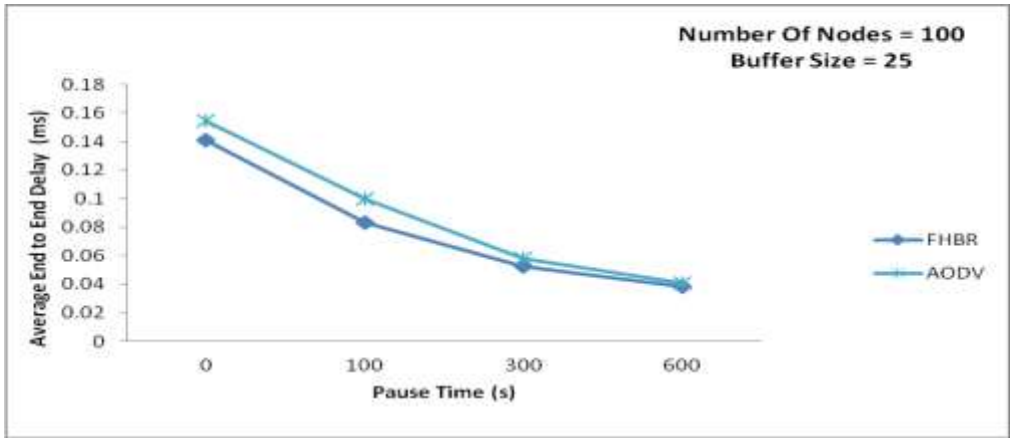

Figure 5-31: average end to end delay of 10 sources each one sends 4 packets/s, with 100 nodes each has 25 packets buffer

Figure 5-32 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 6.45 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 8.13 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 6.34 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 5.73 percent.

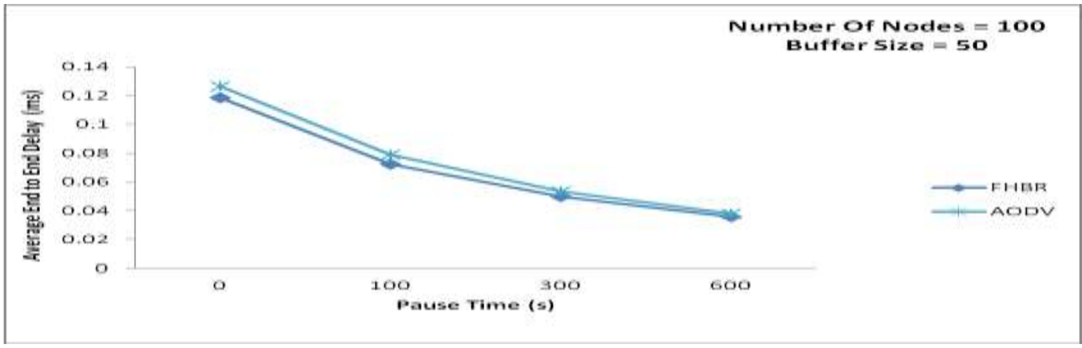

Figure 5-32: average end to end delay of 10 sources each one sends 4 packets/s, with 100 nodes each has 50 packets buffer

We increase the sending rate to six packets per second and change both number of nodes and buffer size as shown in figures 5-33 ~ 5-36. The congestion level in these case was increased because of increasing the number of packets sent in a second. The congestion causes the average end to end delay to be increased. Both FHBR and AODV performance was effected by the congestion but FHBR was more adaptive and outperforms AODV more significantly than other cases in which a light load was generated.

Figure 5-33 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 8.60 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 13.16 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 7.38 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 8.55 percent.

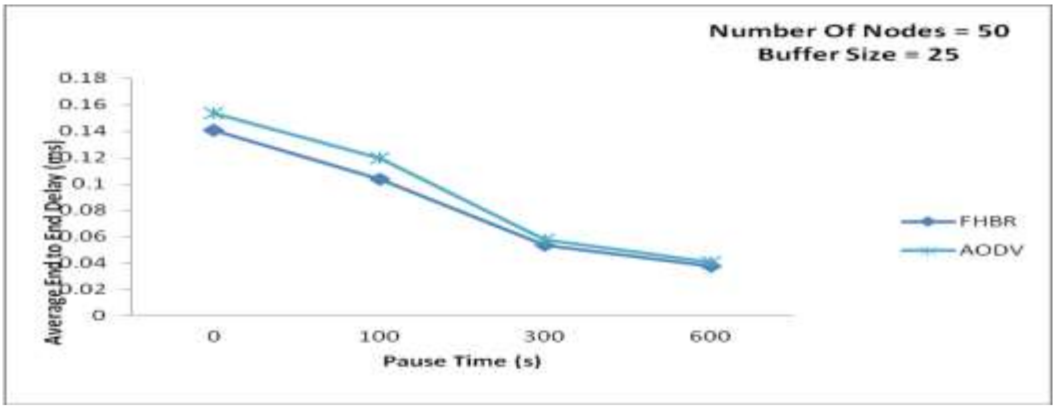

Figure 5-33: Average end to end delay of 10 sources each one sends 6 packets/s, with 50 nodes each has 25 packets buffer

