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Energy Based Route Prioritization for Optimum Multi-path Selection

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Abstract: Energy–aware routing in wireless ad hoc networks is one of the demanding fields of research. Nodes of the network are battery operated that are difficult to recharge and replace, that's why while developing a routing protocol energy consumption metric should always be at high priority. Nodes of mobile ad hoc networks are distributed in different directions forming arbitrary topology instantly. To propose an energy-efficient routing protocol for such a dynamic, self-organized, self-configured, and self-controlled network is certainly a challenge and an open research problem. Energy constraints and mobility leading to link breakage are the motivating factors behind the development of the proposed Optimized Priority-based Ad Hoc on Demand Multi-path Distance Vector Energy Efficient Routing Protocol (OPAOMDV-EE). The routing protocol added three fields (CE, MAX_E, MIN_E) to the traditional AOMDV RREQ and RREP packets, which are further used for calculating total priority field value. This value is used by the source node for selecting an optimal prioritized energy-efficient route. The proposed OPAOMDV-EE protocol has been simulated on Network Simulator-2 (NS-2) for two different scenarios that prove the effectiveness of OPAOMDV-EE in terms of various performance metrics with reduced energy consumption.

Index Terms: Ad Hoc Networks, AODV, AOMDV, Energy Consumption, Optimization, Overhead, Priority, Routing.

1. Introduction

Mobile Ad Hoc Networks (MANETs) is an interconnection of various autonomous mobile nodes, randomly moving with different velocities & instantly forming arbitrary topology among them. Infrastructure less network of nodes does not require any centralized administration [1], thus these types of networks are commonly referred to as self-organized, self-configured, and self-controlled. MANETs resemble peer-to-peer (P2P) communications. In peer-to-peer networks, peer refers to the computer systems that are connected with each other via the internet and software. Nodes or systems in this environment (i.e. P2P) are capable of acting as client/servers themselves [2]. In MANETs, nodes can act as routers or hosts depending upon the need or demand [3]. The dynamic nature of the network creates challenges for the researchers. To establish communication, mobile nodes exchange routing packets. As nodes keep on changing their position with time, the number of routing packets in the network increases with time because nodes keep on exchanging routing information with one another. This continuous process consumes lots of energy. Energy consumption of the network increases with time. Mobile nodes operate on batteries. With time power of the battery gets exhausted and recharging and replacement of the battery during communication is a complicated task [4].

Information sharing and communication establishment in an efficient, reliable, and faster way put many challenges for researchers when working in mobile ad hoc networks. For this purpose, routing tables are maintained at every node of networks. Fields of routing tables vary with the type of protocol used. Routing protocols consist of some set of rules and regulations that governs healthy communication among nodes of the network. Routing protocols are broadly categorized as single-path routing protocols [5] and multi-path routing protocols [6]. Multipath routing protocols are mostly favored as compared to single-path routing protocols due to their advantage of offering multiple paths for communication among the source and destination nodes. AOMDV [7] is a multi-path extension of AODV [8]. In

AOMDV, one session of route discovery discovers three paths. Route discovery is carried out by broadcasting RREQ packets in the neighborhood. RREQs will be broadcast until the destination node is found or a maximum number of allowable hops have been reached. Among the various generated routes, optimum three routes with minimum hop count are chosen and stored at source node that will be utilized in case link failure situation arises in future. For the selection of optimum path battery power of nodes or energy consumption of nodes or the remaining energy of nodes was never considered in basic AOMDV protocol. MANETs focuses on the energy conservation of nodes in a distributed network of wirelessly connected nodes with dynamically changing topology. Limited availability of energy in the case of wireless communication paves a new path for the design of various energy-aware routing protocols [9]. Energy constraint of mobile nodes leads to route failure due to breakage of communication links that directly affects network lifetime. Further, route failure increases routing overhead or network overhead which degrades the performance of the network. All these factors motivate the designing of a novel energy-efficient multipath routing protocol for mobile ad hoc networks.

The contributions of work are highlighted as follows:

- The proposed OPAOMDV-EE has been designed to provide awareness regarding the energy level of nodes in advance before deciding on route selection.
- OPAOMDV-EE selects routes by considering route total priority value which is calculated by using maximum energy, cumulative energy, and minimum energy of nodes of every path.
- Depletion of energy in nodes of mobile ad hoc network with time is natural. OPAOMDV-EE provides a mechanism that can detect the energy level of nodes along a path in advance so that selection of low energy paths can be avoided which will further reduce the cost of route rediscovery.
- In scenario 1, OPAOMDV-EE has been simulated on NS-2 by varying number of nodes which results in an increase in PDR &throughput and reduction in End to End delay & energy consumption as compared to other protocols by reducing network overhead that is by avoiding low energy level nodes to become part of the network which reduces chances of route failure and route rediscovery process.
- In scenario 2, OPAOMDV-EE has been simulated on NS-2 by varying node mobility. It can be observed by simulation results that in a highly mobile environment the proposed protocol outperforms other protocols in terms of PDR, throughput, End-to End delay, and energy consumption as it can predict and control the route failure occurring due to energy constraints.

The paper has been organized as follows: In Section 2, related works and studies of energy-efficient routing protocols in MANETs along with traditional on-demand routing protocols such as AODV and AOMDV are briefly described. Further, in section 3 the proposed OPAOMDV-EE routing protocol has been elaborated in detail. In Section 4, details of the simulation environment and setup are provided. In Section 5, various considered simulation scenarios are described and the performance of the proposed protocol on NS-2 is analyzed. Finally, in Section 6, a conclusion with the further scope of improvement is given.

