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Improving Survivability in Wireless Ad Hoc Network

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***Abstract*—**Topological changes in mobile ad hoc networks frequently render routing paths unusable. Such recurrent path failures have detrimental effects on quality of service. A suitable technique for eliminating this problem is to use multiple backup paths between the source and the destination in the network. This paper proposes an effective and efficient protocol for backup and disjoint path set in ad hoc wireless network. This protocol converges to a highly reliable path set very fast with no message exchange overhead. The paths selection according to this algorithm is beneficial for mobile ad hoc networks, since it produce a set of backup paths with more high reliability. Simulation experiments are conducted to evaluate the performance of our algorithm in terms of route numbers in the path set and its reliability. In order to acquire link reliability estimates, we use link expiration time (LET) between two nodes.

***Keywords*—**Wireless Ad Hoc Networks, Reliability, Routing, Disjoint Path

I. Introduction

MOBILE nodes and wireless networking hardware are becoming widely available, and extensive work has been done recently in integrating these elements into traditional networks such as the Internet. Oftentimes, however, mobile users will want to communicate in situations in which no fixed wired infrastructure is available. In such situations, a collection of mobile nodes with wireless network interfaces may form a temporary network without the intervention of a centralized access point and established administration. This type of wireless network is known as a Mobile Ad hoc NETwork (MANET). Nodes in this network perform network tasks like relaying packets, discovering routes, monitoring the network, securing communication, etc. such networks are likely to be widely used in several future applications of practical importance. Examples include disaster recovering operations, battlefields, communication in remote terrains like reservations, rural areas, events, and so on [11].

Since nodes in this network do not have fixed position and move in an arbitrary manner, we must consider disconnection as a normal network behavior because it can occur after a node has moved or a user has turned his device off.

Route disruption invokes a route recovery process and may lead to excessively long delays at the routing layer and affects the quality of service for delay sensitive applications.A set of link-disjoint paths is a set of paths that have no common links.

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So if a direct link (also called a one hop link) between two nodes breaks, it can discard one and only one path. Therefore, all the other paths are not affected by the failure and the nodes can go on communicating. Moreover, finding disjoint paths set can help developing QoS multipath routing protocols. So for selecting a set of paths to achieve high reliability in aggregate, the correlation of failures between the paths in the set should be as low as possible. A simple solution to determine disjoint paths would be to employ an iterative procedure, in which the shortest paths are found one after the other, removing the links of the path after it is found. Unfortunately, such a solution does not work well in practice.

This paper proposes an effective and efficient protocol for selecting backup and disjoint path set in ad hoc wireless network to maximize the overall reliability of path set as backup set of primary route. This protocol is driven by accurate path reliability metric and it is using a unique negative weight assignment algorithm that allows certain directed links to be temporarily reused during path set construction. Directed link is a link that has forward or backward direction and the routing algorithm has used it already.

II. Related works

More multipath routing protocols have focused on load-balancing and provide fault tolerance and do not discuss in case quality of election paths.

In the most related works, sending route request packets is used for path set selection that compute the route with employing flooding method in the entire network.

Hauspie et all [5] proposed a routing algorithm for selecting the disjoint paths in mobile ad hoc networks which has been designed for client-server based applications. This protocol need to know the distance between every node and the source node. This can be done using periodic beacon messages that generated extremely message overhead. Moreover the destination node uses a set of sequenced number that will consume more largely bandwidth of the network and increase the size of packets.

The multipath extension to DSR (MDSR) presented in [10] maintains alternate disjoint routes to the destination, which are used when the primary one fails. It is demonstrated by simulations that the multipath extension scheme can reduce the frequency of route request-query floods.

Das et all [2] proposed a flooding mechanism that considers a Time To Live (TTL) for each Route Request (RREQ) packet and it decremented after each hop. In this method, each RREQ contains a *route record*, in which is accumulated a record of the sequence of hops taken by the packet as it is propagated through the ad hoc network during this route discovery process. If the message is not duplicated and TTL is not zero, the packet will be rebroadcast to all neighbors. As the node discards the packet only if there were too many hops or if the path is looping, the protocol is more likely to generate a lot of paths. The main problem is that the number of generated packet is very high. Thus, this protocol can be used only in small density and short distance.

