A Robust Ad hoc Reactive Energy-constraint Multi Path routing protocol for High Mobility Networks

Minesh Thaker [#1,2], Dr.S.B.Sharma [*3]
[#1]Department of Electronics and Communication Engineering,CharusatUniversity,Changa,India;
[#2]Department of Electronics and Communication Engineering, IndusUniversity,Ahmedabad,India;
[#3]IndusUniversity,Ahmedabad,India;
[1,2]mineshthaker.ec@indusuni.ac.in
[3] drsbs@indusuni.ac.in

***Abstract*—Existing routing metrics in mobile ad hoc networks are limited to avoid link failures either due to insufficient battery power or high speed of node. Thus, these routing metrics are not able to capture network characteristics completely. This paper proposes a new robust multi path routing protocol for high mobility and scalable ad hoc networks, RARE−MP. It selects route based on the value of Node Reliability Factor which is a function of residual energy, speed and hop count. The key idea of protocol is to compute nodal reliability factor of route in path selection process and sort multiple path by descending nodal reliability factor. In essence, whenever a new route with higher nodal reliability factor is available, data packets are forwarded through a new emerging route. It balances the nodal battery power utilization and reduces the link failures leading to increase the overall life time of network. The simulation result shows that proposed protocol outperforms in comparison with both, energy aware routing protocol and energy unaware routing protocol in high speed and high density environment.**

Keyword-: Mobile Ad hoc Network; routing protocol; multipath; energy efficient; network life time;high mobility networks

I. Introduction

The infrastructure less mobile wireless network is popularly known as Mobile Ad hoc Network (MANET). These short lived, application specific, self-configurable, multi hop wireless networks generally consist of hand-held mobile nodes connected with each other by wireless links. These mobile nodes have limited resources in terms of battery power, processing capability and memory. Each mobile node in a MANET also acts as router. In the absence of centralized infrastructure, nodes in the networks are connected to each other via point to point or point to multi point wireless links. These nodes are capable of generating and routing data and establishing multi hop connections [7,6]. Refer to [19,12,18] for an extensive survey on different routing techniques for MANET applications.

The reactive [14] and proactive approach [13] of routing protocols address designing issues of routing protocols in several folds: routing load, fault tolerance, route discovery frequency, end-to-end delay, Networks life time, load balancing, quality of services are some of them. Designing multipath routing protocol for large scale and high speed network is more challenging. The large scale network is defined in the book on `Mobile Ad hoc Network' Edited by Stefano Basagniet. al.[5]. It is based on the number of peer routers within a region. In large scale networks, single path routing protocols have more challenges as only one path is announced as a route. This leads to frequent route discovery when a link fails. Thus the performance metrics: Network life time, Packet Delivery Fraction (PDF) and end to end delay for multipath routing protocols are more relevant. Multi path routing protocols provide better fault tolerance by installing more routes in the routing table. The mobility of nodes put an additional constraint along with energy consumption for causing link failures. It is shown [11] that in high density networks, single path schemes underperform over multi path schemes. These both issues: route discovery frequency and routing load are well addressed in reactive multipath routing schemes. When a link fails, more number of loop free paths is installed in the routing scheme between any source and destinations. The routing scheme selects another route in the routing table and leading to decrease route discovery frequency. Also, the scheme is reactive, and does not require additional messages for route table maintenance. The existing routing protocol [11] AOMDV has an improvement over AODV [14] in terms of Packet Delivery Fractions, routing load, route discovery frequency and end to end delay. The metric of existing AOMDV routing scheme is hop count. In applications with heavy processing on high speed mobile nodes, in large scale networks use, energy, battery power or transmission power as an important metric for the routing protocols [17,16] . Limited battery power of participating nodes causes more drop out ratio leading to network partitioning.

This necessitates designing routing schemes that address network partitioning issue and extend network's life time and increases fault tolerance. Energy constraint routing has drawn the attention of MANET research community [1]This information about residual energy of a node used for selecting a path helps delay the network partitioning. Residual energy as a metric has been utilized for designing routing protocol in[4]. The Routing protocol MMRE-AOMDV[10] considers residual energy as a metric for sorting routing paths. This paper proposes robust and energy efficient multipath routing protocol for high mobility and high density MANET with three metrics: residual energy, speed of node and hop count. The priority in selecting path is based on the combination of these three metrics. The paths are sorted with best Node Reliability Factor,in descending order. The primary objective of this paper is to extend network's life-time by providing a robust fault tolerant mechanism. Following paragraph explains the novelty of the proposed work. We propose a new frame work for route discovery, route maintenance and route selection algorithms with required message headers to present an end to end routing solution for large scale and high mobility networks. This algorithm prioritizes paths based on node reliability factor nrf. The nrf is defined such that prioritizes the residual energy of node, hop count of a route on which the node participates and speed of node, in that order. The defined nrf captures reliability of a node in a given path. The proposed algorithm is implemented in various routing environments, specifically in high speed and high density environment, and show that proposed algorithm outperforms existing routing protocols. The rest of the paper is organized as follows. Section 2 details existing literature and issues related to on demand multipath and energy efficient routing protocols in MANETs. The RARE-MP protocol is given in Section 3. Simulation resultsrelated to RARE-MP are given in Section 4. Section 5 summarizes and concludes the proposed work.