2. Related Work

Mobile Ad Hoc networks consist of a number of mobile nodes wirelessly connected in an infrastructure-less fashion. The dynamic nature of network nodes puts many challenges in front of researchers. In recent years of study, reducing the energy consumption of the network is a primary concern of all newly developed routing protocols described in table 1. A dynamic energy ad hoc on-demand distance vector routing protocol(DE-AODV) has been proposed by Deepa and Sutha [10], which aims to find out proper mechanism for the selection of energy-efficient and trustworthy nodes for shortest route discovery. Energy reliability criteria thus proposed, successfully selects the reliable path. Simulation results show an increase in energy level, maximized network lifetime, minimized packets loss, decreased nodes link failure, and minimized packet delay. It has been noticed that an increase in network size decreases DE-AODV performance by increasing network overhead. Further, there is no support for multipath routing. Wei et al. proposed an optimized priority-based energy-efficient routing algorithm for mobile ad hoc networks, which was aimed at finding an optimized mechanism for the selection of an energy-efficient path for effective data transfer [11]. The protocol has been proposed based on the available proportion of residual energy. Protocol efficiently maximizes network lifetime & maximizes effective data transfer, but increases overhead to the network. In a view of finding an energy-efficient algorithm that not only increases network lifetime but also guarantees a lifetime of individual nodes of the network. Max-Min path energy efficient routing mechanism makes us of LCM method for developing a relationship between total energy of path and residual energy of individual nodes [12]. The Protocol efficiently maximizes the network lifetime and residual energy level of nodes, but lacks in finding the optimal energy conserved path. Energy-Efficient Channel Awareness AOMDV (EECA-AOMDV) [13] addressed the problem of energy production, quality, and delay in system lifetime. Simulation results proved that selecting a node based on average channel non-fading duration and maximum residual energy of nodes increases PDR, reduces End-to-End delay, improved throughput, and reduced energy consumption for transmission of packets. The effect of the routing algorithm on network overhead is untouched. For cloud-assisted MANETs, an energy-aware routing scheme has been proposed by Riasudheen et al. in

5G[14]. In a highly mobile environment, link failure frequency increases, this in turn adds overhead to the network that consumes more energy in searching and linking of mobile nodes. The solution to the problem has been proposed by modifying the Bellman-Ford algorithm by correlating the residual energy of nodes and total energy to obtain an alternate path in case of link failure. Three control messages have been proposed for connection establishment in cloud-assisted MANETs. Implemented results on NS-3 resulted in improved energy consumption and residual energy of nodes of networks. The protocol had no support for multi-path routing and with an increase in time, the average energy consumption of the network compared with the number of nodes showed uneven variation. Due to the limited available energy of nodes and the mobile nature of nodes energy consumption of nodes increases with time, therefore, to increase the lifetime of the network, an efficient energy conservation mechanism needs to be proposed. Zone-based energy-efficient routing protocol for MANETs makes efficient use of energy of nodes by selecting optimum path using power analysis, labels, and node tracking [15]. Simulation on NS-2.35 presents more reliable results when compared with traditional routing protocols AODV and AOMDV. AEQAOMDV is a multipath extension of ad hoc on-demand distance vector routing protocol, specially developed for WSN to address the problem of energy consumption and network load for establishing routes using hop count [16]. For this purpose, adaptive sensing of node residual energy and buffer queue length has been proposed which significantly increases PDR, reduces route discovery, and decreases network delay. The observed limitation in this work was that AEQAOMDV generates more overhead as compared to traditional routing protocols (i.e., AODV and AODV_LB). Banerjee and Chowdhury [17] selected optimum path for data transfer based on expected network lifetime of nodes calculated from residual energy of nodes and approximate communication time of the session that increases PDR, decreases end to end delay, and increases route lifetime and average energy consumption of network, but fails to explain the concept of network overhead. In the following sub section two popular traditional on demand routing protocols have been discussed in brief that forms the base for the problem formulation.

Table 1. Related work of energy-aware routing protocols in MANETs

S.No.	Routing Algorithm	Simulation Tool	Energy Awareness	Multipath Support	Problem Addressed	Solution Proposed	Metrics Evaluated	Limitation(s) Observed
1.	Dynamic Energy Ad Hoc On-Demand Distance Vector (DE-AODV)	NS-2	Yes	No	To find out the shortest path by applying proper mechanism for selecting trustworthy nodes having sufficient energy efficiency.	Proposed energy reliability criteria to successfully select the reliable path & efficiently forward the packet	Increases Energy Level, maximizes Network Lifetime, minimizes Packetloss, decreases node-link failure, minimizes packet delay	An increase in network size decreases DE-AODV performance by increasing network overhead, No Multi-path support.
2.	Optimized Energy Efficient Routing Algorithm for DSR	NS-2	Yes	No	To find out an Optimized Mechanism for the selection of an energy-efficient path for effective data transfer	Priorities have been assigned based on the available proportion of residual energy	Maximizes network lifetime, maximizes effective data transfer, increases overhead.	Brings some overhead to the Network, No multipath support.
3.	Max-Min-Path (MMP) energy Efficient Routing Algorithm	NS-2	Yes	No	To find an Energy-efficient Algorithm that not only increases network lifetime but also guarantees the lifetime of individual nodes of the network	LCM method is used for relating total consumed energy of path with the residual energy of Individual nodes.	Maximizes the Network lifetime, maximizes the residual energy level of nodes.	Lacks in finding the optimal path that conserves path energy, No multipath support.
4.	EECA-AOMDV Energy-Efficient Channel Awareness AOMDV	NS- 2.35	Yes	Yes	Addressed problem of energy productivity, unwavering quality & delaying system lifetime	Selected a node using two criteria: a) channel nonfading duration b) residual energy of nodes for transmitting packets from S to D.	Increases PDR, reducers EED, improves throughput, reduces Energy Consumptio n	Does not consider the energy along the path. No adaptability of routing protocol according to dynamic MANET Environment