Multipath source routing (MSR) [12, 13] proposes a weighted round-robin heuristic-based scheduling strategy to distribute load among multiple paths. Lee et all [7] proposed the Split Multipath Routing (SMR) algorithm for select maximally disjoint paths. In this protocol multipath routes discover by a modified route request procedure. In this scheme intermediate nodes are allowed to rebroadcast duplicate route request messages if they received them from a link with better quality of service. However in this protocol the reliability of links has not been used and the paths are not entirely disjoint.

In [4], Ant Hoc Net algorithm is proposed for routing in mobile ad hoc networks based on ideas from the nature-inspired ant colony optimization framework. The algorithm consists of both reactive and proactive components and discovers multiple paths for each active data session.

Another multipath extension to DSR, proposed in [14], uses node coloring techniques to find two disjoint paths during the query phase of the route discovery process. Ad hoc on-demand multipath distance vector routing (AOMDV) [8, 9] computes multiple loop-free and link-disjoint paths during the route discovery process.

A similar path selection criterion is adopted in the redundancy based multipath routing (RBMR) [6], which aims to establish a route that contains more redundant paths towards the destination. Meshed multipath routing (M-MPR) [3] uses meshed paths and selective forwarding on all intermediate nodes to achieve better load distribution in sensor networks.

III. Proposed Approach

A. Assumptions

We define the reliability of a network element as the probability of that element being operational. This protocol denote the probability of proper operation of link by P_{ij}^{link} where i, j are the number of nodes that are connected. A MANET is modeled as a probabilistic graph *GP = (V, L)* with probabilities of proper operation assigned to the links where V is the number of node in the network and L is the link numbers between them. A link operates with probability P_{ij}^{link} and fails with probability $q_{ij}^{link} = 1 - p_{ij}^{link}$. Accordingly, for a source node *S* and a destination *D*, $\mathrm{Re}liability_{S \to D}, (S \neq D)$ denotes the probability that there exists at least one path connecting *S* and *D* over *GP* graph.

Each node in this protocol continuously monitors the reliability of each of its incident links. In order to acquire link reliability estimates, we use LET between two nodes. Assume two nodes i and j which are within the transmission range r of each other. Let (x_i, y_i) be the coordinate of mobile host i and (x_j, y_j) be that of mobile host j. Also let v_i, v_j be the speeds, and $\theta_i, \theta_j (0 < \theta_i, \theta_j < 2\pi)$ be the moving directions of nodes i and j, respectively. Then, the amount of time of two mobile hosts will stay connected is calculated by:

$$LET_{i,j} = \frac{-(ab+cd) + \sqrt{(a^2+b^2)r^2 - (ad-bc)^2}}{a^2+c^2} \tag{1}$$

Where

$$a = v_i \cos\theta_i - v_j \cos\theta_j$$

$$c = v_i \sin\theta_i - v_j \sin\theta_j$$

$$b = x_i - x_j, d = y_i - y_j$$

After calculating the LET in all the links within the network, the highest amount of LET $(LET_{\max})$ is determined.

The probability of the proper operation of a link between nodes i and j is obtained by:

$$p_{ij}^{link} = \frac{LET_{i,j}}{LET_{\max}} \tag{2}$$

Where $LET_{\max}$ is the biggest time period which the two nodes are connected in the network. In this protocol the link reliability estimation is distributed to all nodes, therefore significantly higher estimation accuracy is achieved.

B. The computation method of path set reliability

Assume $A = \{path_1, path_2, ..., path_n\}$ denote a disjoint path set that is including n paths. For computing the overall reliability of the set, first the reliability of each path inside it must be determined. i[th] path reliability of the path set is obtained by:

$$relipath_i = \prod_{j=1}^{m} p_j \tag{3}$$

Where, p_j is the probability of j link properly operating and m, is the number of links through this path. The probability of the i[th] path improper operating is computed by:

$$failpath_i = 1 - relipath_i \tag{4}$$

Then the probabilities of improper operation of paths in the set are multiplied to obtain the probability of path failing of overall set. Therefore, the reliability of the entire set is obtained by:

$$\mathrm{Re}liability = 1 - \prod_{i=1}^{n} failpath_i \tag{5}$$

If a single link reliability of each path that belongs to the path set increases the overall graph reliability will increase. In other words, if the collection $A = \{path_1, path_2\}$ is included two paths and the reliability of one of them increased, the overall reliability will be increased. The reliability decreases as the number of links increases, and the overall reliability of a path is worse than the reliability of each of its links. With the addition of reliability increase the number of paths increases and the overall reliability is better than the reliability of every single path. Therefore our goal is to choose as many paths as possible and at the same time include paths which are most reliable. However selecting as many of disjoint paths cannot maximize reliability of the path set because there may be a number of unreliable and long paths in this set, which will cause decreasing reliability of the path set. On the other hand, a choice of fewer, but shorter and more reliable paths may produce a greater overall reliability.

