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Energy Efficient Multipath Routing Protocol for Mobile ad-hoc Network Using the Fitness Function

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Abstract - Mobile Ad Hoc Network (MANET) is a collection of wireless mobile nodes that dynamically form a temporary network without the reliance on any infrastructure or central administration. Energy consumption is considered as one of the major limitations in MANET, as the mobile nodes do not possess permanent power supply and have to rely on batteries, thus reducing network lifetime as batteries get exhausted very quickly as nodes move and change their positions rapidly across MANET. The research proposed in this paper highlights this very specific problem of energy consumption in MANET by applying the Fitness Function technique to optimize the energy consumption in Ad Hoc On Demand Multipath Distance Vector (AOMDV) routing protocol. The proposed protocol is called Ad Hoc On Demand Multipath Distance Vector with the Fitness Function (FF-AOMDV). The fitness function is used to find the optimal path from the source to the destination to reduce the energy consumption in multipath routing. The performance of the proposed FF-AOMDV protocol was evaluated by using Network Simulator Version 2 (NS-2), where the performance was compared with AOMDV and Ad Hoc On Demand Multipath Routing with Life Maximization (AOMR-LM) protocols, the two most popular protocols proposed in this area. The comparison was evaluated based on energy consumption, throughput, packet delivery ratio, end-to-end delay, network lifetime and routing overhead ratio performance metrics, varying the node speed, packet size and simulation time. The results clearly demonstrate that the proposed FF-AOMDV outperformed AOMDV and AOMR-LM under majority of the network performance metrics and parameters.

Index Terms:* *Energy efficient protocol, mobile ad hoc network, multipath routing, and fitness function.

I. INTRODUCTION

The performance of computer and wireless communications technologies has advanced in recent years. As a result, it is expected that the use and application of advanced mobile wireless computing will be increasingly widespread. Much of this future development will involve the utilization of the Internet Protocol (IP) suite. Mobile ad hoc networks (MANETs) are envisioned to support effective and robust mobile wireless network operation through the incorporation of routing functionality into mobile nodes. These networks are foreseen to have topologies that are multihop, dynamic, random, and sometimes rapidly changing. These topologies will possibly be composed of wireless links that are relatively bandwidth-constrained [1]. Ad hoc networks are crucial in the evolution of wireless networks, as they are composed of mobile nodes which communicate over wireless links without central control. The traditional wireless and mobile communication problems like bandwidth optimization, transmission quality enhancement and power control are directly inherited by ad-hoc wireless networks. Furthermore, new research problems like Configuration advertising, discovery and maintenance are also brought on by ad hoc networks because of their multi-hop nature, lack of a fixed infrastructure and ad-hoc addressing and self-routing. There have been numerous proposals on different approaches and protocols as there are multiple standardization efforts being done in the Internet Engineering Task Force and even as academic and industrial ventures [2].

In MANETs, the limited battery capacity of a mobile node affects network survivability since links are disconnected when the battery is exhausted. Therefore, a routing protocol considering the mobile nodes energy is essential to guarantee network connectivity and prolong the network lifetime [3]. Power-aware routing protocols deal with techniques that reduce the energy consumption of the batteries of the mobile nodes. This approach is basically done by forwarding the traffic through nodes that their batteries

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have higher energy levels. This will increase the network lifetime.

Various power-aware routing protocols have been proposed by taking into account the energy consumption for the transmission or the remaining battery level of the mobile nodes or both. By using such power-aware information, various routing costs and path selection algorithms have been investigated for the purpose of improving the energy efficiency in the MANET [4]. Many routing protocols have been developed during the last years to increase the lifetime of a route and in turn the lifetime of the network. One of these developments is multipath routing protocols. Multipath routing protocols enable the source node to choose the best route among many routes during a single route discovery process. This process in multipath routing will decrease the number of route discovery processes since there are backup routes already available and in case one route fails will reduce the end-to-end delay, energy consumption and the network lifetime.

Multipath routing protocols flood a route request to learn more than one path to the destination to forward packets through them. It is not necessary that the source will always find the optimum or the shortest path available. Since the power source of the mobile nodes is limited, the power consumption by these nodes should be controlled to increase the network lifetime. Multipath routing protocols have several issues. One of them is finding an optimum path from the sources to the destinations. The issue becomes more complicated with a large number of mobile nodes that are connected to each other for transferring the data. In this case, most of the energy is going to be consumed at the time of investigating for shortest routes. Subsequently, the more energy is wasted at data transfer.

The research in this paper presents an energy efficient multipath routing protocol called Ad-Hoc On demand Multipath Distance Victor with the Fitness Function (FF-AOMDV). The FF-AOMDV uses the fitness function as an optimization method, in this optimization, we seek for two parameters in order to select the optimum route are; energy level of the route and the route distance in order to transfer the data to the destination more efficiently by consuming less energy and prolonging the network lifetime. Based on the results of the simulation, the FF-AOMDV routing protocol outperformed both Ad-Hoc On demand Multipath Distance Victor (AOMDV) and Ad-Hoc On demand Multipath Routing with Life Maximization (AOMR-LM) routing protocols in terms of throughput, packet delivery ratio, end-to-end delay, energy consumption, network lifetime and routing overhead ratio except the AOMR-LM when comparing with energy consumption and network lifetime where it has better performance than FF-AOMDV with these two metrics.

The rest of the paper is organized as follows: Section 2 discusses the background of AOMDV, fitness function and related studies; Section 3 presents the proposed FF-AOMDV; Section 4 presents the results and evaluation, Section 5 concludes the study and presents the future work.

II. BACKGROUD & RELATED WORK

A. AOMDV Routing Protocol

An on-demand routing protocol, AOMDV has its roots in the Ad hoc On-Demand Distance Vector (AODV), a popular single-path routing protocol. AOMDV creates a more extensive AODV by discovering, at every route discovery process, a multipath (i.e. several other paths) between the source and the destination. The multipath has a guarantee for being loop-free and link-disjoint. AOMDV likewise offers two key services: route discovery and route maintenance. Since it greatly depends on the AODV route information, which is already available, AOMDV incurs less overhead than AODV through the discovery of multiple routes. Compared to AODV, AOMDV's only additional overhead is extra RREPs and RERRs intended for multipath discovery and maintenance, along with several extra fields to route control packets (i.e. RREQs, RERRs and RREPs) [5]. Adding some fields and changing others modified the structure of the AOMDV's routing table. Figure 1 presents the routing table entries' structure for AODV and AOMDV. In AOMDV, *advertised_hopcount* is used instead of the *hopcount* in AODV [6]. A *route_list* stood as a replacement for *nexthop;* this change essentially defining multiple *nexthops* with respective *hopcounts*. All *nexthops*, however, are still allotted the same destination sequence number. Every time the *sequence number* gets updated, the advertised*_hopcount* is initialized.