Figure 5-34 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 8.03 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 12.54 percent. When the pause time is equal to 300 seconds FHBR outperforms

AODV by 5.97 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 5.47 percent.

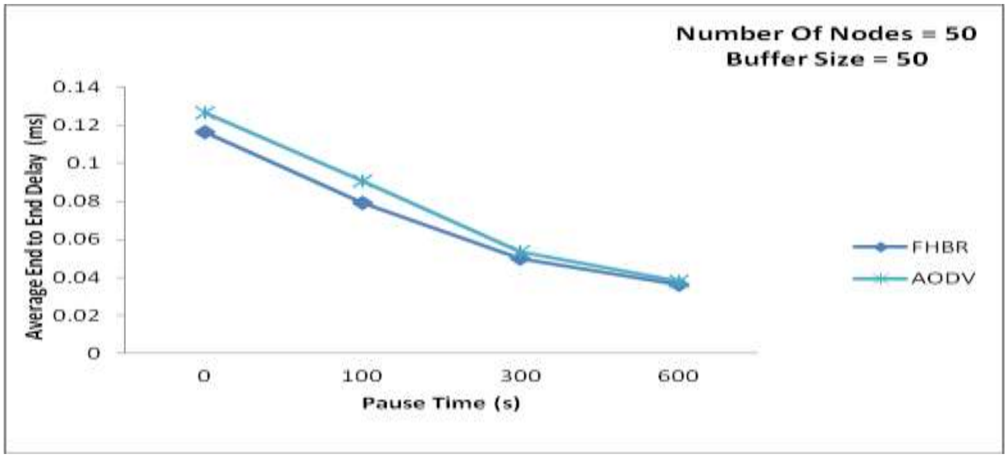

Figure 5-34: Average end to end delay of 10 sources each one sends 6 packets/s, with 50 nodes each has 50 packets buffer.

Figure 5-35 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is ten and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 8.26 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 5.41 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 7.81 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 6.69 percent.

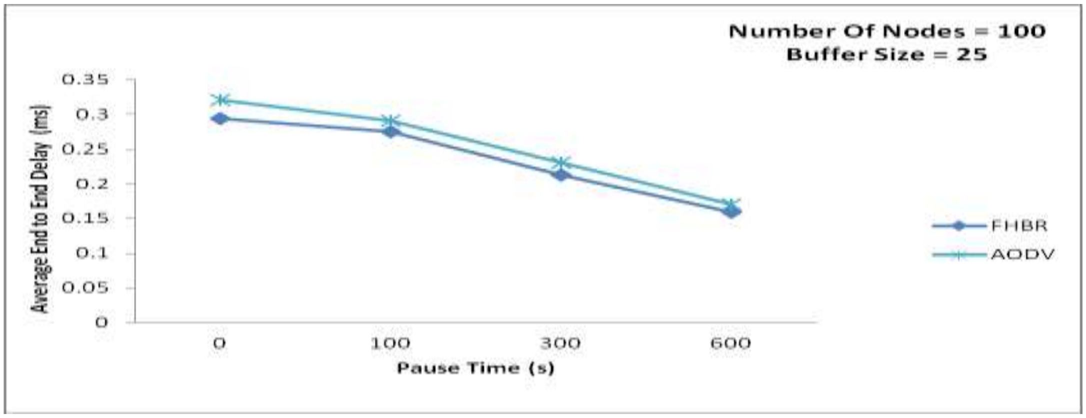

Figure 5-35: average end to end delay of 10 sources each one sends 6 packets/s, with 100 nodes each has 25 packets buffer

Figure 5-36 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is ten and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 7.62 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 13.15 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 6.91 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 6.36 percent.

