

Full Length Research Paper

A new routing algorithm in MANETs: Position based hybrid routing

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***Ad hoc* wireless networks consist of mobile nodes that communicate with each other without an infrastructure. A reduction in routing overload and efficient use of resources are two very important issues in these networks. In this study, 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 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 GPS. The PBHRA was coded and simulated in MATLAB 7.0 to evaluate its performance and compared with other algorithms. The results showed that PBHRA performs better in terms of normalized routing load, packet delivery fraction and end-to-end packet delay compared to table driven, on demand, and position based algorithms.**

Key words: *Ad hoc*, routing, wireless routing, Matlab.

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

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.

MANETs have many characteristics: they do not have central control, all nodes have wireless interface, frequent topology changes as a result of freely moving of nodes, nodes have limited resources (like band width and battery life), they have physical security risk more than wired algorithms and there are inadequate simetric (bidirectional) links. Also, each mobile node has to make the routing processes which are performed in wired network routers because routing process in wireless networks is made by transmitting from node to node (Corson and Macker, 1999).

These characteristics of MANETs must be considered while developing new algorithms. In addition, the

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overload of routing algorithm must be minimized in order to efficiently consume insufficient sources.

The process of finding shortest path is usually realized by using protocols based on distance vector or link state routing algorithms. These algorithms do not give good performance in MANET that has limited bandwidth and does not have a central control structure. For this reason, changes on indicated protocols must be made or new protocols must be developed in the routing process in wireless networks (Ehsan and Uzmi, 2004; Wattenhofer, 2005). Therefore, in this study, a new routing algorithm working based on position information of the nodes (Position Based Hybrid Routing Algorithm – PBHRA) was proposed by considering the characteristics of wireless *ad hoc* networks explained above.

Some preliminary information about routing protocols developed for wireless *ad hoc* networks in order to make PBHRA better understood was given in Section 2. The working principle of suggested algorithm was handled in Section 3. In Section 4, use of fuzzy logic and the effects of it on the algorithm were included. Also the performance evaluation of PBHRA was performed and evaluation results were compared with table driven, on demand, and position based algorithms.

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

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.

Dynamic source routing (DSR)

In this algorithm, sender node determines the entire route

route of sent packet and adds the determined route information to the header of packet. This process can be made as static or dynamic. DSR protocol uses dynamic source routing.

DSR algorithm does not send periodic updates. However, there is routing overload because all route information is added into each data packet. This overload increases in state of mobility and traffic density.

Ad hoc on-demand distance vector (AODV): According to this algorithm, each node keeps routing table, but opposite of DSDV, which is a table driven algorithm, it does not have to keep routes to all other nodes. Like DSR algorithm, route-determining process is made via broadcasts (Johnson and Maltz, 1994).

AODV finds multi routes among source and destination pairs. This situation avoids overload of a new route determination process if there is a break path in a route. In addition, it allows user to select and control route for load balancing and similar operations. Route cache is very useful in state of low mobility. Nevertheless, in the case of high mobility, overload occurs.

The AODV, one of on demand algorithms, obtain superiority by means of packet delivery fraction and packet transmission delay because of adding reverse path information to route request packets, while the DSR obtain superiority by means of low routing overload. On the other hand, the PBHRA has more advantages than both AODV and DSR by means of packet delivery fraction and routing overload because of participating updated routing information in a central node.

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 neighbour on B direction. Each neighbour 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 internodal 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 internodal 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 infrastructured 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 infrastructured 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.

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:

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

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).

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

(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 in (3).

$$M = \begin{bmatrix} l_{1,1} & l_{1,2} & \cdot & \cdot & l_{1,k} \\ l_{2,1} & l_{2,2} & \cdot & \cdot & l_{2,k} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ l_{k,1} & l_{k,2} & \cdot & \cdot & l_{k,k} \end{bmatrix} \dots\dots\dots(3)$$

The diagonal of M will be zero as the distance of every node to itself is zero. Also with a condition $i \neq j$, 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.

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

Where

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

(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 internodal 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 the 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.