Proposal solution based on an iterative procedure of four steps: (1) a search for the most reliable $S \rightarrow D$ path, (2) a decision on whether this newly found path improves the path set reliability, or not, (3) a means of augmenting the path set, and finally, (4) a simple transformation of the underlying graph, so that the path search may temporarily use links of paths already included in the set. If the new path is overlapped with one or multiple routes of the path set, must be decided that whether the removal of the overlapped link and the re-arrangement of the path set will increase the overall reliability ,or not.

C. The selection method of most reliable path between a source and a destination

In this algorithm a route cache is considered for each node that will preserve the order of nodes and probabilities of most reliable visited path from each source. For selecting the most reliable path between any two nodes, the following algorithm is performed:

First the source node propagates the RREQ packet to the nodes which are in its transmission range. This RREQ packet contains the following fields.

Record: In which accumulates a record of the sequence of hops taken by this packet.

Prob: In which the link reliability of the followed paths exists.

When any node receives a RREQ packet, it processes the request according to the following steps:

If this node has already received a RREQ packet with a higher reliability degree, then it will discard the new packet.

If this node address is already listed in the route record in the request, for preventing a loop creation, the RREQ packet is discarded.

If this node has not already received the RREQ packet or if the received packet has a low reliability degree, in this case the node appends its own address to the route record in the RREQ packet, and also its incoming link reliability to the Prob field of the packet and re-broadcasts the request to its neighbors and updates its route cache.

Otherwise, if the target node is achievable, then the most reliable route is chosen and it returns a copy of this route in a *route reply* packet to the source node.

D. Definitions

1. A non directional link is a link between two neighbor nodes which is not selected by the routing algorithm. In other words at first before the routing algorithm process, all the links of the network are non directional links. After the routing algorithm has chosen a new path, the links consisting the path, are separated and removed from the non directional links set. For example in figure 1 the links (F, D), (E, F) are non directional or undirected links; because no path has passed through them.

2. After the routing algorithm has selected a reliable path, the links in that path which are directed from the source to destination node, are defined as forward directed links.

For example, in figure 1-a, after choosing the path $p_1 = \{E, D, H, I\}$, the links (E, D), (D, H), (H, I) which are from the source node E to the destination node I, are considered as forward directed links.

3. As the same way, the links in that path which are directed from the destination node to the source node are defined as backward directed links.

For example in figure 1-a, after choosing the path $p_1 = \{E, D, H, I\}$, the links (D, E), (H, D), (I, H) which are from the destination node I to the source node E, are considered as backward directed links.

4. In the proposed algorithm not only a reliability is assigned to each link (a number between 0 and 1), but also a weight is considered for it.

The reliability of each link is unchangeable, and is determined with respect to some effective parameters in data network.

These parameters are as follows: the velocity of nodes, the delay amount when receiving data packets from that link, the interference phenomenon and signal attenuation, etc. however, the weight is a indicator which is used to the routing algorithm is performed and recognized the forward, backward and non directional links. The weight may be changed when the path set being finds.

E. The proposed algorithm for finding the path set between two nodes

At first, we assume that the path set is empty as default, because there is no route between source and destination and also all the links of the network is non directional. Then the routing algorithm which described in section 3-3 is performed and computed the most reliable path between two nodes. After choosing the new path, it enters into the path set. Then the entire links of it decompose in its parts and denote the forward and backward links. In this algorithm forward links is not allowed to belong to a temporary path but backward links can be one. Therefore after selecting the new path, its forward links are removed and backward and non directional links can be used by routing protocol. Routing algorithm which described in section 3-3 is performing iteratively and finding the most reliable path on the given graph. The selected new path denote candidate path. If the new path do not overlapping with any other route of the set, enter into the path collection so that improve the whole reliability. Otherwise if it contains backward links, it associates with one or more path into the path set. An overlapping is removed by constructing new paths. For example, in Figure 2-a, during one of the later iterations, the candidate path $\{E, C, H, D, G, I\}$ is found, which overlaps with the previously found $p_1 = \{E, D, H, I\}$. The associative link is (D, H). If the overlapped link is removed two disjoint paths p''_1, p''_2 obtained. These paths contain the following links (see figure 2-b).

