Energy Aware On-Demand Multipath Routing Protocol in Mobile Ad Hoc Networks

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Abstract: Mobile Ad Hoc Networks are treated as the emerging filed in the wireless communication. They comprise only mobile nodes that use wireless transmission and can be set anywhere and anytime because they eliminate complexity of infrastructure and central admission. They are essentially suitable when infrastructure is not present or difficult or costly to setup or when network setup is to be done quickly within a short period. They are very attractive for tactical communication in the military, rescue missions, emergency situations and mobile communications. The routing is the major issue in the field of MANET due to the mobility nature and lack of infrastructure of the network. The different routing protocols have been proposed to address the routing issue. The nodes in the MANET are typically powered by batteries which have limited energy reservoir. Sometimes it becomes very difficult to recharge or replace the battery of nodes and in such situation energy conservations are essential. The lifetime of the nodes show strong dependence on the lifetime of the batteries. In the MANET nodes depend on each other to relay packets. The loss of some nodes may cause significant topological changes, undetermined the network operation, and affect the lifetime of the network. Hence the energy consumption becomes an important issue in MANET. We proposed an Energy-Aware On-demand Multipath Routing (EAOMR) protocol by modifying the standard multipath routing protocol Ad hoc On demand Multipath Routing (AOMDV) protocol. It selects energy aware node-disjoint multipath between source and destination pairs by using new two power aware metrics, minimize cost per packet and minimize the maximum node cost to increases the network of lifetime .Finally we compare the performance of

EAOMR with AOMDV protocol by using Network Simulator 2(NS2) to prove better performance of proposed protocol by using different performance metrics, throughput, packet delivery ratio, routing overhead, average end-to-end delay, packet loss and energy consumption by varying

network size, node's speed, pause time, data rate, number of source and destination pairs .

Index terms: MANET, EAOMR, AOMDV, Multipath Energy, Routing.

I. INTRODUCTION

MANETs are considered as autonomous, self-configured, multi-hop wireless networks. They don't rely on any stationary infrastructure; no centralized control and they are quickly deployable anywhere at any time. In the MANET, all nodes are mobile that cooperate in friendly manner, they are connected dynamically and they have the ability to leave existing nodes from the network and enter new nodes into the network at any time, due to this, the topology of the MANET is highly dynamic and it frequently changes. In the MANET, every node the route discovery and route maintenance phase. The MANEs are widely used in military, civilian and commercial applications [1][2]. The routing is the most active research field in the MANET. The routing protocols, which are developed for wired networks are not suitable for wireless networks, due to the mobility. The routing problem becomes more serious in MANET, due to following characteristics of MANET

- Highly dynamic topology due to node's mobility
- No infrastructure for centralized administration
- Bandwidth and Energy constrained
- Hidden and exposed problem
- Error prone wireless channel
- Poor wireless variable link capacity

The routing protocols in MANET can be classified as follows

- Pre-computed routing(table driven) vs. On-Demand Routing
- Link State Routing vs. Distance Vector Routing
- Periodical update vs. Event-Driven Up-Date
- Flat structure vs. Hierarchical Structure
- Decentralized Computation vs. Distributed Computation
- Source routing vs. Hop-by-Hop Routing
- Global Position Based Vs Global Position-Less Routing
- Single Path Routing Vs Multipath Routing
- Power aware routing Vs Power Unaware Routing
- Security routing Vs Non Security Routing
- Multicast routing Vs Uncast routing

Main categories namely table driven routing protocol and On-demand routing protocol. The table driven routing protocol also as called proactive routing protocols or pre-computed routing [2]. In Table-driven routing protocols each node computes route to all other nodes in network in advance, each node maintains one or more tables containing routing information to every other node in the network. All nodes update these tables so as to maintain a consistent and up-to-date view of the network. When network topology changes the nodes propagate and update messages throughout the network in order to maintain consistent and up-to-date routing information about the whole network. Some well known and standard table driven protocols are as follows

- Wireless Routing Protocol (WRP)
- Global State Routing (GSR)
- Fisheye State Routing (FSR)
- Hierarchical State Routing (HSR)
- Zone Based Hierarchical LSR Protocol (ZHLS)
- luster Switch Gateway Routing (CGSR)
- Destination Sequenced Distance-Vector Protocol (DSDV)

The on-demand routing protocols build routes only when a node needs to send the data packets to a destination by invoking the route discovery. Some of the well known and standard on demand routing protocols are as follows

- Dynamic Source Routing (DSR)
- Cluster Based Routing Protocol (CBRP)
- Ad-hoc On-demand Distance Vector Routing Protocol (AODV))
- Temporally Ordered Routing Algorithm (TORA)
- Associatively Based Routing (ABR)
- Signal Stability Based Adaptive Routing (SSR).

The on-demand routing is the most popular approach in the MANET compared to table-driven routing, instead of periodically exchanging route messages to maintain a permanent route table of the full topology, the maintenance of whole information about network topology in routing tables is eliminated and the dissemination of routing information throughout the network is also eliminated because that will consume a lot of the scarce bandwidth and power when the link state and network topology changes rapidly and it also works well when network size increases. Hence in this work, we considered on-demand routing.

II. RELATED WORK

The most of existing routing protocols are single path routing protocols. They find single route and utilize it for data transmission from source to destination. Due to dynamic topology, poor and variable wireless links, dynamic characteristics of radio channel, node failure, the currently using route becomes invalid. Due to this the overhead for finding new route from source to destination may be high and extra delay for new route discovery may be introduced and data transmission becomes late [3]. To overcome this drawback by using multipath routing, it is latest trend in the MANET; it finds multiple paths from any source to destination in a single route discovery.

Due to the introduction of multipath routing, the time for searching the route will be reduced drastically and also it helps to reduce the latency for searching the other route at the situation of path failure. In MANETs, multipath routing is considered as trusted approach for ad hoc networking. Due the mobile nature or weak signal strength, the node failure occurs frequently in the MANETs. At the condition of route failure, the multipath routing serves as the best approach for finding the alternate path. The applications of multipath routing are given below.

- Reliability
- Fault tolerance
- Balancing Of Load
- Bandwidth aggregation
- Reduced delay
- Energy consumption
- Reduction of routing overhead
- Provide the Quality of Service(QoS)
- Improve network security and secure communication

There are two types of multipath, Node-disjoint multipath and Link-disjoint multipath. The node-disjoint multipath does not have any nodes in common, except for the source and the destination. Whereas, link-disjoint multipath does not have any common links, but may have common nodes. In the recent years, many researchers made the contribution to address the multipath routing. The several multipath on-demand routing protocols were proposed. Some well known standard Multipath path routing Protocols are

- Ad hoc On-demand Distance Vector Multipath Routing (AODVM)[4]
- Ad hoc On-demand Multipath Distance Vector (AOMDV)[5]
- Split Multipath Routing (SMR)[6]
- Multipath Source Routing (MSR)[7

The comparison of above on- demand Multipath Routing Protocol is shown in table1

Table.1 Comparison of On demand Multipath Routing Protocol

	AODVM	AOMDV	SMR	MSR
Loop-Free paths	No	No	No	No
Node Disjoint	Yes	Yes	No	Yes
Link-Disjoint	No	Yes	Yes	No
Routing Overhead control	No	No	No	No
Complete Routes Known at source	No	No	Yes	Yes
Multipath used Simultaneously	Yes	Yes	Yes	Yes
TTL limitation	Yes	Yes	Yes	Yes
QOS Support	No	No	No	No
Multicast Support	No	No	No	No
Power / Energy Management	No	No	No	No
Security Support	No	No	NO	No

The MANETs contains only mobile modes and they are originally operated with the battery power, so, the major constraint for mobile nodes are battery power. Therefore, the energy is consumed during the transmission of packets. The energy optimization is another important research challenge [1]. Optimizing the energy consumption is one of the designing issues for multipath routing.

New Power Aware Metrics: Suresh Singh, Mike Woo and C. S. Raghavendra[8] raised the power awareness issue in or the ad hoc routing and introduced new metrics for path selection. Minimizing the number of hops is no longer the objective of a routing algorithm, but rather the optimization of multiple parameters such as packet error rate, energy consumption, bandwidth, routing overhead, route setup, route repair speed and possibility of establishing parallel routes etc. A critical issue is power constrained. Developing routing protocols for MANETs has been an extensive research area during the past few years. In particular, energy efficient routing is the most important design criteria for MANETs since mobile nodes will be powered by batteries with limited capacity. The power failure of a mobile node not only affects the node itself but also its ability to forward packets on behalf of others and thus the overall network lifetime. For this reason, many research efforts have been devoted to developing energy aware routing protocols. Different routing protocols use one more metrics to determine optimal paths. Presently most common metric being used are:

- ***Shortest length***
- ***Shortest delay***
- ***Link quality***
- ***Location stability***

The limitation on availability of power for operation is significant bottleneck given the requirements of portability, weight and size of commercial hand held devices. Hence, the use of routing metrics that consider the capabilities of power sources of network nodes contributed to the efficient utilization of energy and increases the life time of the network. The authors present five power aware metrics that do result in energy-efficient routes. The five new metrics are as follows

- ***Minimize energy consumed per packet***: This metric will minimize the average energy consumed per packet.
- ***Maximize time to network partition***: This metric tries to increase the life of Network.
- ***Minimize variance in node power levels***: This metric ensures that all the nodes in the network remain up and running together for as long as possible.
- ***Minimize cost per packet***: This metric minimizes cost for sending a packet.
- ***Minimize the maximum node cost***: This metric minimizes the maximum cost of the node.