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

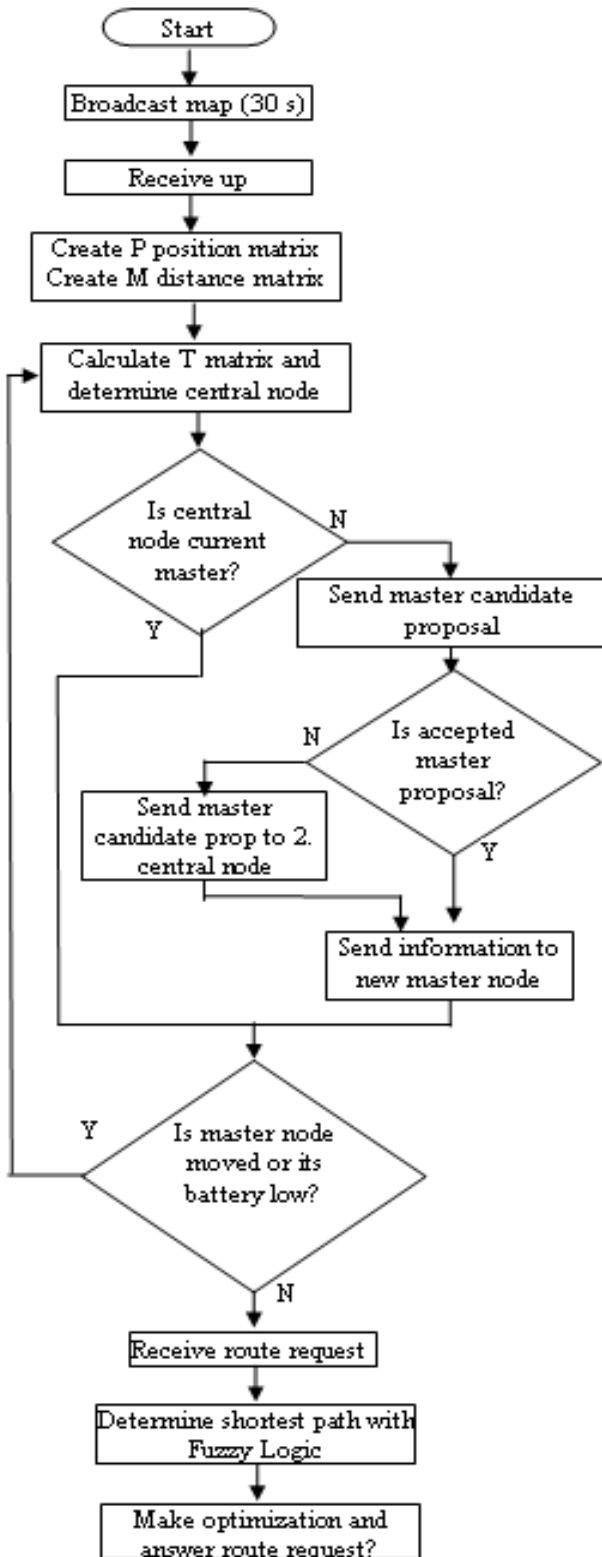


Figure 1. Flow chart of PBHRA algorithm.

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

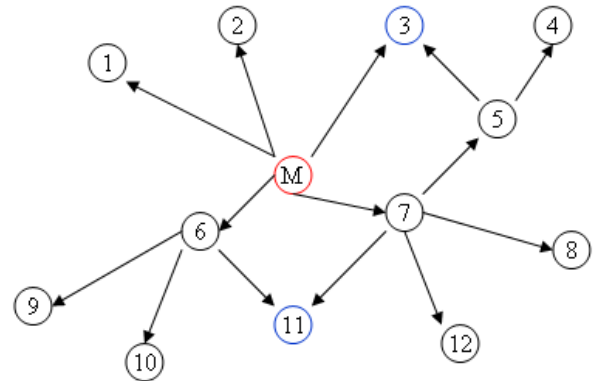


Figure 2. Distribution of master node announcement packets in the network.

