PERFORMANCE EVALUATION OF MESH AND POSITION BASED HYBRID ROUTING IN MANETS

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ABSTRACT

A new routing algorithm called position based hybrid routing algorithm (PBHRA) was developed to optimize bandwidth usage of *ad hoc* networks. The main goal of PBHRA is effective use of bandwidth by reducing the routing overload. Additionally, the other goals of the algorithm are to extend battery life and signal strength or power level of the mobile devices by reducing the required number of operations for route determination and to reduce the amount of memory used. Although in the PBHRA, some features of both table driven and on-demand algorithms were used to achieve these goals at some stages, PBHRA algorithm is a completely different approach in terms of position information usage and global positioning system (GPS).

Keywords: Hybrid routing, Extended battery life, Signal strength, Power level, global positioning system.

I. INTRODUCTION

Wireless networks have been quite popular since they appeared in 1970. The popularity of wireless networks arises from supplying data access opportunity to the users anywhere. The technological tendency of users is to communicate with wireless and mobile devices. The wide spread usage of cellular phones, portable computers and palmtop computers (PDA – personal digital assistant) with WLAN (wireless local area network) is the greatest indicator of this. Wireless networks can be classified into two categories: with infrastructure and without infrastructure networks. Wireless networks with infrastructure, also known as cellular networks, have permanent base stations, which are used to connect each other through links. Mobile nodes communicate with each other as through these base stations.

Wireless networks without infrastructure also known as MANET (mobile *ad hoc* network) are composed of random moving mobile nodes without central controls such as a predefined infrastructure or base station. Nowadays, these mobile nodes that can take place on airports, ships, trucks, automobiles and people in very small devices are widely used in many industrial and commercial applications. The usage areas given above make mobility of the nodes compulsory.

The characteristic of mobile ad hoc networks (MANETs) is that they do not have fixed network infrastructure, nodes can act as both host and router, nodes may be mobile, nodes may have limited resources, limited battery life and they have capability of self organization. MANETs require fundamental changes to conventional routing protocols for both unicast and multicast communication owing to its unique features. With the rapid growth of group communication services, the multicast routing in MANET has attracted a lot of attention recently [1][2][3][4][5].

In multicast routing, a path is set up connecting all group members so that bandwidth is not wasted. Group communication applications include audio/video conferencing as well as one-to-many data dissemination in critical situations such as disaster recovery or battlefield scenarios. Also, their applications are felt in mobile/wireless environments where the mobility and topology changes produces very high overhead and affects the throughput performance in terms of packet delivery ratio. Since group-oriented communication is one of the key application classes in MANET environments, a number of MANET multicast routing protocols have been proposed. These protocols are classified according to two different criteria.

The first criterion maintains routing state and classifies routing mechanisms into two types: proactive and reactive.

Proactive protocols maintain routing state, while the reactive protocols reduce the impact of frequent topology changes by acquiring routes on demand. The second criterion classifies protocols according to the global data structure that is used to forward multicast packets. Existing protocols are either tree or mesh-based. Tree-based schemes establish a single path between any two nodes in the multicast group. These schemes require minimum number of copies per packet to be sent along the branches of the tree. Hence, they are bandwidth efficient. However, as mobility increases, link failures trigger the reconfiguration of the entire tree. When there are many sources, one either has to maintain a shared tree, losing path optimality, or maintain multiple trees resulting in storage and control overhead. Examples of tree-based schemes include [6][7][8]: ad hoc multicast routing protocol (AM Route), ad hoc multicast routing utilizing increasing ID-numbers protocol (AMRIS), and multicast ad hoc on-demand distance vector routing protocol (MAODV).

Mesh-based schemes establish a mesh of paths that connect the sources and destinations. They are more resilient to link failures as well as to mobility. The major disadvantage is that mesh-based schemes introduce higher redundancy of packets since multiple copies of the same packet are disseminated through the mesh, resulting in reduced packet delivery and increase in control overhead under highly mobile conditions.

ROUTING ALGORITHMS IN AD HOC NETWORKS

There are many routing algorithms developed for wireless *ad hoc* networks in the literature. These algorithms are classified into three main groups as table driven, on demand and hybrid algorithms (Hwang et al., 2005), these are:

Table-driven routing algorithms: Destination Sequenced Distance Vector (DSDV) (Ehsan and Uzmi, 2004), Clustered Gateway Switch Routing (CGSR) (Abolhasan et al., 2004), Wireless Routing Protocol (WRP) (Johnson and Maltz, 1994).

On-demand routing algorithms: Dynamic Source Routing (DSR) (Johnson and Maltz, 1994), On-Demand Distance Vector Routing (AODV) (Perkins and Royer, 1999), Temporally Ordered Routing Algorithm (TORA) (Ehsan and Uzmi, 2004), Zone Routing Protocol (ZRP) (Haas and Pearlman, 1998).

Hybrid routing algorithms: Multi Point Relaying (MPR) based algorithms (Joe and Batseli, 2002); Position based algorithms: Directional routing algorithm (DIR), most forward within radius (MFR), geographic distance routing (GEDIR) (Stajmenovic, 2002), distance routing effect algorithm for mobility (DREAM) (Basagni et al., 1998), Voronoi-GEDIR (V-GEDIR) (Stajmenovic et al., 2002).

Some information about general properties of each Kara et al. 329 category and routing algorithms mostly used within every category in terms of performance criteria are given as follows so that the developed algorithm could be better understood and evaluated.

Table driven routing algorithms

Table driven routing algorithms are also called proactive algorithms. Protocols that use this algorithm find all paths between source-destination pairs in a network and form the newest path with periodic route updates. Update messages are sent even if there are no topological changes. The protocols which are in this category are developed by changing distance vector and link state algorithms. These protocols store routing information in routing tables and give result very slowly because of periodic update of tables. This working strategy is not very suitable for wireless *ad hoc* networks because of a great deal of routing overload (Ehsan and Uzmi, 2004).