To serve this purpose, several energy aware multipath routing protocols were proposed [2]. Multipath Power Sensitive Routing (MPSR)[9],Energy-Aware Multipath Routing (EMRP)[10] protocol, Multipath Energy-Efficient Routing Protocol (MEER)[11],Lifetime-Aware Multipath Optimized Routing (LAMOR**[**12], Energy Aware Source Routing (EASR)[13], Grid-Based Energy Aware Node-Disjoint Multipath Routing Algorithm (GEANDMRA**)[**14], Ant-based Energy Aware Disjoint Multipath Routing Algorithm.(AEADMRA)[15], Energy-Aware Grid Multipath Routing(EAGMR) Protocol[16], Power-Aware Multi-Path Routing(PAMP)**[**17] Protocol , Energy Efficient On-Demand Multipath Routing(MMRE-AOMDV)[18]Protocol, Energy Aware Node-Disjoint Multipath(ENDMR)[19], Energy Aware Clustered Based Multipath Routing (EACMR)[20], Power-Aware Node-Disjoint Multipath Source Routing (PNDMSR)[21],An optimized energy aware routing OEAR[22], The Link Stability with Energy Aware(LSEA) routing protocol[23], Energy Efficient Power Aware Multipath Dynamic Source Routing (DSR-SR**)[**24]**,** Energy Efficient Multipath Routing(EEMR)[25], Energy Conservation for Ad Hoc On-Demand Distance Vector Multipath Routing Protocol**[**26], Energy Optimized Ad hoc on-Demand Multipath Routing Protocol[27] and Enhanced Power aware Multipath Routing [28]Protocol.

A) Problem statement: In table 1 shows that AOMDV [5] does not support energy management i.e the main drawback of AOMDV [5] is it does not find energy aware multipath from source to destination. It finds only unaware energy multipath between source to destination. To overcome the drawback, we proposed a novel energy aware node-disjoint multipath routing protocol by using following two new power metrics [8] to find optimal energy aware node node-disjoint multipath between source and destination.

- Minimize the maximum node cost
- Minimize cost per packet

This protocol is named as Energy Aware On-demand Multipath Routing (EAOMR) Protocol. Some protocols have been proposed based on AOMDV to find the energy aware multipath from source to destination, however these protocols failed in considering of the above two new power metrics to find energy aware node-disjoint multipath between source to destination.

III. Energy Aware On-demand Multipath Routing (EAOMR) Protocol.

The main aim of EAOMR is to find the energy aware node-disjoint multipath form source to destination by using by using node's cost and two power aware metrics, minimize the maximum node cost and minimize cost per packet. It consists of the following four main mechanisms

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- Route selection
- Route Discovery
- Route Maintenance

A) Route selection using node's Cost function

The main objective of route selection is to select the optimal paths to prolong network's life time. It is based on cost function .The main objective of cost function is to give more weight (or) cost to node with less energy to prolong its life time [19]. Let c_i^t be the battery capacity (residual energy) of a node n_i at time t. Let $f_i(c_i^t)$ be the battery cost function of node n_i at time t. The cost of node n_i is equal to value of battery cost function, which in turn inversely propositional to residual energy of the node n_i i.e. $f_i(c_i^t) = 1/c_i^t$. We describe the following cost function

$$f_i(c_i^t) = \rho_i \times \left[\frac{F_i}{c_i^t} \right] \times w_i \qquad (1)$$

Where $f_i(c_i^t)$: Cost of node n_i at time t

ρ_i : Transmit power of node n_i

F_i : Full-charge capacity of node n_i

c_i^t :Residual energy (Remaining battery capacity) of a node n_i at time t.

w_i : weight factor which depends upon various factors, like battery's quality, battery's capacity, life time, battery's back up, and price.

Cost of the path

Let P_j be the path from source s to destination d via intermediate nodes n_1- n_2 ---- -----n_{k-1} -n_k at time t.

$$P_j^t = s - n_1 - n_2 - n_3 - n_4 - - - - n_{k-1} - n_k - d$$

We consider two different costs for each path. The first cost is chosen as maximum cost of any intermediate node on the path P_j at time t, it is also called as **primary cost ,** it is denoted by

$$C^{'}(P_j^t) = \max\{f_i(c_i^t) \quad / \quad \forall n_i \in P_j^t \ \} \qquad (2)$$

Note: Where max is function that selects the maximum cost of interrelate node on the path p_j at time t .The second cost is average cost it is sum of cost of all intermediate nodes on the path p_j at time t divided by total number of intermediate nodes, it is also called **secondary cost**, it is denoted by

$$C^{''}(P_j^t) = \frac{\sum_{i=1}^{k} f_i(c_i^t)}{k} \qquad (3)$$

Where K equal to number of intermediate nodes on path p_j at time t, it is also equal to number of hops minus one or hop_count minus one on path p_j at time t.

B) Route Section Techniques in EAOMR

Optimization is the act of obtaining the best results under given circumstances [32]. In design, construction and any maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of such decisions is to either minimize the effort required or maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decisions variables, optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function.

There two techniques have been proposed t for route selection

***1) First Technique**:*

In this technique, the first priority is given to primary cost and second priory is given to secondary cost. By using primary cost all set of feasible paths are selected and secondary cost is used to select the optimal paths. This technique as described as follows

Optimization problem is stated as follows

Let γ be threshold (cut-off) residual energy of battery of a node and it is considered that this threshold energy of battery is equal for all the nodes irrespective of their battery capacities. If node's energy reaches threshold, then node will die shortly. Let M be set of node-disjoint multipath that were found during route discovery technique from source s to destination d at time t, a feasible path is node-disjoint path that must minimize the equation subject to $\gamma < c_i^t \le F_i$, it is denoted by

$$P_f^t = \{P_j^t \ / \ C^{'}(P_j^t) = Min\{\ C^{'}(P_j^t) / \ \forall P_j^t \in \text{M}\}\} \quad (4)$$

Where Min is a function that selects least cost. Let F be the set of all feasible paths based equation (4) .An optimal path is the feasible path with least average cost , it denoted by

$$P_o^t = \{P_j^t \ / \ C^{''}(P_f) = Min\{C^{''}(P_j^t)\}, \forall P_j^t \in F\} \quad (5)$$

2) Second Technique by using Resulting Cost of path

In some situations there may be more than one criterion to be satisfied simultaneously [33]. An optimization problem involving multiple objective functions is known as a multi-objective programming problem. With multiple objectives there arises possibility. In this technique, equal priority is given to both costs and the route is selected by combination of both costs primary cost and secondary cost and is called resulting cost. The resulting cost of path P_j^t at time t is denoted by

$$RC(P_j^t) = C^{'}(P_j^t) + C''(P_J^t) \quad (6)$$

All these costs of node-disjoint multipath are stored in on-dimensional array and apply quick sort algorithm to sort these resulting costs in ascending order for selecting routes. During selection of routes, the routes are selected according to their ascending order of their resulting costs. The first priority is given to route whose resulting cost is least in sorted array and least priority is given to route whose resulting cost is highest in sorted array. In the simulation, we used this technique.

C) Route Discovery of EAOMR

The EAOMR is extension of AOMDV [5] to find energy aware node-disjoint paths by some modifications. The AOMDV protocol is the use of routing information already available in the underlying AODV [30] protocol as much as possible. For each destination, a node maintains the advertised _hopcount, which is defined as the maximum hop count for all the paths, which is used for sending route advertisements of the destination. Each duplicate route advertisement received by a node defines an alternate path to the destination. Loop freedom is assured for a node by accepting alternate paths to destination if it has a less hop count than the advertised_hop count for that destination. Because the maximum hop count is used, the advertised hop count therefore does not change for the same sequence number. When a route advertisement is received for a destination with a greater sequence number, the next-hop list and the advertised hop count are reinitialized. AOMDV [5] can be used to find node-disjoint or link-disjoint routes. To find node-disjoint routes, each node does not immediately reject duplicate RREQs. Each RREQs arriving via a different neighbor of the source defines a node-disjoint path. This is because nodes cannot be broadcast duplicate RREQs, so any two RREQs arriving at an intermediate node via a different neighbor of the source could not have traversed the same node. In an attempt to get multiple link-disjoint routes, the destination replies to duplicate RREQs, the destination only replies to RREQs arriving via unique neighbors. After the first hop, the RREPs follow the reverse paths, which are node disjoint and thus link disjoint. The trajectories of each RREP may intersect at an intermediate node, but each takes a different reverse path to the source to ensure link disjointness. The advantage of using AOMDV is that it allows intermediate nodes to reply to RREQs, while still selecting disjoint paths. But, AOMDV has more message overheads during route discovery due to increased flooding and since it is a multipath routing protocol, the destination replies to the multiple RREQs those results are in longer overhead.