After performing the simulations using NS-2, the overall performance comparison between AOMDV-AODV shows that the former algorithm was able to cope up with route failures more effectively that are mobility-induced. Particularly, AOMDV decreases the packet loss to 40% and greatly improves the end-to-end delay. It also causes a reduction of routing overhead to about 30% by decreasing route discovery operations' frequency hence improving the overall

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performance of MANET compare to AODV algorithm.

destination
sequence number
hopcount
nexthop
expiration_timeout

(a) AODV

destination
sequence number
advertised_hopcount
route_list $\{(nexthop_1, hopcount_1), (nexthop_2, hopcount_2), ..\}$
expiration_timeout

(b) AOMDV

Fig. 1. Routing table structure for AODV and AOMDV [21]

B. Route discovery and maintenance

Route discovery and route maintenance involve finding multiple routes from a source to a destination node. Multipath routing protocols can try to discover the link-disjoint, node disjoint, or non-disjoint routes [7, 8]. While link-disjoint routes have no common links, it may have nodes in common. Node-disjoint routes, which are also referred to as totally disjoint routes, do not have common nodes or links. Non-disjoint routes, on the other hand, can have both nodes and links that are in common [9]. AOMDV's primary idea is in discovering multiple routes during the process of route discovery. The design of AOMDV is intended to serve highly dynamic ad-hoc networks that have frequent occurrences of link failure and route breaks. A new process of route discovery is necessary in the event that all paths to the destination break.

AOMDV utilizes three control packets: the route request (RREQ); the route reply (RREP); and the route error (RERR). Initially, when a source node is required to transmit data packets to a specific destination, the source node broadcasts a RREQ [10]. Because the RREQs is a flooded network-wide, several copies of the very same RREQ may be received by a node. In the AOMDV, all duplicate copies undergo an examination to determine the potential alternate reverse path. However, of all the resulting set of paths to the source, only the use of those copies, which preserve loop-freedom and disjointedness, get to form the reverse paths. In the event the intermediate nodes get a reverse path through a RREQ copy, it conducts a check to determine the number of valid forward paths (i.e. one or many) to the destination. If so, a RREP is generated by the node and the request is sent back to the source using the reverse path. Since this route discovery, the RREP has a forward path that was not employed in any prior RREPs. The RREQ is not further propagated by the intermediate node. Otherwise, the node would broadcast the RREQ copy again in case any other copy of this RREQ has not been previously forwarded and this copy has led to the updating or the formation of a reverse path.

Like intermediate nodes, the destination likewise forms reverse paths when it receives RREQ copies. As a response to each RREQ copy arriving through a loop-free path towards the source, the destination produces a RREP, despite forming reverse paths that use only RREQ copies arriving through loop-free and disjoint alternate paths towards the source. A RERR packet is used in AOMDV route maintenance. In the event a link breaks, it generates a RERR message, listing lost destinations. The RERR is sent upstream by the node towards the source node. In the case of the existence of the previous multiple hops, which were using this link, the RERR is broadcast by the node. If there are no previous multiple hops, the request is unicast. Upon getting a RERR, the receiving node initially checks whether the node which sent the RERR is its own next hop towards any of the destination that is listed in the RERR [11]. If the sending node is indeed the recipient node's next hop, the receiving node makes this route table invalid, after which it propagates the RERR back to the source. In this manner, the RERR continues to be forwarded until the source receives the request. Once this happens, it can initiate the route discovery again if it still requires the said route.

C. Disjoint Path

Two types of disjoint path exist, the node-disjoint path and link-disjoint path [12]. In a node-disjoint path, there is no common node exists in a specific path other than the source and destination nodes. In a link-disjoint path, there is no common link at all [13].

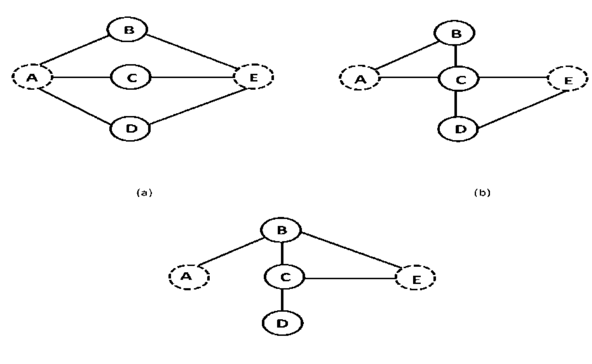

Fig. 2. Link and node disjoint path. (a) Link and node disjoint path, (b) Link disjoint path, (c) Not disjoint path

Figure 3.3 illustrates the notion of node and link disjoint paths. The routes ABE, ACE, and ADE have no common node or link, as illustrated in Figure 2 (a). Thus, they are link and node-disjoint paths. Figure 2 (b) shows the routes ABCDE and ACE have node C in common; however, there is no link in common, which makes a link-disjoint path without a node disjoint path. Lastly, Figure 2 (c) illustrates the routes ABCE and ABE, which have both the link AB and the node B in common; therefore, they do not have a disjoint path.

D. Fitness Function

The fitness function is an optimization technique that comes as a part of many optimization algorithms such as genetic algorithm, bee colony algorithm, firefly algorithm and particle swarm optimization algorithm. The fitness function finds the most important factor in the optimization process, which could be many factors depending on the aim of the research. In MANET, the fitness factor is usually energy, distance, delay, and bandwidth. This matches the reasons for designing any routing protocol, as they aim to enhance the network resources. In this research, the fitness function used is part of the Particle Swarm Optimization (PSO) algorithm as proposed in [14]. It was used with wireless sensor networks to optimize the alternative route in case the primary route fails. The factors that affect the choice of the optimum route are:

- The remaining energy functions for each node
- The distance functions of the links connecting the neighboring nodes
- Energy consumption of the nodes
- Communication delay of the nodes

The PSO algorithm is initialized with a population of random candidate solutions, conceptualized as particles. Each particle is assigned a randomized velocity and iteratively moved through the problem space. It is attracted towards the location of the best fitness achieved so far by the particle itself and by the location of the best fitness achieved so far across the whole population [15]. The PSO algorithm includes some tuning parameters that greatly influence the algorithm performance, often stated as the exploration–exploitation trade-off: “Exploration is the ability to test various regions in the problem space in order to locate a good optimum, hopefully the global one. Exploitation is the ability to concentrate the search around a promising candidate solution in order to locate the optimum precisely [16, 17]”. In this case, the particles are attracted towards two fitness parameters which are; energy level of the mobile nodes and the distance of the route. With these two parameters, the optimization could be found by forwarding traffic through the route that has the highest level of energy and less distance in order to minimize the energy consumption related studies.

Smail et al. proposed an energy-efficient multipath routing protocol, called Ad hoc On-demand Multipath Routing with Lifetime Maximization (AOMR-LM), which preserves the residual energy of nodes and balances the consumed energy to increase the network lifetime. They used the residual energy of nodes for calculating the node energy level. The multipath selection mechanism uses this energy level to classify the paths. Two parameters are analysed: the energy threshold and the coefficient. These parameters are required to classify the nodes and to ensure the preservation of node energy. The AOMR-LM protocol improves the performance of MANETs by prolonging the lifetime of the network. This novel protocol has been compared with both AOMDV and ZD-AOMDV. The protocol performance has been evaluated in terms of network lifetime, energy consumption, and end-to-end delay [18].

Manickavelu & Vaidyanathan concentrated on the route discovery process effect on the data loss, communication overhead and energy consumption. For these reasons, they proposed a particle swarm optimization (PSO) based lifetime prediction algorithm for route recovery in MANET. This technique predicts the lifetime of link and node in the available bandwidth based on the parameters like the relative mobility of nodes and energy drain rate. Using predictions, the parameters are fuzzified and fuzzy rules were shaped to decide on the node status. This information is made to exchange among all the nodes. Thus, the status of every node is verified before data transmission. Even for a weak node, the performance of a route recovery mechanism is made in such a way that corresponding routes are diverted to the strong nodes. The simulation results indicate that the proposed technique minimizes the packet loss and communication overhead [19].

