ENERGY AWARE NODE DISJOINT MULTIPATH ROUTING IN MOBILE AD HOC NETWORK

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ABSTRACT

With the advance of wireless communication technologies, small-size and high-performance computing and communication devices like commercial laptops and personal digital assistants are increasingly used in daily life. After the success of second generation mobile systems, more interest was started in wireless communications. This interest has led to two types of wireless networks: infrastructured wireless network and infrastructureless wireless network, it is also called Mobile Ad-Hoc Network (MANET). The Mobile Ad Hoc Networks 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 and rescue missions. They are also expected to play an important role in the civilian fora such as convention centers, conferences, and electronic classrooms. The nodes in the MANET are typically powered by batteries which have limited energy reservoir. Some times it becomes very difficult to recharge or replace the battery of nodes; 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 lost of some nodes may cause significant topological changes, undermine 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 Node-disjoint Multipath Routing (ENDMR) protocol, which balances node energy utilization to increase the network lifetime, it takes network congestion into account to reduce the routing delay and increases the reliability of the packets reaching the destination.

Keywords: *MANET, Energy consumption, DSR, Node Disjoint Multipath.*

1. INTRODUCTION

The history of wireless networks started in the 1970s and the interest has been growing ever since. The tremendous growth of personal computers and the handy usage of mobile computers necessitate the need to share the information. The great popularity of Internet services make more people enjoy and depend on the networking applications. However, the Internet is not always available and reliable, and hence it cannot satisfy people's demand for communication at anytime and anywhere. A Mobile Ad hoc Network (MANET) is a wireless network without any fixed infrastructure or centralized control; it contains mobile nodes that are connected dynamically in an arbitrary manner. Based on infrastructure, the wireless networks broadly classified into two types, first type infrastructure networks contains base-stations. An example of this wireless networks are the cellular-phone networks where a phone connects to the base-station with the best signal quality is shown fig. 1. When the phone moves out of range of a base-station, it does a "hand-off" and switches to a new base-station within reach [2].

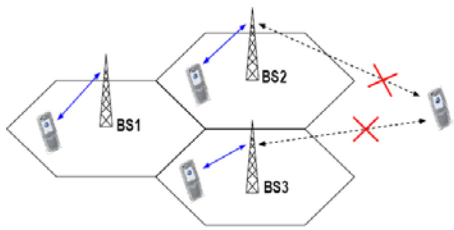

Fig.1. Illustration of the infrastructure network

The second type is called Mobile Ad hoc Networks enable users to communicate without any physical infrastructure regardless of their geographical location. The construction of temporary network with no wires, no communication infrastructure and no administrative intervention required. Fig.2 shows MANET with three nodes.

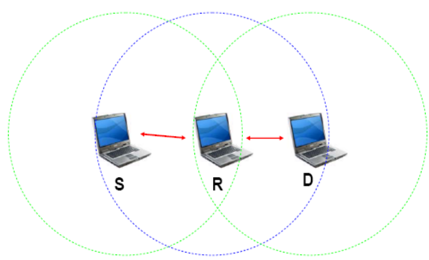

Fig. 2. Illustration of the infrastructure less network

The nodes are the main components of the network, these nodes are mobile can move freely at any time, so the network structure changes dynamically due to node mobility. Each node behaves as a router; it takes part in discovery and maintenances the routes to other nodes in the network. The main characteristics of the MANET are dynamic topology, bandwidth constrained, variable capacity links, energy constrained operation. The nodes can move freely at any time and can leave or join the network. The research challenges in MANET are related to routing, security, reliability, scalability, quality of services, internetworking, energy consumption and multimedia applications. The MANET is essential in natural disasters like earthquake, flood, tsunami, fire and emergency services [2].

1.1 Applications of Mobile Ad Hoc Networks

The following are some well-known applications [3] of MANET.

Military

- Automated battlefield
- Special operations
- Homeland defense

Civilian

- Disaster Recovery(flood, fire, earthquakes etc)
- Law enforcement (crowd control)
- Search and rescue in remote areas
- Environment monitoring (sensors)
- Space/planet exploration

Commercial

- Sport events, festivals, conventions
- Patient monitoring
- Ad hoc collaborative computing (Bluetooth)
- Sensors on cars (car navigation safety)
- Vehicle to Vehicle communications
- video games at amusement parks, etc

1.2. Multipath Routing in MANET

The routing is the most active research field in the MANET. The routing protocols designed for wired networks are not suitable for wireless networks due to the node mobility issues in wireless networks. The different protocols are proposed to deal with routing problem in the MANET. These routing protocols can be classified into two main categories: Table driven routing protocols and on demand routing protocols [1].

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 [6].

A fundamental problem in ad hoc networking is how to deliver data packets among nodes efficiently without predetermined topology or centralized control, which is the main objective of ad hoc routing protocols. Because of the dynamic nature of the network, ad hoc routing faces many unique problems not present in wired networks. Due to node mobility, node failures, and the dynamic characteristics of the radio channel, links in a route may become temporarily unavailable and making the route invalid. The overhead of finding alternative routes may be high and extra delay in packet delivery may be introduced. The multipath routing addresses this problem by providing more than one route to a destination node. Multipath routing appears to be a promising technique for ad hoc routing protocols.

Providing multiple routes is beneficial in network communications, particularly in MANETs, where routes become obsolete frequently because of mobility and poor wireless link quality [4]. The source and intermediate nodes can use these routes as primary and backup routes. Alternatively, traffic can be distributed among multiple routes to enhance transmission reliability, provide load balancing, and secure data transmission. The multipath routing effectively reduces the frequency of route discovery therefore the latency for discovering another route is reduced when currently used route is broken. Multiple paths can be useful in improving the effective bandwidth of communication, responding to congestion and heavy traffic, and increasing delivery reliability.

2. RELATED WORK

Ongoing research activities in the areas of power conservation and efficiency have targeted different layers of the network protocol stack. However, most such research has been targeted at the MAC layer and the network layer. Developing core protocols at different layers is an area of extensive research in the past few years. In this work, we are interested in power-aware route selection mechanisms for MANET's routing protocols. Recently some routing protocols have been proposed to utilize energy in an efficient manner.