The proposed modifications are explained briefly as follows.

1) Modifications of Control Packets Format

There are three types of control packets used in the AOMDV

- RREQ packet
- RREP packet
- RERR packet

RREQ and RREP packets are used in route discovery technique, where RERR packet is used in the route maintenance technique and they are modified as follows

a) Modification of Route Request Packet (RREQ)

The Route Request Packet (RREQ) of AOMDV [5] is same as RREQ of AODV[30] .The RREQ of AOMDV is extended as RREQ of the EAOMR by adding one extra field at the end, is called first hop field . Several changes are needed in the AODV [30] route discovery procedure to enable computation of node-disjoint paths between source-destination pairs. Each RREQ now carries an additional field called ***firsthop*** to indicate the first hop (neighbor of the source) taken by it. Also, each node maintains ***firsthop_ list*** for each RREQ to keep track of the list of neighbors of the source through which copy of the RREQ has been received. The size of ***firsthop*** field is 4bytes as shown in fig.1

RREQ of AODV
Firsthop

Fig .1. RREQ of EAOMR

b)Modification of Route Reply Packet (RREP)

The Route Reply Packet (RREP) of AOMDV[5] is same as RREP of AODV[30]. The RREP of AOMDV is extended as the RREP of the EAOMR by adding two extra fields at the end, first field is called as Max-Cost field and second field is called as Total-Cost field, it is also called as sum field. The size of each field is 4 bytes as shown in fig. 2.

RREP of AODV
Max-Cost Field (4bytes)
Total-Cost Field (4bytes)

Fig.2**.** RREP packet format of EAOMR

Destination
Sequence Number
Advertised_ hopcount
Route_list {$Nexthop_1$, $Lasthop_1$, $Hopcount_1$, Max_Cost_1 ,$Total\_Cost_1$, $Timeout_1$ } {$Nexthop_2$,$Lasthop_2$, $Hopcount_2$, Max_Cost_2 ,$Total\_Cost_2$, $Timeout_2$ } ------------------------- {$Nexthop_n$, $Lasthop_n$,$Hopcount_n$ Max_Cost_n ,$Total\_Cost_n$, $Timeout_n$}
Expiration Timeout

Max_Cost field: When RREP packet passes through a node, it compares its cost with cost in Max_Cost field of RREP packet, if its cost is greater than cost in Max-Cost field of RREP packet, then this field is updated by the node by copying its cost; otherwise this field is not disturbed. Initially by default value of this field is set to zero value by destination during generation of RREP packet to source node. This field is not disturbed by source node.

Total_Cost field (Sum field): It carries the cumulative cost of all intermediate nodes of a path from destination to source**,** when the RREP packet passes through a node; its cost is added to this field. Initially, by default value of this field is set to zero by destination during generation of the RREP packet to source node and this field is not disturbed by source node.

c) Route Error (RERR) packet format:

There is no modification in the Route Error (RERR) packet of EAOMR, it is same as RERR of AOMDV [5] it is also same as RERR of AODV [30] .

2) Modifications of Routing Tables

The *advertised_hopcount* of a node i for a destination d represents the "maximum" hop-count of the multiple paths for d available at i. "Maximum" hopcount is considered, as then the advertised hop-count can never change for the same sequence number. The protocol only allows accepting alternate routes with lower hop-counts. In AOMDV [5], Advertised_hopcount replaces hopcount in AODV [30]. A route_ list replaces nexthop in AODV and essentially defines multiple next hops with respective hopcounts. However, all next hops still have the same sequence number. When route list is empty, by default initial value of advertised_ hopcount is infinity ∞ .

In EAOMR , the structure of routing table of each node is shown in fig3 , the structure of routing table of each node is extended by adding two extra fields to each entry of Route list of AOMDV [5], first field is Max_Cost and second filed Total _Cost and initially these fields are empty , the question is why should node i has store these two field values? In case If node i has to be reply to source node. Then it constructs RREP reply packet in that case these values is required. That's why these field values are stored for future purpose in it routing table

Fig. 3. Structure of Routing Table entries in EAOMR

3) Modification of Functions of Nodes:

a) Source Node: In AOMDV [5], when a source node wants to send data to a destination, it looks up its route cache to determine if it already contains a route to the destination. If it finds that an unexpired route to the destination exists, then it uses this route to send the data. If the source node does not have such a route, then it initiates the route discovery process by broadcasting a route request (RREQ) packet to neighbors and if destination is found, it replies by sending RREP to source. In the EAOMR, the functions of the source node similar, but source node maintains unexpired energy aware node- disjoint Multipath to a destination in its cache. They are selected according to route selection technique described in section 3.11.

***b) Intermediate Node*:** The main functions of an intermediate node in AOMDV [5] is as follows

- Preventing loops by using Route Update Rule

- Updating Routing Table for maintaining multiple paths
- Setting Reverse Path for sending RREQ packets
- Setting Forward Path for data transmission

Each node must follow the route update rule for prevention loops as well as to update its routing table for maintaining multiple paths when it receives RREQ Packet or RREP packet from its neighbor node. The modified route update in EAOMR is described section 4 in fig 5. Other two functions are **as** follows

Forwarding of RREQ and setting up reverse path to source node:

In AOMDV**,** while forwarding of RREQ, at the intermediate nodes, unlike in AODV, duplicate copies of RREQ are not immediately discarded. Each copy is examined to see if it provides a new node-disjoint path to the source. This is ascertained by examining the ***firsthop*** field in the RREQ copy and the ***first-list*** in the node for the RREQ. If it does provide a new path, the AOMDV [5] route update rule is invoked to check if a reverse path can be set up. If a reverse path is set up and a valid route to the destination is available at the intermediate node, it sends back a RREP to the source. Just as in AODV, only the first arriving RREQ copy is forwarded if a route to destination is unavailable. This technique is same as in EAOMR and while forwarding RREQ packets, route update rule of EAOMR is same as route update rule of AOMDV.

Forwarding RREP Packets and Setting up forward path to destination node:

Each RREP arriving at an intermediate node takes different reverse routes when multiple routes are already available. When node i receives a RREP packet from its neighbor node j for destination d then it uses route update rule is shown fig .5. It constructs or generates route reply by using following rule. It compares its cost with cost in Max_Cost field of RREP of node j, if its cost is greater than cost in Max_Cost field of RREP of node j, then this field is updated by the node i by copying its cost, otherwise this field is not disturbed by node i and adds its cost to Total-Cost field. Then node i set up the forward path from source to destination and sends its RREP to its neighbor node in its reverse path. The propagation of RREP packets from destination node to source node in EAOMR is in the following fig .4. Each RREP packet carries and provides the primary cost and secondary cost of a path to source node for selecting feasible and optimal energy aware node-disjoint paths for sending data to destination.

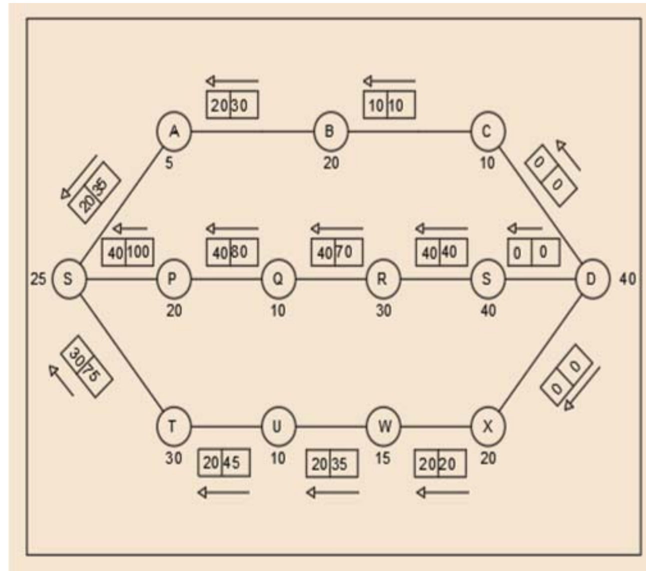

Fig.4. the Propagation of RREP packets

c) Destination node:

At the destination, reverse routes are set up just like in the case of intermediate nodes. However, in the hope of getting link-disjoint paths which would be more numerous than node-disjoint paths, the destination node adopts a "looser" reply policy. It replies up to copies of RREQ (arriving via *unique* neighbors), regardless of the ***firsthop***s taken by these RREQs. Unique neighbors guarantee link-disjointness in the first hop of the RREP. Beyond the first hop, the RREP follow the reverse routes that have been set up already which are node-disjoint (and hence link-disjoint). Each RREP arriving at an intermediate node takes a different reverse route when multiple routes are already available. Note that because of the "looser" reply policy it is possible for the trajectories of RREPs to cross at an intermediate node.

4) Modified Route update rule (Algorithm) in EAOMR

//This is used whenever a node i receives a route advertisement to a destination d from a neighbor node j,

// Variables seq_i^d, $advertised\_hopcount_i^d$ and $route\_list_i^d$ represent the sequence number, advertised_ hopcount and route_ list for destination d at node i respectively.