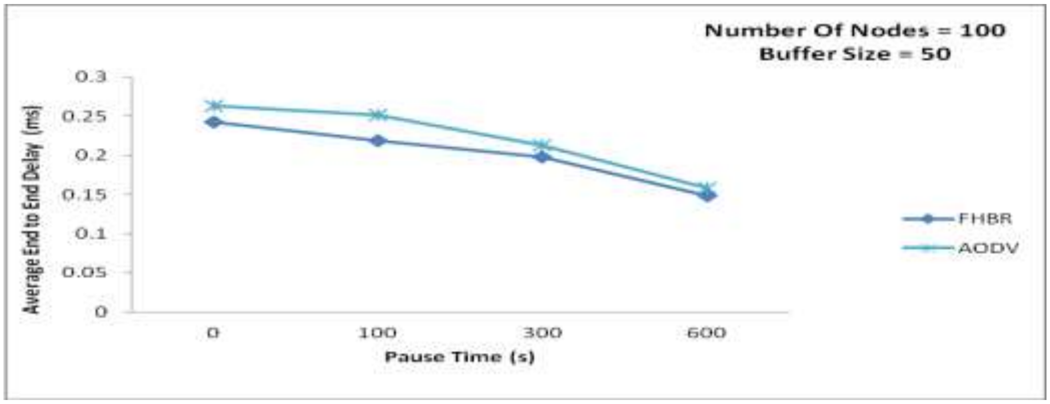

Figure 5-36: average end to end delay of 10 sources each one sends 6 packets/s, with 100 nodes each has 50 packets buffer

In figures 5-37~5-48 we increase number of sources from ten sources to twenty sources to increase congestion level by loading more traffic from more sources. We also try three sending rate: two, four, and six packets per second. We change number of nodes between fifty and one hundred and change buffer size between twenty-five and fifty packets.

Figure 5-37 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 9.13 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by

5.98 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 9.31 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 7.13 percent.

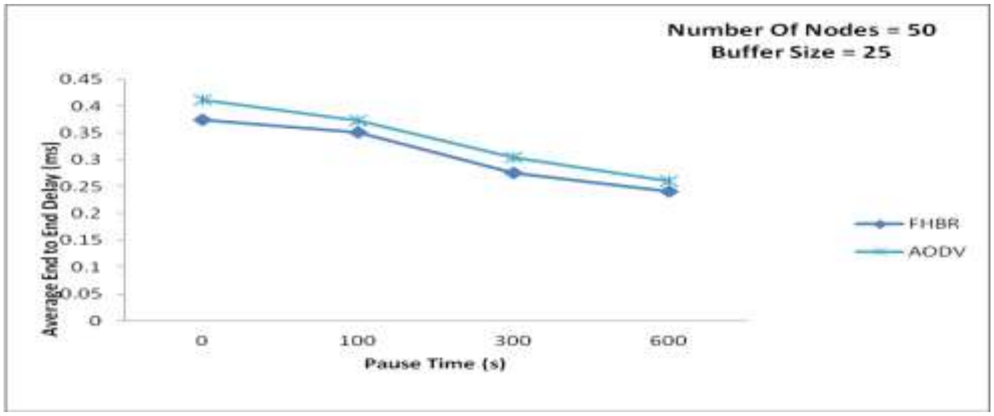

Figure 5-37: average end to end delay of 20 sources each one sends 2 packets/s, with 50 nodes each has 25 packets buffer

Figure 5-38 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 4.77 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 17.03 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 11.06 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 7.63 percent.

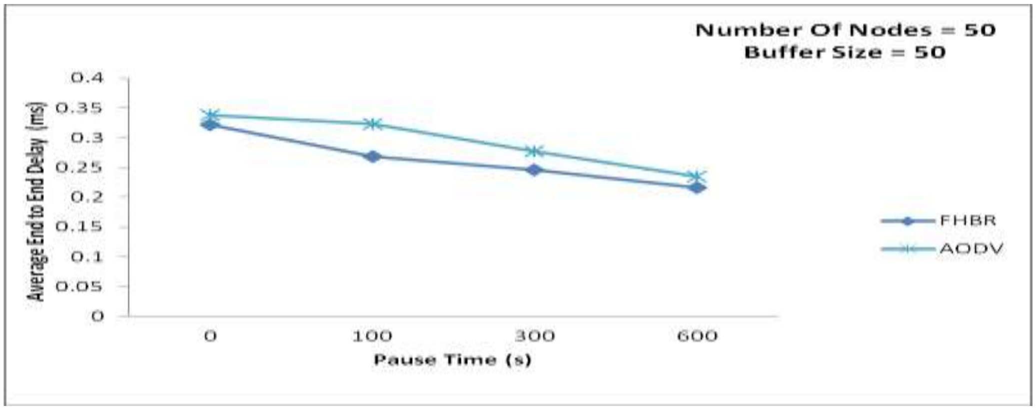

Figure 5-38: end to end of 20 sources each one sends 2 packets/s, with 50 nodes each has 50 packets buffer

Figure 5-39 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 11.28 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 7.68 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 9.12 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 9.68 percent.