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 sent 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 fuzzifying 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.
- 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

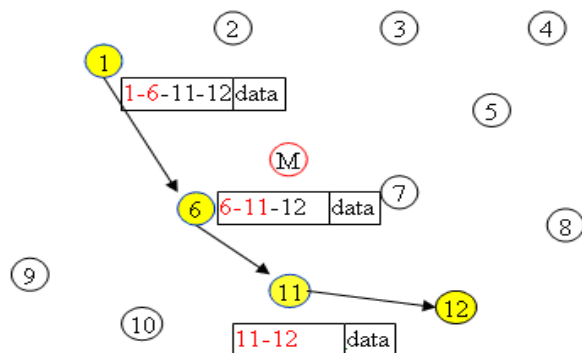


Figure 3. Distribution of a data packet in the network.

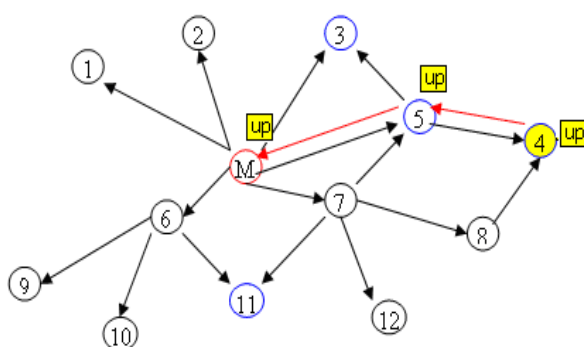


Figure 4. Distribution of updating packets in the network.

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 j^{th} 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 the the same map through both M-7-8-4 and M-5-4, it sends the up through 4-5-M.

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 internodal 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 internodal 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 l_T (broadcasting distance) unit far from itself and can only send its packet to nodes far away from l_T 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 l_T . Five triangle membership functions are equally replaced between 0 and l_T . The l_T is scaled between 0 and 100. The assigned linguistic variables are "very close", "close", "medium", "far", "very far". The parameters of membership

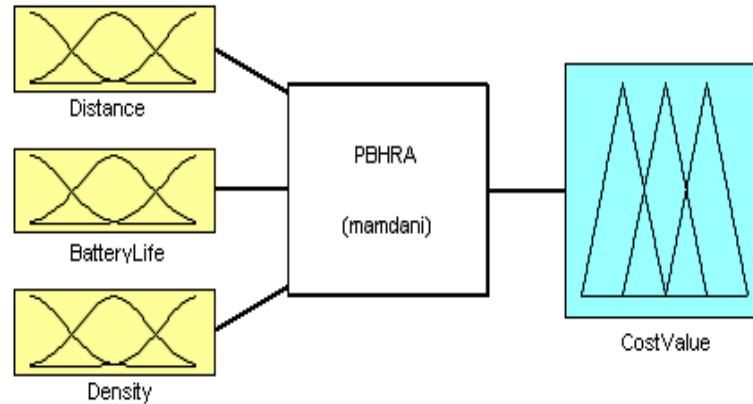


Figure 5. Determination of cost value based on fuzzy logic.

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).
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 defuzzi-fication 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

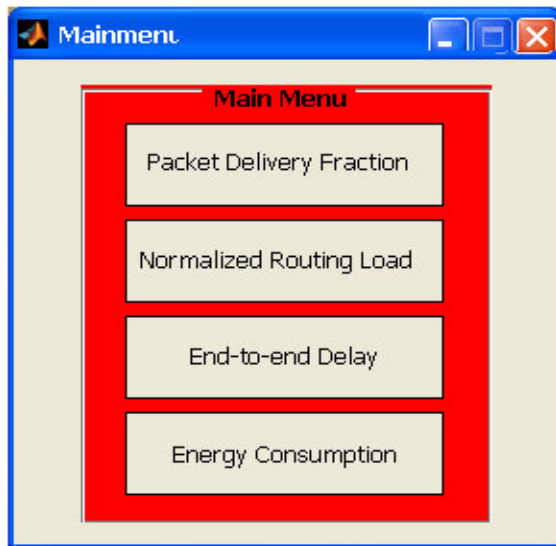


Figure 6. A screenshot of simulation program.

typical values of input variables and accordingly estimated cost values.