// $RREP_i$ and $RREP_j$ are route reply packets which are generated by node i and node j respectively.

// Update MAX-Cost and Total cost by node i for constructing RREP

$$If\ \ (f_i(c_i^t) > RREP_j[\mathrm{Max\_Cost}])$$

$$RREP_i[Max\_\mathrm{Cos}t] = f_i(c_i^t)$$

Else

$$RREP_i[Max\_\mathrm{Cos}t] = RREP_j[Max\_\mathrm{Cos}t]$$

// Update Total -Cost by node i

$$RREP_i[Total\_\mathrm{Cos}t] = RREP_j[Total\_\mathrm{Cos}t] + RREP_i[Total\_\mathrm{Cos}t]$$

$if\,(seq_i^d = seq_j^d)$ then

$$seq_i^d = seq_j^d$$

$$if\,(i \neq d)$$

{

$$route\_list_i^d = Null$$

// update route list by creating new entry

$insert\ \ (j,\ advertised\_hopcount_j^d + 1,\ RREP_i[Max\_\mathrm{Cos}t],$

$RREP_i[Total\_\mathrm{Cos}t])$ in to $route\_list_i^d$

}

Else

$$advertised\_hopcount_i^d = 0$$

End if

Else if ($seq_i^d = seq_j^d$) and

$((advertised\_hopcount_i^d, i) > (advertised\_hopcount_j^d, j))$

// update route list by creating new entry

$insert\ \ (j,\ advertised\_hopcount_j^d + 1,\ RREP_i[Max\_\mathrm{Cos}t],$

$RREP_i[Total\_\mathrm{Cos}t])$ in to $route\_list_i^d$

End if

Fig.5. Modified Route Update Rule in EAOMR

D) Route Maintenance

The EAOMR handles route maintenance in a manner similar to the AOMDV [5]. Whenever a link breakage happens in a route due to a node moving away, the previous hop node of the moved away node is responsible for sending a Route Error (RERR) message back to the source to inform the breakage. It chooses alternative routes to maintain the connection. If there are no more redundant routes left, then it will start a new route discovery.

IV. PERFORMANCE ANALYSIS OF EAOMR BY USING NS2.

In this section, we describe the Performance Evaluation And Comparison of EAOMR and AOMDV by using Network Simulator 2 (NS2) [34] with simulation setup The NS2 is popular and standard simulation tool for implementing all types of network protocols. It was developed by the University of California at Berkeley and it is widely used by research scholars. The NS2 was developed by using two computer programming languages one is C++ another is OTcl (Object oriented Tool Command Language) interpreter as a command and configuration interface. The Network Animator (NAM) is an animation tool for inspecting network topology and data transmission shown in fig 5

Different performance metrics are employed to test the EAOMR against the AOMDV both are implemented using Network Simulator 2, in the new version of simulator is NS2.23, Ubuntu operating system was used. The area for network configuration is chosen as 1000m x 1000m and the nodes are deployed with in this region. . For the mobile scenarios, the random waypoint model is used for node mobility. In this model, the random waypoint model is used for node mobility. In this model, a node chooses a random destination point in the network and moves towards that destination point at a constant speed then the node reaches its destination, where it stays for a certain pause time, after which it chooses another random destination point and repeats the process.

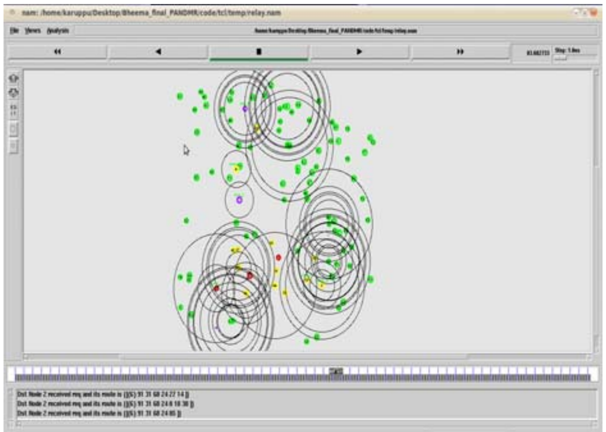

Fig. **5. Shown in Network Animator (NAM) with 50 nodes**

The channel bandwidth is 2Mbps, a free space radio propagation model is used in which the signal power attenuates is $1/r^2$, where r is the distance between the nodes. All the nodes have the same transmission range of 250 meters. The distributed coordination function of IEEE802.11 DCF is used as MAC layer. All nodes operate in promiscuous mode, so it can overhear packets destined for others. The simulation ends after 100sec. The data traffic is generated by Constant Bit Rate (CBR) sessions initiated between the source and destination. All the nodes are assumed to have the same amount of battery capacity with full residual energy at the beginning of the simulation and initial energy of each node is set to 50 Joules. The transmitting power and receiving power of each node are set to 0.079Watts and 0.066Watts respectively. The idle power of each node is set to 0.005Watts the following table 2 shows the simulation setup.

The following quantitative performance metrics are used to measure the performance of both protocols.

- Overhead
- Throughput
- Packet Delivery Ratio
- Packet loss Ratio
- End to End Delay of packets
- Energy Consumption

By varying the following parameter

Number of nodes (density) [25, 50, 75, 100]
Fixed {Speed=30m/S, Pause Time=4s, Data Rate=50Kbps and Load=4}

Mobility of node(speed) [10 m/s, 20m/s, 30m/s, 50m/s],

Fixed {Network Size=50, Pause Time=4s, Data Rate=50kbps and Load=4}

Data Rate [10Kbps, 20Kbps, 30Kbps, 50Kbps]

Fixed {Network Size=50, Speed= 2m/S, Pause Time=4s and Load=4}

Pause time [2sec, 4sec, 6sec, 8sec],

Fixed {Network Size=50, Speed= 30m/S, Data Rate =50kbps and load=4}

Number of source nodes and Destination pairs (increasing load) [1, 2, 3, 4]

Fixed {Network Size=50, Speed= 2m/S, Pause Time =4ms, Data Rate =50kbps}

Here we have derived some facts or relationships among performance metrics and parameters based on our previous work

Fact 1: The overhead

Table.2. Different Parameters and Values

It is directly proportional to probability of collisions, packet loss, packet error rate, packet delay, bandwidth consumption and energy consumption. It is indirectly proportional to packet delivery ratio and throughput. Hence the overhead depends on overall performance of the routing protocol.

Fact 2: Speed

It is directly proportional to path failure rate, energy consumption, Packet loss, bandwidth and congestion. It is indirectly to throughput, Packet Delivery Ratio and Packet delay,

Fact 3**: **Pause Time

The increase pause time means increasing network stability. Hence it is indirectly proportional to path failure rate, energy consumption, Packet loss, bandwidth and

congestion. It is directly proportional to throughput, Packet Delivery Ratio and Packet delay.

Sno	Parameter and Values
1	Network size and Node's Placement 1000 x 1000 Sq meters (Size of NAM),
2	Number of Nodes: 25, 50, 75, 100
3	Total Simulation time : 100s
4	Node's Mobility : Random Way Point Mobility odel(RWPMM)
5	Node's Speed: 10 m/s, 20m/s, 30m/s, 50m/s
6	Node's Pause Time: 2s, 4s, 6s, 8s
7	Application Layer : Constant Bit Rate(CBR)
	Packet Payload size: 512 bytes
	Data rate :10Kbps, 20Kbps,30Kbps ,50Kbps
	Number of source and destination pairs : 1, 2, 4,8
8	Transport Layer: User Datagram Protocol(UDP) ,CBR
9	Network Layer: EAOMR and AOMDV Routing Protocols
10	Data Link Layer: Logical Link Control Layer (LLC)
	Medium Access Layer(MAC):IEEE 802.11 DCF
11	Physical Layer:
	Antenna Model : Omni Directional
	Wave Propagation Model: Two-way Ground Model
	Channel Type: Wireless Channel Physical layer Channel Bandwidth: 2Mbps Lucent Wave LAN card with frequency 915MHz Transmission range of node : 250 meters Interference range of node: 500 meters
	Interface Queue Type: CMU Priority Queue with size 50 packets
12	Energy Model:
	Initial energy of each node: 50Joules
	Transmission Power: 0.079 Watts
	Receiving Power:0.066 Watts
	Idle Power: 0 .035 Watts
	Sleep Power: 0.005 watts
	Transition Power :0.2 watts
	Transition Time: 0.005 sec

Fact 4: Data Rate

It is directly proportional to congestion, energy consumption, Packet loss and bandwidth. It is indirectly to throughput, Packet Delivery Ratio and Packet delay.

Fact 5: Number of source and destination pairs (load)

It is directly proportional to energy consumption, Packet loss, bandwidth and congestion. It is indirectly proportional to throughput, Packet Delivery Ratio and Packet delay.

A) Analysis of Routing Overhead

The optimization of routing overhead is crucial part when designing new routing protocol because the overhead is directly proportional to congestion, probability of collisions, packet loss, packet error rate, packet delay, bandwidth consumption and energy consumption. It is indirectly proportional to packet delivery ratio and throughput. Hence the overhead depends on overall performance of the routing protocol. The routing overhead is defined as the number of control packets as generated at the time of simulation. The overhead is the most important performance metric to compare the routing protocols.