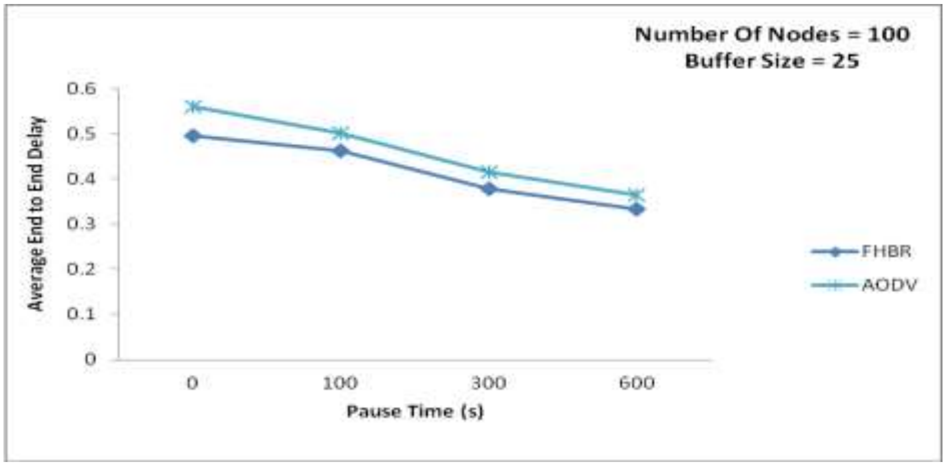

Figure 5-39: average end to end delay of 20 sources each one sends 2 packets/s, with 100 nodes each has 25 packets buffer

Figure 5-40 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends two packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 5.55 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 14.65 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 5.84 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 10 percent.

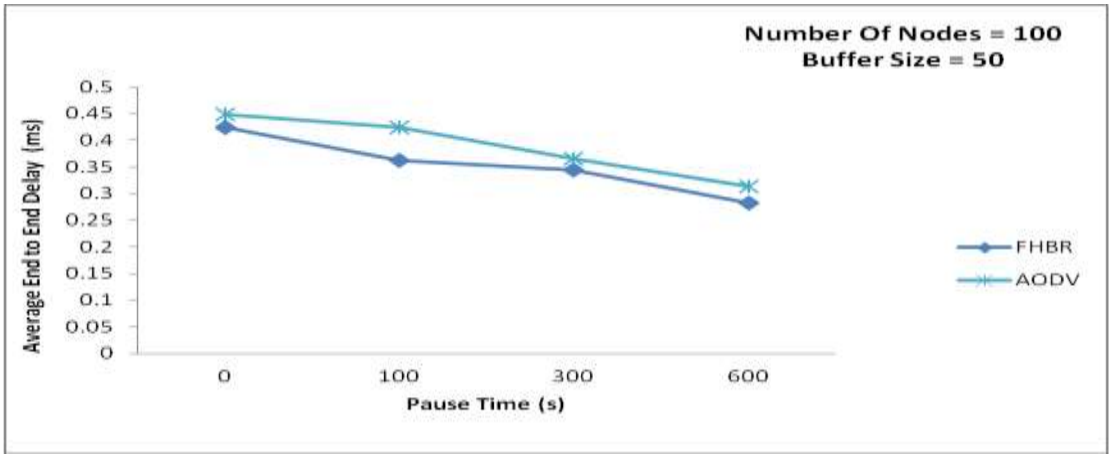

Figure 5-40: average end to end delay of 20 sources each one sends 2 packets/s, with 100 nodes each has 50 packets buffer.

Figure 5-41 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 8.22 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 5.19 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 7.42 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 6.56 percent.