Sharma et al. proposed an energy efficient reactive routing protocol that uses the received signal strength (RSS) and power status (PS) of mobile nodes. Proposed Link Failure Prediction (LFP) algorithm used the link-layer feedback system to update active routes. Comparing the results of the proposed algorithm with existing algorithms, in terms of energy consumption, link failure probability, and retransmission of packets, the proposed algorithm outperform the existing algorithms [20].

Nasehi et al. tried to discover the distinct paths between the source and destination nodes by using Omni directional antennas, to send information

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through these routes simultaneously. For this purpose, the number of active neighbors are counted in each direction. These criterions are effectively used to select routes. The proposed algorithm was based on AODV routing protocol and was compared with AOMDV, AODVM, and IZM-DSR routing protocols which are multipath routing protocols based on AODV and DSR. Simulation results showed that the proposed algorithm created a significant improvement in energy efficiency and reducing end-to-end delay [21].

Hiremath & Joshi proposed an energy efficient routing protocol that conserves energy of the mobile nodes enhancing the lifetime of the MANET. It is an On demand routing protocol based on adaptive fuzzy threshold energy (AFTE). The experimental results were compared with the Load-Aware Energy Efficient Protocol (LAEE) protocol proposed by the same authors. The results clearly showed that AFTE performs better compared to LAEE. The average network lifetime was enhanced upto 13% considering first node failure, 15% considering 50% node failure and 23% considering 100% node failure compared to LAEE [22].

In [23] De-Rango et al. considered path duration and energy awareness to accomplish certain QoS constraints as to reduce the route discovery procedures. Even though energy saving and path duration and stability are two contrasting efforts and to satisfy both of them can be very difficult. The authors proposed a novel routing strategy which tries to account for link stability with a minimum rate of energy consumption. In order to verify the accuracy and accomplishment of the proposed algorithm, an optimization formulation technique was designed along with a routing protocol called Link-stability and Energy-aware Routing (LAER) protocol. The performance of proposed protocol was compared with PERRA, GPSR, and E-GPSR, in terms of packet delivery ratio, normalized control overhead, link duration, node lifetime, and average energy consumption.

Chen & Weng analyzed two factors that influence the transmission bandwidth: the signal strength of the received packets and the contentions in the contention-based MAC layer. These two factors may cause more power to be consumed during data transmission. They proposed a power aware routing protocol called MTPCR. It discovers the desired routing path with reduced power consumption during data transmissions. It does so by taking into account the situations in which, the transmission bandwidth of the routing path may decrease, resulting in much power consumption during data transmission because of the mobility nature of the mobile nodes in MANET. MTPCR analyzes the power consumption during data transmission with the help of the neighboring nodes and using a path maintenance mechanism to maintain optimal path bandwidth. This mechanism helps to reduce the power consumption more efficiently during data transmission along with the number of path breakages. The proposed routing protocol was compared with multiple routing protocols including (AODV, DSR, two power aware routing protocols (MMBCR and xMBCR) and multipath routing protocol (PAMP)). The comparison was conducted in terms of throughput, energy consumption during path discovery, energy consumption during data transmission and network lifetime [24].

Rajaram & Sugesh addressed the issues of energy consumption and path distance from the source to the destination in MANET. They proposed a multipath routing protocol based on AOMDV called as, Power Aware Ad-hoc On Demand Multipath Distance Vector (PAAOMDV). The proposed protocol updates the routing table with the corresponding energy of the mobile nodes. As this was a multipath protocol, it shifts the route without further overhead, delay and loss of packets. The simulation results showed that PAAOMDV performs well compared to AOMDV routing protocol after introducing energy-related fields in PAAOMDV [25].

Sun et al. proposed an Energy-entropy Multipath Routing optimization algorithm in MANET based on GA (EMRGA). The key idea of the protocol was to find the minimal node residual energy of each route in the process of selecting a path by descending node residual energy. It can balance individual nodes battery power utilization and hence prolong the entire networks lifetime and energy variance. Experimental results show that the algorithm is efficient and has a promising performance advantage for multipath traffic engineering and evaluates the route stability in dynamic mobile networks [26].

III. PROPOSED FF-AOMDV

In this paper, we proposed a new multipath routing protocol called the FF-AOMDV routing protocol, which is a combination of Fitness Function and the AOMDV's protocol. In a normal scenario, when a RREQ is broadcasted by a source node, more than one route to the destination will be found and the data packets will be forwarded through these routes without knowing the routes' quality. By implementing the proposed algorithm on the same scenario, the route selection will be totally different. When a RREQ is broadcast and received, the source node will have

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three (3) types of information in order to find the shortest and optimized route path with minimized energy consumption. This information include:

- Information about network's each node's energy level
- The distance of every route
- The energy consumed in the process of route discovery.

The route, which consumes less energy, could possibly be (a) the route that has the shortest distance; (b) the route with the highest level of energy, or (c) both. The source node will then sends the data packets via the route with highest energy level, after which it will calculate its energy consumption. Alike to other multipath routing protocols, this protocol will also initiates new route discovery process when all routes to the destination are failed. In the event when the selected route fails, the source node will then selects an alternative route from its routing table, which represents the shortest route with minimum energy consumption. The optimal route with less distance to destination will consume less energy and it can be calculated as follows:

$$Optimum\ route1 = \frac{\sum v(n) \in r \quad ene(v(n))}{\sum v \in V ene(v)} \qquad (1)$$

In this equation, *v* represents the vertices (nodes) in the optimum route *r* and *V* represent all the vertices in the network. It compares the energy level among all the routes and chooses the route with the highest energy level. The alternative route will be calculated according to its distance. The AOMDV maintains the route with the least hop count. FF-AOMDV implements the same techniques after selecting the route with the highest energy level, the routing table keeps information about the route with the least distance. The calculation of the shortest route is as follows:

$$Optimum\ route2 = \frac{\sum e(n) \in r \quad dist(e(n))}{\sum e \in E} \qquad (2)$$

Where *e* represents the edges (links) in the optimum route *r* and *E* represent all the edges in the network. It compares the distance of the links in the optimum route and compares it with all the links in the network. The pseudo-code for the fitness function is provided as follow:

1: Select the Source and Destination.
2: Source Initialize the route Discovery.
3: Broadcast the Routing Packet to direct nodes.
4: Update the routing information in the Source Routing Table.
5: Source Initialize the Beacon.
6: Broadcast the Routing Packet to direct nodes.
7: Update the Energy and location information in the Source Energy Table for all the nodes in the entire network.
8: check
If(*ene*>= High &&*dist*<= Low &&*hop Count*<= Low) … (Eq. 1 & 2)
Select that route for Communication.

Else if (*ene*>= High &&*dist*>= high &&*hop Count*<= Low) … (Eq. 1)
Select that route for Communication.
Else if (*ene*<= Low&&*dist*<= Low &&*hop Count*<= Low t) … (Eq. 2)
Select that route for Communication
9: Send the periodic route discovery.
10: Send the periodic beacon message.

Simulations are conducted to run the FF-AOMDV protocol. In this simulation, an OTcl script has been written to define the network parameters and topology, such as traffic source, number of nodes, queue size, node speed, routing protocols used and many other parameters. Two files are produced when running the simulation: trace file for processing and a network animator (NAM) to visualize the simulation. NAM is a graphical simulation display tool. To have a better understanding of how the fitness function works with AOMDV routing protocol, figure 3 shows the route selection of FF-AOMDV based on specific parameters.