II. Related works and motivation

A. Review of AOMDV

Ad hoc On demand Multipath Distance Vector (AOMDV) routing protocol [11] is an extension of AODV routing protocol[14].The objective of AOMDV is to provide fault tolerance. This is archived by reducing the route discovery frequency and enhancing the overall network performance. AODV provide only one route at a time. Once the link between source and destination fails, it re-initiates the route discovery and a new path is re-computed. AOMDV solves this problem of re-discovery and re-computation. Results in [11] show performance improvement of AOMDV over AODV. AOMDV installs multiple paths in routing table. This increases the probability of loop in the paths. A mechanism to reduce these loops and provides loop free disjoint paths is proposed in [11].A flip side of AOMDV is that the protocol is not energy aware.

B. Energy Aware Routing Protocols

There are several advances on energy aware single/multi path routing protocols in literature [4]. Min-max battery cost routing (MMBCR) [20] considers the remaining power of nodes as a metric for the selection of paths and boosts the lifetime of the network. Current wireless network research literature show a surge in results for on-demand multipath routing protocols [15, 17, 18, 21]. The common objective of these results is to design routing mechanism for saving energy thus to reduce network failures.

C. Collision Constrained Minimum Energy Node-Disjoint Multipath Routing in Ad Hoc Networks(ECCA)

Liu et. Al [9] discusses about the trade-off between collision avoidance and energy saved. Their algorithm (ECCA) computes an upper limit of the correlation factor for required service and selects a disjoint multipath with energy. The simulation results of ECCA show that the packet delivery ratio and energy consumption is reduced significantly. The flip side of this protocol is non-consideration of power status of the nodes.

D. Multipath Energy-Efficient Routing protocol (MEER)

Yuan et. al. [15] used control mechanism for power in multipath energy-efficient routing protocol (MEER). The route discovery process is altered by adding two field in Route Request (RREQ) message: minimum power and average power. Source looks for route with high energy on the basis of split multipath routing. This approach prevents the nodes from consuming more energy in comparison to the other nodes. This algorithm provides no guarantee on loop free path. This leads to unfair energy distribution among the network nodes.

E. Multipath Routing protocol for network life time maximization (MRNLM)

Liu et al. [8] proposes the multipath routing protocol for Network Lifetime Maximization (MRNLM), a protocol in which a threshold is exercised to boost the forwarding mechanism. It depicts an energy-cost function for the path selection criteria, for multiple-path selection. Results further adopt turn by turn data transmission method during forwarding mechanism in multiple paths. Due to this mechanism energy consumption is balanced out but at the same time end to end delay is not improved.

F. Multipath Multimedia Dynamic Source Routing (MMDSR)

Frias et. al. [2] exploits cross layer mechanism to improve the end to end delay for video-streaming traffic over networks using IEEE 802.11e. An analytical model is derived to estimate the path error probability and hence to estimate the lifetime of routing paths. In this way, it helps in taking proactive decisions before the paths are broken. However, comparing single path protocol DSR with multipath routing protocol MMDSR seemed awkward. It would have been fair to compare multipath routing protocol with MMDSR rather than DSR.

G. Multipath Energy-Efficient Routing Protocol (MEERP)

Gole and Subhasiniet. al. [3] suggests new route discovery mechanism, whereby each intermediate node is barred from creating a route reply message. The selection of energy efficient multiple loop free node disjoint paths are based on the residual energy and successful transmission rate. In this approach, only one path is used for data forwarding at a given time, even though multiple paths are selected. The simulation results show that this scheme improves network lifetime,end to end delay and routing overhead.