Destination Sequenced Distance Vector (DSDV): It is commonly used algorithm by means of its performance criteria among table-driven protocols category. DSDV protocol adds a sequence number to the Routing Information Protocol's routing table. This sequence number field is used to differentiate between old and new routes. Each node maintains a routing table which contains next hop information for all reachable destinations. The routing table is updated by periodic advertisements or whenever new information is available.

The performance of protocol is mainly dependent on interval value of sending of periodic updates. If this interval is very short, a big amount of routing overload will occur. If the interval is long, delay will appear in receiving the most updated information. If there are many moving nodes in the network, this protocol will not be efficient. It was shown in section 3 that proposed PBHRA algorithm is more performed than

DSDV by means of routing overload because it does not send periodic update packets in the network.

On demand routing algorithms

Unlike table driven algorithms, on demand routing algorithms do not form route information among nodes. Routes are founded only in case of necessity. Routes are formed only when needed, in other words when any of the nodes wants to send a packet. Therefore, routing overload is less than table driven algorithms. However, packet delivery fraction is low because every node does not keep updated route information.

II. PROPOSED WORK

In this paper, we propose a link stability based multicast routing scheme that establishes a route from source to multicast destinations in MANET. A multicast mesh is created with stable links when a source node needs to send data to receiver nodes. The scheme consists of following phases.

1. Mesh creation through the route request (RR) packets and route reply (RP) packets.
2. Finding stable routes between source to destination by selecting SFNs using link stability metric.
3. Mesh maintenance and handling link failures.

The link stability is computed using power received at a node, distance between nodes and the packet losses. Our contributions in this paper are as follows.

1. Defining route request and route reply packets to create a mesh by using transmission power and antenna gains.
2. Creation and maintenance of routing information for hop by hop routing for a multicast connection by using route request and route reply packets based on link stability.
3. Selecting stable forwarding node for multicast paths based on link stability computed using the parameters such as received power, distance between the nodes and link quality.
4. Attempts to select different stable forwarding node in a mesh during link failures rather than immediately going in for route discovery.
5. Comparing the performance of the proposed scheme with ODMRP.

Route Request, Route Reply and Route Error Packets

To create a multicast mesh and a stable route in a mesh from source to destination, various control packets such as route request, route reply and route error (RE) packets are used. In this section, we describe some of the fields of the control packets required for multicast mesh creation, stable path establishment and handling link failure situations. The fields of RR packet are as follows.

- Source address: It is the address of the node originating the packet.
- Multicast group address: It is the address of the multicast group.
- Sequence number: The sequence number assigned to every packet delivered by the source that uniquely identify the packet.
- Route request flag (RR flag): This flag is set for the duration of forward travel of RR packet from source to destination.
- Previous node address: It is the address of previous node that RR packet has visited during its forward movement.

In the route request phase, a node receiving RR packet stores this address with multicast address in its MRIC as next hop node to send the packets to RR packet source. This field is updated after every movement to the next node until it reaches the receiver with multicast address.

- Power: This is the power at which a node has transmitted the packet to neighbor.

RP packet format for multicast mesh creation is almost similar to RR packet with few changes in RR packet. They are as follows: RR flag value will be made 0, previous node address is removed, and source address is replaced by receiver address. RP packet moves on path traversed by RR packet by using MRIC and also updates the MRIC towards receiver/multicast address by adding one more next hop (node address from where RP packet has come) to multicast address. In general, next hop at every node to reach a source is set by using RR packets whereas RP packets set next hop at every node to reach receivers from the source. RE packet is generated when a node is unable to send the packets. Some of the fields of this packet are source address, destination address, sequence number, and route error flag (RE flag). Whenever a node identifies link failures, it generates RE packet with route error flag set and sends the packet to either source or receiver. If link failure occurs in forward journey of a RR packet from source to multicast receiver, RE packet is sent to the source and if link failure occurs for reverse journey of the RP packet from receiver to the source, RE packet is sent to the multicast receiver.

Multicast Routing Information Cache (MRIC)

Each node in the network maintains its own MRIC that aids in forwarding packets to group members. A node adds information to its MRIC as it learns of new routes for various multicast groups in MANET; for example, a node may update new routes when it receives RR and RP packets, and likewise. A node removes information from its MRIC as it learns that existing routes in the ad hoc network have failed due to link and node failures. For every visited packet (RR or RP) at a node, MRIC is updated with some of the following fields required for establishing multicast mesh and stable paths (see Figure 1).

Group ID/DST. ADDR.	Nexthop ADDR.	FW FLAG	Stability Factor	SEQ. NO.
228.10.10.0/	128.80.10.1	01	0.7	100
92.19.10.10	128.80.0.80	01	0.9	105
	128.80.0.11	10	1.0	234

Fig. 1. Multicast routing information cache

- Group address and Destination address: Group address is the address of multicast group. Destination address is the address of the node where packet has to be forwarded with multicast address. This helps to accommodate the routes created by RR packets and RP packets.
- Next hop addresses: These are the addresses of the next hop interfaces for forwarding to a multicast group.
- Forwarding flag (FW flag): This field stores two bit flag that indicates the status of node in three modes; *mode 00*- node is multicast group node, *mode 01*- node is a forwarding node and *mode 10*- node is a forwarding node and is on the stable path.
- Sequence number: This is the number given by the node which has a route to multicast receivers. It helps in differentiating the time order in which route is created. A node updates routes if the received sequence number in RR/RP packet is higher than the existing sequence number. It is set to infinity if a next hop link fails.
- Next hop stability: This defines stability factor of a link connecting next hop (taken from link stability database). FW flag for a forwarding node of a multicast group will be set to 10 if the node has high stability factor compared to other next hops. In figure 1, stable next hop used for forwarding to multicast address/ destination address 228.10.10.0/92.19.10.10 is 128.80.0.110.