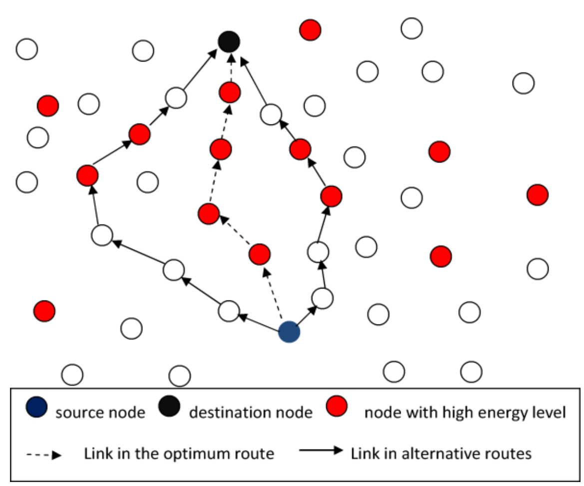

Fig. 3 Optimum route selection in FF-AOMDV

The FF-AOMDV initially broadcasts a RREQ in order to gather information regarding the available routes towards the destination as shown in figure 3 where the fitness function performs a scan on the network in order to locate nodes that have a higher level of energy (red nodes). The source point will then receive a RREP that contains information on the available routes towards the destination along with their energy levels. Calculating each route's energy level, the fitness function will then compare to finding the route with highest energy level. The distance of this route will be considered.

The optimum route refers to the route that has the highest energy level and the less distance. Priority is given to the energy level, as seen on the route with the discontinuous arrow (Figure 3). In another scenario, if the route has the highest energy level, but does not have the shortest distance, it can also be chosen but with less priority. In some other scenarios, if the intermediate nodes located between the source and destination with lesser energy levels compared to other nodes in the network, the fitness function will choose the route based on the shortest distance available. In all the cases, with these two parameters, only those routes will be chosen by the fitness function which has less energy consumption and will prolong the lifetime of the network.

IV. RESULTS & EVALUATION

I. *Simulation Model and Parameters*

To evaluate the performance of our proposed FF-AOMDV protocol, three different scenarios were selected (i.e. node speed, packet size, and simulation time). In this simulation, we utilized the Constant Bit Rate (CBR) as a traffic source with 50 mobile nodes that are distributed randomly in a 1500 m* 1500 m network area; the network topology may therefore, undergo random change since the nodes' distribution and its movement are random. The transmission range of the nodes was set to 250 m, while, for each node, the initial energy level was set to 100 joules. Three different scenarios were chosen to see how they are affecting the performance of the proposed FF-AOMDV protocol. In the first scenario, we varied the packet size as (64, 128, 256, 512, 1024) bytes and kept both the node speed and simulation time fixed as (2.5 meter/second and for 50 seconds) respectively. All other network parameters are the same for all runs and for all simulated protocols. In the second scenario, we varied the node speed as (0, 2.5, 5, 7.5, 10) seconds and kept the packet size and simulation time fixed as (256 bytes and 50 seconds) respectively. Finally, in the third scenario, we varied the simulation time as (10, 20, 30, 40, 50) seconds and kept the both the node speed and packet size fixed as (2.5 meters/second and 256 bytes) respectively. Table 1 presents all the simulation parameters.

Table (1) Simulation Parameters

Parameter	Value	Unit
Number of runs	5	
Number of nodes	50	Node
Node speed	0, 2.5, 5, 7.5, 10	Meter/second
Queue size	50	packet
Simulation area	1500 * 1500	$meter^2$
Routing protocols	FF-AOMDV, AOMR-LM, AOMDV	Protocol
Mobility model	Random way point	
Packet size	64, 128, 256, 512, 1024	Byte
Transmission range	250	Meter
Traffic type	CBR	
Initial energy	100	Joules
Transmission power consumption	0.02	Joules
Receive power consumption	0.01	Joules
Sleep power	0.001	
Simulation time	10, 20, 30, 40, 50	seconds

II. *Performance metrics*

The performance metrics used in the simulation experiments are as follows:

1. ***Packet Delivery Ratio*: (PDR)** means the ratio of the data packets that were delivered to the destination node to the data packets that were generated by the source [27]. This metric shows a routing protocol's quality in its delivery of data packets from source to destination. The higher the ratio, the better the performance of the routing protocol. PDR is calculated thusly:

$$PDR = \frac{number\ of\ packets\ recieved}{number\ of\ packets\ sent} * 100 \quad (3)$$

2. ***Throughput:*** Throughput is known as the number of bits that the destination has successfully received. Expressed in kilobits per second (Kbps) [28]. Throughput measures a routing protocol's efficiency in receiving data packets by destination. Throughput is calculated as follows:

*TP = (number of bytes received * 8 / simulation time) * 1000 kbps* (4)

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3. ***End-to-end delay***: End-to-End delay refers to the average time taken by data packets in successfully transmitting messages across the network from source to destination [29, 30]. This includes all types of delays, like queuing at interface queue; propagation and transfer times; MAC retransmission delays; and buffering during the route discovery latency. Stated below is the formula to calculate the E2E delay:

$$E2E\ delay = \frac{\sum_{i=1}^{n}(Ri - Si)}{n} \quad (5)$$

4. ***Energy Consumption:*** Energy consumption refers to the amount of energy that is spent by the network nodes within the simulation time. This is obtained by calculating each node's energy level at the end of the simulation, factoring in the initial energy of each one. The following formula will produce the value for energy consumption:

$$Energy\ Consumption = \sum_{i=1}^{n}(ini(i) - ene(i)) \quad (6)$$

5. ***Network Lifetime:*** The network lifetime refers to the required time for exhausting the battery of *n* mobile nodes, which is calculated using the following formula:

$$Network\ Lifetime = \sum_{i=1}^{n}(ene(i) = 0) \quad (7)$$

6. ***Routing Overhead Ratio:*** The routing overhead ratio metric is the total number of routing packets, which is divided by the overall number of data packets that were delivered. This study analysed the average number of routing packets that is required to deliver a single data packet. This metric offers an idea about the extra bandwidth that is consumed by the overhead in order to deliver data traffic. The routing overhead has an effect on the network's robustness in terms of the bandwidth utilization and battery power consumption of the nodes. The following formula represents the computation of the routing overhead:

$$Routing\ overhead(\%) = \frac{No\ of\ routing\ packets}{No\ of\ routing\ packets + No\ of\ data\ packets\ sent} * 100 \quad (8)$$

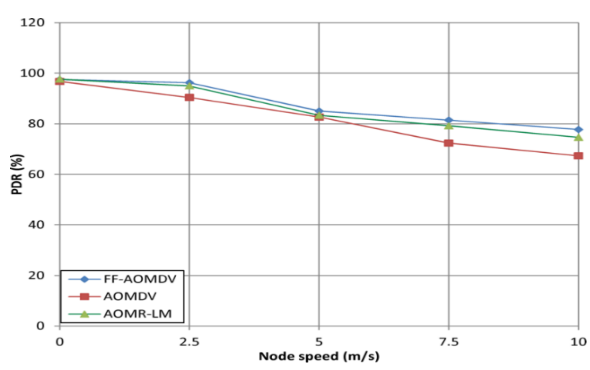
III. *Experimental Results*

a. Packet delivery ratio

Fig.4 (a) shows the variation of packet delivery ratio for FF-AOMDV, AOMR-LM and AOMDV. When the node speed increases as (0, 2.5, 5, 7.5, 10) m/s, the packet delivery ratio decreases. FF-AOMDV decreases from 97.55% to 77.8%, AOMR-LM decreases from 97.7% to 74.7% and AOMDV decreases from 96.79% to 67.35%. The FF-AOMDV has higher packet delivery ratio than both AOMR-LM and AOMDV. The FF-AOMDV routing protocol selects the most stable route toward the destination. The selected route could be the route with the highest energy level and consumes less energy than other routes, with the shortest route. This decreases the possibility of link failure and minimizes packet loss.