Routing Overhead= Number of Control Packets (RREQ, RREP, REEP) generated by routing protocol during simulation.

The normalized routing overhead is calculated as follows

$$\text{Normalized Routing Overhead}=\frac{x}{y} \qquad (7)$$

Where x is total number of routing packets generated

and y is total number of packets received

The Link-disjoint and Node-disjoint Multipath variant of AOMDV protocol have been evaluated the performance between them [33]. These protocols investigated with varying node density and pause time. The various QoS matrices are computed to analyze the performance. It is evident from the results that node disjoint multipath performs better as compared to link disjoint multipath routing technique. Theoretically, it is noticed that node-disjoint is better compare to link-disjoint. It proved that simulation results also justified the same [33].

1) Overhead by Varying Number of nodes (Density):

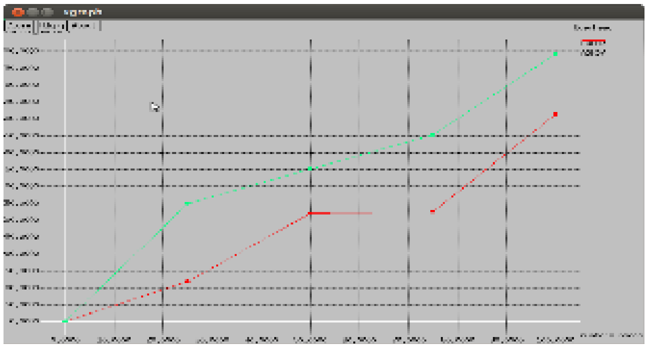

Fig. 4.1 Overhead Vs Network's Size (density)

Fig.4.1. shows, Overhead Vs Number of nodes by varying number of nodes (density) 25, 50, 75 and 100. The overheads of both protocols increased. In case of 50 and 75 nodes the overhead of EAOMR has not been changed but the overhead of AOMDV is increased drastically and exponential compared to the EAOMR. However in all above four cases EAOMR produces less overhead than AOMDV, because the EAOMR was designed to find node-disjoint multipath that are energy aware and AOMDV was designed to link-disjoint multipath that are energy unaware.

2) Overhead by varying node's speed

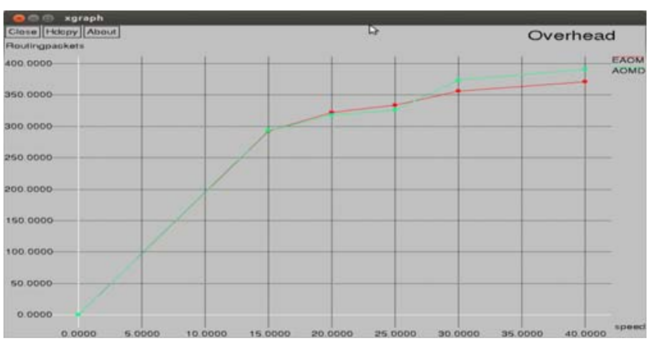

Fig.4.2 Overhead Vs Speed (m/s)

Fig 4.2 shows the Overhead Vs Speed of node , speed is varied as 10m/s, 20m/s, 30m/s, 50m/s, usually speed increases overhead are also increases because probability of path failure rate increases. At speed 10m/s, the overhead of both protocols is same. At speed 20m/s, the overhead of EAOMR is slightly increased than overhead of AOMDV and it is approximately equal. Later at high mobility, the EAOMR produces less overhead than AOMDV and it performs much better than AOMDV when speed increases.

3) Overhead Vs Varying pause time

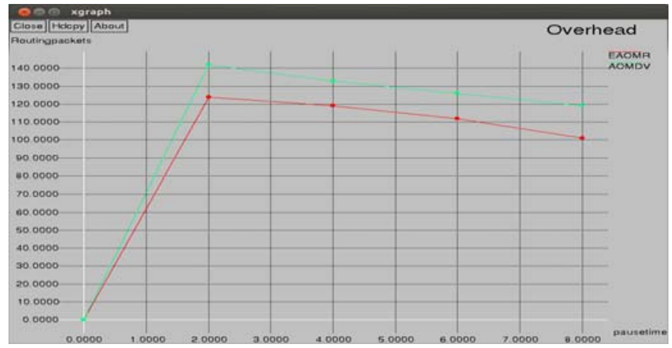

Fig. 4.3. Overhead Vs Pause Time

Fig.4.3 shows, Overhead Vs Pause Time, here pause time is varied as 2s, 4s, 6s and 8s. Usually, the pause time increases network stability also increases and path failure rate decreases. So pause time is indirectly proportional to overhead. Fig 4.3 shows the overheads of both protocols decreased when increasing the pause time and EAOMR yielded less overhead than overhead of AOMDV.

4) Overhead Vs Varying Data Rate

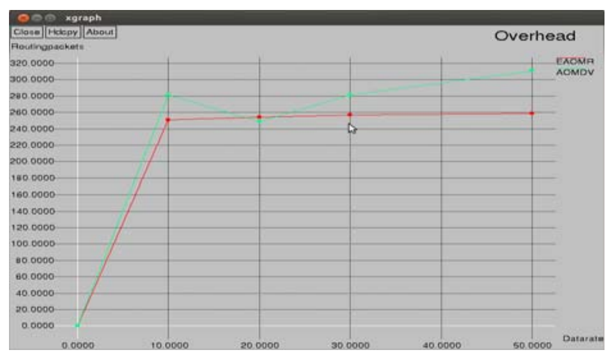

Fig . 4.4. Overhead Vs Data Rate (Kbps)

Fig. 4.4 shows overhead Vs Data rate, here data rate is varied as 10Kbps, 20Kbps, 30Kbps and 50Kbps and usually data rate is directly proportional to the overhead. In three cases 10Kbps, 30Kbps and 50Kbps, EAOMR yielded less overhead than overhead of AOMDV. At 20Kbps the overhead of the EAOMR is slightly increased than overhead of AOMDV, because the overheadoes not purely depend on the data rate.

The path failure rate is also depends on the dynamic characteristics of ad hoc network. i.e it depends on unpredictable in node mobility, poor wireless link quality, error-prone radio shared channel, hidden and exposed problems.

5) Overhead by varying Source and Destination pairs (connections)/load.

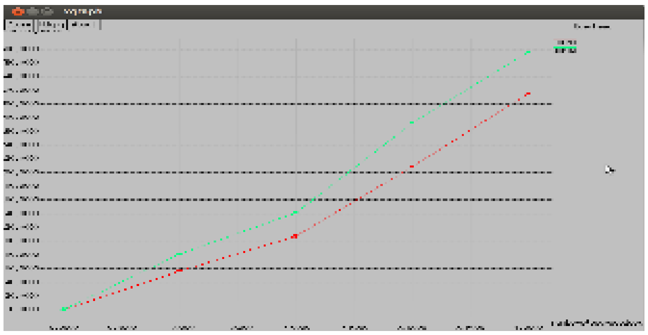

Fig.4.5. Overhead Vs Number of Source and Destination pairs (connections)

Fig.4.5 shows overhead Vs number of sources and destination pairs (load), here number of source and detonation pairs is varied as 1, 2, 3 and 4. The number of sources (load) is directly proportional to the overhead. When increasing load, the overheads of both protocols increased exponentially. However in all four cases the EAOMR yielded less than overhead of AOMDV and the overhead of the AOMDV drastically increases compared to the overhead of EAOMR, because the overhead of EAOMR was designed to find node-disjoint multipath that are energy aware and AOMDV was designed to find link-disjoint multipath that are energy unaware . Theoretically, it is noticed that node- disjoint is better compare to link-disjoint. It proved that simulation results also justified the same [33].

B) Analysis of Energy Efficiency

It is an important qualitative metric to measure the performance of different protocols. The energy efficiency is calculated as the ratio of total received data (bytes) to the total energy consumption using equation 8 [10]

$$\text{Energy Efficiency}=\frac{x}{y} \qquad (8)$$

Where x is total received data in terms of bytes and y is total energy consumption in terms of joules

$$\text{Total energy consumption}=\sum_{i=1}^{n}(E_i - R_i) \qquad (9)$$

Where E_i denotes the initial energy of i^{th} node , R_i denotes the residual energy of i^{th} node and n total number of nodes in the network. In Table 2, in energy model, we used the following new parameters

- Sleep Power is power consumption (Watt) in sleep state
- Transition Power is power consumption (Watt) in state transition from sleep to idle (active)
- Transition Time is time (second) used in state transition from sleep to idle (active)

The overhead is directly proportional to energy consumption. The following four scenarios shown that overall EAOMR has less energy consumption compared to the AOMDV because the EAOMR has yielded less overhead compared to the AOMDV.