Hybrid Routing algorithms

Hybrid routing algorithms aim to use advantages of table driven and on demand algorithms and minimize their disadvantages. Position based routing algorithms that is classified in the hybrid routing algorithms category include the properties of table driven and on demand protocols and are usually interested in localized nodes. Localization is realized by GPS that is used to determine geographical positions of nodes.

Position changes which occur because of nodes mobility in MANET cause changes in routing tables of nodes. The GPSs, which are embedded in nodes, are used to update information in tables in position-based algorithms. That makes position-based algorithms different from the table driven and on demand algorithms.

The GPSs have become preferred systems as they provide latitude, longitude and height values at high reliability and low cost. Some of the GPS based hybrid routing algorithms are: directional routing algorithm (DIR), most forward within radius (MFR), geographic distance routing (GEDIR) and distance routing effect algorithm for mobility (DREAM). geographic distance routing (GEDIR) algorithm use geographical information of neighbor and destination nodes in order to determine message packet receivers.

The meaning of the neighbor node is the closest node to target node. Algorithm determines the target within a few CPU cycles (Lin, 1999).

GEDIR algorithm use only latitude and longitude parts of geographical information of whole nodes. Every node knows geographical positions of only its own neighbors. Sender knows the location of target node at the same time. When node A wants to send message m to node D, it uses location information of D and location information of the closest one to D among which are 1-hop neighbors.

Distance routing effect algorithm for mobility (DREAM), one of the improved algorithms based on node position information, was suggested in Basagni et al., (1998). According to DREAM, the position information obtained by GPS of whole nodes in the network is stored in every node's routing table. This algorithm is a table driven algorithm since it holds information belonging to whole nodes. According to the algorithm, while node A is sending m message to node B, it uses its position information in order to determine B's direction. Then it sends m message to 1-hop neighbor on B direction. Each neighbor repeats the same process. This process continues until message arrives to B (if possible). It resembles on demand algorithms in this respect.

The V-GEDIR is another of the position-based algorithm (Stajmenovic et al., 2002). In this method, the intersection nodes are determined with destination's possible circular or rectangular voronoi diagram. Another position-based algorithm suggests reducing number of route demander transmitter nodes (Imielinski and Navas, 1999). The algorithm called Location Aided Routing (LAR) algorithm handles route finding by reducing the search area (Watanabe and Higaki, 2007). GEDIR, MFR, DIR and DREAM calculate intermodal position information (latitude and longitude) to decide routing. On the other hand, in suggested PBHRA algorithm, position information is calculated as three dimensional. Moreover, routing decision in PBHRA is made not only with inter nodal distance but also by using node densities and battery life.

POSITION BASED HYBRID ROUTING ALGORITHM

In the previous section, algorithms in MANET were classified into three categories as table driven, on demand and hybrid algorithms. The proposed algorithm, PBHRA takes place in position based algorithm class in hybrid main category. The working principle of infrastructured wireless networks is also benefited in the proposal. As known, there is a central node or base station in infrastructure wireless networks and it is stationary. The nodes in coverage of this station take the information for routing from that and realize the operation of sending and receiving process through this station. However, procedures in infrastructured wireless networks could not be used in *ad hoc* networks since there is not a central node in *ad hoc* networks or in other words, all nodes are mobile.

In the proposed algorithm, a central node, in other words a master node is assigned as it is in infrastructure wireless networks and directs the routing information. When nodes require to send data to a target node, they take the location of target node and the route to achieve it from master node. Accordingly, they send their data through that route. At this stage, the proposed algorithm differs from infrastructured wireless networks since data is sent via central station in infrastructured wireless networks. However in proposed algorithm, the master node behaving as if it is central node helps only while finding the route to achieve the target.

III. WORKING STEPS OF ALGORITHM

The detailed working steps of the algorithm are these:

(a) The first node that stands up, while network is firstly started is assigned as master node. If two nodes are opened at the same time and two master nodes form, these nodes compare MAC addresses in the first packets that they took from each other and the node whose MAC address has higher value decides not to be the master node. The details of master determining process are given in the following section.

(b) Master node broadcasts packets in regular intervals and declares to the other nodes in the network that it is the master node. These packets are called "master node announcement packet (map)".

(c) The nodes excluding master node send "update packets (up)" to master node. In these packets there is information about the geographical position of nodes (as x, y, z coordinates), rest of battery life as percentage and node density. There are destination address, source address and id area in the update packet. Id area is used for in order to update the related line of position information matrix that master node will form.

The receiver address is the current address of the node that sent updating data. Sender node increases id area in the packet each update. In this format of updating information is processed as a row element in P matrix kept on master node. If updating information is taken from the same node formerly id values are compared. The packet that has higher id value is recorded and follows:

$$P - \begin{bmatrix} x_1 & y_1 & z_1 & b_1 & d_1 & id_1 \\ x_2 & y_2 & z_2 & b_2 & d_2 & id_2 \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ x_k & y_k & z_k & b_k & d_k & id_1 \end{bmatrix} \quad ...(1)$$

former record is changed.

(d) Master node forms position information matrix by using packets that come from other nodes. There are position information as (xi, yi, zi), battery life as bi, density di and node update sequence number idi in the columns of this matrix called P matrix. The row numbers of the matrix are equal to number of nodes. This matrix for k-node network is given in (1).

$$l_{i,j} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2} \quad ...(2)$$

(e) Master node calculates the distance of each node to each other by using the first, second and third columns of P matrix that is given in (1). It makes this process by using the (2). In the result of this, q square matrix that's dimension is equal to number of nodes in the network. M distance matrix for k-node network is obtained as given (3).

$$M = \begin{bmatrix} l_{1.1} & l_{1.2} & . & . & l_{1.k} \\ l_{2.1} & l_{2.2} & . & . & l_{2.k} \\ . & . & . & . & . \\ . & . & . & . & . \\ l_{k.1} & l_{k.2} & . & . & l_{k.k} \end{bmatrix} \quad ..(3)$$

The diagonal of M will be zero as the distance of every node to itself is zero. Also with a condition i_j, the distance between i and j and the distance between j and i are the same, thus the matrix M will be symmetrical matrix. Therefore the upper triangular part of matrix M will only be calculated. The lower triangular part of M will be filled by upper triangle. As a result of this, the computational time, which is an important factor for battery life of a node, is reduced.