5.	EECRM Energy Efficient Cloud Assisted Routing Mechanism for CA-MANET.	NS-3	Yes	No	Reducing Energy Consumption in Researching & re-linking mobile nodes due to link failure & mobile overhead etc. The further route recovery process is improved significantly	Modified in Bell Man Ford algorithm for correlating nodes residual energy & total consumed energy, helping in forming alternate paths used in the situation of link failure. Three control messages have been proposed for connection in CA-MANET	Better in energy consumptio n and residual energy	Varied with simulation time by increasing the number of nodes, average energy consumption increases and shows uneven variations No multipath support
6.	ZBLE Zone-Based Leader Election Energy Constrained AOMDV Routing Protocol	NS -2.35	Yes	Yes	Reducing energy consumption of network due to limited battery and mobile nodes of the network	Makes efficient use of nodes energy by selecting an optimum path by labeling nodes, tracking nodes and analyzing the power nodes.	Minimizes Energy Consumptio n, increases Network lifetime.	Fails to cover network overhead issue.
7.	AEQAOMDV	NS -2	Yes	Yes	The addressed problem of AODV in WSN such as establishes route using Hop Count only without considering energy consumption & network load	Adaptively sensing the residual energy of nodes & queue length of the buffer.	Increases PDR, reduces Network overhead, reduces Route discovery, & decreases network delay.	More overhead as compared to traditional routing protocol AODV & AODV_LB.
8.	ERL-AOMDV	NS-2	Yes	Yes	To find a better strategy for reduction in energy consumption of the network.	Selecting optimum path for data transfer based on expected residual nodes energy & approximate session completion time of a communicati on	Increases PDR, decreases EED, increases average route lifetime, reduces link breakage per second, decreases average per node energy consumptio n	ERL-AOMDV effect on Network Overload has not been highlighted.

2.1. AODV

Ad hoc on-demand distance vector routing protocol is a self-starting, dynamic and multi-hop mobile ad hoc network routing protocol. AODV uses distance vector routing algorithm for maintaining routes information on mobile nodes [18]. It automatically invalidates all the inactive routes. It uses RREQ, RREP, RERR, and RACK control messages for route discovery and route maintenance**.**

2.2. AOMDV

Ad-Hoc on-demand multipath distance vector algorithm (AOMDV)[19] is a multipath extension of AODV (i.e. single path routing protocol) AOMDV ensures reliability by offering multi-paths for data transmission between a particular source and destination. It also provides two services [20] route discovery and route maintenance services. In AOMDV single route discovery process discovers multiple routes for a destined node. Whenever the source node needs to communicate with the destination node, the source node disseminates RREQ in neighbor. Destination establishes and maintains multiple reverse paths corresponding to received RREQs at destination and intermediate nodes [21]. RREPs traverse all these reverse paths back at the source node covering all intermediate nodes. AOMDV locally updates path information in routing tables of nodes that ensures that the multiple paths thus generated, are disjoint and free from loops.

3. The Proposed Optimized Priority-based Ad Hoc on-demand Multipath Distance Vector Energy Efficient Routing Protocol

3.1. Problem Definition

Multipath routing protocols ensure reliability for maintaining healthy and continuous communication among nodes of the networks. Every routing protocol constitutes two phases i.e., route discovery and route maintenance. Route discovery is carried out by using control packets namely, RREQ and RREP. These packets carry information and vary depending on the type of protocol used. Energy is one of the crucial factors which should always be kept in mind. Whenever, nodes of the network are involved in the communication. With simulation time, the use of nodes in the network decreases the energy level of nodes. This point needs to be considered while choosing a route before starting the data packet transfer phase. Priority decides the order of preference given to an entity. Priority is given based on certain criteria. Here priority is used to design a multi-path routing protocol. The proposed OPAOMDV-EE routing protocol extended the concept of Multipath priority-based routing mechanism [22] by calculating the total priority value by using the concept of maximum energy, minimum energy, and cumulative energy of routes, which helps to make the choice of a route for sending a data packet. Algorithm 1 presents the step-by-step description of the calculation done at various nodes. Visual description of the complete routing protocol is explained with the help of the flowchart shown in fig. 1.

3.2. The OPAOMDV-EE Route Discovery Phase

The route discovery phase is initiated when the source node wishes to set up communication with a certain destined node.

A. Route Discovery at Source Node

Source Node (SN) disseminates OPAOMDV-EE RREQ packets after scanning all the stored routes in their routing table. If there is no route available, route discovery phase is initiated. RREQ packets will be broadcast in the neighbor with hop limit 1. The structure of OPAOMDV-EE RREQ packet is shown in table 2. These packets have three additional fields named as Minimum Energy (MIN_E), Maximum Energy (MAX_E), and Cumulative Energy (CE) as shown in the RREQ packet structure of OPAOMDV-EE.

Table 2. Structure of OPAOMDV-EE RREQ packet

PKT Type
HC
Destination Node (DN)
Destination Node sequence Number
Source node (SN)
Source Node IP address
Lifetime
BID
First HOP
Minimum Energy Value (Min_E)
Cumulative Energy Value (CE)
Maximum Energy Value (Max_E)

B. Route Discovery at Intermediate Node

The intermediate node will receive the RREQ packet and check whether it contains its information or not. If it contains the route in its routing table, then it replies to the source route by generating the RREP packet on the reverse path. Otherwise, it will rebroadcast the OPAOMDV-EE RREQ packet in its neighbor and update the value of CE, MAX_E, MIN_E fields as per the following equations:

$$\text{CE after Node (i)} = (\text{CE before Node (i)} + \text{Energy of Node (i)}) \tag{1}$$

$$\text{MIN\_E after Node (i)} = \text{MIN (MIN\_E before Node (i), Energy of Node (i))} \quad (2)$$

$$\text{MAX\_E after Node (i)} = \text{MAX (MAX\_E before Node (i), Energy of Node (i))} \quad (3)$$

C. Route Reply at Destination Node

The destination node receives the route request packets and replies by generating the corresponding OPAOMDV-EE RREP packet as shown in table 3. Multiple RREQ's will be received by the destination node, thus it will reply with multiple RREP packets.