H. Multipath energy-conserving routing proto. for wireless ad hoc networks lifetime improvement(AOMR-LM)

Smaile and cousin et. al.[21] suggest the multipath routing scheme AOMR-LM. The selection of multiple paths is based on three energy levels Low medium and high. These energy levels are based on threshold value. It balances the consumed energy over multi path. It was designed for large scale low speed environment. The maximum speed of node for this protocol is kept 5 m=s. The simulation results show that it performs better than AOMDV and ZD-AOMDV in low speed environment.

I. Maximal Minimal Residual Energy Ad hoc On demand Multipath Distance Vector(MMRE-AOMDV)

In [10] Maximal Minimal Residual Energy Ad hoc On demand Multipath Distance Vector (MMRE-AOMDV) routing protocol uses maximal minimal nodal residual energy of each node and then selects the path with maximal residual energy to forward the data packets. The additional routing overhead had been drastically reduced in the MMRE-AOMDV by using the available routing information in the underlying AOMDV protocol. The simulation results show that MMRE-AOMDV routing protocol performs much better than AOMDV in terms of packet delivery fraction, throughput, and network lifetime. However, this protocol is not meant for high speed network and thus it does not perform well. The summary of above studies says that energy conservations improve the network performance but mere power saving schemes based on residual energy does not establish the best path between source and destination. On the contrary, a node accepts all routing request only because it currently has sufficient energy. This attracts more route packets towards that node and resulting in excessive traffic load. Ultimately node exhausts its battery power and results in network partitioning. Just one metric (residual energy) is not sufficed to select the best path which can balance the consumed energy. However, a care is to be taken for selecting a reliable node for reliable path. Majority of studies have done work on low speed and low density environment. This was motivation for our study. It is understood that the balanced energy consumption is the best solution for this sort of problems. The path is chosen such that it has maximum reliable nodes. This reliability of node is not only function of remaining energy but also a function of maximum speed of node and path length too. We use MMRE-AOMDV as a reference for our performance evaluation because it aims to improve the lifetime of the ad hoc network and uses the residual energy as metric and its multipath character.

III. ROBUST AD HOC REACTIVE ENERGY-CONSTRAINT MULTI PATH(RARE-MP) ROUTING PROTOCOL

In this section, we propose a routing protocol that computes multiple routes with reactive approach for ad hoc wireless networks. The protocol is mainly designed with the objective of reducing the link failures and hence prolonging the life time of node and in turn the life time of a high mobility network. The existing energy efficient routing protocols use either one metric or at most two routing metrics. We utilize three metrics with appropriate priority to qualitatively derive an efficient reliability parameter - node reliability factor. One of the main reasons for link failures and route failures in MANET is exhaustion of battery power. Speed and mobility being other important reasons. Further, the protocol reduces the chances of depleting the node because of lack of residual energy or selecting the slow moving nodes for route construction.

A. Concept

RARE-MP is designed with the concept that selects the node in route having maximum residual energy, lowest speed and lowest hop count. Proposed protocol considers highest priority for the maximum residual energy of a node to increase every node's life time with the ultimate goal of increasing overall network life time.The next priority is given to the hop count to decrease end to end delay. The last priority is given to the speed of a node to control the link failure, hence the route failure. It is important to note that, there is a trade-off between end to end delay and network life time. If end to end delay is to be improved hop count is given priority over speed. If network life time is to be improved speed is given priority over hop count. As residual energy is given first priority for extending the network life time, the hop count is chosen over speed to improve overall performance of the network. The next subsection proposes the model and algorithms for RARE-MP. The RARE-MP selects the paths based on the term Node Reliability factor (nrf).

B. Model

An ad hoc wireless network is represented by a graph G=(V;E), where V is the set of network nodes and E represents the set of communication links. In proposed model considers these links to be bidirectional. Total number of elements in V is n. Given the set of nodes, we define two special nodes $N_S$and $N_d$to be a source

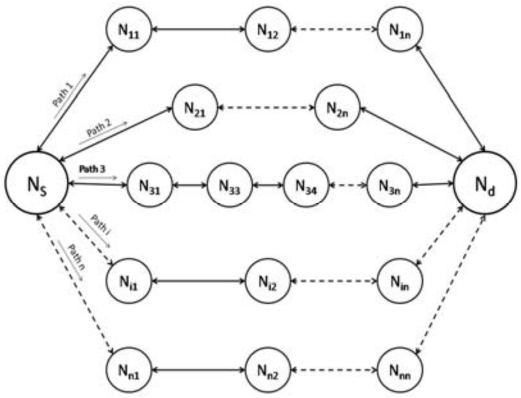


Figure1.GraphG(V,E)ofanadhocnetwork.