(f) The node in the center of the network is determined. The total of row elements of M distance matrix given in (3) are derived and transferred to column matrix T that is given in (4). The number of the row that has the smallest element of T matrix is equal to the number of the node that is in the center of the network.

$$T = [t_1\ t_2\ t_3\ . .\ t_k] \quad ...(4)$$

Where

$$t_1 = \sum_{n=1}^{k} l_{n,1} \quad ...(5)$$

(g) New master node candidate is the node that is in the center of the network. Master node asks candidate master node if it can be the new master node. If the answer is positive, it sends the whole routing information that it keeps on itself to the new master node and also it declares new master and its position information to the other nodes. If the answer is negative, the second central node for the T matrix is the new master candidate. The same processes are realized for this node. Candidate node can refuse to be the master node because of low battery life or high density.

(h) New master node sends broadcast packets to the network relating to being master node. The updating packets that will come from other nodes are collected in P matrix as the former master node did. New master node repeats the steps between a to h.

(i) The other nodes send event based updating packets to the master node when they changed their position, their battery life got under threshold level and their density increased. Thanks to id value sent in P matrix related to that node. Because other nodes send id value that is one bigger than the former in the update packet they sent.

(j) According to this algorithm, normal nodes requisition from master node path information to destination node when they want to send a data to any destination.

Master node assigns a cost value to the intermodal borders with fuzzy logic by using M matrix and P matrix when a request relating to a destination comes to itself. In this way a graph consisted of nodes and borders forms. G matrix is formed in order to keep the cost values of graph. The forming of G matrix will be handled in the next section.

(k) Master node supplies an optimization in order to found the path between source and destination with the least cost over the formed graph. The shortest path, in other words the path has lowest cost is determined by using Dijkstra or Bellman Ford algorithm.

(l) Master node declares the result got from j and k steps to the node which requested path and related node send its data using this path. When any node will demand routing path from master node, it sends a "route request packet (rqp)" to the master node. Master node sends "route reply packet (rrp)" to the node which requested a route. Master node answers to the node that is the owner of request by determining most optimum path to the destination node from the source node and replacing an optimization on graph structure that is formed when master node received route request packet.

(m) If master node goes far from central position or battery life falls down a threshold, it transfers the mastership to other node, which has minimum row total value in M. Nodes decide to be a master node or not in accordance with battery lives and densities. In the case of master node's closure with any reason, a "secondary master" node is assigned in order not to make network stay without a master. This assignment process is made by the master node. Master node selects the nearest node to itself as the secondary master. It sends the routing information that it holds on itself to the secondary node in certain periods. The frequency of data sending to the secondary master is four times of the interval of master node broadcast packet sending.

(n) The other nodes do not hold information belonging to whole nodes and do not make any process related to routing. But they hold "master node packet" that comes from master node in their memories.

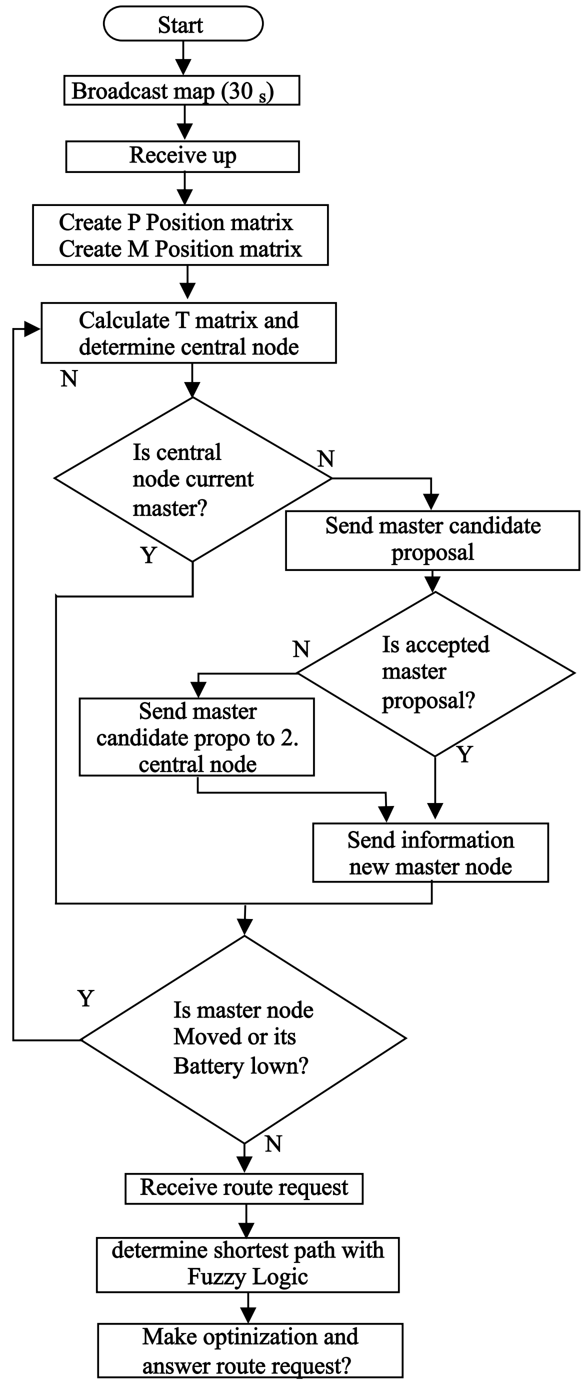

Fig. 1. Flow chart of PBHRA algorithm.

Figure 1 shows the flow chart of the algorithm whose detailed steps were given.