Table 3. Structure of OPAOMDV-EE RREP packet

PKT Type
HC
Destination Node
Destination Node sequence Number
Source Node (SN)
Source Node IP address
Lifetime
BID
First HOP
Minimum Energy Value (MIN_E)
Cumulative Energy Value (CE)
Maximum Energy Value (MAX_E)

D. Route Reply at Intermediate Node

When OPAOMDV-EE RREP packets reach the intermediate node, then the intermediate node will update its routing table as shown in table 4 and update the fields of cumulative energy, maximum energy, and minimum energy as per eq. (1), (2), and (3).

Table 4. OPAOMDV-EE routing table maintained at intermediate nodes

PKT Type
HC
Destination Node (DN)
Destination Node sequence Number
Source Node
Source Node IP address
Lifetime
BID
First HOP
Minimum Energy Value (MIN_E)
Cumulative Energy Value (CE)
Maximum Energy Value (MAX_E)

E. Route Reply at Source Node

When the source node will receive OPAOMDV-EE RREP packets, then it will assign a priority value (PV) to every field (CE, MAX_E, MIN_E) individually for every RREPs. Thereafter, it will calculate the total priority value (TPV) for every OPAOMDV-EE RREP packet as per the following equation:

$$\text{TPV of RREP } (A_i) = [(\text{PV for CE per Node}) + (\text{PV for MAX\_E}) + (\text{PV for MIN\_E})] \quad (4)$$

Source node will decide on optimum path selection for data transfer based on the highest value of total priority field.

3.3. OPAOMDV-EE Route Maintenance Phase

Route maintenance is an important phase in mobile ad hoc networks. As nodes are mobile in nature, so topological changes are quite dynamic, which may lead to the breakage of certain links or paths. These paths require maintenance at regular intervals to conduct a smooth transfer of information. OPAOMDV-EE stores values of cumulative energy, maximum energy, and minimum energy at all the nodes in the respective fields of routing table corresponding to every reachable route. If some nodes do not contain a sufficient amount of energy for carrying the data packet, then the paths corresponding to the nodes can be invalidated and a route error message (RERR) can be sent to the source node as well as to the intermediate nodes. All the intermediate nodes can update their routing table correspondingly. If there are no alternate paths available at the source node, then it can start the OPAOMDV-EE route discovery phase again. The structure of the OPAOMDV-EE RERR message has been shown in table 5.

Table 5. Structure of OPAOMDV-EE route error message

Route Error Type
Destination Count
Unreachable Destination IP Address
Unreachable Destination Sequence Number

Algorithm 1: Pseudo Code for the Proposed Optimized Priority-based Ad Hoc On-Demand Multipath Distance Vector Energy Efficient Routing Protocol (OPAOMDV-EE)

Input: Source Node(S) has a data packet to send to Destination Node (D)
Output: One or more RREP packets carrying information of Maximum Energy (MAX_E), Cumulative Energy (CE), & Minimum Energy (MIN_E)

Begin
If *(Current Node (n) = Source Node (S))* ***then***
{
Generate ***RREQ*** *Packet with CE, MAX_E. & MIN_E. field and Broadcast in the neighbor*
Initialize values in RREP fields as CE = 0, MAX_E. = 0 %, MIN_E. = 100%
Update CE MAX_E, MIN_E at every Intermediate Node as per eq. (5), (6) & (7)

$$\textit{CE after Node (i) = (CE before Node (i) + Energy of Node (i)} \quad (5)$$

$$\textit{MIN\_E after Node (i) = MIN (MIN\_E before Node (i), Energy of Node (i)} \quad (6)$$

$$\textit{MAX\_E after Node (i) = MAX (MAX\_E before Node (i), Energy of Node (i)} \quad (7)$$

}
Else if *(Current Node (n) = Intermediate Node (I))* ***then***
Collect *information in Stack and further broadcast it*
Else if *(Current Node (n) = Destination Node (D))* ***then***
{
Generate RREP corresponding to every received RREQ
Add & Compute Every RREPs CE, MAX_E and MIN_E fields along Reverse path as per eq. (5), (6) & (7)
}

Calculate ***CE per Node = CE for RREP Packet / Route Length for RREP***

If *(RREP reached at Source Node(s))* ***then***
{
Assign PV to every RREP packet CE, MAX_E, MIN_E fields individually
Calculate the Total priority value of each RREP packet as follows:

$$\text{TPV RREP } (A_i) = [(\text{PV for CE per Node}) + (\text{PV for MAX\_E}) + (\text{PV for MIN\_E})] \quad (8)$$

Add ***the TPV*** *to every RREP packet*
Source Node(S) sends data packets along the route having a higher total priority field value
Else if (*RREP reached Intermediate Node (I)****) then***
Update CE, MAX_E, MIN_E as per eq. (5), (6), (7)
End