$p''_1 = \{E, D, G, I\}, p''_2 = \{E, C, H, I\}$

In general, the candidate path may be overlapped with $\{path_1, path_2, ..., path_l\}$ belong to the overall set A, which the removal of the overlapping is generalized in a straightforward manner. If the new path overlap with any other path into the path set, must be decided that whether the removal overlapping links and rearrangement the path set increase the overall reliability or not. Therefore the following algorithm will be executed.

Decision algorithm for removal overlapping links

Assume that $A = \{path_1, path_2, ..., path_n\}$ contains n disjoint paths which the new path overlapped with some of them and a set of disjoint paths $B = \{path''_1, path''_2, ..., path''_{n+1}\}$ is constructed after all the overlapped links is removed.

At first we calculate the reliability of any path into the set A:

$$\mathrm{Re}\,li.A_k = \prod_{i=1}^{m} p_i \tag{6}$$

Where m is the link numbers of k[th] path and $\mathrm{Re}\,li.A_k$ is the path reliability of the set A.

Then the reliability of A is computed as follows:

$$\mathrm{Re}\,liability_A = 1 - \prod_{k=1}^{n} (1 - \mathrm{Re}\,li.A_k) \tag{7}$$

And then we determine the reliability of k[th] path of the set B as following equation:

$$\mathrm{Re}\,li.B_k = \prod_{j=1}^{w} P_j \tag{8}$$

Where p_j is the probability of proper operation of j[th] link and w is the link numbers of k path. The reliability of set B is computed by:

$$\mathrm{Re}\,liability_B = (1 - \prod_{k=1}^{n+1} (1 - \mathrm{Re}\,li.B_k)) \tag{9}$$

Decision

If $\mathrm{Re}\,liability_B > \mathrm{Re}\,liability_A$ then the overlapping links are removed and rearrangement the path set, otherwise those links are not removed and the new path discarded.

If an overlapping is removed, the routing algorithm can use them in next iteration again; because they do not belong to any route into the path set.

If the overlapping links are not removed, then the routing algorithm can not use them in next iteration.

This procedure continues until no new path between source and destination can be found. Therefore the result set, most reliable and disjoint path set which connected the source node and destination node.

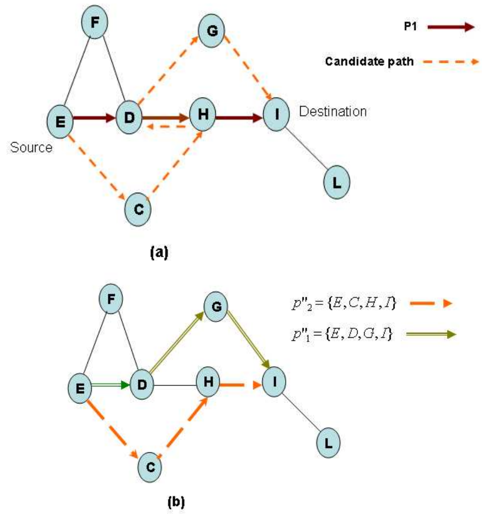

Fig. 2 overlapping Removal between two path

IV. Network Model

The simulation consists of a number of parts. The first and underlying part is the mobility model that dictates how nodes move throughout the network and the structure of the network itself. The second part of the simulation is finding the path set between any two nodes using the proposed algorithm. The three part of it is the neural network prediction system. All parts were implemented in MATLAB.

Our simulation modeled a network of N mobile hosts placed randomly within $1000 \times 500 m^2$ .The random waypoint model [1] was used in the simulation runs. In this model, a node selects a destination randomly within the simulation area and moves towards that destination at a predefined speed. Once the node arrives at the destination, it pauses at the current position for 5 seconds. The node then selects another destination randomly and continues the process again. Each node moves with a velocity between 0 km/h to 72 km/h. Each simulation executes for 100 seconds of simulation time.

With respect to mobility speed, direction of movement associated with every node and the link expiration time between any two nodes; we assign the reliability for each link.

Some metrics is used for evaluation of proposed algorithm:

- The reliability of the path set between source and destination nodes.

- The number of reliable and disjoint paths as backup routes which there exist into the path set.