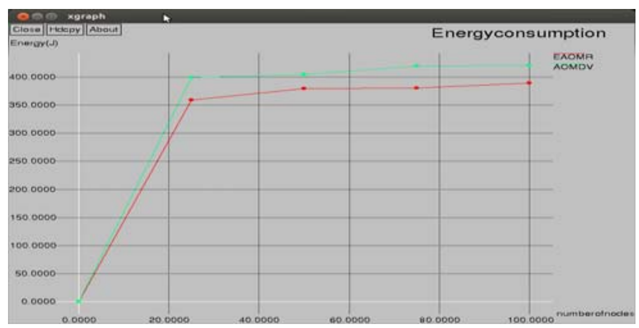

Fig.4.6. Energy Consumption Vs Number of Nodes

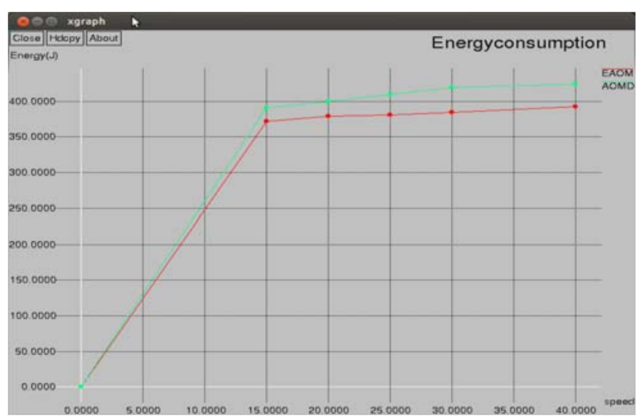

Fig.4.7. Energy Consumption Vs Speed

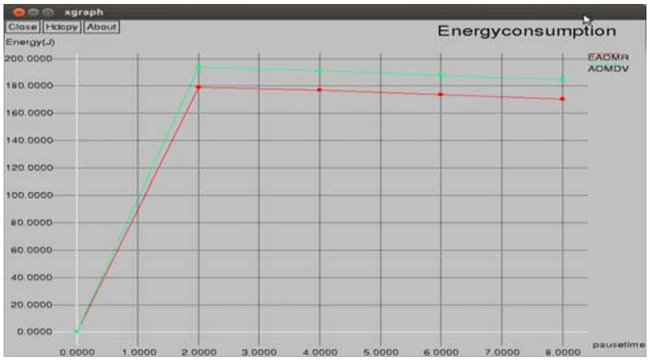

Fig.4.8. Energy Consumption Vs Pause time

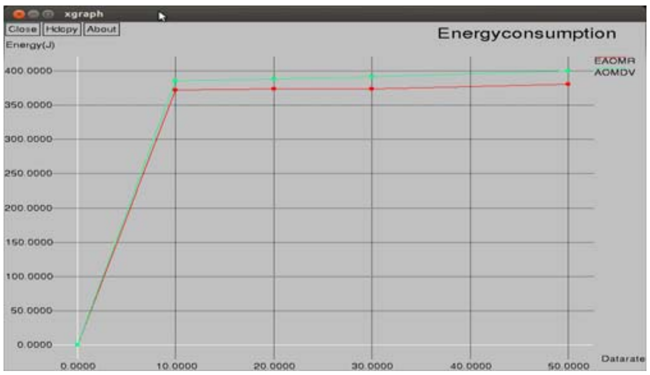

Fig..4.9. Energy Consumption Vs Data Rate

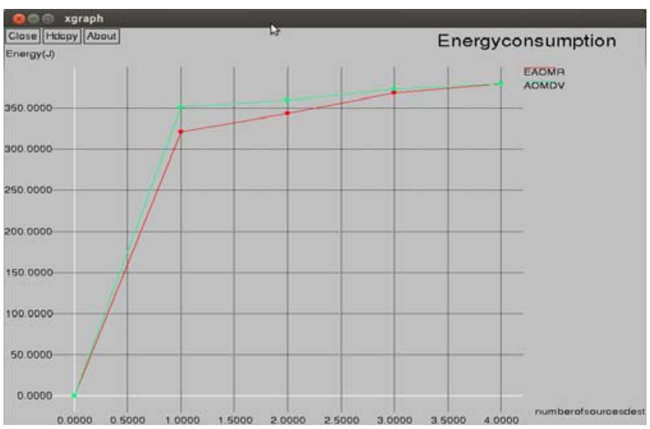

Fig.4.10. Energy Consumption Vs Number of Source and Destination Pairs

C) Throughput (Kbps) analysis:

To measure the protocol performance, throughput serves as the better parameter. The throughput is defined as the ratio of number of packets received to the number of packets transmitted [10] and it is indirectly proportional to the overhead.

The throughput is calculated by using the following equation. $\text{Throughput} = \frac{x \times 8}{t \times 100} Kbps \quad (10)$

Where x is number of bytes received and t is simulation time

The following five cases show that the overall EAOMR yielded higher throughput than the AOMDV because overhead of EAOMR is less than the overhead of AOMDV

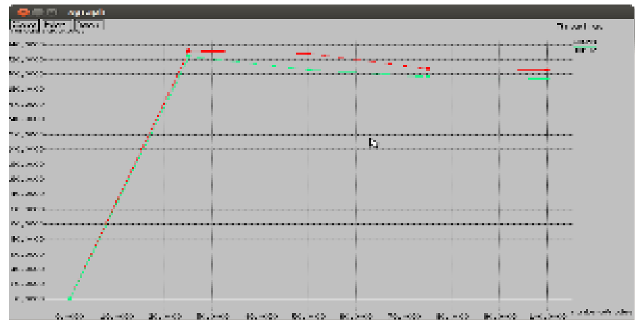

Fig. 4.11. Throughput Vs Number of Nodes (Network size)

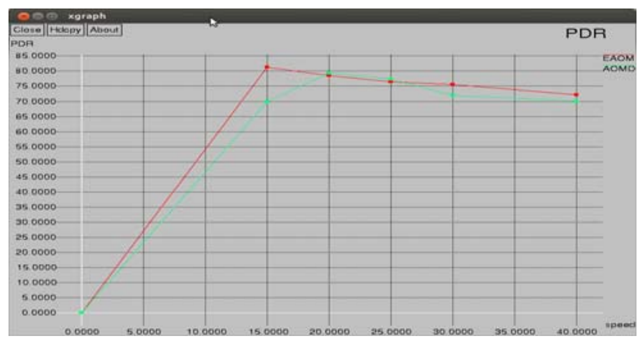

Fig 4.12. Throughput Vs Speed

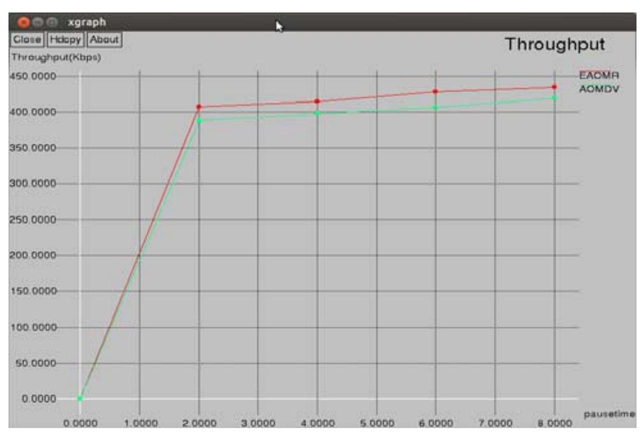

Fig 4.13.Throughput Vs Pause time

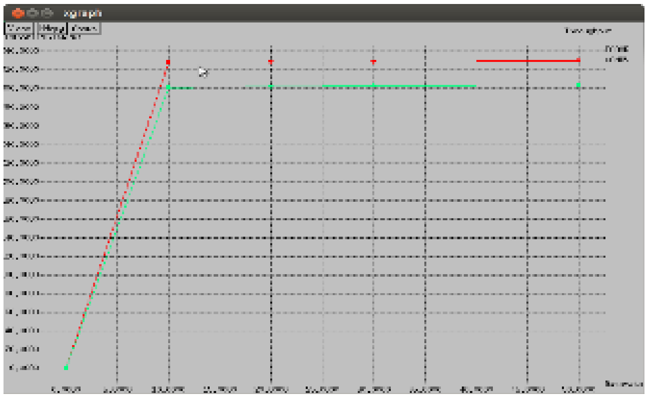

Fig . 4.14. Throughput Vs Data Rate (CBR)

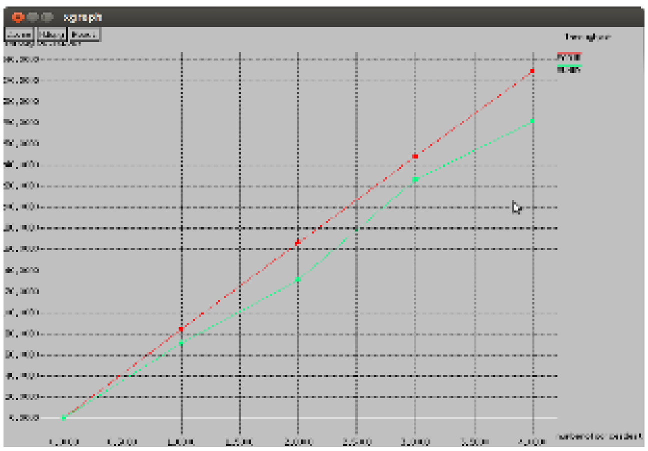

Fig. 4.15. Throughput Vs Number of Source and Destination pairs (connections)

D) Analysis of Packet Delivery Ratio (PDR):

To find the efficiency of the protocols, *PDR* is one of the important qualitative metrics. It is defined as the ratio of data packets received and packet sent [10], it is calculated as follows

$$PDR=\frac{x}{y}\times 100 \qquad (9)$$

Where x is the total number of packets received and y is the total number of packets sent at end of the simulation time.