Suresh Singh and C. S. Raghavendra[5] proposed the PAMAS protocol that uses two different channels to separate data and signaling. The Suresh Singh, Mike Woo and C.S. Raghavendra [6] presented several power-aware metrics that do result in energy-efficient routes. The Minimum Total Transmission Power Routing (MTPR)[7] was initially developed to minimize the total transmission power consumption of nodes participating in the acquired route. The Min-Max Battery Cost Routing (MMBCR) [8] considers the remaining power of nodes as the metric for acquiring routes in order to prolong the lifetime of network. C.K.Toh [8] presented the Conditional Max-Min Battery Capacity Routing (CMMBCR) protocol, which is a hybrid protocol that tries to arbitrate between the MTPR and the MMBCR. The several multipath proactive routing protocols were developed. These protocols use table-driven algorithms (link state or distance vector) to compute multiple routes. But they do not consider the power aware metrics and these protocols generate excessive routing overhead and perform poorly because of their proactive nature.

The on-demand routing is the most popular approach in the MANET. Instead of periodically exchanging route messages to maintain a permanent route table of the full topology, the on-demand routing protocols build routes only when a node needs to send the data packets to a destination. The standard protocols of this type are the Dynamic Source Routing (DSR) [9] and the Ad hoc On-demand Distance Vector (AODV) [10] routing. However, these protocols do not support multipath. The several multipath on-demand routing protocols were proposed. Some of the standard protocols are the Ad hoc On-demand Multipath Distance Vector (AOMDV)[11], the Split Multipath Routing (SMR) [12], the Multipath Source Routing (MSR) [13], the Ad hoc On-demand Distance Vector Multipath Routing (AODVM) [14] and the Node-Disjoint Multipath Routing (NDMR)[2]. These protocols build multiple routes based on demand but they did not consider the power aware metrics.

Recently several Energy Aware On-demand Multipath Routing protocols have been proposed. The Grid-Based Energy Aware Node-Disjoint Multipath Routing Algorithm(GEANDMRA)[15] considers energy aware and node-disjoint multipath, it uses grid-head election algorithm to select the grid-head which is responsible for forwarding routing information and transmitting data packets. The Ant-based Energy Aware Disjoint Multipath Routing Algorithm (AEADMRA)[16] is based on swarm intelligence and especially on the ant colony based meta heuristic.

The Multipath Energy-Efficient Routing Protocol (MEER)[17] prolongs the network lifetime by using a rational power control mechanism, the route discovery phase in which the source is finding energy-efficient routes is similar to that of SMR [12]. The Lifetime-Aware Multipath Optimized Routing (LAMOR)[18] is based on the lifetime of a node which is related to its residual energy and current traffic conditions. The Power-Aware Multi-Path Routing Protocol (PAMP)[19] is an extension of the existing AODV by modifying RREQ and RREP management mechanism to handle energy reservation and multiple paths. The Multipath Power Sensitive Routing (MPSR)[20] shows how an efficient heuristic based multipath technique can improve the mean time to node failure and maintain the variance in the power of all the nodes as low as possible. The Energy Aware Source Routing (EASR) [21] discovers paths without overlapping, each path hardly overhears other data transmission and it reduces the overhearing energy waste among selected paths by using the overhearing ratio.

2.1 Motivation and problem

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. Suresh Singh, Mike Woo and C. S. Raghavendra[6] first raised the power awareness issue in the ad hoc routing and introduced new metrics for path selection. The five power aware metrics are described that do result in energy-efficient routes 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 node.

The existing power aware multipath on demand routing protocols do not reduce the overhead during finding of the node-disjoint paths and not using neither the minimize cost metric nor minimize the maximum node cost metric.

3. ANALYTICAL MODEL

This section describes four models that related to our proposed work.

3.1. Network Model

A MANET is represented by undirected graph, $G=(V,E)$ where V is the set of nodes and E is the set of bidirectional links. Each node is equipped with a single network interface card (NIC) and has a transmission radius of r. Each node has mobility, the speed is uniformly chosen between the minimum and maximum speeds. When the node reaches its destination, it stays there for a certain pause time, after which it chooses another random destination point and repeats the process, the mobility is defined as the distance moved per unit time by a node in the network. Suppose at time t_1 the node n_i is at position (x_1, y_1) in two dimensional space and by time t_2 the node n_i has moved to position (x_2, y_2), then the mobility of the node n_i denoted by

$$M_{n_i} = \frac{1}{(t_2 - t_1)} \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)}^2$$

The cost is assigned to each node based its cost function. It is assumed that the number of route requests is denoted by λ that follows the poison distribution process and call holding time follows the exponential distribution, when a route request occurs, two nodes are randomly selected as source and destination.

3.2 Energy Consumption

According to IEEE specifications of the network interface card (NIC) with 2 Mbps. The energy consumption varies from 240mA at receiving mode and 280mA in the transmitting mode using 0.5V energy. Thus, when calculating the energy consumed to transmit a packet p is $E(p)$=i *v*t_p Joules are needed[22] **.** Here, i is the current, v is the voltage and t_p is the time taken to transmit the packet p. The energy required to transmit a packet p is given by $E_{tx}(p)$=280mA*v*$t_{p.}$ The energy is required to receive a packet p is given by $E_{rx}(p)$=240mA*v*$t_{p.}$ The energy consumption of overhearing the data transmission may be assumed as equivalent to energy consumption of receiving of the packet.

3.3. Multipath Node-disjoint Model

This model describes the probability estimation of node disjoint paths between source and destination in a network. Let P_j be the path from the source node s to destination node d via intermediate nodes n_1 --------n_k at time t, it denoted by

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

Two paths are said be node-disjoint if and only if there is no common intermediate node between them and source and destination nodes are common to both. Let X be a set of all the intermediate nodes on path P_i, Let Y be a set of all intermediate nodes on path P_j, if P_i and P_j are said be node-disjoint if and only if $X \cap Y = \phi$.