Fig.4 (b) shows the variation of the packet delivery ratio for FF-AOMDV, AOMR-LM and AOMDV. When the packet size increases as (64, 128, 256, 512, 1024) bytes, the packet delivery ratio decreases. The FF-AOMDV decreases from 95.45% to 81.06%, the AOMR-LM decreases from 93.12% to 79.9% and AOMDV decreases from 89.56% to 70.67%. The performance of the FF-AOMDV outperformed both AOMR-LM and AOMDV routing protocols in terms of packet delivery ratio, as FF-AOMDV minimizes the packet loss by selecting more reliable routes and routes with less distance.

Fig.4 (c) shows the effect of varying simulation time on the packet delivery ratio for FF-AOMDV, AOMR-LM and AOMDV routing protocols. Simulation time is varied as (10, 20, 30, 40 and 50) seconds. When the simulation time increases, the packet delivery ratio also increases. The FF-AOMDV protocol has better performance in terms of packet delivery ratio than both AOMR-LM and AOMDV protocols. The FF-AOMDV protocol achieved 75.36% of packet delivery ratio in 10 seconds of simulation time and 77.91% in 50 second simulation, the AOMR-LM protocol achieved 74.8% of packet delivery ratio in 10 seconds simulation time and 77.3% in 50 seconds of simulation time and finally, the AOMDV achieved 70.23% in 10 seconds simulation time and 76.22% of 50 seconds simulation time. The results clearly demonstrate that The FF-AOMDV protocol has better performance because of the strong and short routes it selects to forward the data traffic, which reduces the packet loss.



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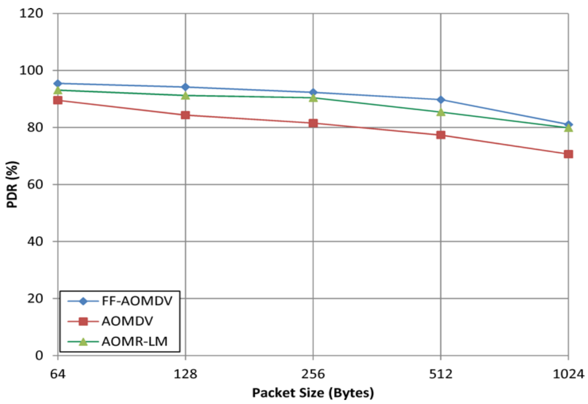

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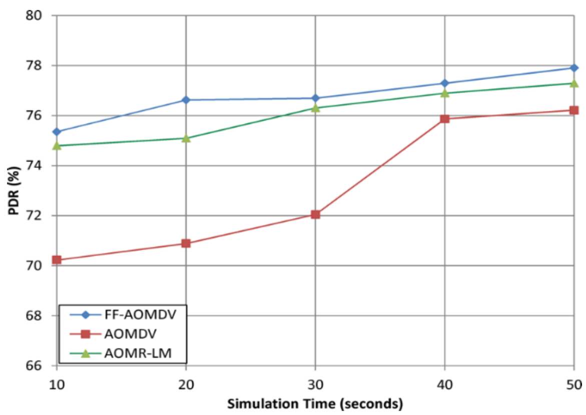


(c)

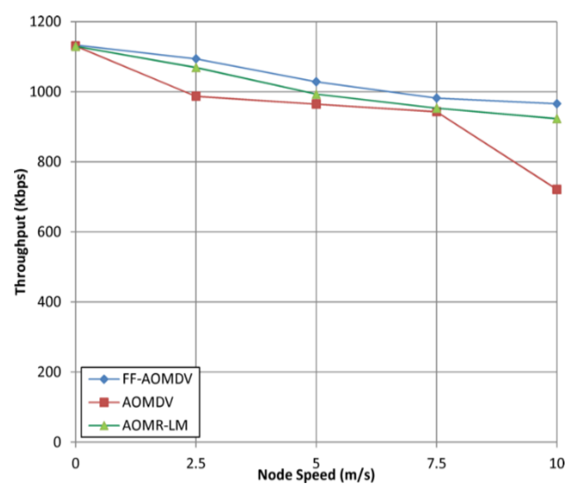
Fig. 4: Packet delivery ratio (a) node speed (b) packet size (c) simulation time

b. Throughput

The results after performing simulations clearly demonstrate the variation of throughput for FF-AOMDV, AOMR-LM and AOMDV. These protocols have different throughput when increasing the node speed. When the speed of the mobile nodes increases as (0, 2.5, 5, 7.5, 10) m/s, the throughput of FF-AOMDV decreases from 1133.08 Kbps to 965.94 Kbps, AOMR-LM decreases from 1129.68 Kbps to 923.41 Kbps and AOMDV decreases from 1130.64 Kbps to 721.31 Kbps. The FF-AOMDV routing protocol has higher throughput than both AOMDV and AOMR-LM protocols. In this scenario the nodes are either not moving (speed is zero) or at different humans speed. Random movement makes the nodes move in different directions for each run, FF-AOMDV routing protocol has better throughput as it selects the most active routes to the destination. These routes have less distance or more energy level than other routes; therefor the link is more stable and ultimately very few drop packets. This in turn increases the throughput as shown in figure Fig.5 (a).

Fig.5 (b) shows the variation of throughput for FF-AOMDV, AOMR-LM and AOMDV. When the packet size increases as (64, 128, 256, 512, 1024) bytes, the throughput decreases. The FF-AOMDV decreases from 1134.78 kbps to 981.26 kbps, the AOMR-LM decreases from 1121.73 kbps to 930.66 kbps and the AOMDV also decreases from 1114.67 kbps to 830.09 kbps. The FF-AOMDV routing protocol has better performance than both AOMR-LM and AOMDV in terms of throughput. The route distance and stability give an advantage to FF-AOMDV routing protocol to minimize the packet loss and maximize the throughput.

Fig.5 (c) shows the effect of varying simulation time on the throughput for FF-AOMDV, AOMR-LM and AOMDV routing protocols. Simulation time is varied as (10, 20, 30, 40 and 50) seconds. When the simulation time increases, the throughput increases also. The FF-AOMDV protocol has better performance in terms of throughput than both AOMR-LM and AOMDV protocols. The FF-AOMDV has 140.78 kbps throughput in 10 second simulation time and 1113.63 kbps in 50 second of simulation time, the AOMR-LM has 126.67 kbps throughput in 10 second simulation time and 1058.4 kbps in 50 second simulation time and finally, the AOMDV has 104.77 kbps throughput in 10 second simulation time and 889.1 kbps in 50 second simulation time. As long as the route is strong, short and stable, the throughput will be at its maximum level as in FF-AOMDV by minimizing the dropped packets.