The following all five cases show that overall the EAOMR yields higher PDR than the PDR of the AOMDV because overhead of EAOMR is less than the AOMDV

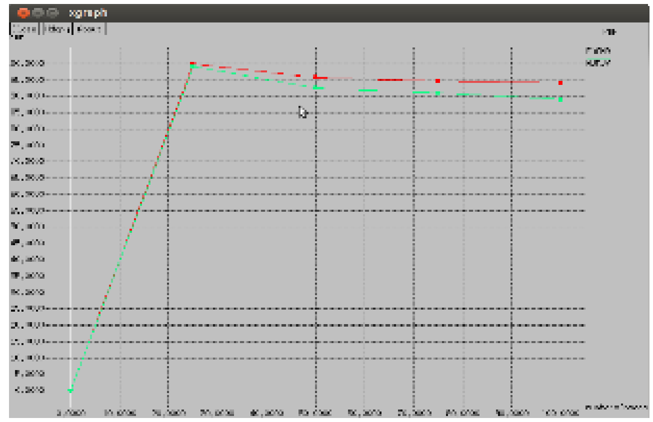

Fig. 4.16**.** PDR Vs Number of Nodes

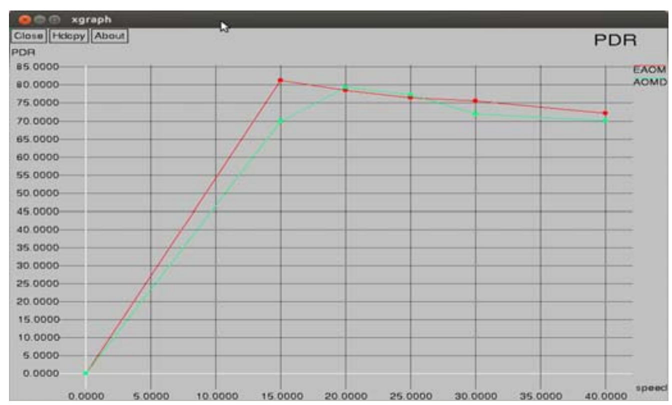

Fig. 4.17. PDR Vs Speed

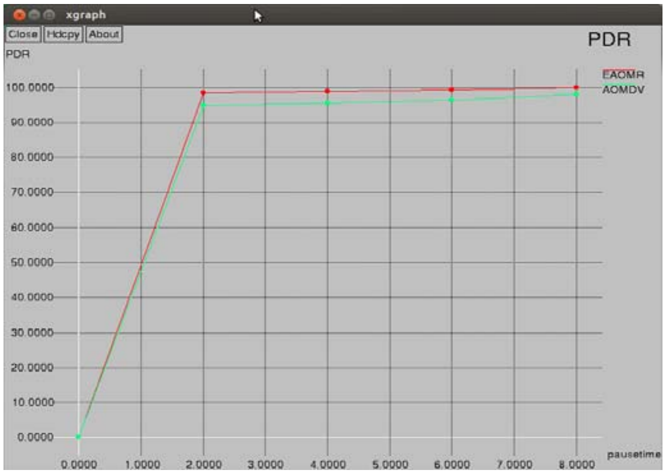

Fig..4.18. PDR Vs Pause time

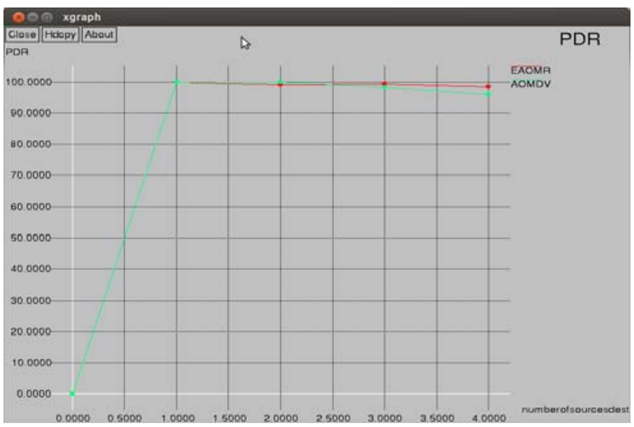

Fig.4.19. PDR Vs Data Rate (load)

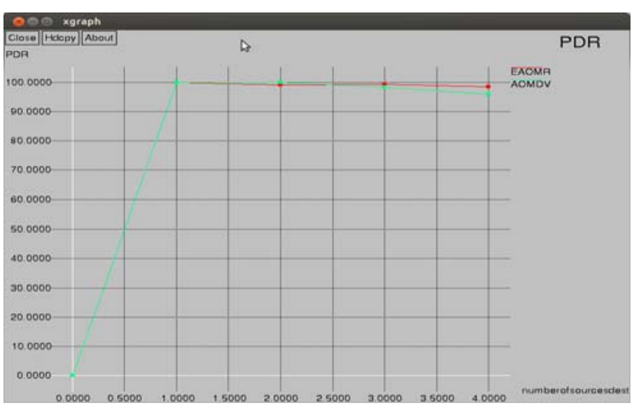

Fig.4.20. PDR Vs Number of Source to Destination Pairs

E) Analysis of Average End-to-End Data Packet Delay (ms)

To measure the performance of the proposed protocols end to end delay is the major performance factor which should be considered. The Average end to end delay is defined as the time taken to transmit the packet from source node to the destination node. The total end to end average delay of data packets includes queuing delay, buffering delay, propagation delay and retransmission delay. The average end to end delay of n received data packets [10] by using the following equation .

$$\text{delay} = \frac{\sum_{i=1}^{n}(R_i - S_i)}{n} \qquad (11)$$

Where R_i denotes the time at which the packet i is received and S_i denotes the time at which the packet i has been sent to the destination or it also defined as follows

$$\text{Average delay} = \frac{\text{Total delay of each data packets}}{\text{Total data packets received.}}$$

Following five cases show that overall, the EAOMR yielded low average end-to-end packet delay than the average end-to-end packet delay of AOMDV.

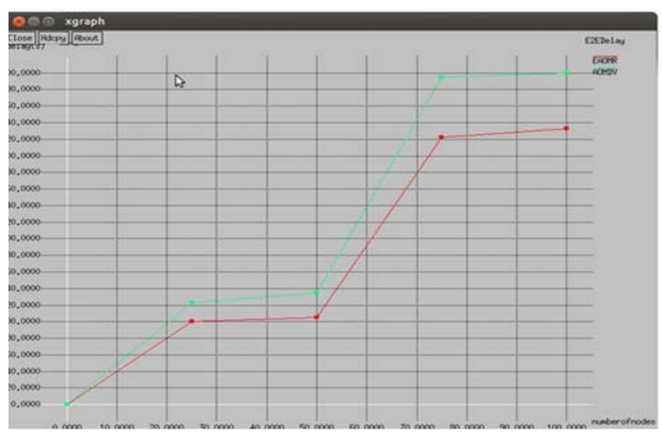

Fig 4.21. Delay Vs Number of Nodes

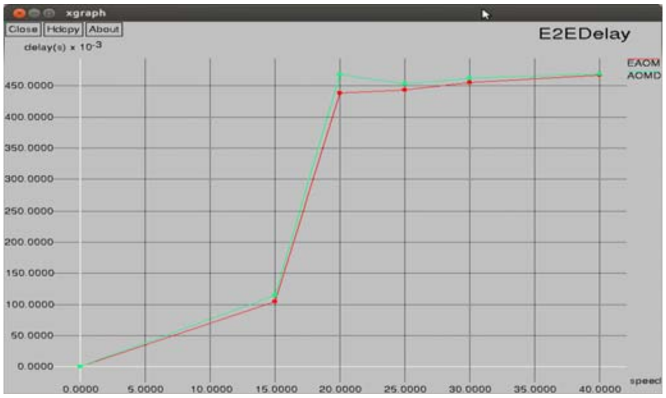

Fig. 4.22**.** Delay Vs Speed

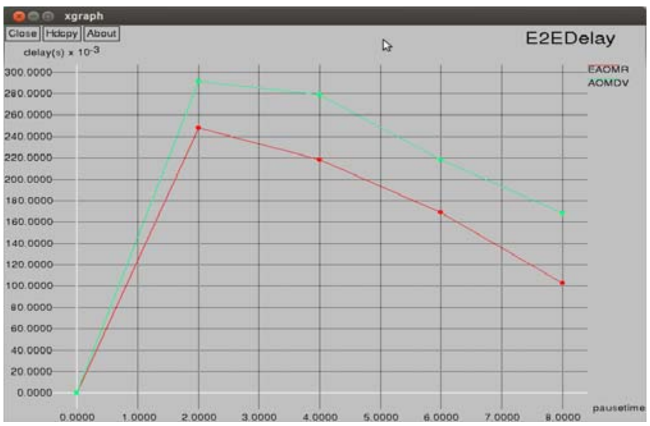

Fig. 4.23. Delay Vs Pause Time

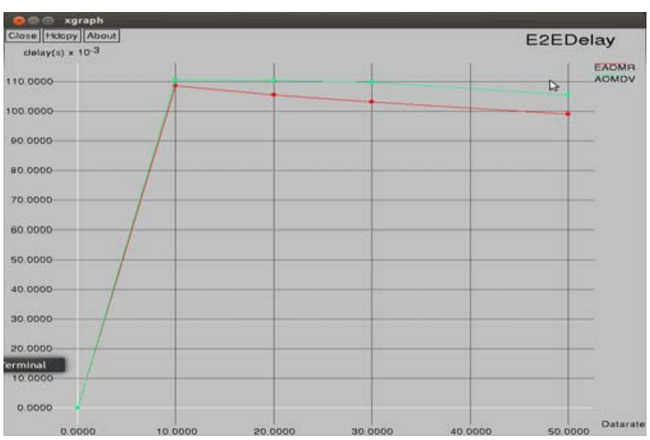

Fig .4.24. Delay Vs Data Rate (Kbps)

