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# Optimization of Routes in Mobile Ad hoc Networks using Artificial Neural Networks

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***Abstract.*** An ad hoc network is a collection of wireless mobile hosts forming a temporary network without the aid of any established infrastructure or centralized administration. Infrastructures less networks have no fixed routers; all nodes are capable of movement and can be connected dynamically in an arbitrary manner. Nodes of these networks function as routers which discover and maintain routes to other nodes in the network. 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. Most proposed on-demand routing protocols however, build and rely on single route for each data session. Whenever there is a link disconnection on the active route, the routing protocol must perform a route recovery process. 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 produces a set of backup paths with higher 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. In another experiment, we save the LET of entire links in the ad-hoc network during a specific time period, then use them as a data base for predicting the probability of proper operation of links. Links reliability obtains from LET. Prediction is done by using a Multi-Layer Perceptron (MLP) Network which is trained with back propagation error algorithm. Experimental results shows the MLP net can be a good choice to predict the reliability of the links between the mobile nodes with more accuracy.

***Keywords***: *Mobile ad hoc networks, Reliability, Routing, Artificial neural networks*

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## 1. Introduction

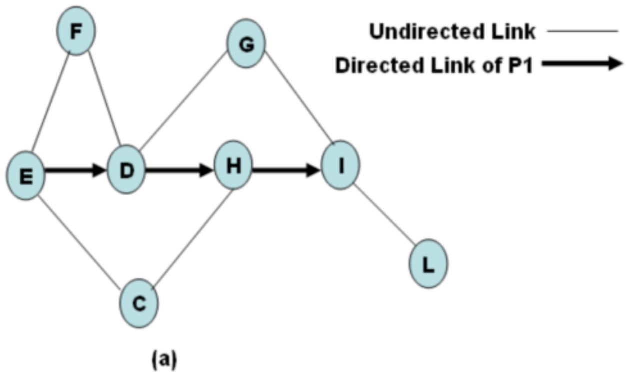
Mobile nodes and wireless networking hardware are becoming widely available, and extensive work has been done recently in integrating these elements into traditional networks such as the Internet. Oftentimes, however, mobile users will want to communicate in situations in which no fixed wired infrastructure 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 [1,17].

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.

Sending control packets for new route discovery consume network resources such as batteries power, bandwidth and leads to excessive delay for sending data packets, because first of all the route must be discovered then the data transmitted. Providing multiple backup paths helps minimizing route recovery process and signaling message overhead. Since whenever a link of overlap paths is failed, the entire paths are disrupted, so any connection between the links of the routes in a path set should be as small as possible.

A set of link-disjoint paths is a set of paths that have no common links. 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.

In general, a long path is less reliable than a short one and by selecting a larger number of disjoint paths the overall reliability increases. Therefore we should be looking for a large set of short and disjoint paths. 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. Figure 01 illustrates the potential pitfall. In this example, discovering the reliable path $p_1 = \{E, D, H, I\}$ and removing links of it would prevent this simple algorithm from finding the two other paths, $p_2 = \{E, D, G, I\}, p_3 = \{E, C, H, I\}$ although the combination of these two paths has greater reliability than the first path alone. 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.



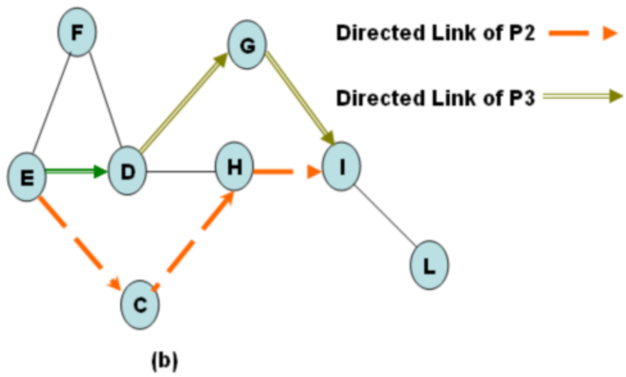




Figure01. Potential disadvantage in simple algorithm of path selection

In this paper, we introduce an approach for predicting the probability of proper operation of links using Multi-Layer Perceptron (MLP) neural network. The method predicts the reliability of links between nodes in ad hoc networks.
The remainder of the paper is organized as follows. First, we describe the background on multipath routing in section 2. Then, section 3 presents proposed approach for selecting disjoint paths in detail. Section 4 presents the used ad hoc network model in our algorithm. Section 5 demonstrates the simulations, and experimental results obtained. In Section 6, we introduce the link reliability prediction using neural network. Finally we conclude our work in Section 7.

## 2. Background

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.
Some papers such as [2] proposed an algorithm for selecting the paths in mobile ad hoc networks. Also Sheikhan et all [3] has proposed artificial neural networks as computational

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tools to solve constrained optimization problems. In that approach, node-disjoint and link-disjoint path sets can be found simultaneously with route discovery algorithm.