Determining role of master node

According to PBHRA algorithm, there are three roles for a node in the network. These are master, secondary master and normal node. The process of determining secondary master's role is determined by master node. For this reason, a node has to know whether it is a master node or a normal node. Determining of being a master is realized with following steps:

(a) A node in the network waits for 30 second after it stands up.

(b) Did the node receive master node announcement packet (map) in this period?

(c) If the answer step b is yes; (c1) Did it receive one map, or more maps than once? (c1a) If it receives one map, it records at its memory the address and position of node from which it receives a packet as master node. Thus, it decides itself that it is a normal node. (c1b) If it receives maps more than once, it compares the address in the packets received. It records the one with low address and its position into its memory as master node. It decides that it is a normal node itself. (c2) It sends an update packet (up) containing its position to master node whose address is stored in memory.

(d) If the answer of 2nd step is No; (d1) There is no master node in the network. It decides that it is a master node itself; (d2) It broadcasts maps for period of 30 seconds.

(e) Finish.

Distribution of master node announcement packets in the network

Master node announcement packets (map) are the most priority packets in the network. When any node receives a map in order to transmit to another node, firstly transmits this packet. After the map is left from the master node, it is sent to the nodes, which are in the broadcast distance of master node. If a node receives a map from other nodes more than once, it retransmits only once. Nodes do not send map to the sender node. In other words, map packets are send in single direction in the network. Consequently, network is protected to be intensively busy with map packets.

The distribution of map packets that were sent by M master node is shown in Figure 2.

Routing information request and reply

According to proposed algorithm, the node that will send data packet requests the path information of destination from master node in accordance step I of algorithm. Accordingly, master node sends the lowest cost path, which was found because of Belmond–Ford algorithm applied on information in its memory. For the process of determining the lowest cost path, master node defines the network as a graph consisting of edges and nodes. The cost values that are found because of fuzzy logic are assigned as weight value to the edges. Consequently, route request and reply processes are implied as follows:

- Node demand route.
- Master node calculates the internodal cost values by fuzzying battery life, density in the position information matrix and internodal distance information in distance matrix.
- Master node determines the cheapest path between demander node and destination node by using Belmond-Ford algorithm.

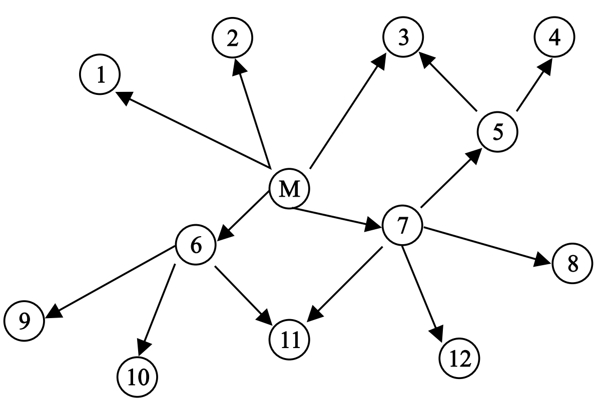

Fig. 2. Distribution of master node announcement packets in the network.

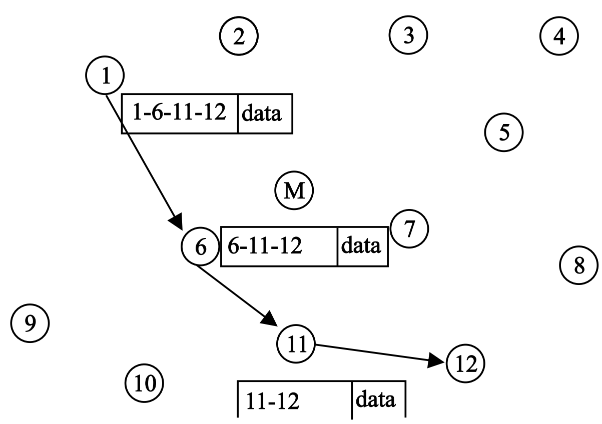

Fig. 3. Distribution of a data packet in the network.

- Master node sends its path to the demander node.
- Node sends packet to network by writing path information to the head part of data packet.

Data packets are transmitted in the network according to source routing method. When a node receives a data packet in order to transmit, it extracts the address information belonging to destination part of the packet's heading and transmits the packet to the owner of next address.

Distribution of data packets in the network

Distribution of data packets in the network is made according to the source routing mechanism. The node that will send data packet, writes whole path information from itself to destination into the header of the packet. A sample path of an instance data packet is shown in Figure 3. The next node to which will be sent data packet is guaranteed to be in the sender node's broadcasting distance by PBHRA algorithm. This process is realized according the jth step of the proposed algorithm that is given in section 3.2. The node, which receives packet to transmit, sends the packet to the next node according to the path information on the packet header. Data packet arrives to the destination node because of repeating this process.

Distribution of position information packets

When the normal nodes in the network first stand up, when their positions changed, when their battery lives get lower than a threshold level and when their densities in buffers get over than a threshold level, they send updating packets (up) to the master node.

Nodes send updating packets back through the path from which master node's broadcast packet comes.

Address of every node from which was passed are added into "row number" of map. When the address in row area vice versa, a path from node to master node is obtained, up is carried to master node over this path.

If a node takes the same map from various routes, it uses the route which has the least nodes for sending up. In Figure 4, although the node 4 can take

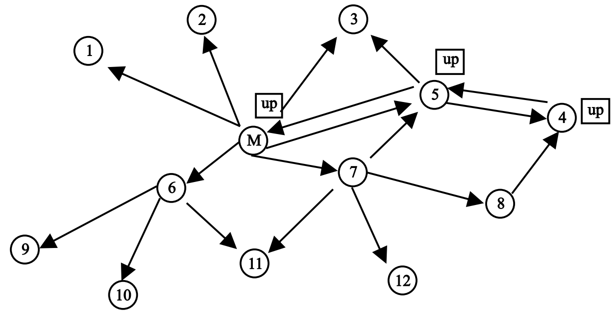

Fig. 4. Distribution of updating packets in the

the same map through both M-7-8-4 and M-5-4, it sends the up through 4-5-M.