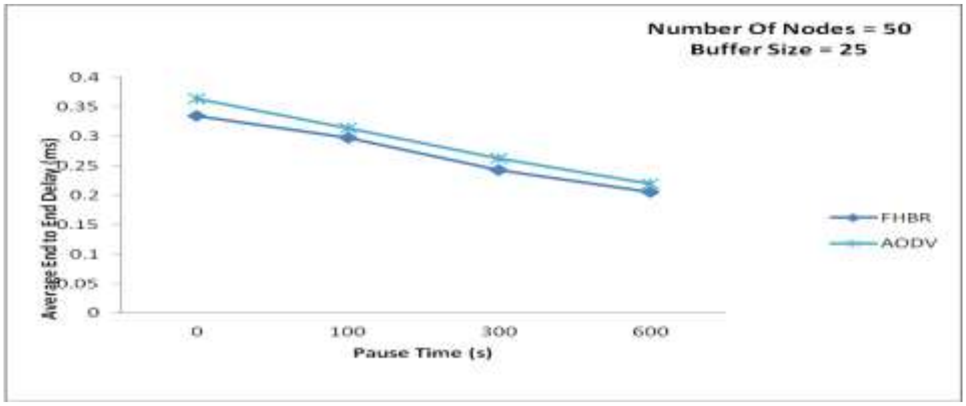

Figure 5-41: Average end to end delay of 20 sources each one sends 4 packets/s, with 50 nodes each has 25 packets buffer

Figure 5-42 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 6.57 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 14.67 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 7.34 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 5.24 percent.

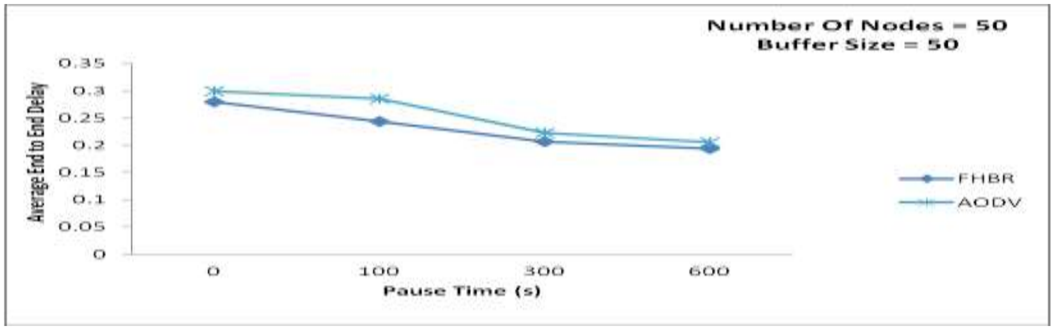

Figure 5-42: Average end to end delay of 20 sources each one sends 4 packets/s, with 50 nodes each has 50 packets buffer

Figure 5-43 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 9.13 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 5.89 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 9.31 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 7.13 percent.

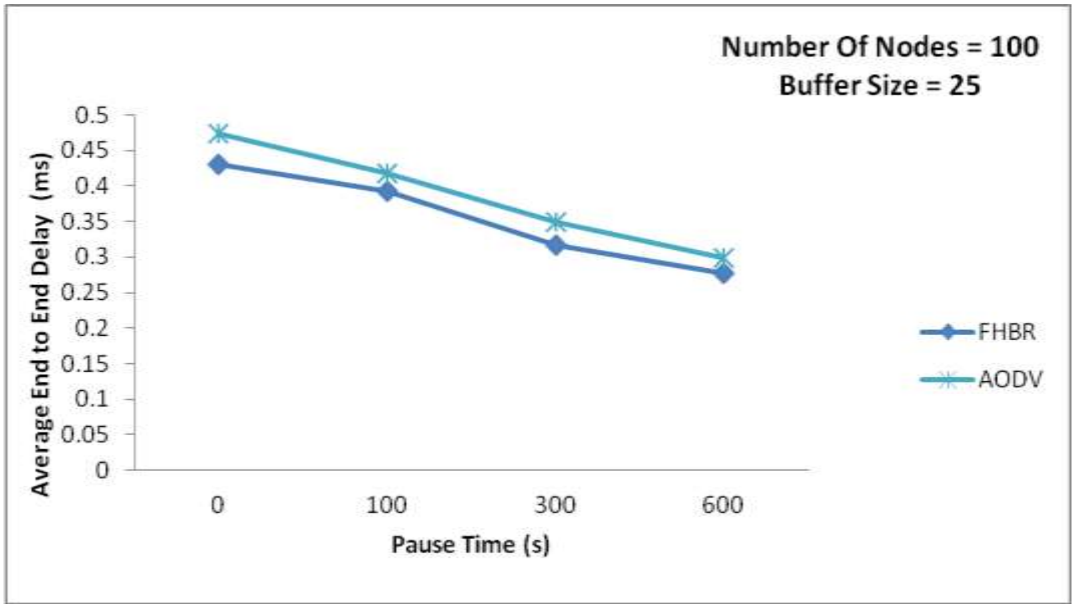

Figure 5-43: Average end to end delay of 20 sources each one sends 4 packets/s, with 100 nodes each has 25 packets buffer

Figure 5-44 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends four packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 5.02 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 17.03 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 10.78 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 7.63 percent.