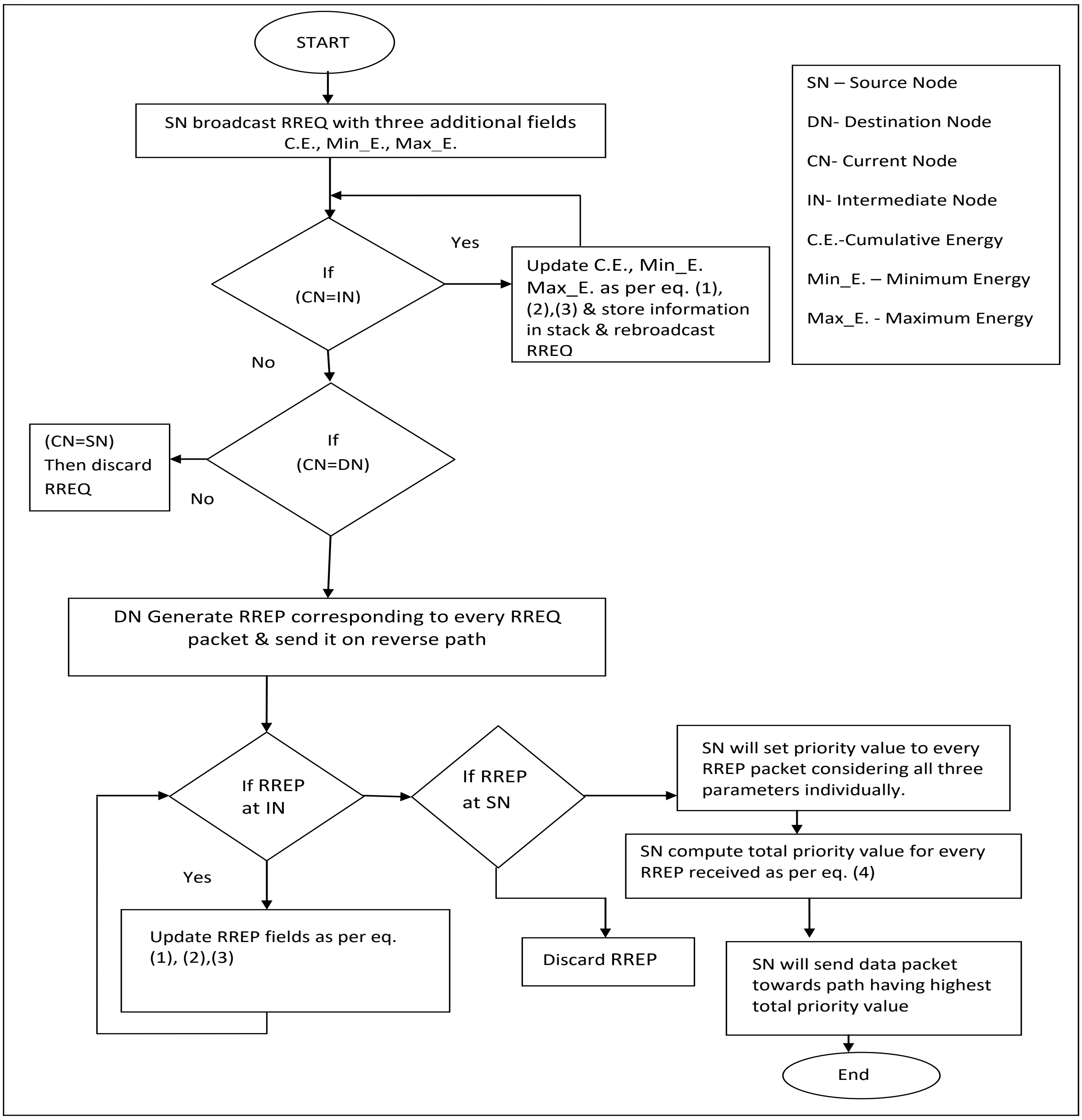

Fig.1. Flowchart of OPAOMDV-EE

4. Simulation Environment and Set Up

The OPAOMDV-EE works on prioritizing the routes, based on energy utilization along a particular route and hence assuring that the route selected will be the one with optimum utilization of energy. The factors like maximum energy and total energy along a path are used to give the priority to the path based on available energy and at the same time, the factor of minimum energy assures that the total resultant priority should also consider that a node along the path may not get failed due to the limited energy life. To analyze the performance of OPAOMDV-EE, a simulation has been carried out using Network Simulator 2. The table 6 lists different parameters that have been used for the simulation. The results corresponding to different metrics have been compared with protocol like AOMDV and another energy-based protocol EECA-AOMDV [15]. The results have been compared corresponding to two scenarios. In scenario 1, the performance of three protocols has been compared by varying node density i.e., different numbers of nodes while keeping other factors constant. Scenario 2 compares the protocols for different values of node mobility.

Table 6. Simulation set-up

Simulation Tool	NS-2.35
Routing Protocols	AOMDV, EECA-AOMDV, OPAOMDV-EE
Radio Propagation Model	Two Way Ground
Area of Simulation	1000*1000m^2
Variation in Number of Nodes	10, 20, 50, 100
Antenna Model	Omni
Type of Traffic	CBR/TCP
Initial Energy	1000 Joules
Size of Packet	512 bytes
Time of Simulation	500 sec
Transition Power	0.002 W
Type of Interface Queue, Queue Length	Drop Tail/ PriQueue, 50
Idle Power	0.0001 W
Data Payload	512 bytes
Transmission Power	1.0 W
Connection Rate	4 packets/sec
Receiving Power	1.0 W
Variation in Nodes Speed	0,5 and 10 m/s
Transition Time	0.005 sec
Sleep Power	0.01

5. Analysis of the OPAOMDV-EE Performance under Generated Scenarios

5.1. Scenario 1: Performance Analysis by Varying Node Density

Scenario1 compares OPAOMDV-EE performance by considering End-to-End delays, Packet Delivery Ratio, Throughput, and Energy Consumption by varying node density. The results obtained have been analyzed as follows:

A. End-to-End Delay

The results shown in fig. 2 prove the effectiveness of OPAOMDV-EE in terms of End-to-End delay. The procedure of OPAOMDV-EE tends to minimize the propagation delays occurring on account of the failure of nodes, thus decreasing the chances of rediscovery of the route on account of route failure. Further, the smaller route is preferred among the routes with equal priorities, thereby decreasing the value of delay. Further, it can also be deducted from the fig. 2 that End-to-End delay although is increasing with the number of nodes due to large network size, but the increase is very nominal in the case of OPAOMDV-EE. The End-to-End delay in OPAOMDV-EE is nearly half as compared to AOMDV for a different number of nodes and nearly 15 percent less as compared to EECA-AOMDV for a larger number of nodes. For example, for nodes equal to 100, End-to-End Delay is 0.341s for AOMDV, 0.245s for EECA-AOMDV, and 0.21s for OPAOMDV-EE.