(Transmitting) and destination nodes (receiving). As we consider unicast multipath routing there is a unique (N_s;N_d) pair. Between such unique pair of points, we have multiple connecting paths. Let P_j denotes a path from $N_s$to N_d, then every node on P_j (other than $N_s$and N_d) is denoted by $N_j^i$where i increases as we go towards destination node $N_d$on path P_j . For every node N_j^i , we denote residual energy of this node by x_j^i and its speed by y_j^i . Further for every path P_j , we denote number of node on this path by hop count Zj . For every node N_j^i on a path P_j , we define its reliability parameter node reliability factor as follows:

Definition 1 (Node Reliability Factor): Given residual energy x_j^i , speed y_j^i of a node N_j^i , node reliability factor of node N_j^ion path P_j is

$$nrf_j^i = \left(\frac{x_{ij}}{Z_j - \left(\frac{1}{2+y_{ij}} \right)} \right) \quad \text{-----} \qquad \text{(I)}$$

This is a factor which describes the reliability of node. The node is considered highly reliable having highest residual energy, lowest hop count and lowest speed. It prioritizes the three metrics. First and maximum weightage is given to residual energy. Second and moderate weightage is given to hop count and third and minimum weightage is given to speed. In other words, it is the function of residual energy,hop count and speed of node. The nrf is directly proportional to the residual energy of node and inversely proportional to the subtraction of the reciprocal of speed from the hop count. Higher the residual energy lower the hop count and speed of node gives higher values of node reliability factor. The reciprocal of speed is chosen such that the path length is preferred more than the speed and subtraction is used to improve the node reliability factor. It is likely that some node may not be mobile, i.e. v_j^i = 0. To avoid this situation we consider a constant 2 in the above equation.

C. The operation

This subsection describes the overall operation of proposed routing protocol. The operation is divided broadly in three phases.(1)Route Discovery,(2)Route Selection and (3) Route Maintenance

C.A.1 Route Discovery

This sub-subsection describes route discovery algorithm in detail for proposed RARE-MP routing protocol. When a source node demands a route to a destination, the source node initiates a route discovery process by oding RREQ messages. We make two changes in the original RREQ message format(used in AOMDV) for proposed protocol RARE-MP. This is shown in table 1[2]

TABLE I. Route Request Message (RREQ) format

8bit	1	1	1	6	7	8
Type	**D**	**G**	**Reserved**	**Residual Energy**	**Speed**	**hop count**
RREQ ID						
Destination IP Address						
Destination Sequence Number						
Originator's IP Address						
Originator's Sequence Number						
Next Path Node IP Address						
Next Path Node Sequence Number						

These two extra fields are residual energy of node and speed of node. Owing to this network wide coding, a node may receive several copies of the same RREQ messages. All duplicate copies are monitored for all probable alternate reverse paths, but only loop free and disjoint reverse paths are formed from the received duplicate copies like AOMDV. When an intermediate node acquires a reverse path via a RREQ copy, it looks for the multiple valid forward paths to the destination. If multiple path exists, the node prepare an RREP and sends it back to the source node along the reverse path. We also make changes in the RREP message format as shown in table 2.

TABLE II.Route Reply Message (RREP) format

8	1	5	5	5	8
Type	**A**	**Reserved**	**APN count**	**prefix size**	**hop count**
Destination IP Address					
Destination Sequence Number					
Originator's IP Address					
Originator's Sequence Number					
Next Path Node IP Address					
Next Path Node Sequence Number					
Originator's nrf					
Destination nrf					
Next Path Node1 nrf					

The additional field for computed node reliability factor(nrf) is appended in RREP message. Once, the destination receives RREQ messages, it also forms reverse paths in the same way as intermediate nodes. When reverse path is formed till RREP reaches to source then valid multiple forward paths are formed. These multiple paths are loop free and disjoint. The route discovery mechanism is shown in Route Discovery Algorithm 1 through Step 1 to 9.

C.A.2 Route Selection

On receiving nrf information of all nodes on every route following algorithm for route selection is executed. Once all the routes are installed in the routing table, each node sends its nrf to source nodes. Source node maintains new table namely nrf table for all nrf values of all nodes for respective routes. The structure of route table and nrf table is shown in Table 3 and 4. We use merge sort algorithm for sorting routes based on minimum nrf. The worst case running time of this sorting algorithm is O(n log n).