The probability that there exist number of k node-disjoint paths is estimated as follows. Consider that there are total of n nodes in the network and all n are assigned unique id. If we select k subsets of nodes at randomly then ith subset contains m_i nodes such that $\sum_{i=1}^{k} m_i << n$. The probability that all these k subsets are disjoint is denoted by χ [23].

$$\chi = \prod_{i=2}^{k} \left(\frac{\binom{n-2-\sum_{j=1}^{i-1} m_j}{m_i}}{\binom{n-2}{m_i}} \right) \quad (1)$$

Where 2 is subtracted from n to exclude source and destination nodes. Let us assume that for a given source s and destination d, there exist k node-disjoint paths and ith path has m_i nodes is shown in Fig.3.

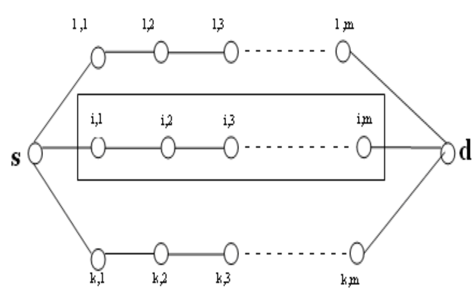

Fig.3. m_i nodes are lying on i^{th} disjoint path

We denote j^{th} node of i^{th} path by the subscript i, j, where $1 \le i \le k, 1 \le j \le m_i$. Note that end points of all k paths are fixed by s and d. Consider i^{th} path, the probability that there exists a link between nodes 1 and 2 is $\tau_{1,2}$ and subsequently probabilities that there exist in links <2,3>, <3,4>, ... <m_{i-1},m_i> are $\tau_{2,3}$, $\tau_{3,4}$ ……$\tau_{mi-1,mi}$, respectively. Let Ω be the probability that there exist links from s to d in an order <1,2,3,..,m_i> according to multiplication theorem of probability

$$\Omega = \tau_{s,1} \times \tau_{1,2} \times \tau_{2,3} \times \tau_{3,4} \times ..... \times \tau_{m_{i-1},m_i} \times \tau_{m_i,d}$$

We further assume that $\tau_{u,v} = \tau, \forall (u,v) \in E$, so $\Omega = \tau^{m_i+1}$. For m_i intermediate nodes along a path, there can be m_i! possible orderings. Suppose $E_o |_{o=1}^{m_i!}$ denotes the event of occurrence of oth such ordering. For O=m_i ! . Let $P(E_i)$ be the probability that occurrence of event E with ith ordering . According to addition theorem of probability, we have

$$P\left(\bigcup_{o=1}^{O} E_o\right) = \sum_i P(E_i) - \sum_{i<j} P(E_i E_j) + \sum_{i<j<k} P(E_i E_j E_k) ....(-1)^{O+1} P(E_1 E_2 ....E_O)$$

Let P be the probability that there exists a path with m_i intermediate nodes from the source to destination, So

$$P = \binom{O}{1} \Omega .....(-1)^{O+1} \binom{O}{O} \Omega^{O}$$
$$= \left[1 - (1-\Omega)^{O}\right]$$
$$= \left[1 - (1-\tau^{m_i+1})^{m_i!}\right]$$

Let P_k be the probability that there exist k multiple paths between s and d. So

$$P_k = \prod_{i=1}^{k} \left[1 - (1-\tau^{m_i+1})^{m_i!}\right] \quad (2)$$

Let P_{kd} be the probability that there exist k node-disjoint paths from the source s to the destination d, it is obtained by multiplying the equations (1) and (2). $P_{kd} = \chi P_k$

3.4. Path Failure Model

This model describes the possibility of failure of multiple paths. Let k be number of node-disjoint paths from a source to a destination. Let $P_i(\delta t)$ denotes the probability of failure of *ith* path of these k paths in a time-interval (t, $t+\delta t$), where $1 \le i \le k$. The path failures occur due to the node failures that are a result of lack of battery power and link failures caused by mobility [24]. It can write the path failure probability for a path of *ith* path

$$P_i(\delta t) = 1 - \left(\prod_{(i,j)\in path\ i} A_{(i,j)}(\delta t) \prod_{j\in\ path\ i} B_j(\delta t) \right)$$

Where $A_{(i,j)}(\delta t)$ is the link availability of the connecting any pair of nodes i and j on path i and $B_j(\delta t)$ is the node availability of the node j on path i. Independence of link failures and node failures is used only to compute the path failure probability. Once the path failure probabilities are known, we can consider the possibility of failure of multiple paths. Thus, The probability of failure of the paths $p_1, . . p_k$ in the interval(t, $t+\delta t$) is given by $P_{(1,....,k)}(\delta t) = \prod_{i=1}^{k} P_i(\delta t)$

4. PROPOSED WORK: ENERGY AWARE NODE-DISJOINT MULTIPATH ROUTING (ENDMR) WITH LOW OVERHEAD

The main aim of proposed routing is to increase the life time of network with low overhead while achieving many desired features of routing protocol of MANET. It selects the optimal paths using power aware metric and optimizes the power consumption, overhead and bandwidth. It supports reliability by providing node-disjoint paths and it provides the stability (increasing mean life time of the nodes) by distributing the burden of routing and congestion control.

It consists of the following four main mechanisms

- Route selection
- Route Discovery
- Maximization of Network lifetime and congestion control
- Route Maintenance

4.1 Cost function and Route selection

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. 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 turns 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

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

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.

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

We consider two different costs for the path. The first cost is chosen as maximum cost of any intermediate node on the path P_j, it is denoted by

$$C^{'}(P_j) = \max\{f_i(c_i^t) \quad / \quad \forall n_i \in P_j \ \} \qquad (3)$$

The second cost is sum of cost of all intermediate nodes on the path p_j, it is denoted by

$$C^{''}(P_j) = \sum_{i=1}^{k} f_i(c_i^t) \qquad (4)$$

Optimization problem is stated as follows

Let γ be threshold (cut-off) 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 to threshold, then node will die shortly. Let M be the set of node disjoint multipath that were found during route discovery with low overhead technique from source s to destination d at time t, a feasible path minimizes the equation 3 subject to $\gamma < c_i^t \le F_i$, it denoted by

$$P_f = \{P_j \ / \ C^{'}(P_j) = Min\{C^{'}(P_j)\}, \forall P_j \in M\} \quad (5)$$