Das et all [4] 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.

Xu Yi et all [5] presented a Node-Disjoint Multipath routing protocol with multiple QoS constraints (NDMRP). The NDMRP successfully solved the QoS routing problems when nodes change dynamically in the networks. It only required the local state information of the link (or node), but did not require any global network sate to be maintained. Lal et all [6] proposed and implemented a node-disjoint multipath routing method based on AODV protocol. The main goal of the proposed method was to determine all available node-disjoint routes from source to destination with minimum routing control overhead. 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 [2], 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 [9], 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) [10, 11] computes multiple loop-free and link-disjoint paths during the route discovery process.

While most multipath extensions to DSR and AODV prefer disjoint paths, new path selection criteria have recently been adopted in several multipath schemes. The neighbor-table-based multipath routing (NTBMR) scheme builds non-disjoint paths by maintaining a two-hop neighbor table and a route cache in every node [12, 13].

A similar path selection criterion is adopted in the redundancy based multipath routing (RBMR) [14], which aims to establish a route that contains more redundant paths towards the destination. Meshed multipath routing (M-MPR) [15] uses meshed paths and selective forwarding on all intermediate nodes to achieve better load distribution in sensor networks.

## 3. Proposed method

### 3.1. 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

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$P_{ij}^{link}$ and fails with probability $q_{ij}^{link} = 1 - p_{ij}^{link}$. 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:

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

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 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:

$$p_{ij}^{link} = 1 - \frac{LET_{\max} - LET_{i,j}}{LET_{\max}} \quad , (2)$$

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.

### 3.2. 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 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 ingoing 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.

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### 3.3. Proposed Approach

At first, we assume that the path set is empty as default, because there is no route between source and destination and also all links of the network is non directional. Then the routing algorithm which described in section 3.1, is perform and compute the most reliable path between two nodes. After choosing the new path, it enters into the path set. Then all 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 3.1, is perform 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 path set. An overlapping is removed by constructing new paths. For example, in Figure02-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 figure02-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 collection 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 of the overlapped links is removed.

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

$$\mathrm{Re}\,li.A_k = \prod_{i=1}^{m} p_i \qquad , (3)$$

Where m is 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 set is computed as follows:

$$\mathrm{Re}\,liability_A = 1 - \prod_{k=1}^{n} (1 - \mathrm{Re}\,li.A_k) \qquad , (4)$$

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

$$\mathrm{Re}\,li.B_k = \prod_{j=1}^{w} P_j \qquad , (5)$$

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 B set is computed by:

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$$\mathrm{Re}\,liability_B = (1 - \prod_{k=1}^{n+1} (1 - \mathrm{Re}\,li.B_k)) \qquad , (6)$$

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 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.

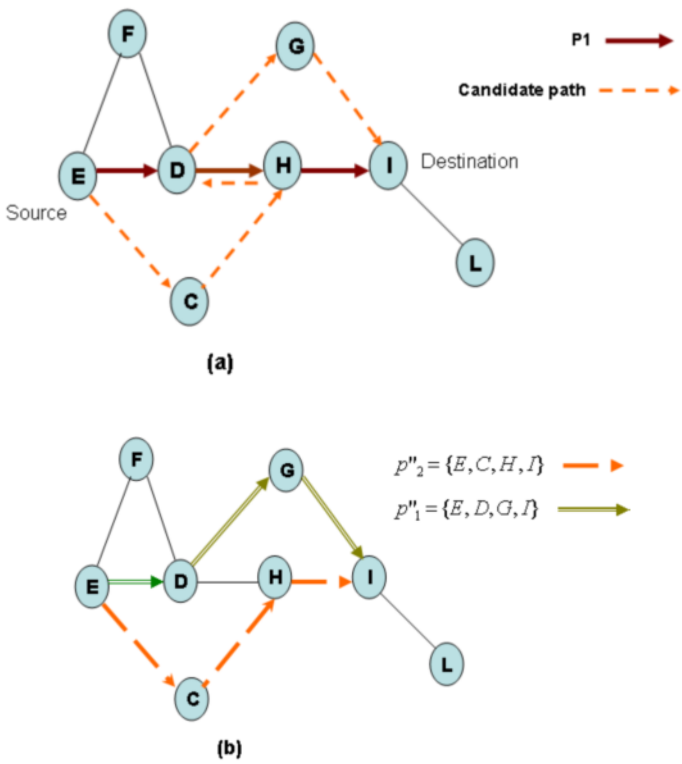


Figure02. Overlapping removal between two path

## 4. 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 $1000 \times 1000 m^2$ .The random waypoint model [16] 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, moving direction of nodes and the link expiration time between any two nodes; we assign the reliability for each links.

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 are inside the path collection.

## 5. Experimental Results

Figure03 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 paths in the set are disconnected in larger time, and the reliability decrease with lower speed.