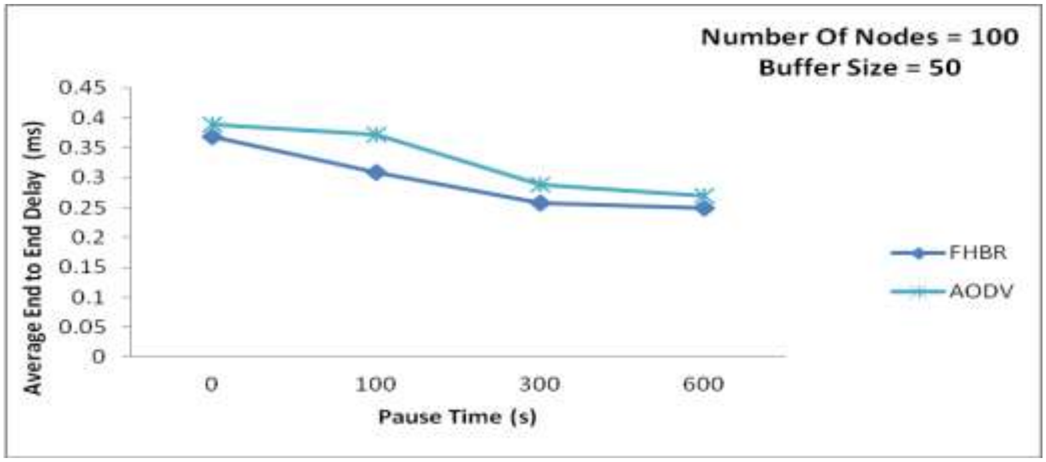

Figure 5-44: Average end to end delay of 20 sources each one sends 4 packets/s, with 100 nodes each has 50 packets buffer

Figure 5-45 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 10.29 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 7.99 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 8.09 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 8.14 percent.

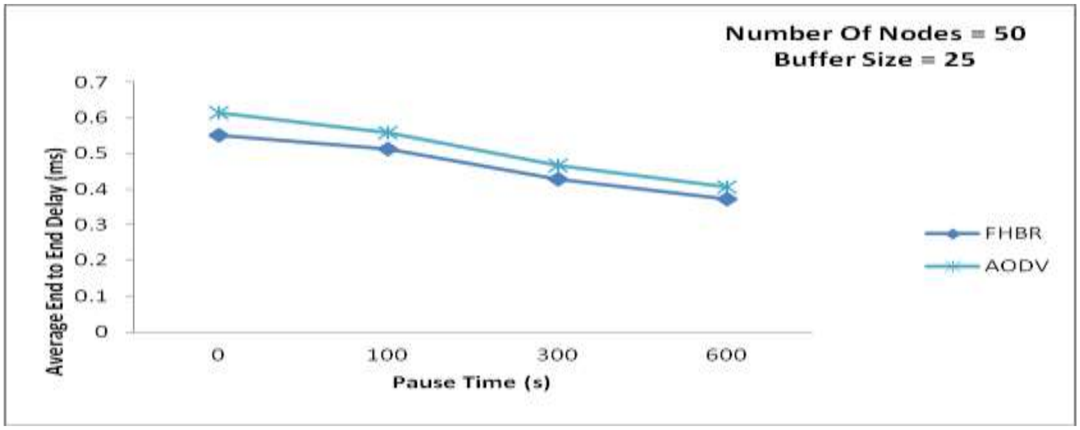

Figure 5-45: Average end to end delay of 20 sources each one sends 6 packets/s, with 50 nodes each has 25 packets buffer

Figure 5-46 shows the average end to end delay for FHBR and AODV for a network contains fifty nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 5.20 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 13.67 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 9.51 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 9.49 percent.