IV. DETERMINING OF INTERNODAL COST VALUE WITH FUZZY LOGIC

The reason for using fuzzy logic method in algorithm is its more efficient usage of nodes for routing. Routing made according to inter nodal distance by using only position information results in extremely use of some nodes and consequently consuming their batteries in a short time. Moreover, if the buffer density of one of two very close nodes is high, the transmission time of routed packet will increase. The use of fuzzy logic in the algorithm aims to optimize energy usage of nodes and reduce point to point delay.

Nodes in the network and inter nodal distance are represented by a graph structure. To be able to apply fuzzy logic, it is supposed that nodes provide following criteria:

(i) Each node can directly send packets to nodes IT (broadcasting distance) unit far from itself and can only send its packet to nodes far away from IT through other nodes.

(ii) Link between nodes is bidirectional that means that two neighboring nodes can send packets each other. In the proposed strategy, master node does not only use distance between nodes but also use battery life of nodes and processing loads. If the processing load of two very close nodes is high or its battery life is about to finish, sent data reaches to receiver later than expected. Therefore, we propose to estimate the cost value between nodes by means of fuzzy logic on distance, battery life and processing density variables. Nodes in a network and distances between nodes are shown in directed and weighted graph as vertex and edges, respectively.

There are three input variables: distance, battery life and processing density in fuzzy reasoning system. The output variable is only cost value. The input and output variables are shown in Figure 5.

Distance changes from 0 to IT. Five triangle membership functions are equally replaced between 0 and IT.

The IT is scaled between 0 and 100. The assigned linguistic variables are "very close", "close", "medium", "far", "very far". The parameters of membership

Table 1. Parameters of triangular membership functions assigned to input and output variables.

Distance	Parameters	Cost	Parameters
Very close	0 0 25	Very Low	0 0 25
Close	0 25 50	Low	0 25 50
Medium	25 50 75	Medium	25 50 75
Far	50 75 100	High	50 75 100
Very Far	75 100 100	Very High	75 100 100
Density	Parameters	Battery Life	Parameters
Low	0 0 40	Low	0 0 40
Medium	10 50 90	Medium	10 50 90
High	60 100 100	High	60 100 100

Table 2. Sample cost values calculated with fuzzy logic.

Distance	Battery life	Density	Cost value
50	50	50	50
10	90	60	25
30	25	80	66
70	25	100	80
80	20	50	76

Functions are given in Table 1. Density and battery life vary from 0 to 100%. Three membership functions for these input variables: "low", "medium", "high" have been assigned. The parameters of triangle membership functions of density and battery life are shown in Table 1.

Output variable, cost value, varies from 0 to 100 units. Five membership functions for these input variables: "very low", "low", "medium", "high", "very high" have been assigned. The parameters of triangle membership functions of cost value are shown in Table 1.

The inference mechanism consists of 45 rules. Some of the rules are as follows:

1. If (Distance is very close) and (battery life is high) and (Density is Low) then (cost value is coklow).
2. If (distance is very close) and (battery life is high) and (density is medium) then (cost value is low).

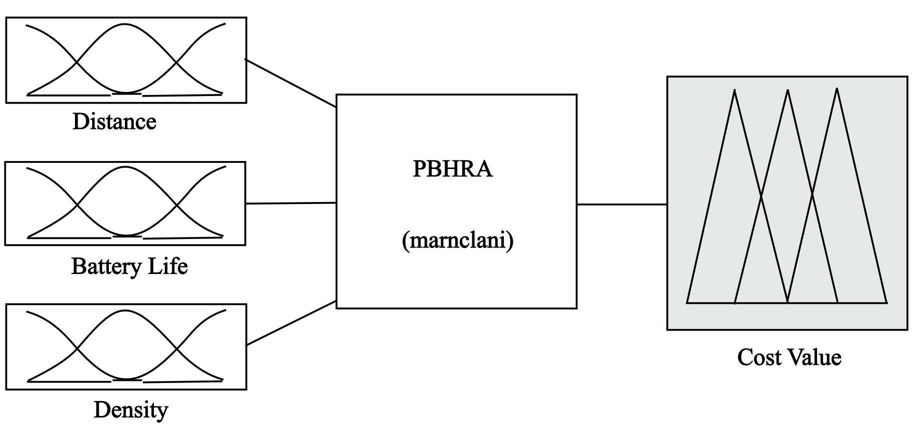

Fig. 5. Determination of cost value based on fuzzy logic.

3. If (distance is very close) and (battery life is high) and (density is high) then (cost value is medium).
4. If (distance is very close) and (battery life is medium) and (density is low) then (cost value is low).

Center of gravity method has been used for defuzzification of output variable. Consequently, the cost value of each node to other nodes (if they are within coverage) has been obtained. Table 2 shows some samples of typical values of input variables and accordingly estimated cost values.

V. PERFORMANCE EVALUATION

Simulation program of developed PBHRA algorithm was coded in Matlab 7.0 and performance evaluation is made with the criteria of normalized routing load, packet delivery fraction and end-to-end packet delay.

The parameters of simulations model are chosen as follows:

- Data packet size: 512 byte constant length packets.
- Node number in the network simulation: 20, 50 and 100 nodes.
- Topology area: Nodes are distributed randomly on a 500 × 500 m2. (Network topology was chosen 500 × 500 m2. Because nodes coverage area is 100 m.

Thus, some nodes may be in others coverage area.

- Mobility: A medium where nodes move in different velocities from 0 to 20 m/s.
- Simulation time: 100 s.
- Pause time of nodes: The simulation process was made in immobility simulations that change in 0-10-20-50-100 second's periods. The value 0 shows that nodes are fully mobile while the value 100 means that nodes are completely stable. Figure 6 shows a screenshot of the simulation program that was improved by using MATLAB 7.0.