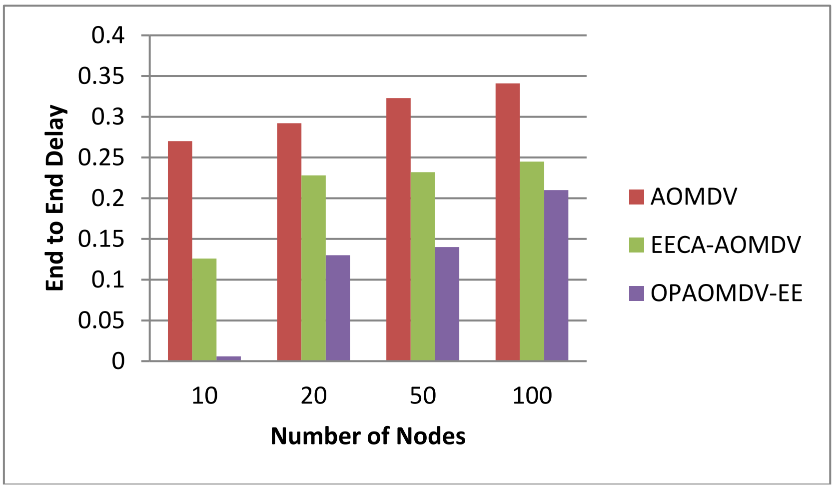

Fig.2. End-to-end delay by varying node density

B. Packet Delivery Ratio

The general observation from the results shown in fig. 3 is that the packet delivery ratio for all protocols shows a downfall with the increase in the number of nodes. This continuous decrease is attributed to the increase in congestion with an increase in traffic. This congestion causes more packets to be dropped and hence decreases the packet delivery ratio. However, OPAOMDV-EE being a multipath protocol tries to avoid the congestion in the network, and calculation of priority based on factors like Min_E, Max_E, and CE also contributes to this direction. It can be observed from the results shown in fig. 3 that packet delivery ratio in all the cases is more than EECA-AOMDV. However, with an increase in the number of nodes, the packet delivery ratio does not decrease too much in the case of OPAOMDV-EE, whereas this decrease is much sharp in the case of the other two protocols. For example, when the number of nodes is 50, packet delivery ratio is 80.81 for AOMDV, 90.76 for EECA-AOMDV &94.67 for OPAOMDV_EE, and for the number of nodes equal to 100, packet delivery ratio is 74.6 for AOMDV, 84.03 for EECA-AOMDV &89.93 for OPAOMDV_EE.

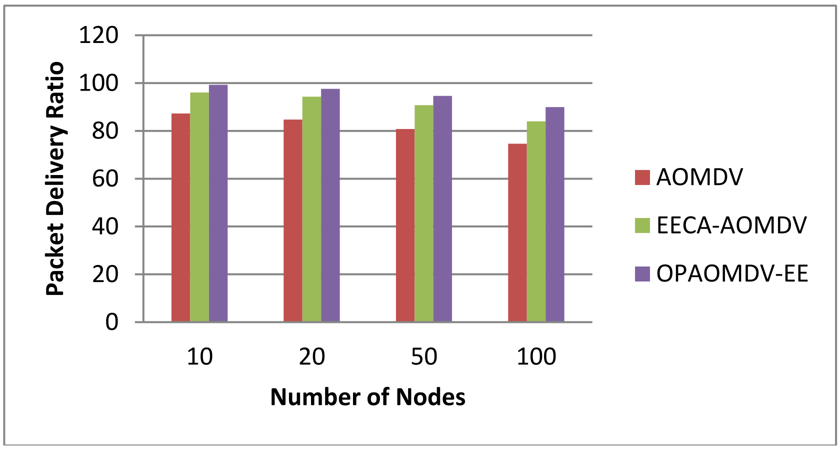

Fig.3. PDR by varying node density

C. Throughput

With the increase in the number of nodes, more packets are transmitted among the nodes, hence must lead to an increase in the number of packets being successfully delivered to the destination per second. The result for throughput in fig. 4 shows the supremacy of OPAOMDV-EE as compared to other protocols particularly for the greater number of nodes. For example, in the case of 50 nodes, the throughput is 129 for AOMDV, 140 for EECA-AOMDV &143.15 for OPAOMDV_EE and in the case of 100 nodes, it is 113 for AOMDV, 128 for EECA-AOMDV &141.13 for OPAOMDV_EE.

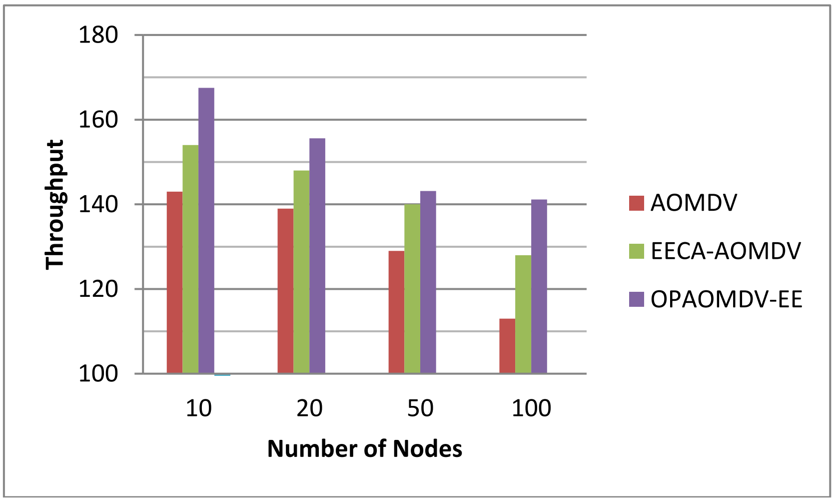

Fig.4. Throughput by varying node density

D. Energy Consumed

The primary area that has been focused on by the OPAOMDV-EE is energy. All the three factors Min_E, Max_E, and CE have been selected keeping in view the energy requirements of the network and the method of priority calculation also focuses on selecting the route that stabilizes the network in terms of energy. The results shown in fig. 5

corresponding to OPAOMDV-EE are also in line with the idea of the design of the protocol. For example, for 100 nodes, energy consumption is 9865 J for AOMDV, 8055 J for EECA-AOMDV, and 5651 J for OPAOMDV-EE.