Where Min is a function that selects least cost. Let F be the set of all feasible paths based equation 5.An optimal path is the feasible path with least total cost, it denoted by

$$P_o = \{P_f \ / \ C^{''}(P_f) = Min\{C^{''}(P_f)\}, \forall P_f \in F\} \qquad (6)$$

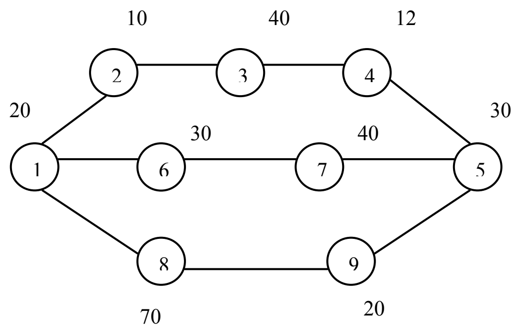

Fig .4. Network with 9 nodes

For example, in fig.4 there are three node disjoint multipath say P_1, P_2, P_3 from source node 1 to destination node 5, where P_1=1-2-3-4-5, P_2=1-6-7-5 and P_3=1-8-9-5. As per equation (3) their costs are $C^{'}(P_1)=40$, $C^{'}(P_2)=40$ and $C^{'}(P_3)=70$. According to equation (5) P_1 and P_2 are feasible paths. According to equation (4), the total costs of P_1 and P_2 are $C^{''}(P_1)=10+40+12=62$, $C^{''}(P_2)=30+40=70$. According to equation (6), an optimal path is P_1.

4.2 Route Discovery

The route selection is based on route discovery. We choose the Dynamic Source Routing (DSR) [9] protocol as a candidate protocol and make modifications to enable the discovery of energy aware node disjoint paths. The proposed modifications are explained briefly as follows.

Modifications of control packets

We modify the format of Route Request (RREQ) packet and Route Reply (RREP) packet of the DSR. The RREQ of the DSR is extended as RREQ of the ENDMR adding with two extra fields, one is cost field and another is max-cost field is shown in fig.5. It contains type field, source address field, destination field, unique identification number field, hop field, max-cost field, cost (cumulative cost) field and path field.

T	SA	ID	DA	TTL	Hop	Max cost	Cost	Path

Fig.5. Fields of RREQ packet

Type (T) field: It indicates the type of packet. **SA (Source Address) field**: It carries the source address of node. **ID field:** unique identification number generated by source to identify the packet. **DA (Destination Address) field:** It carries the destination address of node. **Time To Live (TTL) field:** It is used to limit the life time of packet, initially, by default it contains zero.**Hop field:** It carries the hop count; the value of hop count is incremented by one for each node through which packet passes. Initially, by default this field contains zero value. **Max-Cost field**: When packet passes through a node, if its cost is greater than max-cost of packet, then this field is updated by the node by copying its cost other wise this field is not disturbed. Initially by default this field contains zero value. **Cost field:** It carries the cumulative cost**;** when packet passes through a node; its cost is added to this field. Initially, by default this field contains zero value. **Path field:** It carries the path accumulations**,** when packet passes through a node; its address is appended at end of this field. The Route Reply packet (RREP) of the the DSR is extended as RREP of the ENDMR adding with cost field.

Modifications at source node:

In the DSR, 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. But if the source node does not have such a route, then it initiates the route discovery process by broadcasting a route request (RREQ) packet. In the ENDMR, the functions of the source node similar, but source node maintains energy aware node disjoint multipath to a destination and it chooses the optimal path to send the data.

Modifications at intermediate node:

In the DSR, when an intermediate node receives a RREQ packet, it checks whether its own address is already listed in the route record of received RREQ packet. If its address is not found, then it appends its address to the route record of received RREQ and it is broadcasted to all its neighbors. Other wise the received RREQ packet will be dropped. Later if an intermediate node receives duplicate RREQ packets(whose Source address and ID are same as Source address and ID of currently received RREQ) from other paths, then those duplicate RREQ packets will be dropped. The pair (Source address, ID) is used to distinguish the packets.

In the ENDMR when an intermediate node receives a RREQ packet, it checks whether its own address is already listed in the route record of received RREQ packet. If its address is not found, then it appends its address to the route record along with its cost is also added to cost field of RREQ. The resulting RREQ packet is broadcasted to all its neighbors by using broadcast ***with low overhead*** approach (explained in the section 4.2.1) to reduce the overhead other wise it drops the RREQ packet.

In the DSR, an intermediate node is allowed to send route reply, if it has fresh and valid to route the destination in its cache. Currently this route has been found using route discovery. Where as in the ENDMR, it is modify that an intermediate node is not allowed to send route reply if it has fresh and valid to route the destination in its cache, because it does not possible to find node disjoint paths from the source to the destination and at the same time it destroys the aim. So the disabling the intermediate to send route reply yields node-disjoint multipath from the source to the destination. So the above reasons all the intermediate nodes are disabled to send route reply to the source but the destination is only allowed to send reply to the source and it is also modified that an intermediate node is allowed to broadcast duplicate RREQ packets based some constrains.

Modifications at Destination node:

In the DSR, when the destination receives the RREQ packet, its address is appended to it and it generates the route reply by inserting path. In DSR, destination sends single route reply. Later duplicate RREQ packets will be dropped and it doesn't send any reply. Where as in the ENDMR, when the destination generates several replies and sends them to the source. Finally all multiple RREQ (Route requests) packets will be reached to the destination, then destination appends its address and adds total cost to each route request, now each route request contains a path from source to destination. In the conventional on-demand multipath routing protocols, the source node computes optimal path(s) from multiple paths that were supplied by the destination in the route reply. But here we have introduced new concept, the computation of optimal paths is assigned to the destination instead of the source to reduce to reduce the overhead. The following four cases the overhead increases for sending multiple paths through replies.