V. EXPERIMENTAL RESULTS

In the first simulation group, we assumed that the number of nodes was 36, and the nodes moved randomly in all possible directions with a predefine speed and the radio transmission range was varied between 100 and 300.

Figure 2 shows the rate of reliability changes with respect to transmission range of nodes. As shown in the figure, the overall reliability will increased when the transmission range of nodes increased and it converged to one. Because of increasing the transmission range of nodes, there will be more link numbers between source and destination nodes which can be used; thus the whole set reliability will increased.

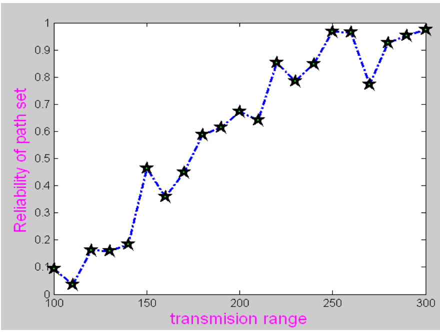

Fig. 2 the rate of reliability changes with respect to transmission range of nodes

Also as shown in figure 3, increasing the transmission range of nodes enlarges path numbers in the path set. Because when the radio transmission range of nodes increased, there are more routes between source and destination.

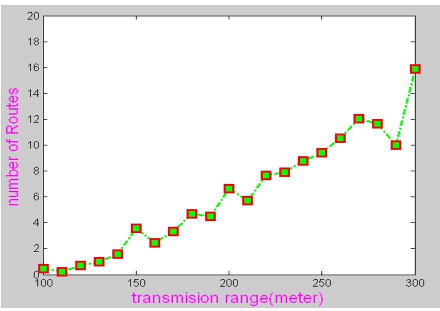

Fig. 3 the rate of path numbers changes as a function of the transmission range of nodes

According to figure 3, so that around 6 paths between source and destination node, we can select the transmission range of nodes as 200 meters and the overall reliability of the path set is .65.

Figure 4 illustrates the rate of reliability changes with respect to time. As the figure shows on the increase of time a number of paths in the set are disrupted which causes to decrease the whole reliability gradually. Around 250 meters transmission range, the set reliability is higher and all the paths in the set are disconnected in longer time, and the reliability decrease with lower speed.

Figure 5 shows the rate of backup paths number changes in the path set as function of time. In this datagram with more transmission range of nodes, route numbers in the set less degrade. We can see from the result that with 200 meters transmission range after 50 seconds, there are two valid paths between source and destination and communication can go on.

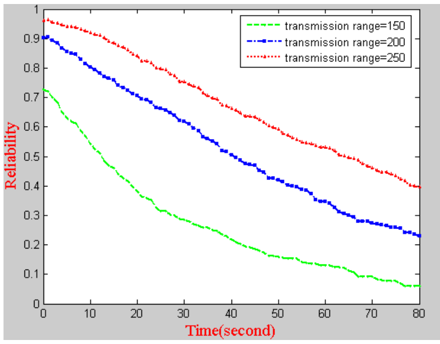

Fig. 4 the rate of whole reliability changes versus time with different transmission range

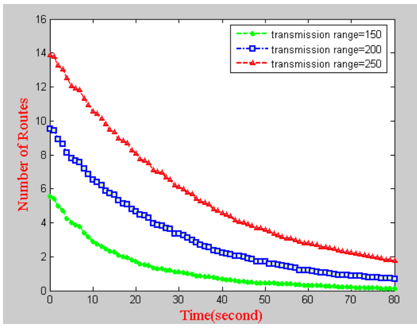

Fig. 5 the rate of path numbers changes in the path set versus time

Figure 6 shows the rate of backup path numbers changes in the path set as function of time. In this scenario, we assume that the network contains N=36, and all nodes move with a same velocity and transmission range of nodes has taken 200 meters into consideration. If the nodes move with less velocity, links expiration time will be more and the paths number of set degrades with lower speed. Figure 9 illustrates the rate of the path set reliability changes with respect to time. In this figure at less velocity, a lower number of paths are disrupted and reliability rate will be more. Therefore, in case of 36 km\h nodes speed, there is at least one backup path between source and destination for 50 seconds and communication can be maintained.