(a)

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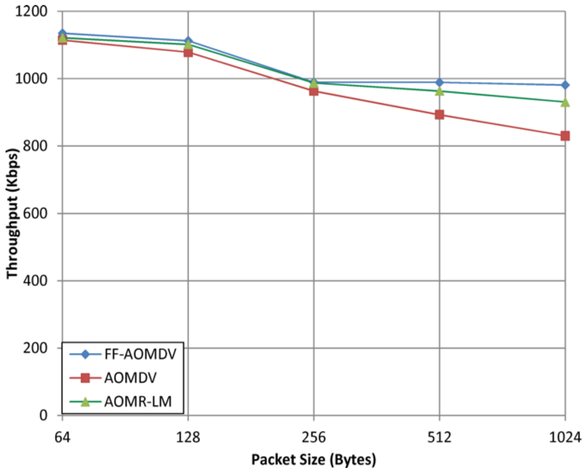

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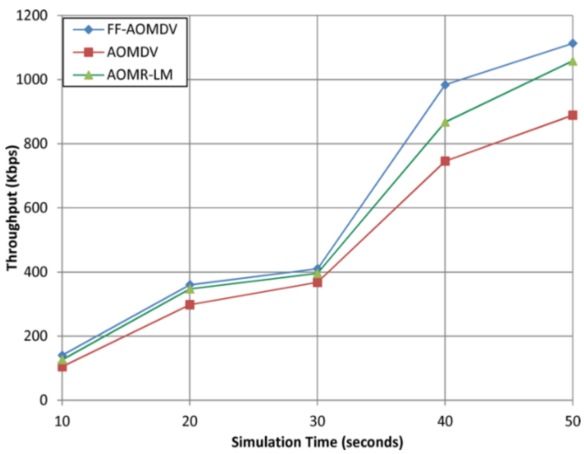


(c)

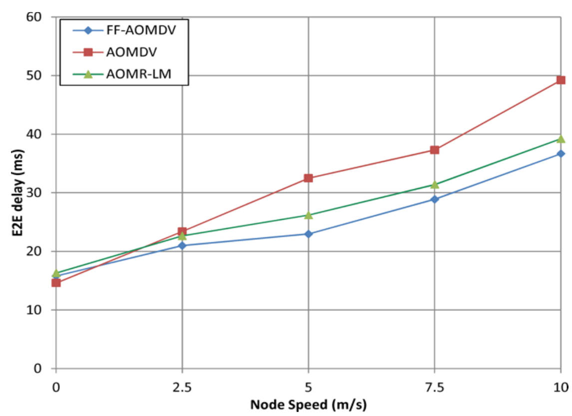
Fig. 5: Throughput (a) node speed (b) packet size (c) simulation time

c. End-to-end delay

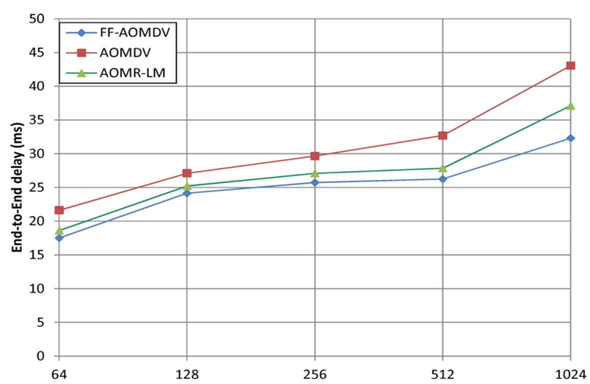
Fig.6 (a) shows the variation of end-to-end delay for FF-AOMDV, AOMR-LM and AOMDV. When the node speed increases as (0, 2.5, 5, 7.5, 10) m/s, the end-to-end delay increases. The FF-AOMDV increases from 15.81 ms to 36.67 ms, AOMR-LM increases from 16.31 ms to 39.21 ms and AOMDV increases from 14.63 ms to 49.21 ms. The FF-AOMDV has less end-to-end delay compare to both AOMR-LM and AOMDV.

Fig.6 (b) shows the change of end-to-end delay for FF-AOMDV, AOMR-LM and AOMDV. When the packet size increases as (64, 128, 256, 512, 1024) bytes, the end-to-end delay increases also. The FF-AOMDV routing protocol increases from 17.53 ms to 32.32 ms, the AOMR-LM protocol increases from 18.64 ms to 37.12 ms and finally, the AOMDV protocol increases from 21.63 ms to 43.06 ms. The FF-AOMDV routing protocol has better performance than both AOMR-LM and AOMDV in terms of end-to-end delay. The reason is, FF-AOMDV selects the route with least distance and hop count, which saves time for the packets to be transmitted over the network.

Fig.6 (c) shows the end-to-end delay for FF-AOMDV, AOMR-LM and AOMDV when varying the simulation time as (10, 20, 30, 40, 50) seconds, when increasing the simulation time the end-to-end delay increases as well. The FF-AOMDV has an end-to-end delay from 9.07 ms in 10 seconds simulation time to 23.61 ms in 50 second simulation time, AOMR-LM has 9.67 ms in 10 seconds time to 26.07 ms in 50 seconds time, while AOMDV has end-to-end delay from 11.6 ms in 10 seconds to 34.68 ms in 50 second simulation time. The FF-AOMDV routing protocol outperform both AOMR-LM and AOMDV because the source node will always select short and stable routes which minimize the time taken for a packet to transfer over the network.



(a)



(b)

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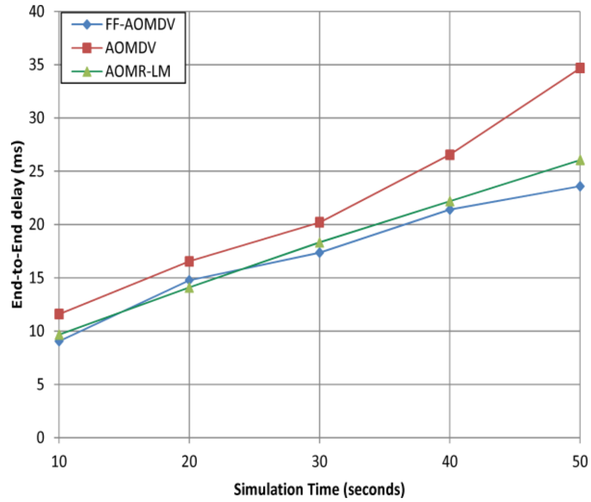


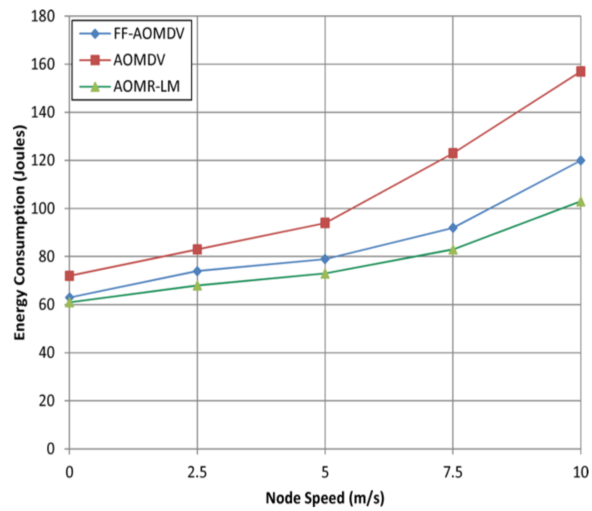
(c)

Fig. 6. End-to-end delay (a) node speed (b) packet size (c) simulation time

d. Energy consumption

Fig. 7 (a) shows the variation of energy consumption for FF-AOMDV, AOMR-LM and AOMDV. When the node speed increases as (0, 2.5, 5, 7.5, 10) m/s, the energy consumption increases. The FF-AOMDV increases from 63 joules to 120 joules, AOMR-LM increases from 61 joules to 103 joules and AOMDV increases from 72 joules to 157 joules. The AOMR-LM routing protocol has less energy consumption than both FF-AOMDV and AOMDV. The AOMR-LM protocol classifies the routes to the destination according to their energy levels i.e.; high, average and low. When sending the data packets, the source node distributes the packets through the routes with a high level of energy and the average one to balance the load on more than one route. This process consumes less energy than sending the traffic through one route. As for the FF-AOMDV, the source node forwards the traffic through the route with the highest level of energy and consumes less energy, or through the route with the shortest distance or both.