One of the criteria used for the performance evolution is normalized routing load. Normalized routing load is the number of control packets per data packets transmitted in the network. Normalized load value has to be low in order to make algorithm performance value high. Normalized routing load graph for PBHRA, AODV, DSDV and DSR algorithms for a 50 noded and 20-sourced network are given in Figure 7. As it can be seen in Figure 7, normalized routing load value of PBHRA is lower than other algorithms. As a result, routing overload is reduced with the proposed algorithm especially in case of high mobility. Reducing routing overload in network will supply effective usage of bandwidth and energy consumption.

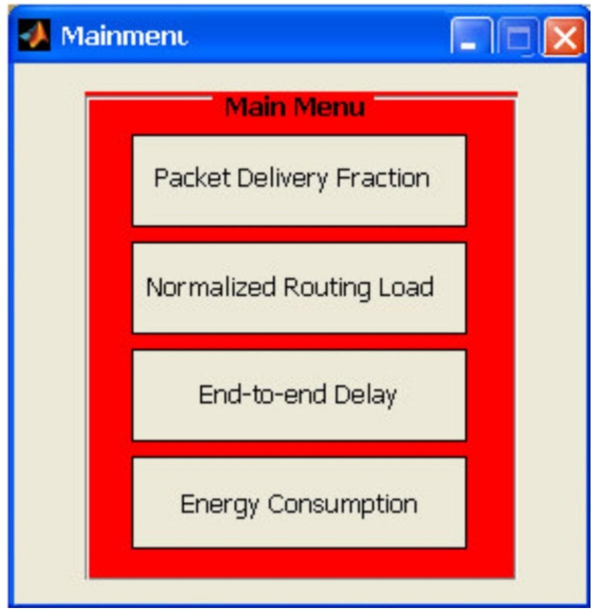

Fig. 6. A screenshot of simulation program.

Packet delivery fraction, other performance evaluation criteria, is expressed as percentage of packet which arrive destination. If the packets belonging to source node could not achieve their destination, packet delivery fraction would be negatively affected.

Packet delivery fraction results for a 50 noded and 20 sourced network are given in Figure 8. When the comparison of PBHRA, AODV, DSDV and DSR protocols is made, it could be seen that the PBHRA for a 20 sourced has a better packet delivery fraction. PBHRA was compared with AODV, DSDV and DSR in terms of average end-to-end packet delay in Figure 9. Average end-to-end delay is the time which released data packet from source node to arrive destination node. PBHRA has better performance than other algorithms in this respect.

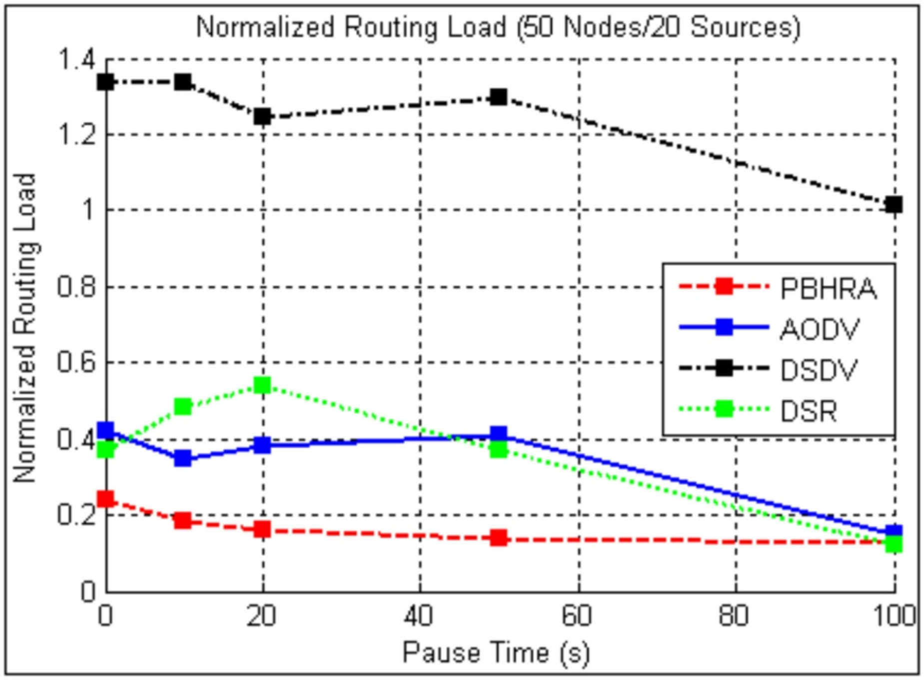

Fig. 7. Normalized routing load for 20 sourced / 50 noded network.

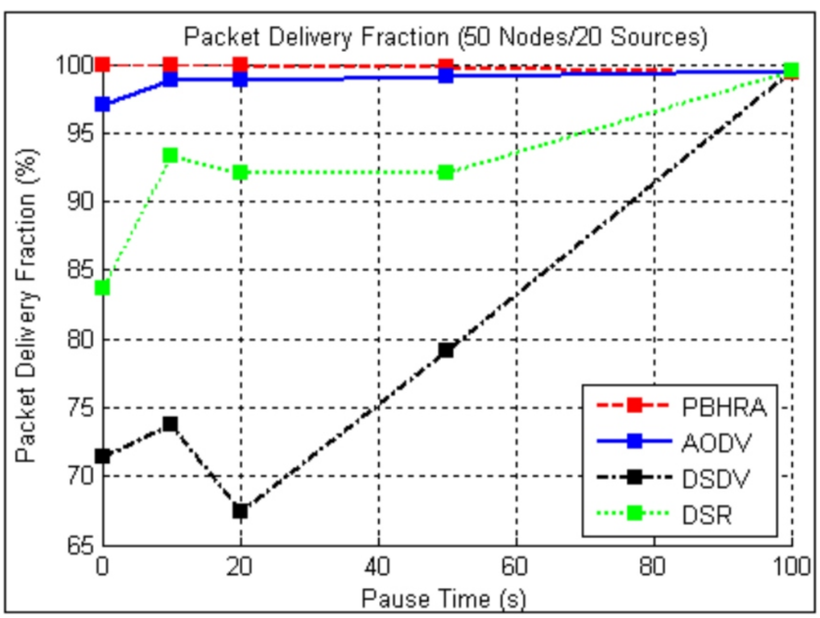

Fig. 8. Packet delivery fraction for 50 noded / 20 sourced network.