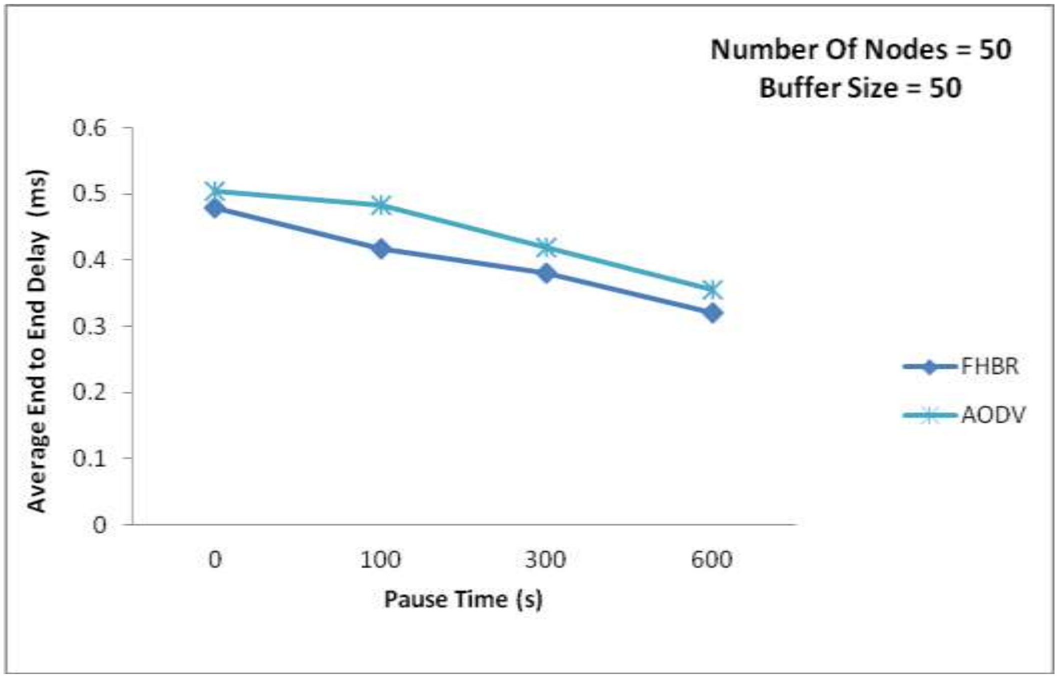

Figure 5-46: Average end to end delay of 20 sources each one sends 6 packets/s, with 50 nodes each has 50 packets buffer

Figure 5-47 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of twenty-five packets when the number of sources is twenty and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 11.44 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 6.36 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 14.39 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 13.58 percent.

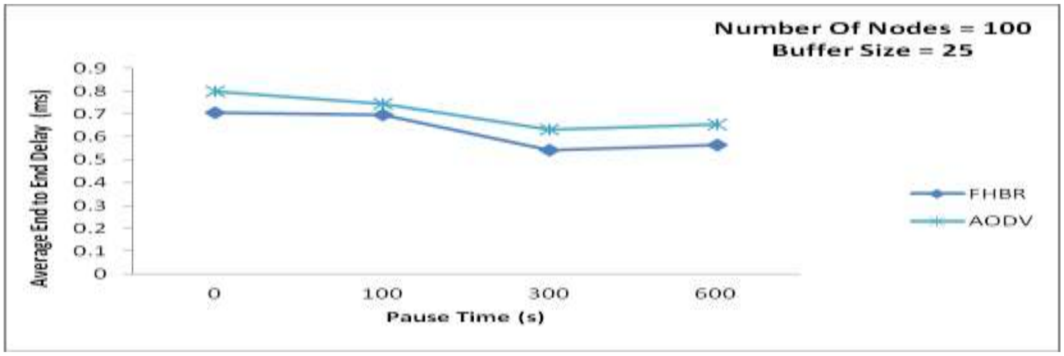

Figure 5-47: Average end to end delay of 20 sources each one sends 6 packets/s, with 100 nodes each has 25 packets buffer

Figure 5-48 shows the average end to end delay for FHBR and AODV for a network contains one hundred nodes each node has a buffer size of fifty packets when the number of sources is twenty and each source sends six packets per second. The figure shows that FHBR protocol outperforms AODV for all pause times. When the pause time is equal to zero (high mobility network), FHBR outperforms AODV by 5.89 percent. When the pause time is equal to 100 seconds FHBR outperforms AODV by 10.17 percent. When the pause time is equal to 300 seconds FHBR outperforms AODV by 5.98 percent. When the pause time is equal to 600 seconds (low mobility network), FHBR outperforms AODV by 7.60 percent.