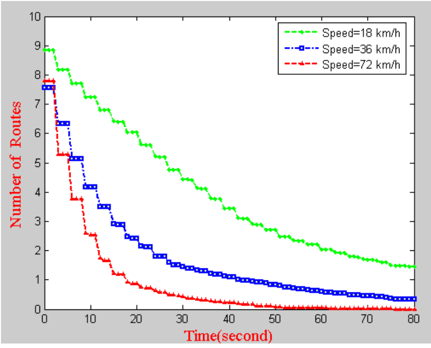

Fig. 6 the rate of path numbers in the path set as a function of time

In the next simulation group, the number of nodes in the network was varied between 10 till 70 and they moved arbitrarily in any direction with a random speed.

Figure 7 illustrate the rate of the path set reliability changes as a function of the node numbers in the MANET. As shown in the figure, when the node numbers is little, there will be less connection between mobile nodes and the reliability of the path set is degraded. Increasing the node numbers in the networks, increase the link numbers and the whole reliability of the path set will be more gradually.

Note that if the radio transmission range was 200 meters, the rate of reliability of the path set with respect to the node numbers was increased. The reason is that when transmission range is low and the network is sparse, each node can cover the little area of the simulation grid, hence it is possible to no reliable paths between source and destination nodes or the number of them is low. However, the increase in the node numbers will be caused that the network is dense, and the routing algorithm can be found more disjoint and reliable paths which the whole set reliability will be increased significantly. As shown in this figure, the reliability of the path set was increased approximately 200 percent when the node numbers was varied between 10 till 70 and transmission range was 200 meters. On the other hand, the increase of the path set reliability versus of node numbers is relatively low when the radio transmission range is increased. We observe in the figure, when the transmission range was 300 meters and the node numbers varied; the reliability of the path set increased only 15 percent. Because when the transmission range is high and the number of nodes is low, every node can cover a larger distance; thus the link numbers in the network and the reliability of the path set increased. While the increased of the node numbers in this transmission range only increased the unreliable links in the network, hence the whole reliability increased very negligible.

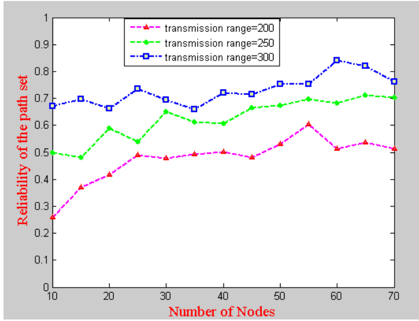

Fig. 7 the path set reliability changes with respect to the node numbers

VI. Comparison

Hauspie [5] procedure is one of famous method which is used for computing disjoint paths. Figure 8 shows the rate of backup paths number changes in the path set with respect to time using Hauspie method. As the figure represents when nodes move with speed of 36km/h, there is at least one valid path between source and destination nodes for 30 seconds. Compare to our proposed method, in the same condition as mentioned before in figure 6, there is at least one backup path remained till 50 second which is about more than 30 second respect to Hauspie method. Therefore by using the proposed algorithm, the connection between source and destination nodes will maintain longer and there will be no need to discover new paths.

Table I illustrates the comparison between the proposed method and Hauspie method.

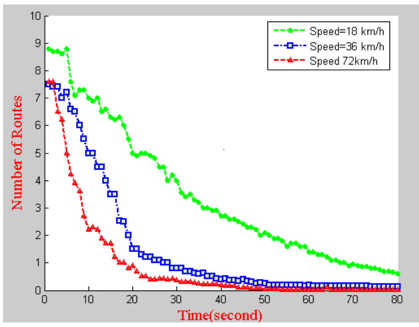

Fig. 8 the rate path numbers changes exists in the path set with respect to time using Hauspie algorithm

TABLE I
A COMPARISON BETWEEN PROPOSED ALGORITHM AND HAUSPIE METHOD

	Proposed method	Hauspie method
The time complexity for finding the path set with 250 meters of transmission range	12sec	15sec
Average backup paths with speed of 36km/h till 80 seconds.	1.88	1.55
Reliability	higher	lower

VII. CONCLUSION

In this paper we propose an effective and efficient protocol for select backup and disjoint path set in ad hoc wireless network. This algorithm converges to a highly reliable path set very fast. The experimental results show that a less number of paths are disrupted with respect to time and the connection can be maintained larger. Also we depicted results of transmission of range and velocity of nodes on the path numbers in the path set and its reliability.

We compare the proposed method and Hauspie method. The proposed algorithm can find the most reliable path set between any two nodes and there will be no need to discover new paths in the on demand routing algorithm.

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