Algorithm 1 RARE-MP : Route Discovery Algorithm

Begin

1. *Source node* N_s*broadcasts route request message (RREQ) to all its neighbours*
2. ***If*** *one of the neighbors is a destination node* N_d ***THEN***
3. *Destination node* N_d *sends back unicast route reply message (RREP) to source node through intermediate node*
4. ***End If***
5. ***IF*** *Neighbors has route information for the said (destination)* N_d *node* ***THEN***
6. *through route reply message RREP route is advertised to the intermediatenode*
7. ***ELSE***
8. *neighbor broadcasts route request message RREQ to its subsequent*
9. *neighbors until it reaches destinationwhen destination* N_d *is found follow Step 3*

End If

End

When RREQ reaches destination, it has hop count information along with residual energy and speed of its own. Every node computes the nrf and sends this information to source node through RREP message. This nrf values are stored in nrf table along with their routes. All path with maximum of minimum nrf are sorted in descending order. Once all routes are sorted, the table is sent to every other node on the respective paths through route update messages. The route table is also modified as shown in Table 3. The comparison of AOMDV and RARE-MP for routing table entry is shown. The minimum nrfvalues for the advertised path is shown as an extra field.

TABLE III. Structure of routing table entries

Destination
Sequence Number
Advertised Hop Count
Advertised Max(min nrf)
Route List
(Nexthops1,hopcounts1,Min-nrf1,Time out1)
(Nexthops2,hopcounts2,Min-nrf2,Time out2}

First of all, the minimum nrf is identified for each route from the nrf table. Then each route with maximum of all minimum nrf routes are sorted in descending order i.e that is route with higher nrf are arranged on top of the table. If two equal route exists with the same nrf then it further checks for next node with higher nrf for the respective routes. Once minimum nrf of all the routes are computed, all routes are labelled with respective minimum nrf. Then routes are sorted based on highest nrf in descending order. The route with highest nrf is installed at the top and route with lowest nrf is installed at bottom.

TABLE IV.Node Reliability Factor(nrf) Table

Route	**nrf values of Nodes**						
N1-N2-N3-..-N30	nrf 1	nrf 2	nrf 3			...	nrf 30
N1-N3-N5-N7	nrf 1		nrf 3		nrf 5		nrf 7
N2-N3-N4-N5-N11		nrf 2	nrf 3	nrf 4	nrf 5	...	nrf 11
..	..	..	..	..	..	..	..

This phenomenon takes care of balanced energy consumptions. Due to this route selection method of RARE-MP protocol, nodes with highest reliability are selected at the priority. Hence the consumption of energy decreases and hence the exhaustion of battery power also decreases and as a result exhaustion of node decreases and thus, network life time of node increases. Table 3 shows the structure of routing.

Algorithm 2 RARE-MP : Route Selection Algorithm

Begin

1. *sort nrf values of nodes on every path in increasing order*
2. *sort paths based on maximum of minimum nrf values*
3. *advertise the path with highest minimum nrf to all nodes on every path using route update messages*
4. ***IF** two paths have the same highest minimum nrf then*
   go to next minimum nrf values on the same path and repeat step 3 with this new nrf value
5. ***END IF***

End If

End

Table entry for RARE-MP. We add new field in route table entry for the advertisednrf_j^i. In addition to that, one more field is added in a route list used in RARE-MP to store additional information for each alternate path including: next hop, last hop , hop count, minimum nrf_j^i and expiration timeout. The next hop and last hop information is used for disjoint paths for all alternate paths alike AOMDV. These extra fields advertised nrf_j^i and minimum nrf_j^i helps in selecting the path based on node reliability. Whenever the destination sequence number for $N_d$atN_j^i is updated,the corresponding advertised nrf_j^i along with advertised hop count is initialized. For a given destination sequence number, let nrf_j^i denote the node reliability factor and hop count $N_d N_j^i$denote the hop count of jth path (for some j) in the routing table entry for N_d at N_j^i , that is (Nexthop $_{N_j^i}^{\mathrm{Nd}}$,(Lasthop $_{N_j^i}^{\mathrm{Nd}}$,nrf_j^i) routelistN_d j . When N_j^i is about to sends its first route advertisement For Nd, it updates the advertised hop count and advertised nrf_j^i as follows:

$$Advertised-hop-count_{N_j^i}^{\mathrm{Nd}} := \begin{cases} \max\,(hop-count_{N_j^i}^{\mathrm{Nd}}, & if\ i\#j\ otherwise \\ 0, & \end{cases}$$

And

$$Advertised-nrf_j^{\mathrm{i}} := \begin{cases} \max\,(min-nrf_j^{\mathrm{i}}, & if\ i\#j\ otherwise \\ 0, & \end{cases}$$

At any point of time a node receives a route advertisement, it applies the RARE-MP route update rules, listed in algorithm 3. The route update algorithm describes the overall route update mechanism from line 1 to 18.