Fig.7 (b) shows the effect of varying packet size on the energy consumption for FF-AOMDV, AOMR-LM and AOMDV routing protocols. Packet size is varied as (64, 128, 256, 512 and 1024) bytes. When the packet size increases, energy consumption also increases. The FF-AOMDV protocol consumed energy from 69 joules to 93 joules, AOMR-LM protocol consumed energy from 63 joules to 87 joules and AOMDV consumed energy from 81 joules to 120 joules when increasing the packet size. The AOMR-LM routing protocol consumes less energy than both FF-AOMDV and AOMDV routing protocols. Both AOMR-LM and FF-AOMDV are energy efficient routing protocols and both of them are based on AOMDV, but their routing mechanism is different. The FF-AOMDV depends on two parameters in order to select a route; which is energy level of the route and the route's distance. The selected route could be the shortest route and the route with the highest level of energy. This will minimize the energy consumption, or it could be the route with the highest level of energy regarding its distance. On the other hand, the AOMR-LM protocol classifies its routes into three categories depending on their energy level; high, average and low. The AOMR-LM balances the traffic load by sending the data packets through more than one route to minimize the energy consumption.



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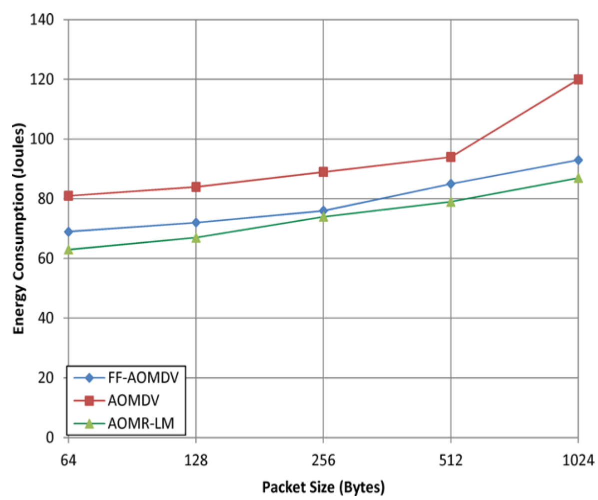

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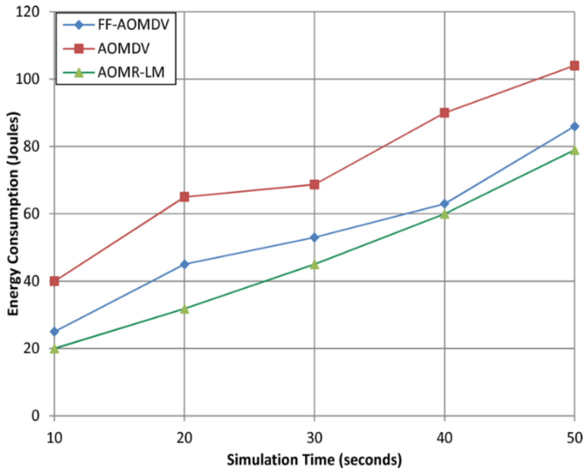


(c)

Fig7: Energy consumption (a) node speed (b) packet size (c) simulation time

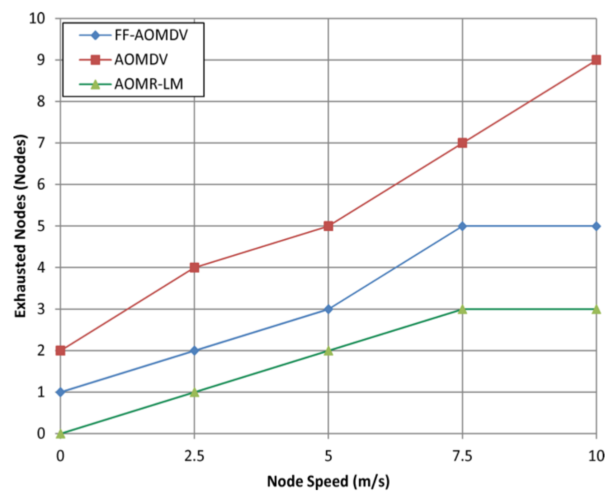
Fig.7 (c) shows the energy consumption in FF-AOMDV, AOMR-LM and AOMDV. For 10 seconds the FF-AOMDV consumes 25 joules and for 50 seconds it consumes 86 joules, while AOMR-LM consumes 20 joules in 10 seconds and 79 joules in 50 seconds and finally, AOMDV consumes 40 joules in 10 seconds and 104 joules in 50 seconds. The AOMR-LM protocol has better energy consumption than both FF-AOMDV and AOMDV.

e. Network lifetime

Fig. 8 (a) shows the variation of exhausted nodes for FF-AOMDV, AOMR-LM and AOMDV. When the node speed increases as (0, 2.5, 5, 7.5, 10) m/s, the number of exhausted nodes increases. The FF-AOMDV exhaust from 1 to 5 nodes, AOMR-LM exhaust from 0 nodes to 3 nodes and AOMDV exhaust from 2 to 9 nodes.

Fig. 8 (b) shows the effect of varying the packet size on the number of exhausted nodes for FF-AOMDV, AOMR-LM and AOMDV routing protocols. Packet size is varied as (64, 128, 256, 512 and 1024) bytes. When the packet size increases, the number of exhausted nodes increases also. The FF-AOMDV exhausts from 2 nodes to 4 nodes in 50 seconds, the AOMR-LM protocol exhausts 0 to 2 nodes in 50 seconds and AOMDV exhausts 4 to 6 nodes in 50 seconds of simulation time. The AOMR-LM routing protocol has better performance than both FF-AOMDV and AOMDV in terms of network lifetime. It exhausts less nodes because it distributes the traffic load among its classified routes. This technique conserves more energy by load balancing the traffic load. While FF-AOMDV has less exhausted nodes than AOMDV as it keeps the poor energy nodes for later use and uses the nodes with high energy for data transmission.

Fig. 8 (c) shows the number of exhausted nodes for FF-AOMDV, AOMR-LM and AOMDV when varying the simulation time. The FF-AOMDV exhausts 0 nodes in 10 seconds and 3 nodes in 50 seconds, the AOMR-LM exhausts 0 nodes in 10 seconds and 2 nodes in 50 seconds, while, the AOMDV exhausts 0 nodes in 10 seconds but 6 nodes in 50 seconds. Again the AOMR-LM has better performance in network lifetime than both FF-AOMDV and AOMDV. The mechanism of the AOMR-LM results in conserving more energy than FF-AOMDV. The FF-AOMDV has better performance than AOMDV in network lifetime as it conserves better energy in the mobile nodes and exhausts less nodes.