It has been analyzed that delay and energy consumption is increasing with an increase in node mobility but the proposed protocol is still performing better than the compared two protocols (i.e., AOMDV and EECA-AOMDV). With the increase in node mobility congestion in the network increases but prioritization of paths based on available energy does not affect the performance metrics much in the case of OPAOMDV-EE hence making the network more stable.

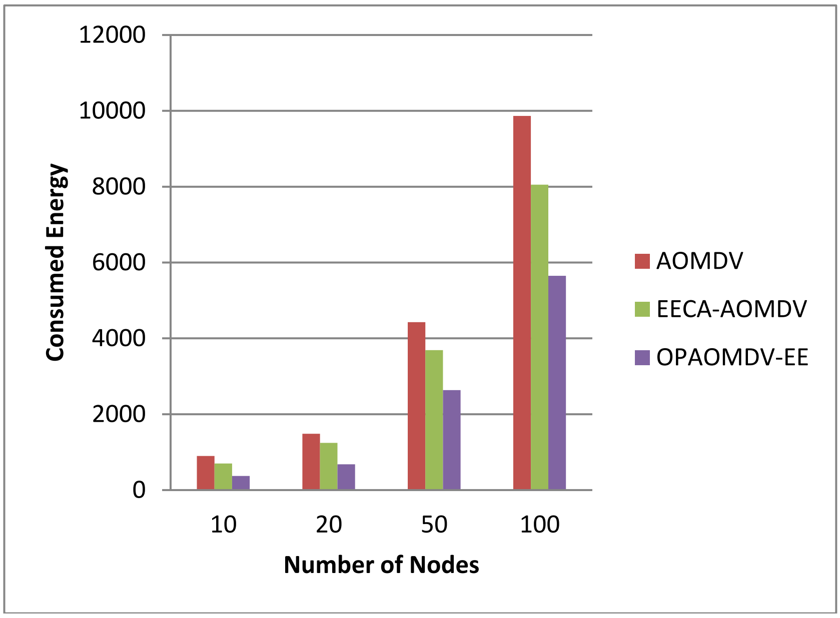

Fig.5. Energy consumption by varying node density

5.2. *Scenario 2: Performance Analysis by varying Nodes Mobility*

The mobility of nodes is a crucial factor in Mobile Ad hoc Networks. Nodes of such networks keep changing their locations and thus lead to the development of stale routes. This further results in the depletion of energy of the nodes as extra energy is consumed due to failures in transmissions. Scenario 2 compares the OPAOMDV-EE performance for End-to-End delay, Packet Delivery Ratio, Throughput, and Energy Consumption metrics by varying node mobility. The results obtained have been analyzed as follows:

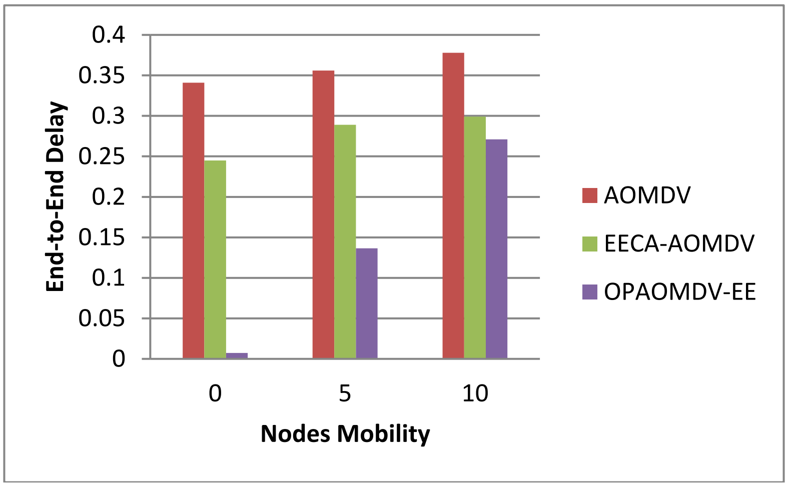

Fig.6. End-to-end delay by varying node mobility

A. *End-to-End Delay*

The results, as shown in fig. 6, prove the effectiveness and applicability of OPAOMDV-EE in the mobile environment. The routes are selected and prioritized dynamically based on cumulative energy, maximum energy, and minimum energy of any node along that route. Thus, we get an updated route having sufficient energy level at any instant of time. Further, the procedure of OPAOMDV-EE is based on the concept of multipath routing that minimizes delays. It can also be noted that End-to-End delay although are increasing with the increase in speed of nodes i.e., node mobility, due to an increase in the number of disconnections. However, End-to-End Delay is consistently less in the case of OPAOMDV-EE. For example, at a speed of 5 m/s, End-to-End Delay is 0.356s for AOMDV, 0.289s for EECA-AOMDV, and 0.1365s for OPAOMDV-EE and at 10 m/s, End-to-End Delay is 0.378s for AOMDV, 0.299s for EECA-AOMDV, and 0.271s for OPAOMDV-EE.

B. Packet Delivery Ratio

The general observation from the results shown in fig. 7 is that the packet delivery ratio for all protocols decreases with the increase in mobility of nodes. This decrease is attributed to the increase in the number of disconnections and invalidation of routes. However, in OPAOMDV-EE, the method of prioritizing the routes based on energy tends to assign the priorities dynamically according to the current topology of the network and thus we get an updated route every time. The values of packet delivery ratio corresponding to different nodes speed also prove the effectiveness of OPAOMDV-EE. For example, at 10 m/s, packet delivery ratio is 89.50 for AOMDV, 92.05 for EECA-AOMDV &96.71 for OPAOMDV-EE.