Line 1-7 explains that when node i is not the destination d and if sequence number in new RREQ is smaller than the existing destination sequence number, route is not to be updated. The hop count values becomes infinite and nrf value become zero. Finally, null route is inserted. On the other hand, If node i is destination, hop count is incremented by 1 and nrf remains unchanged. However, if sequence number is greater than or equals the existing one and if$advrtsd-nrf_j^{\mathrm{i}}$is higher than $advrtsd-nrf_j^{\mathrm{i}}$ at the same times $advrtsd-hopcount_{N_j^i}^{\mathrm{Nd}}$ also higher than a $advrtsd-hopcount_{N_j^i}^{\mathrm{Nd}}$then new route is updated as shown in line 13 to 18.

C.A.3 Route Maintenance

RARE-MP exploits the the route maintenance mechanism and packet salvagingmechanism of AOMDV given in [11] RARE-MP also uses RERR packets alike AOMDV. A node generates or forwards a RERR for a destination when the last route to the destination fails. RARE-MP use the packet salvaging by re- forwarding them over alternate routes. Once all the routes are failed, the re-route discovery starts if source demands a new route to the destination.

Algorithm 3 The Route Update algorithm for RARE-MP

Begin

1. ***IF*** *(*$seqnum_{N_j^i}^{Nd}$ < $seqnum_{N_j^i}^{Nd}$ *then*
2. *(*$seqnum_{N_j^i}^{Nd} = seqnum_{N_j^i}^{Nd}$*)*
3. ***IF****(i # d))* ***THEN***
4. $nrf_j^{\mathrm{i}} := 0$
5. $advrtsd - hopcount_{N_j^i}^{\mathrm{Nd}} := \infty$
6. $advrtsd - nrf_j^{\mathrm{i}} := 0$
7. $route - list := NULL$
8. *Insert (j,* $advrtsd - nrf_j^{\mathrm{i}}$, $advrtsd - hopcount_{N_j^i}^{\mathrm{Nd}} + 1)$
9. *Into(route-*$list_{N_j^i}^{\mathrm{Nd}}$*)*
10. ***ELSE***
11. $advrtsd - hopcount_{N_j^i}^{\mathrm{Nd}} := 0)$
12. ***END IF***
13. ***ELSE IF****((*$seqnum_{N_j^i}^{Nd}$ >= $seqnum_{N_j^i}^{Nd}$ *) and (*$advrtsd - nrf_i$ > $advrtsd - nrf_{j)}$ *and (*$advrtsd - hopcount_{N_j^i}^{\mathrm{Nd}} > advrtsd - hopcount_{N_j^j}^{\mathrm{Nd}}$ *)**THEN***
14. $advrtsd - nrf_j^{\mathrm{i}} := advrtsd - nrf_j^{\mathrm{j}}$
15. $advrtsd - hopcount_{N_j^i}^{\mathrm{Nd}} := advrtsd - hopcount_{N_j^j}^{\mathrm{Nd}}$
16. $insert\ (j, advrtsd - nrf_j^{\mathrm{i}}, advrtsd - hopcount_{N_j^i}^{\mathrm{Nd}} + 1)$
17. *Into(route-*$list_{N_j^i}^{\mathrm{Nd}}$*)*
18. ***END IF***

End

C.A.4 The implementation: RARE-MP

The proposed algorithms is practically implemented on event driven Network Simulator 2.34 on desktop with linux Platform Fedora ver. 8, Intel Core i35157U Processor (3M Cache,2.50 GHz), 4 GB RAM. Simulations results are analysed for various scenarios of RARE-MP protocol. In this paper, we analyse four performance parameters: Network life time, dying nodes, Packet Delivery Fraction (PDF), Average end to end Delay (AED) against speed with the help of AWK programming.

IV. EXPERIMENTAL RESULTS

This section explains the simulation environment and the analysis of results. Wedemonstrate that the RARE-MPT is more robust as compared to MMRE-AOMDV. This is true when the node speed and node density, both are higher.We make assumptions in computation of nrf based on following practices in theexisting literature. A node's residual energy is considered to be between 10J to60J, which corresponds to the average battery capacity of mobile node (Y. Liu etal., 2008). The upper bound on network diameter is 30 hops (Perkins & Royer,1999; Marina & Das, 2006). We assume that node consumes 281.8 mWpower whilereceiving a packet and 281.8 mW while transmitting a packet.