- Increasing of multiple number of paths or
- Increasing of length of a path or increasing of lengths of paths or
- Increasing of distance between the source and the destination or
- all above

4.2.1 Route Discovery at Intermediate Node using broadcast with low overhead.

In the DSR, if a source node does not know a route to a destination, it will initiate a route discovery by broadcasting a Route Request (RREQ) packet. When an intermediate node receives a RREQ packet, if it is the first time that the node receives this RREQ packet, then the node will broadcast the RREQ packet. Otherwise, the node will drop the RREQ packet, using this method of broadcasting the RREQ, the possibility of finding node-disjoint multiple paths is almost zero, the reason is that later duplicate RREQ packets will come from different paths will be dropped. However, if all of the duplicate RREQ packets are broadcasted, this will lead to a routing packet broadcast storm and decrease dramatically the performance of the ad hoc networks.

Hence a novel method has been introduced to optimize the overhead. When an intermediate node receives a RREQ packet, it starts a timer (*Tr*) and keeps its cost as Min-Cost (Minimum Cost).If additional subsequent RREQs arrive from the same source with the same sequence number (ID) from different paths then the cost of the newly arrived RREQ packet is compared with the Min-Cost. If the new packet has a lower cost, Min-Cost is changed to this new value and the new RREQ packet is forwarded. Otherwise, the new RREQ packet is dropped. Hence in this approach many duplicate RREQs will be dropped if they arrive with higher cost than to recorded

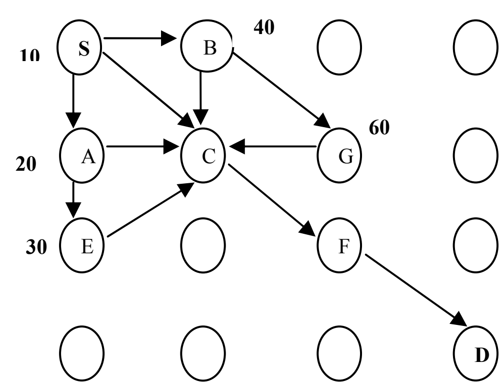

Fig. 6. Broadcasting with low overhead

For example, consider a part of the network in Fig.6. From source node S to node C there are five paths: S-C, S-B-C, S-A-C, S-B-G-C, S-A-E-C. Their hop lengths are 1, 2, 2, 3 and 3 respectively and their costs are 0, 40, 20, 100 and 50 respectively. When node C receives the RREQ packet at the first time from the path S-C, it records 0 as the cost and path length as 1 hop. Later if node C receives the four duplicate RREQs from other paths then they will be dropped because their costs are higher than recorded cost. In this approach most of the RREQ packets are discarded. Furthermore, it can also avoid forming loop paths and dramatically decreases the routing overhead.

The detail description of this approach as follows, when a RREQ packet arrives at an intermediate node, it is scanned; if target address of the RREQ is same as address of intermediate node then the intermediate node acts as destination node to send route reply else if ether TTL value of RREQ is reached to zero, or address of intermediate node is already exists then received RREQ will be dropped, otherwise its partial information is recorded into route request information table (RRIT) whose format is shown the fig.7.

SA	ID	DA	Hop	Max-cost	Cost

Fig.7. Fields of Route Request Information Table

After recoding the partial information, the intermediate node broadcasts the RREQ by incrementing the value of hop field by one and by updating the max-cost, cost and path fields of RREQ.

The updations are as follows

i. Its cost is assigned to Max-cost field if its cost is greater than value of Max-cost field
Otherwise Max-cost field will not be disturbed.
ii. Its cost is added to cost field.
iii .Its address is appended to path field.

Fig.8. shows the updations of fields during propagation of RREQ from source node A to destination node E and it also shows propagation of RREP from node E to node A. Then intermediate node waits for duplicate RREQ packet, it is also RREQ packet with the same source address and with the same ID.
The pair (Source address, ID) is used to distinguish the packets. If new duplicate RREQ arrives at intermediate node, then its cost is compared with cost of previous RREQ whose information was already recorded in the Route Request information table. If the cost of new duplicate RREQ is greater than cost of pervious RREQ, then new duplicate RREQ will be dropped.else if both costs are equal then max-costs of both packets are compared, if max-cost of new duplicate RREQ is greater than max-cost previous RREQ, then new duplicate RREQ will also be dropped otherwise partial information about new duplicate RREQ is recorded by deleting the corresponding entry of previous RREQ duplicate in the Route Request information table. Then the intermediate node broadcasts the duplicate RREQ packet by updating the fields. If tie occurs i.e max-costs are equal then hops of both packets will be considered instead of max-costs for comparison, again tie occurs new duplicate RREQ will be dropped.

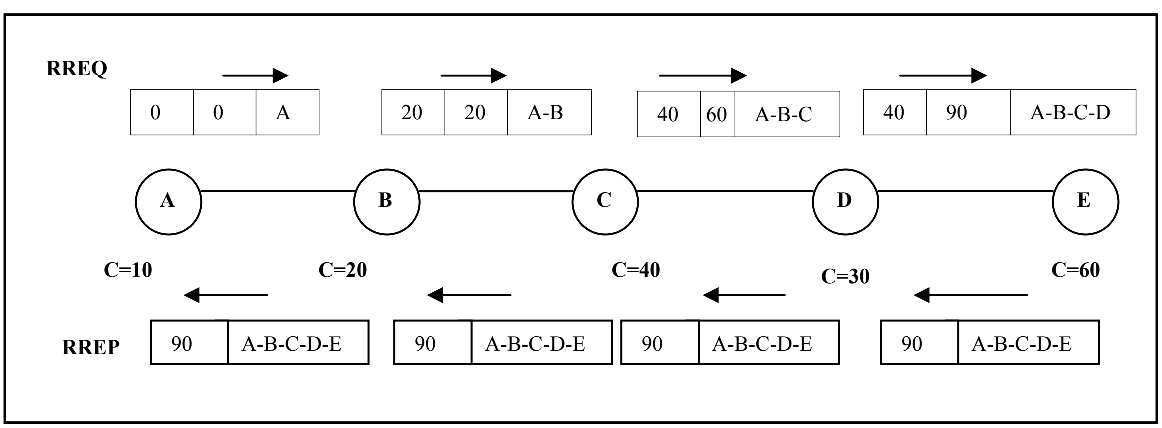

Fig.8. propagation of RREQ and RREP

This process is repeated until time out. After time out , later duplicate RREQ packets will be dropped, even through they have lower cost , because to minimize the route discovery time.