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 $500 \times 500 \text{ m}^2$. (Network topology was chosen $500 \times 500 \text{ m}^2$. 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

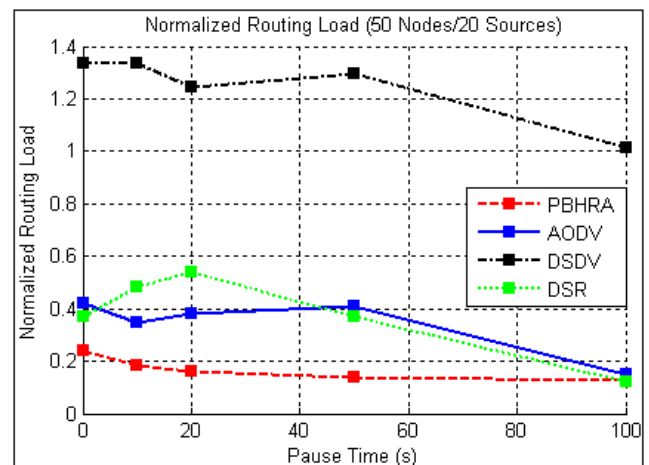


Figure 7. Normalized routing load for 20 sourced / 50 noded network.

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.

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.

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 are given in Figure 10. 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

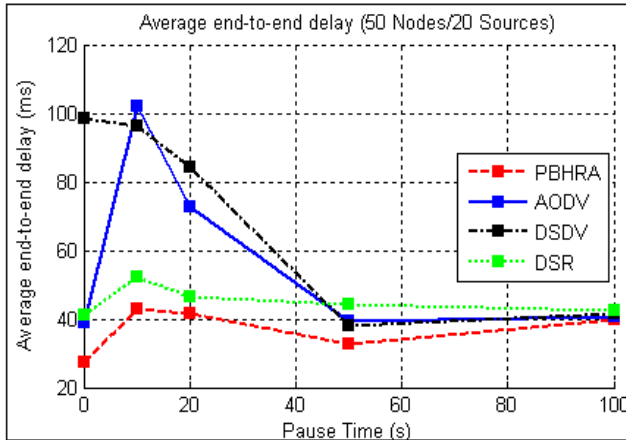


Figure 9. Average end-to-end delay for 50 noded 20 sourced network.

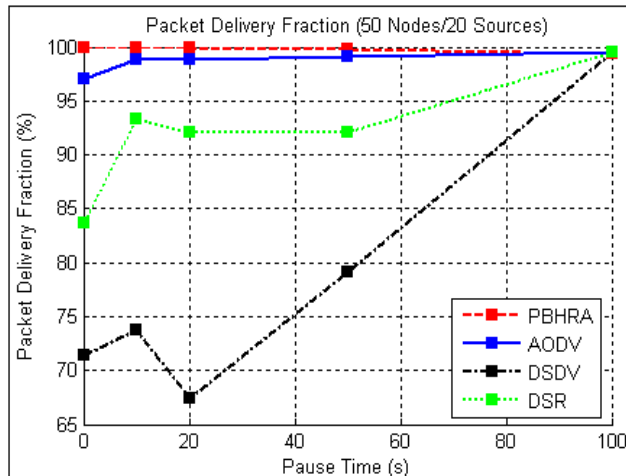


Figure 8. Packet delivery fraction for 50 noded / 20 sourced network.

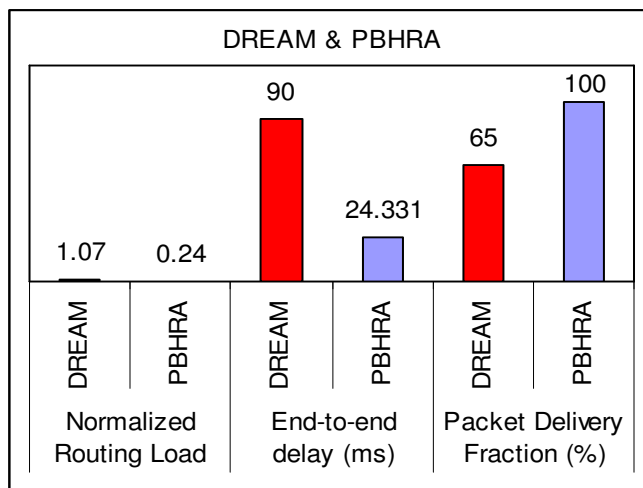


Figure 10. PBHRA and DREAM performance results.