A. Simulations environment

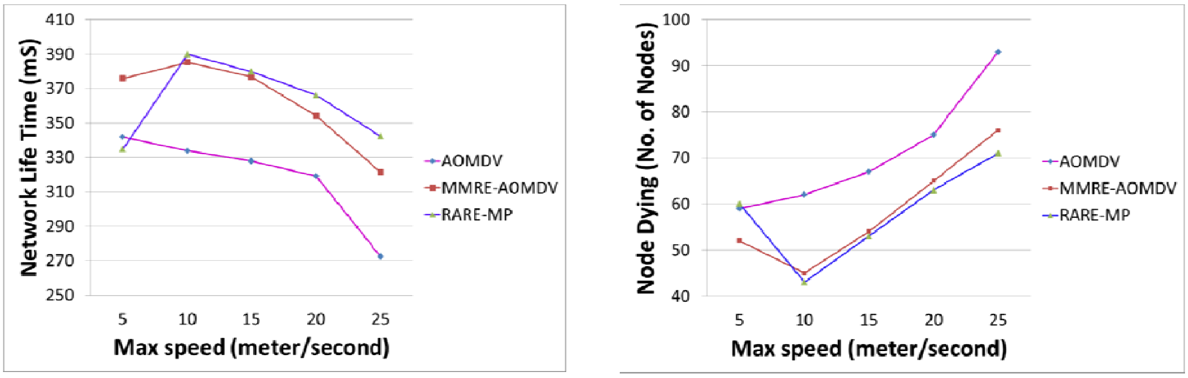
We carry out simulations to assess the effectiveness of proposed protocol. The principal objective of these simulations is to analyse and to compare proposed protocol with existing multipath protocols, mainly AOMDV [11] andMMRE-AOMDV [10] To evaluate RARE-MP, we use the network

simulator ns-2.34 on linux fedora 8 with intel. Each simulation run has a durationof 500 seconds. During each simulation, constant bit rate (CBR) connections aregenerated; each of them sends four packets per second with a packet size of 512bytes. We vary the speed from 5 m/s to 25 m/s to obtain different scenarios in2200x1000 m environment. The Random Way point model is used as a mobility model to simulate node movement. We use Lucents Wave LAN as radio model.Wave LAN is a shared-media radio with a nominal bit rate of 2 Mbps and a nominalradio range of 250 m. This is also compatible with the IEEE 802.11 standard. We

carry out each simulation under varying pause time and different node density. Thenode density varies from minimum node density of 100 to maximum node density of200. The pause time is varied from 0 seconds to 30 seconds. We get the performanceparameters with the help of taking average of 10 simulation run from 40 source to40 destination randomly selected.

B. Results

We consider that the overall network performance depends on four parameters:network life time, node dying, packet delivery fractions and average end to enddelay. This section describes how these parameters play a role in overall networkperformance. The network life time can be defined in many ways. These definitionsare as follows the time taken to exhaust the battery of the first network node, thetime taken to exhaust the battery for N network nodes, and the time when thebattery of the last network node is exhausted. We take the life time which measuresthe time when all N nodes exhaust. In our case, total number of nodes N equals200 nodes. Figures 2 and 3 depicts that at the speed of 5 m/s of node, the overallnetwork performance is inferior to MMRE but is comparable to AOMDV. Thisis observed as the initial route discovery in highly dense network causes morecongestion and more multiple access interference. Once the network gets settled theperformance improves. Subsequently, at the speeds higher than that of 10 m/sperformance of RARE-MP shoots up and shows gain in every parameter. It shouldbe noted that these performance are shown for a highly dense graph with 200nodes. In practice these numbers are significantly small. In such scenarios, overallperformance gain due to RARE-MP against MMRE□AOMDV and AOMDV aresignificant. Further, for high mobility networks RARE-MP performs significantlybetter, considering practical speed limits of ground vehicles(25 m/s), we showperformance of RARE-MP in the graphs.As primary aim of this work is to extend network life time of high mobility networks,we plot the network lifetime parameter vs. speed of network in figure 2(a) andobserve that the network lifetime of RARE-MP is longer than that of AOMDVand MMRE□AOMDV protocol based networks.