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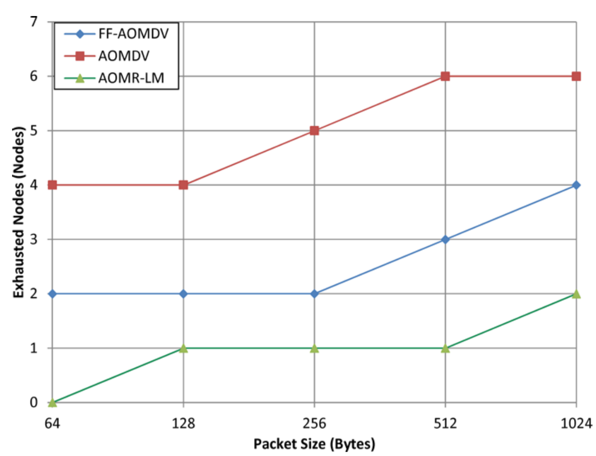

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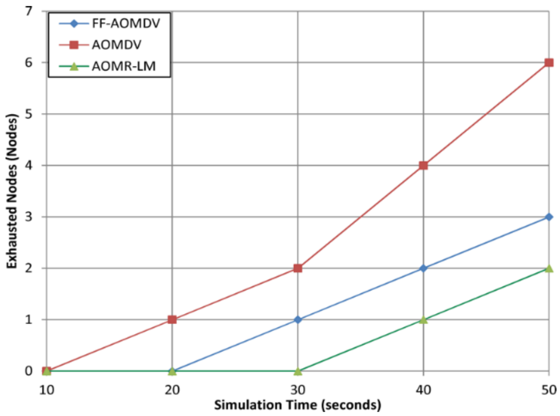


(c)

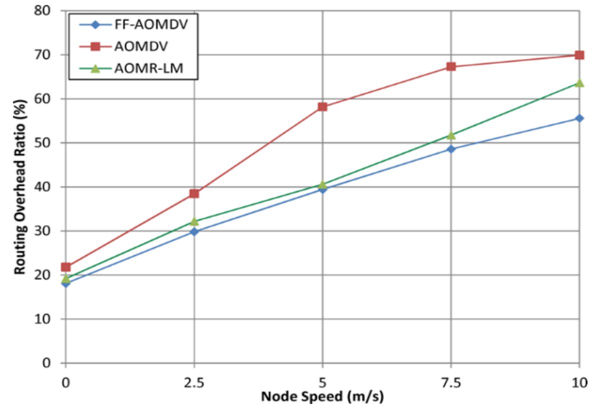
Fig. 8: Network lifetime (a) node speed (b) packet size (c) simulation time

f. Routing overhead ratio

Fig.9 (a) shows the variation of routing overhead ratio for FF-AOMDV, AOMR-LM and AOMDV. When the node speed increases as (0, 2.5, 5, 7.5, 10) m/s, the routing overhead ratio increases as well. The FF-AOMDV increases from 18.12% to 55.6%, AOMR-LM increases from 19.2% to 63.64% and AOMDV increases from 21.79% to 69.92%. The FF-AOMDV protocol has better performance than both AOMR-LM and AOMDV protocols in terms of routing overhead ratio because, it establishes strong and more stable routes and the possibility of route failure becomes almost minimal with less route discovery process.

Fig.9 (b) shows the effect of varying the packet size on the routing overhead ratio for FF-AOMDV, AOMR-LM and AOMDV routing protocols. Packet size is varied as (64, 128, 256, 512 and 1024) bytes. When the packet size increases, the routing overhead ratio increases also. The FF-AOMDV protocol has routing overhead ratio from 28.36% to 47.82%, AOMR-LM from 30.83% to 52.99% and AOMDV from 34.67% to 60.21%. This clearly shows that the FF-AOMDV protocol has better performance in terms of routing overhead ratio than both AOMR-LM and AOMDV routing protocols. The main reason is the stability of routes from source to destinations along with lesser initiation of path discovery process.

Fig.9 (c) shows the effect of varying the simulation time on the routing overhead ratio for FF-AOMDV, AOMR-LM and AOMDV routing protocols. The simulation time varies as (10, 20, 30, 40, 50) seconds. The FF-AOMDV routing protocol has a routing overhead ratio from 31.97% to 41.53%, AOMR-LM from 34.19% to 44.54% and AOMDV from 39.74% to 48.27%. This clearly suggests that, FF-AOMDV routing protocol has better performance in terms of routing overhead ratio than both AOMR-LM and AOMDV routing protocols.



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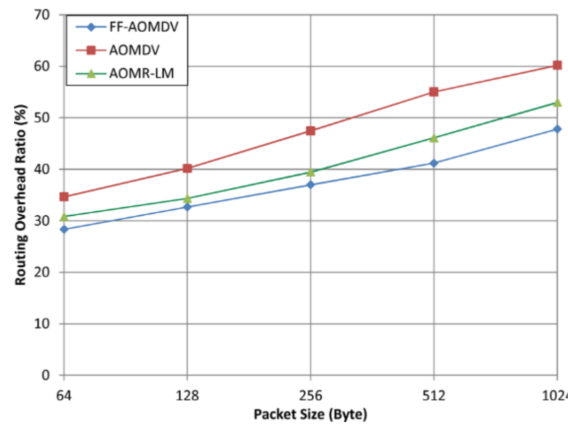

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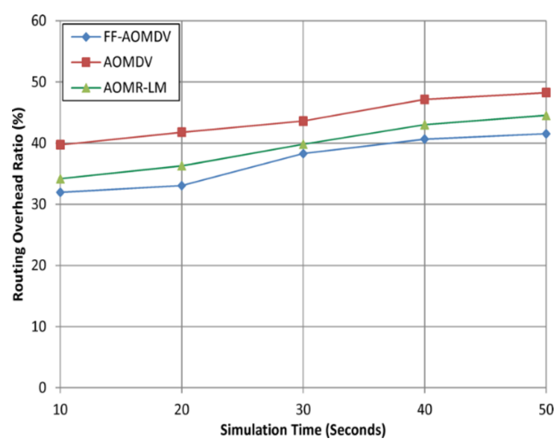

(c)

Fig. 9: Routing overhead ratio (a) node speed (b) packet size (c) simulation time

V. CONCLUSION & FUTURE WORK

In this research, we proposed a new energy efficient multipath routing algorithm called FF-AOMDV simulated using NS-2 under three different scenarios, varying node speed, packet size and simulation time. These scenarios were tested by five (5) performance metrics (Packet delivery ratio, Throughput, End-to-end-delay, Energy consumption and Network lifetime). Simulation results showed that the proposed FF-AOMDV algorithm has performed much better than both AOMR-LM and AOMDV in throughput, packet delivery ratio and end-to-end delay. It also performed well against AOMDV for conserving more energy and better network lifetime.

As a future work, there are several scenarios that could be implemented with this study to enhance the energy consumption and network lifetime. For instance, it is possible to consider another network resource which is the bandwidth as another fitness value. In this case the calculations for selecting routes towards the destination will be according to energy, distance and bandwidth. Basically this will consider many network resources which will prolong the network lifetime and enhances the QoS. Another possibility is to test the fitness function with another multipath routing protocol that has a different mechanism than AOMDV and compare the results with the proposed FF-AOMDV.

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