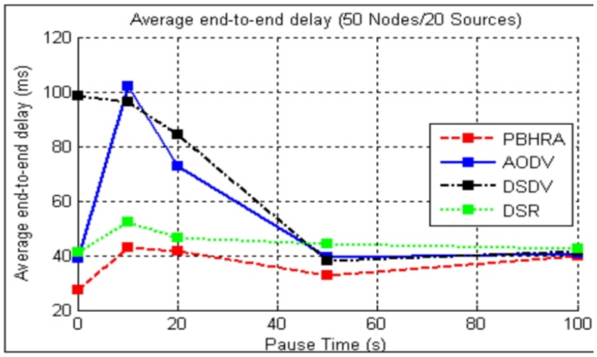

Fig. 9. Average end-to-end delay for 50 noded 20 sourced network.

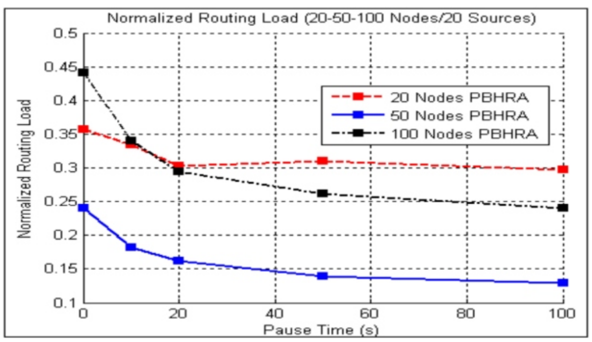

Fig. 10. Normalized routing load comparison for 20, 50 and 100 noded 20 sourced networks

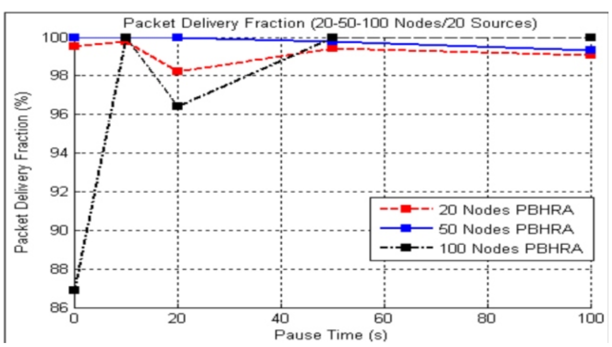

Fig. 11. Packet delivery fraction comparison for 20, 50 and 100 noded 20 sourced networks.

The developed algorithm was compared with DREAM, which has so far more attain than others among position based algorithms. Normalized routing load, packet delivery fraction and end-to-end delay graph of PBHRA and DREAM algorithms. According to the simulation results, PBHRA Algorithm has better values. How the normalized routing load, packet delivery fraction and average end-to-end delay are affected, was determined by simulating networks with 20, 50 and 100 nodes. Comparison of normalized routing load, packet delivery fraction and average end-to-end delay for different numbers of nodes is given in Figure 10, Figure 11 and Figure 12 respectively. As could be seen, in the case of increased number of nodes in the network, the normalized routing load increases by 8-20 % between a 50 noded and 100 noded networks is seen. Variation of the packet delivery fraction with number of nodes in the network was shown in Figure12. It was observed that network with 100 nodes has lower packet delivery fraction than that of a network with 50 nodes. As can be seen in Figure 13, increase the number of nodes in the network increases the value of average end-to end delay.

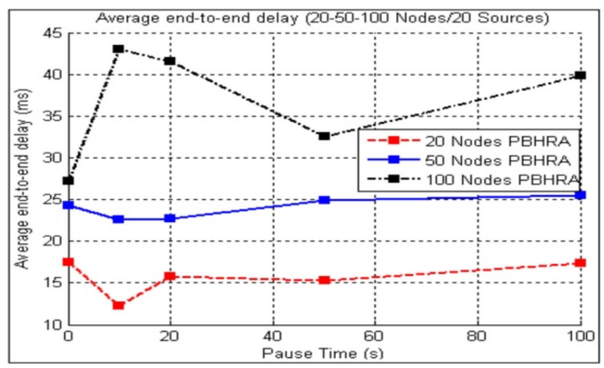

Fig. 12. Average end-to-end delay comparison for 20, 50 and 100 noded 20 sourced networks.

VI. CONCLUSION

In this study, we proposed stability based multicast routing scheme in MANET. It finds the multicast routes to receivers by using route request and route reply packets with the help of routing information maintained in MRIC and link stability parameters maintained in link stability database on every node in a MANET. A routing algorithm for optimizing bandwidth usage and decreasing energy consumption, power level by reducing routing overload for wireless ad-hoc networks were developed. The proposed PBHRA algorithm is compared with table driven, on demand and position based algorithms in terms of normalized routing load, packet delivery fraction and end-to-end packet delay. It was observed from performance values that the PBHRA gives better results than table driven, on demand and position based algorithms especially in the case of high mobility. The PBHRA algorithm uses available bandwidth efficiently because of its high packet delivery fraction and low normalized routing overload. The algorithm is not affected with the number of nodes increased in the network. It only increases the size of routing matrix held by master node.

On the other hand, this drawback could be removed by clustering procedure of network. The nodes are clustered according to their geographically closeness of each other. Clustering speeds up the route determination process. In addition, determination of the cost values using fuzzy logic in the network aims to minimize energy usage of the nodes and to reduce end-to-end delay.

As the continuation of this study, we are going to emphasize on classification of nodes, energy efficiency of the nodes and signal strength between the nodes.

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