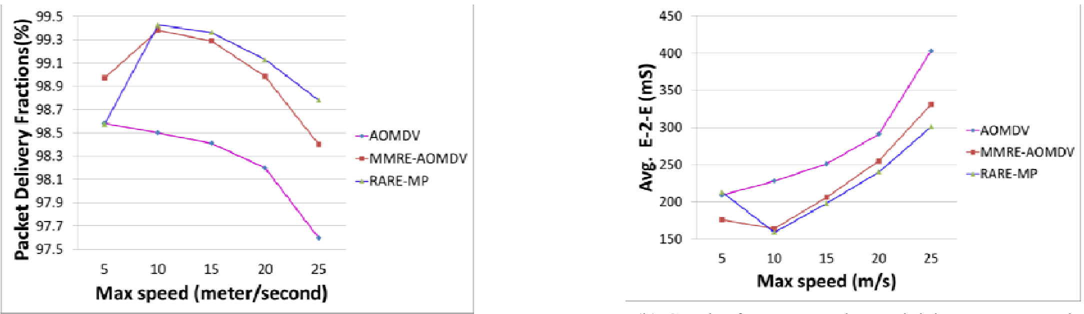


(a) Graph of network life time versus speed.

(b) Graph of dying node versus speed.

Figure 2. Comparison of performance metrics between RARE-MP and MMRE□AOMDV with varyingspeed

proposed protocol exhausts fewer nodes at higher speed as shown in figure 2(b),but during initial route discovery phase RARE-MP exhausts more nodes. Incomparison to MMRE-AOMDV and AOMDV protocols, the RARE-MP showsimprovement in the lifetime of the network after speed of nodes are higher than 9m/s. Thus, it is clear that RARE-MP is a balanced energy aware protocol thatselects path with prolong life route hence increases overall network lifetime.Figure 3(b) shows the average end to end delay of all the three protocols. Theaverage end to end delay for all tested protocols increases when increasing thenetwork size. Though, the average end to end delay of RARE-MP is lower thanthose of MMRE-AOMDV and AOMDV, when speed of nodes reaches to 9 m/sand onwards. Once the size of the network increases, proposed protocol provides alower delay for any node speed after 9 m/s onward.



(a) Graph of packet delivery fraction versus speed.

(b) Graph of average end to end delay versus speed

Figure 3. Comparison of packet delivery fraction and average end to end delay between RARE-MP andMMRE-AOMDV

The reason is that RARE-MP protocol favours nodes with high energy level, lowerhop counts and lower speed and prevents the critical nodes from participating inthe data packet transmission. This is handled by choice of highly reliability routes.This provides fewer broken links and reduces the end to end delay once the routediscovery phase is over.

V. CONCLUSION

We proposed a new multipath routing protocol, RARE-MP. The routing protocolappreciates the problem of frequent link failures due to exhaustion of energy in thebattery of a node and speed of a node. Further, the routing protocol appreciatesthe problem of routing on a shortest path by the route hop count parameter. Wedefined node reliability factor, a parameter of a node on a path, that takes in toconsideration all the above parameters and defines reliability of a node on a path.This RARE-MP routing protocol is an extension of the existing multipath routingprotocol AOMDV. RARE-MP uses node reliability factor of nodes on a path todecide which paths are more robust.Simulation results show that RARE-MP performs significantly better thanAOMDV and MMRE for over all network parameters on high speed. RARE-MPis able to balance the energy consumed. It increases the lifetime and packetdelivery ratio. Whereas exhausting nodes and average end to end delay decreasesin comparison to the other simulated protocols. We notice the reason that routesare computed depending on the highest node reliability factor and the best routeamongst the available routes is selected. One of the avenues that we would liketo explore, in future, is to reduce route selection time and thus by increasingperformance of RARE-MP for low speed parameters. Further, the proposedwork has decoupled reliability parameter of a node from route selection. Thisfine segregation would allow research to be carried out with different reliabilityparameters against various route selection algorithms.

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Authors Profile:

Minesh P Thaker is Assistant Professor with Indus Institute of Technology and Engineering, Indus University.He completed his master's degree, M.E in Communication Systems Engineering, from Gujarat University,Ahmadabad,India in year 2009 and his Bachelor degree in B.E (Electronics and Telecommunication) from University of Poona, Pune ,India in year 1994.He has 6 years of industrial experience as network administrator. Fault tolerance in MPLS, Network layer in MANET,VANET and Sensor networks, information security, internet of things are his area of interests.

Dr S B Sharma obtained his B.E. and M.E. from University of Roorkee in 1970 and 1972 respectively in Electronics and Communication. He received his Ph.D. from Gujarat University in 1987 on surface wave antenna. He retired as Outstanding Scientist and Deputy Director, Antenna Systems Area at Space Applications Centre, ISRO after serving the organization for 36 years. He has filed 23 International patents as prime inventor and published 150 papers of which 50 are frequently cited. Presently he is Dean (Research and Project)