The following cases only new duplicate RREQ will be forwarded until time out.

- If its cost is less than to cost of previous RREQ.
  Or
- If its cost is equal to cost of previous RREQ and its max-cost is less than to max-cost of previous RREQ. Or
- If its cost is equal to cost of previous RREQ and its max-cost is equal to max-cost of previous RREQ and its hop is less to hop of previous RREQ.

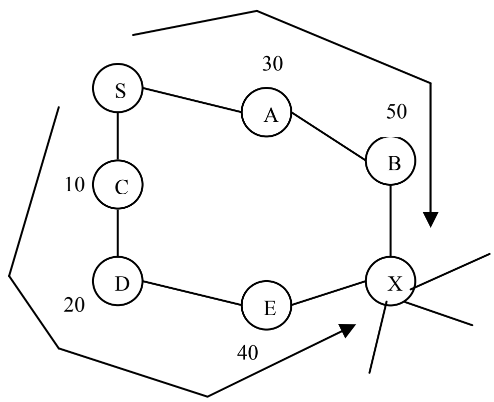

Fig. 9. Part of network

Consider the a part of network in fig.9 , there are two paths from source node S to some intermediate node X , Let us assume that first path is S-A-B-X and second path is S-C-D-E-X. their total costs are equal , if first a RREQ arrives through second path and later another RREQ arrives through first path . Then their max-costs are compared, the max-cost of later RREQ is 50 which is greater than max-cost 40 of first RREQ. So later RREQ will be dropped. Other wise if first a RREQ arrives through first path and later another RREQ arrives through second path, in that case later RREQ will be broadcasted because whose max-cost is lower.

Pseudo code for detail operation of intermediate node

Let us assumed that myaddress, mycost are the address and cost of intermediate node respectively. DA, SA TTL indicate Destination Address, Source Address and Time To Live respectively. Let concatenation operator is denoted by symbol ⊕ .

Step1: Receive RREQ
// Check for node address equal to target //
if (myaddress = RREQ [DA])
Act as destination to send reply ;
goto step 7.
Step 2: // If either TTL value is zero or node address exists in RREQ of path then drop RREQ //
if ((RREQ[TTL]==0) or (my address Є RREQ[path]))
Drop RREQ; go to step 6.
Step 3: // Compare the pair (Source Address, ID) of RREQ with each entry of Route Request information table (RRIT)//
Compare (RREQ [SA, ID] ≈ IT [SA, ID)
If match is found then go to step4.
Else
//Record the partial information RREQ into RRIT by creating new entry by stating the timer//
RRIT[SA]=RREQ[SA];
RRIT[ID]=RREQ[ID];
RRIT[DA]=RREQ[DA];
RRIT[hop]=RREQ[hop];
RRIT[max-cost]=RREQ[max-cost];
RRIT[cost]=RREQ[cost];

//Assign the cost to c1, max-cost to MC1, hop to L1 //
C1=RREQ[cost];
MC1=RREQ[max-cost];
L1= RREQ[hop];
//Update the fields of RREQ by adding node cost to cost field, appending node address to path field , increasing hop and if is condition satisfied copying node cost to max-cost//
RREQ [cost]= RREQ[cost]+mycost;
RREQ[path]=RREQ[path] ⊕ myaddress;
RREQ [hop]= RREQ[hop]+1;
If (mycost > max-cost) then
RREQ[max-cost]=mycost.
Broadcast the RREQ.
Step 4: if match is found, then currently received RREQ becomes new duplicate RREQ say DRREQ, Assign its cost to C2 and its max-cost to MC2, its hop to L2
C2= DRREQ [cost];
MC2=DRREQ [max-cost];
L2= DRREQ [hop];
Step 5: // compare the currently received RREQ (New duplicate) with previous RREQ //

If (C2 > C1)
Drop DRREQ; go to step 6.
Else if ((C2==C1) and (MC2>MC1)) and (L2>=L1);
Drop DRREQ; go to step 6.
Else
//Record the partial information of DRREQ into information table by deleting corresponding entry of previous RREQ//
RRIT[SA]=DRREQ[SA];
RRIT[ID]=DRREQ[ID];
RRIT[DA]=DRREQ[DA];
RRIT[hop]=DRREQ[hop];
RRIT[max-cost]=DRREQ[max-cost];
RRIT[cost]=DRREQ[cost];
//Assign the its cost to c1, its max-cost to MC1 //
C1=DRREQ [cost];
MC1=DRREQ [max-cost];
L1= RREQ[hop];
Broadcast the DRREQ.

Step 6: Repeat step1 to step 5 until time out.
Step 7: END.

4.2.2 Route Reply by destination node

Let assume that m be the number of multiple paths from the source to the destination, among them, Let k be the number of node-disjoint paths; here question is how many node-disjoint paths are to be sent back to the source? There is a tradeoff between reliability and overhead, k is directly proportional to reliability but at the same time it is indirectly proportional to overhead. Hence here we chosen k =3; only three node-disjoint paths are considered, that are selected by the destination and they were named as primary (first) path, secondary (second) path and ternary (third) path.

Using equation (6) the destination selects the optimal path, now optimal is considered as primary path. Then it selects the secondary path which is an optimal path among m multiple paths excluding primary and it is node-disjoint to primary path. Then it selects the ternary path which is an optimal path among m multiple paths excluding primary path and secondary path and node-disjoint to primary path and secondary path if possible. By constructing three route reply packets, three paths are retuned to source through their respective backward paths is shown in fig. 13. Each route reply carries the path along with its cost. Based on cost, the source distinguishes the three paths and it stores them in an order in its cache as primary path, secondary path and ternary path.

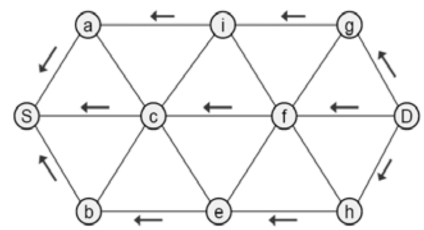

Fig.10. Propagation of RREP through Node-Disjoint Paths

The Following Algorithm is used to find Node-Disjoint Paths to Primary Path.