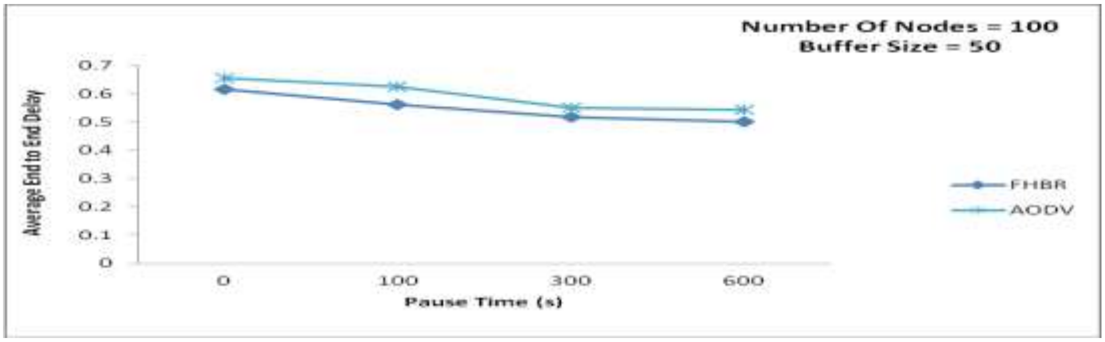

Figure 5-48: Average end to end delay of 20 sources each one sends 6 packets/s, with 100 nodes each has 50 packets buffer

Chapter 6

Conclusion and Future Work

6.1 Conclusion

In our study a new algorithm was designed and implemented to address the case of routing for MANETs called Failure History-Based (FHBR). FHBR chooses the path between source and destination by selecting the best intermediate nodes according to their failure history. A node that has a higher level of stability is selected rather than other nodes that have a bad history in frequent failures.

The idea of FHBR is that each node has a Failure History Factor (FHF) that express the history of a node. Each node adds its FHF to the route request packet. The destination selects the best route by selecting the route constructed from higher accumulated FHF of intermediate nodes.

FHBR was designed over the original AODV protocol by modifying route request and route reply phases. The maintenance phase in the original AODV was kept as it to maintain the network in case of link failures.

FHBR performance was evaluated against AODV by many scenarios conducted using Network Simulator (NS-2). The performance of FHBR and AODV was compared by two metrics: packets delivery ratio and average end-to-end delay. These two metrics were selected to ensure that FHBR handled the performance of a network with a minimum number of dropped packets and a minimum delay as possible.

We design many scenarios to evaluate the performance in different conditions according to nodes mobility, congestion level, ability of nodes to handle different number of packets and how network is dense.

The results of simulations show that FHBR outperforms AODV by a significant value in terms of packet delivery ratio because it selects the more stable intermediate nodes between source to destination and always avoid the shortest but congested paths.

The results always show that a higher buffer size made a higher packet delivery ratio in the network because of decreasing the packets that dropped in intermediate nodes.FHBR has a better average end to end delay than AODV but with a lower enhancement when compared with the enhancement measured by packet delivery ratio metric.

.6.2 *Future Work*

We can do the following future work to address the performance of FHBR in more practical environment:

- The performance of FHBR may be addressed by calculating the energy consumption in nodes because energy is another key point that should be monitored in MANETs real operations.
- Another route selection schema may be designed to make source share with destination in selecting best route between them.

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نموذج رقم (1)

جامعة آل البيت

نموذج تفويض

عمادة الدراسات العليا

أنا امال خالد قاسم العبابنه، أفوض جامعة آل البيت بتزويد نسخ من رسالتي للمكتبات أو المؤسسات أو الهيئات أو الأشخاص عند طلبهم حسب التعليمات النافذة في الجامعة.

التوقيع :

التاريخ :

نموذج رقم (2)

جامعة آل البيت

عمادة الدراسات العليا

إقرار والتزام بقوانين جامعة آل البيت وأنظمتها وتعليماتها لطلبة الماجستير والدكتوراه

أنا الطالب : امال خالد قاسم العبابنه   الرقم الجامعي : 1520901002

التخصص : علم الحاسوب   الكلية : الأمير الحسين بن عبدالله الثاني لتكنولوجيا المعلومات

أعلن بأنني قد التزمت بقوانين جامعة آل البيت وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة بإعداد رسائل الماجستير والدكتوراه عندما قمت شخصيا بإعداد رسالتي بعنوان :

Failure History-based Routing Protocol for Mobile Ad Hoc Networks.

وذلك بما ينسجم مع الأمانة العلمية المتعارف عليها في كتابة الرسائل والأطاريح العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستله من رسائل أو أطاريح أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تحزينها في أية وسيلة إعلامية، وتأسيساً على ما تقدم فأنني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في جامعة آل البيت بإلغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي حق في التظلم او الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

توقيع الطالب :   التاريخ :