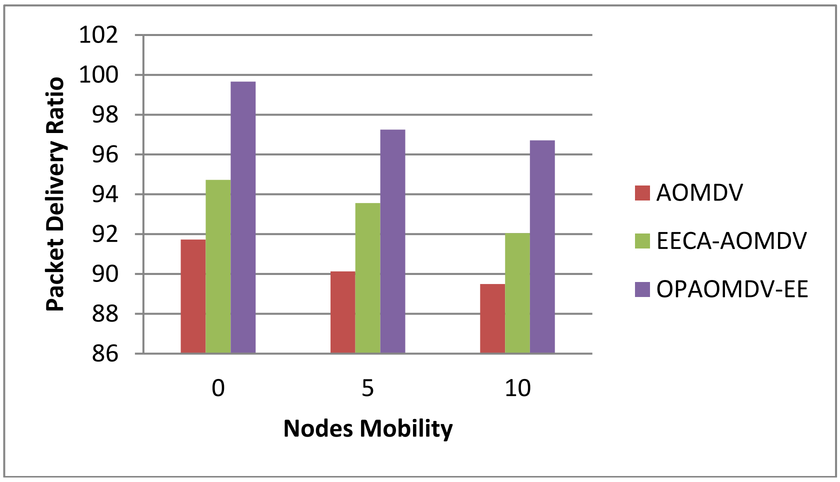

Fig.7. PDR by varying node mobility

C. Throughput

With the increase in speed, more packets start getting dropped with frequent disconnections and hence lead to a decrease in throughput. The results for throughput (i.e., fig. 8) prove the better control of OPAOMDV-EE over the successful delivery of the packets to the destination at a faster pace. For example, in the case of 10 m/s, throughput is 135 for AOMDV, 141 for EECA-AOMDV & 142.35 for OPAOMDV-EE.

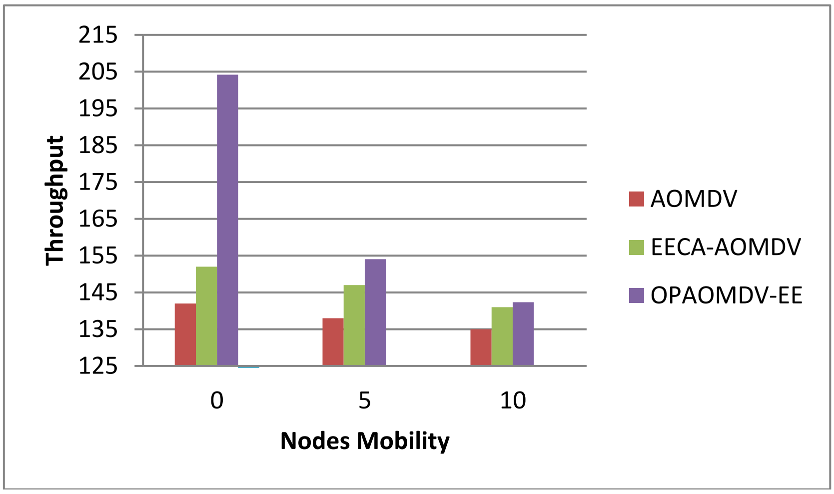

Fig.8. Throughput by varying node mobility

D. Energy Consumption

The procedure of OPAOMDV-EE aims to control the energy consumption of the network. The route that is most energy efficient is assigned a greater priority value and thus leads to the selection of route that is the most energy-efficient. The results shown in fig. 9 corresponding to OPAOMDV-EE also prove the efficiency of OPAOMDV-EE in terms of energy consumption. For example, at 10 m/s nodes, energy consumption is 1367 J for AOMDV, 1134 J for

EECA-AOMDV, and 703.196 J for OPAOMDV-EE.

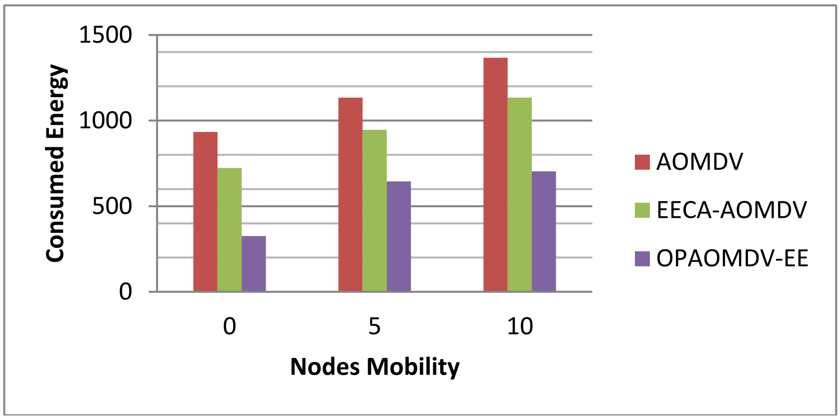

Fig.9. Energy consumption by varying node mobility

6. Conclusions

Energy being the primary constraint in the field of Mobile Ad hoc Networks has been a resource that needs to be optimized to the maximum possible extent. Further, these kinds of networks find their wide acceptability in the field of IoT. The field of IoT further demands that energy be controlled to a greater extent and hence the relevance of OPAOMDV-EE is further strengthened with the growing requirement of energy-efficient networks. The OPAOMDV-EE makes use of various energy constraints and the current energy state of the network. The decision of routing in the case of OPAOMDV-EE for the network is done based on the energy state of the network. Further, the factor of minimum energy calculation helps in predicting and controlling the route failures arising due to the limited energy of mobile nodes, thus leading to energy-efficient routing. The simulation results also support the effectiveness of the design of the OPAOMDV-EE. OPAOMDV-EE producing 12.5% and 9.36% less end-to-end delay in case of node density and node mobility respectively. The proposed protocol is successful in decreasing the energy consumption of the network by 30% as compared to the EECA in both the scenarios. However, there is always a scope of improvement and a few more factors that can help in further stabilizing the networks through better prediction of the future state of the network in terms of mobility, energy, and overhead, which can further optimize OPAOMDV-EE.

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