Algorithm Node-Disjoint path ( )
Start // Let M is a set of m-1 multiple paths from excluding primary
// Let $p_1,p_2,p_3,\ldots\ldots\ldots p_{m-1}$ be the m-1 multiple paths that are stored at two dimensional array M .
// Let P_p is primary path stored 1-D array N .
// Let D=set of paths that are node- disjoint to primary. Initialize D= Φ.
// D is computed as follows
For k=1 to m-1 do
{
//Select P_k from M and Check it is is node disjoint to primary//
If ($P_k \cap P_p = \Phi$)
then add P_k to D;
}
If D= Φ then Print “No node –disjoint path is found”;
Else
Print “Node –Disjoint path(s) found” ;
Stop.

The same above procedure is applied to find node-disjoint paths to secondary.

4.3 Maximization of network lifetime and congestion control

If battery capacity of node reaches zero then node will die. The network lifetime can be defined in many ways:

- It may be defined as the time taken for K% of the nodes in a network to die
- It might be the time taken for the first node to die.
- It can also be the time for all nodes in the network to die.

To maximize the lifetime of network, each node maintains minimum energy level, it is also called threshold or cut-off value. Threshold is always greater than one. During the transmission of data, each node checks whether its energy reaches to threshold or not. If its energy reaches to threshold then node sends a choke packet to the source node in reverse path shown in fig.16.

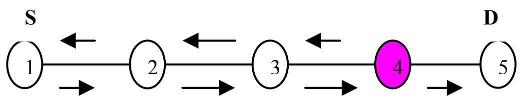

Fig .11. Sending choke packet in reverse path

After receiving the choke packets, the source node stops the data transmission on selected path and it uses the alternate path if available otherwise it initiates discovery process to continue the data transmission. This choke packet can also be used for congestion control, during the transmission of data if any node is congested then it sends the choke packet to the source node. After receiving choke packet, the source node stops the data transmission selected path and it uses the alternate path if available otherwise it initiate discovery process to continue the data transmission. Here choke packet is used for dual purpose, one purpose is for increasing life time of the network, another purpose for congestion control.

According to third metric in [6]. ***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 and all nodes are treated equally.* The aim of this metric is to achieve stability so that mean time to failure of the nodes increases. To achieve the stability, we proposed the following new approach, during the data transmission; the source node can switch among three paths in round robin fashion so that burden of routing is distributed to all the nodes on three paths instead of single path. This approach also reduces the congestion in the network.

4.4 Route Maintenance

Route error detection is same as in the DSR, triggered when a link breaks between two nodes along the path from the source to the destination. Node who discovers the break sends a Route Error (REER) packet to inform the source node about the broken link. After receiving the REEP, the source node erases the route from the cache, and uses other cached routes if available otherwise it initiates discovery process to continue the data transmission.

5. SIMULATION

This section describes the simulation, various chosen parameters for simulation and the various performance metrics. We have design own simulator with the following modules with reference to simulation model developed in [25].

Network Formation Module: This module is used to generate a random network, inputs of this module are space (length x breadth), number of nodes, cell radius of each node, initial position of node and initial energy of each node , The output of this module is a random network.

Node Mobility Module: This module sets the speed, direction and pause time of each node. It allows each node to move in random direction. All the nodes in an ad hoc network are mobile. In this simulation, the random waypoint mobility model is chosen for node mobility. The speed of each mobile node from 0 to 2m/sec. The pause time of each node is set to 10 sec.

Route Requests Event Generator Module: This module accepts the number of route requests from user, and then selects source and destination pairs randomly. Each route request follows the poison process and each call duration time follows exponentially distribution.

ENDMR module: This is core module that incorporates several functions like route discovery, route selection, route maintenance, congestion control and increasing network life time.

Computation module: This module estimates power consumption, residual energy, number of nodes expired, overhead, throughput, end-to-end delay and other parameters.

Randomly the forty nodes are distributed in the area of size 1000m x 1000m. It is assumed that distributed coordination function of IEEE 802.11 at MAC layer and free space radio propagation model with 2 Mbps channel bandwidth. Each node is equipped with a single network interface card and has a transmission radius of $r=14$. All the nodes have the equal transmission range of 88 meters. All nodes operate in promiscuous mode, so it can overhear packets destined for others. It is assumed that the transmission power, receiving power are fixed for all the nodes and two nodes can hear each other if their distance is in the transmission range.

Table 1. Simulation parameters and values

Sno	Parameter	Value
1	Simulation area and Network Size	1000mx1000m , 40 Nodes
2	Transmission Range	88 meters
3	Transmission Power Receiving Power	0.7 Joule / packet, 0.3 Joule / packet,
4	Node Mobility Model, Speed and Pause Time	Random waypoint mobility model, , 0-2m/s, 10 sec
5	Initial Energy , Maximum Battery Capacity	100 Joules, 100 Joules
6	Weight factors	10,20,30
7	Threshold Value	5 Joules
8	Route request arrival rate (λ)	5,10,15 per 10 sec
9	Traffic type, Packet arrival rate, Service rate, Maximum Data Packet size.	Constant Bit Rate (CBR), 512 bytes.
10	Queue type and queue Size	Drop tail, 60 * 512 bytes
11	Total Simulation Time.	100 sec

The speeds are uniformly chosen between the minimum and maximum speeds and are set to 0m/s and 2m/s respectively. When the node reaches its destination point, it stays there for a certain pause time, after which it chooses another random destination point and repeats the process. The simulation ends after 100s. All nodes are assumed to have the same amount of battery capacity with full energy at the beginning of the simulation. Initial energy of each node is set to 100 Joules. We have chosen three different weight factors 10, 20, 30 and randomly, a weight factor is assigned to a node.

It is assumed that the number of route requests is denoted by λ follows the poison distribution process and call holding time follows the exponential distribution. When a route request occurs, two nodes are randomly selected as source and destination. The data traffic is generated by Constant Bit Rate (CBR) sessions initiated between the source and destination. Each node maintains threshold value (cut-off). The table 1 shows simulation parameters and their values. During simulation, we observed and estimated Several performance parameters are shown from fig.12 to fig .14. Total energy consumption is directly proportional to various factors like network size, route requests arrival rate, packet arrival rate, packet size (header size and payload size), packet collision and retransmissions. Total residual energy is indirectly propositional to the energy consumption. The Network life depends on the node expiration which in turn depends upon energy consumption and threshold value. The node life time is indirectly proportional to the energy consumption and it is also directly proportional to the threshold value of the node.