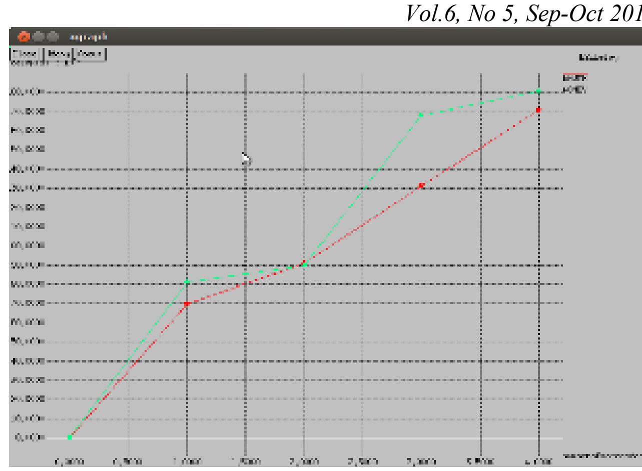

Fig. 4.25. Delay Vs Number of Source and Destination pairs

F) Packet Loss Ratio (PLR) (%):

The PLR is used to measure the performance of the routing protocols. The PLR is defined as the ratio of number of packets not delivered to the destination to the total number of packets sent [10]. The PLR is calculated by using the equation 5.

$$PLR = \frac{x-y}{x} \times 100 \quad (11)$$

Where x is total number of data packets sent and y is total number of data packets received.

Number of data packets lost=x- y.

Some data packets that are not reach the destination and they are lost during transmission to due to congestion and collision in the network.

The following five cases shown that overall the EAOMR has less packet loss compared to the AOMDV because the EAOMR has yielded less overhead compared to the AOMDV.

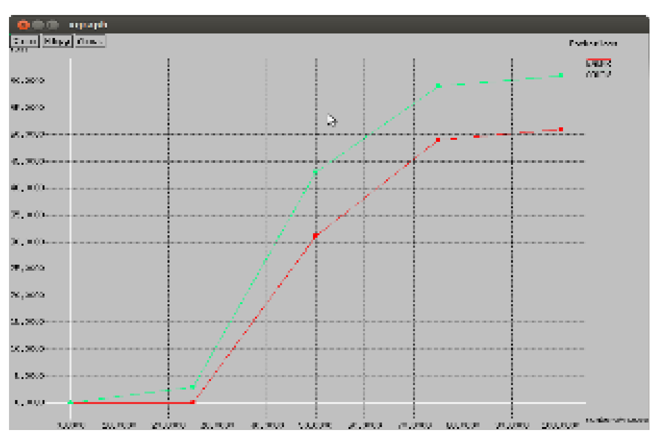

Fig .4.26. Packet loss Vs Number of nodes

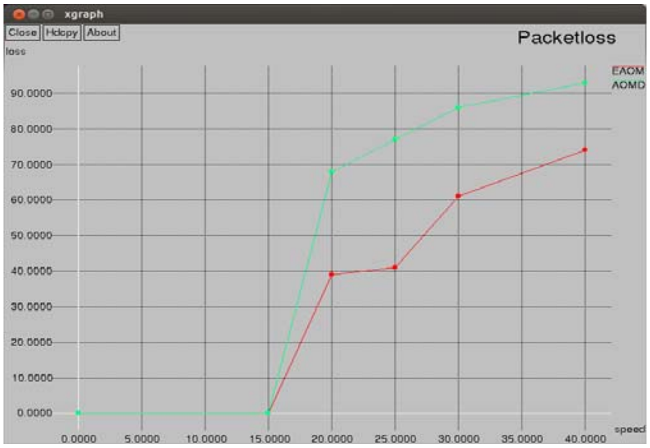

Fig. 4.27. Packet loss Vs Speed (m/s)

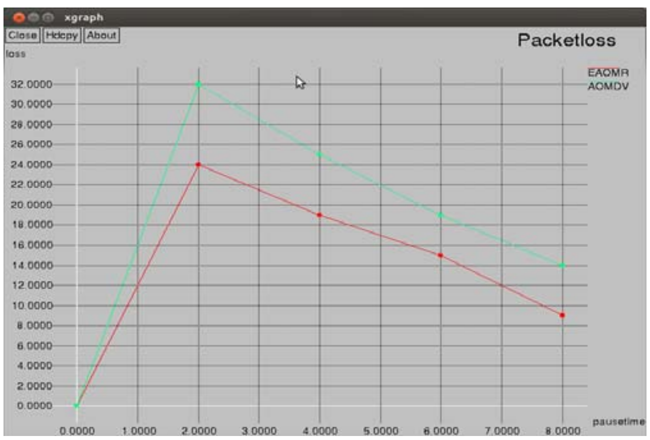

Fig .4.28. Packet loss Vs Pause Time (Sec)

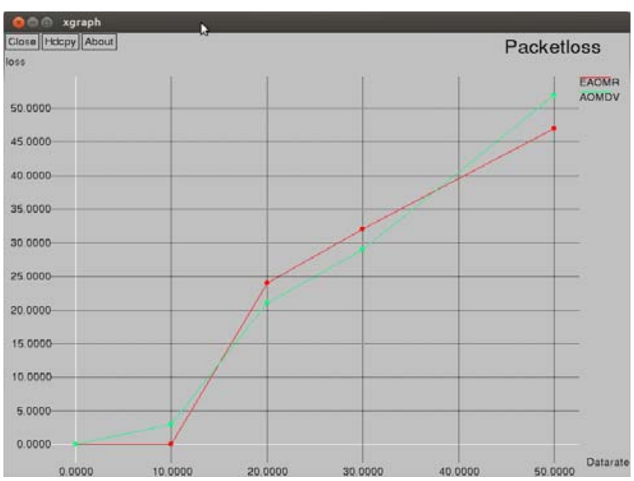

Fig .4.29. Packet loss Vs Data Rate (Kbps)

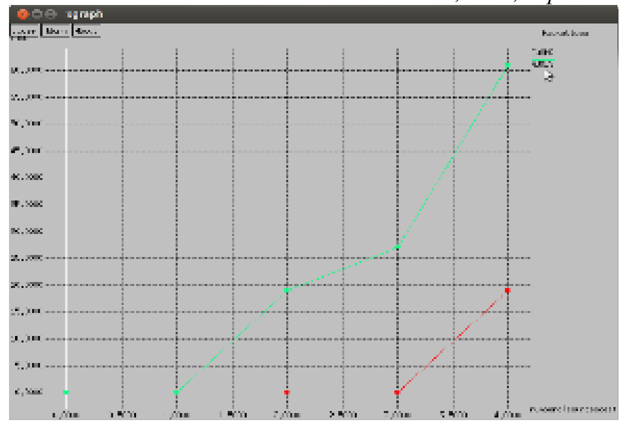

Fig .4.30. Packet loss Vs Number of Source and

V .CONCLUSIONS AND FUTURE WORK

In this paper, we proposed a novel energy aware node-disjoint multipath routing protocol , Energy Aware On-demand Multipath Routing (EAOMR) Protocol to find energy aware node-disjoint multipath between source and destination by using two new power aware metrics and based on AOMDV. We have derived some facts related to performance metrics and parameters. We also made a contribution to measure the performance of two different multi-path dynamic routing protocols such as EAOMR and AOMDV. The performance of the two protocols is tested with well-known simulator called as NS2 [34]. The performance of the EAOMR and AOMDV are tested by using various quantitative performance metrics like, end-to end delay of packets, throughput, routing control overhead, packet delivery ratio, energy efficiency, and packet loss rate and by varying various parameters like network's size, mobility of node, pause time, data rate and load .It is proved that EAOMR has better performance than AOMDV and it is concluded that the EAOMR is one of scalable, robust and energy efficient multipath routing protocol in MANET. In future work, we will propose new EAOMR by consider the selection of routes using first proposed technique.

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