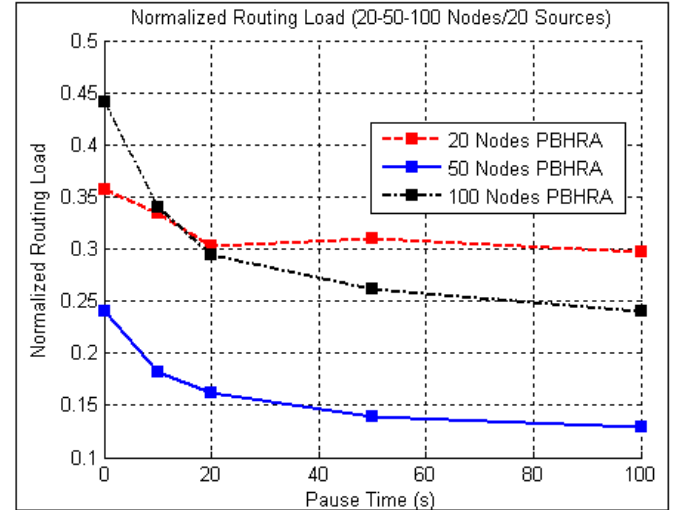


Figure 11. Normalized routing load comparison for 20, 50 and 100 noded 20 sourced networks

fraction and average end-to-end delay for different numbers of nodes is given in Figure 11, Figure 12 and Figure 13 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.

Conclusion

In this study, a routing algorithm for optimizing bandwidth usage and decreasing energy consumption 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

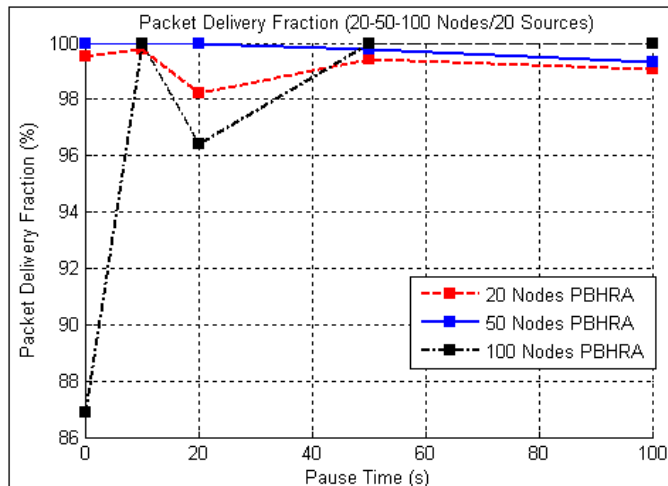


Figure 12. Packet delivery fraction comparison for 20, 50 and 100 noded 20 sourced networks.

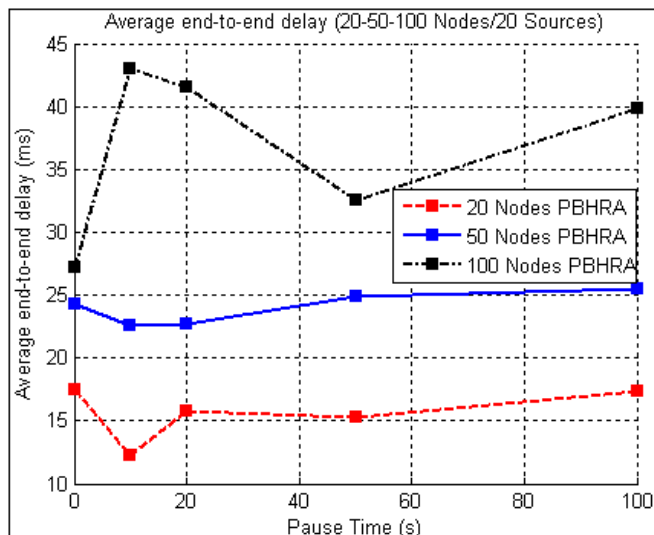


Figure 13. Average end-to-end delay comparison for 20, 50 and 100 noded 20 sourced networks.

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 and energy efficiency of the nodes.

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