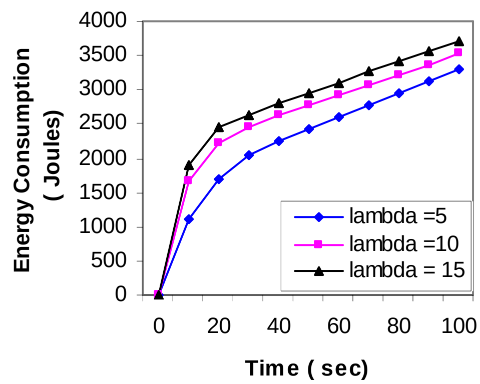

Fig .12. Total energy consumption Vs Time

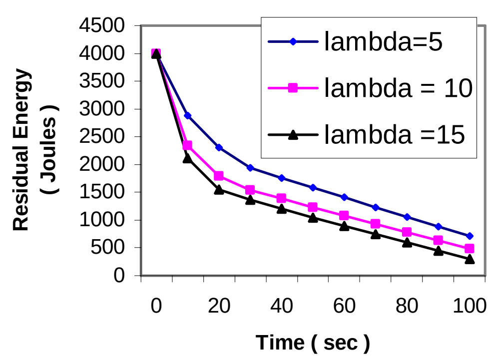

Fig. 13. Total Residual energy Vs Time

If battery capacity of node reaches zero then node will die. The network lifetime can be defined in many ways:

- It may be defined as the time taken for K% of the nodes in a network to die
- It might be the time taken for the first node to die.
- It can also be the time for all nodes in the network to die

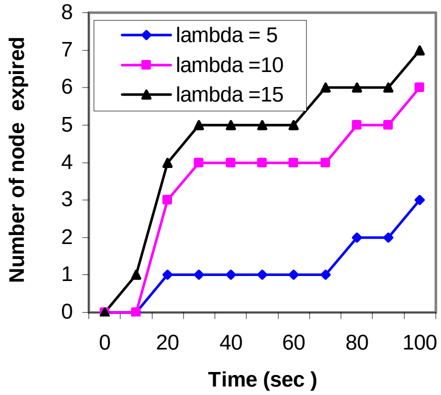

Fig.14. Number of nodes expired Vs Time

We compare performance of ENDMR with respect to the Multipath Power Sensitive Routing Protocol (MPSR)[20] .The ENDMR consumes less energy than to MPSR because in MPSR each route quest (RREQ) carries the energy of each intermediate node through which it passes. The separate 4 byte field is used to carry the energy of each intermediate node. Due to this, the length of RREQ will increase, this result in overhead increases, if number of intermediate nodes is increases, overhead increases drastically , route reply is also contains same above route record . Due this overhead drastically increases, if number of intermediate node increases.

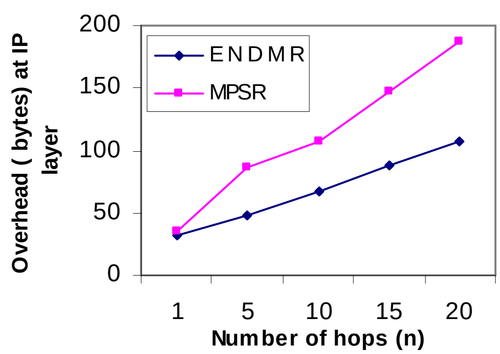

Fig. 15. Overhead vs number of hops

Fig.15 shows the overhead comparison between ENDMR and MPSR at network layer (IP layer). At IP layer, IP header is added to each RREQ, the total length of IP header is 20 bytes, 8 bytes are fixed for control fields like Option Type, Target Address ect. 4byte field is used to store address of intermediate node, In ENDMR , overhead for each RREQ is 20+8+4*n =28+4*n, where n is number of hops. In MPSR, overhead is for each RREQ is 20+8+(4+4)*n =28+8*n, where n is number of hops.

We compare performance of ENDMR with respect to Multipath Power Sensitive Routing Protocol (MPSR) by is shown in fig. 13. The ENDMR consumes less power than to MPSR because in MPSR each route quest (RREQ) carries the power of each intermediate node through which it passes. The separate field is meant for emery per node. Due to this length of RREQ will increase, this result in overhead increases, if number of intermediate nodes is increases, overhead increases drastically , route reply is also contains same above route record . Due this overhead drastically increases, if number of intermediate node increases .The overhead is directly proportional to power consumption, bandwidth consumption, congestion, packet collision and packet retransmission.

6. CONCLUSION AND FUTURE WORK

The ENDMR protocol significantly reduces the total number of route request packets, this result in an increased packet delivery ratio, decreasing end-to-end delays for the data packets, lower control overhead, fewer collisions of packets, supporting reliability and decreasing power consumption. Each route request carries the cumulative cost, so very little bit overhead is increased to carry the cumulative cost but it is negligible. The ENDMR has the following desired features:

- It is based on standard on demand routing protocol i.e. **Dynamic Source Routing (DSR)** and it uses new power aware metric i.e. minimum node cost to find the optimal paths. Due to on-demand nature, 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.
- It reduces the overhead during broadcasting of route requests using a novel approach, which in turn induces little bit overhead to carry node's cost in route quest.

- It supports node-disjoint multiple paths for reliability, and congestion control.
- It supports stability i.e. it increases mean time to failure of the nodes by distributing the burden of routing.
- Computation of optimal paths is assigned to destination node instead of source node to reduce the overhead. In conventional protocols; source node computes optimal paths from multiple paths that were supplied by destination node. Due to this overhead increases because if sending many multiple paths back to source, the lot of bandwidth and power are wasted and delay also increases.
- It has many qualitative properties and desired futures.

We analyzed its performance using various parameters .In future work we will implement this protocol using NS2 (Network Simulator 2) to measure the various performance metrics in different applications and scenarios.

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