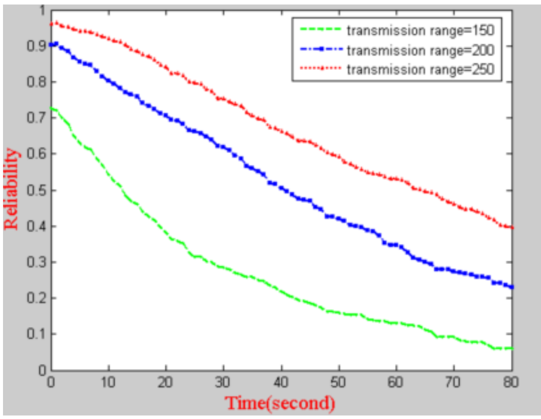


Figure03. the rate of whole reliability changes versus time with different transmission range

Figure04 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.

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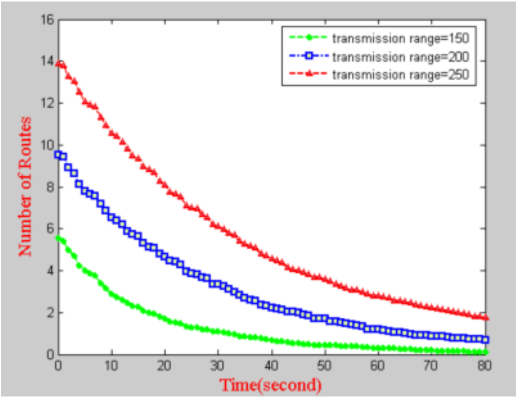


Figure04. the rate of path numbers changes in the path set versus time.

Figure05 shows the rate of backup path numbers changes in the path set as function of time. In this scenario, we assume the network with 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 speed, links expiration time will be more and the paths number of set decreases with less speed. Figure06 illustrates the rate of 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.

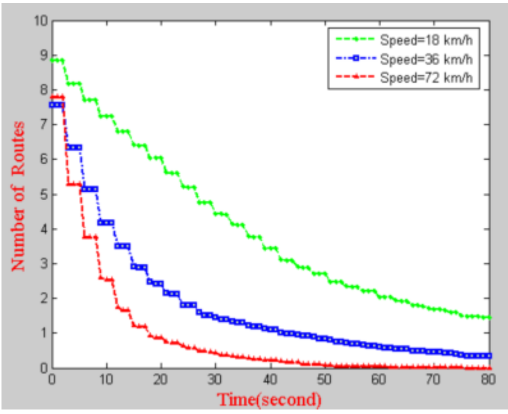


Figure05. the rate of path numbers in the path set as afunction of time.

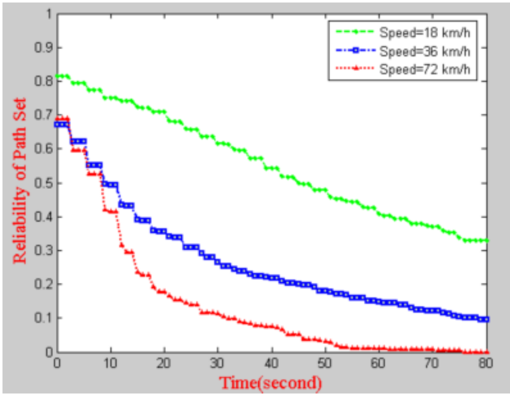


Figure06. the rate of reliability of path set with respect to time.

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.

Figure07 shows the variation of the average number of routes between source and destination hosts with respect to the node numbers. The results are shown for varying the radio transmission range. We observe that the average number of routes increases with the increase in the node numbers. This is due to the fact that when the network is sparse, the mobile nodes are relatively far, and there is less link numbers between them. Thus the number of disjoint paths is decreased. However, increasing the node numbers in the network, increase the total links in it, and the routing protocol can investigate the more one for finding the most reliable path. Therefore the backup route numbers will be increased.

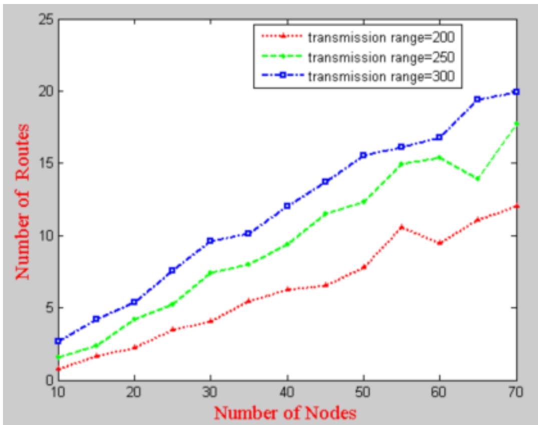


Figure07. the rate of route numbers versosthe number of nodes in the network.

Figure08 illustrate the rate of path set reliability changes as 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.

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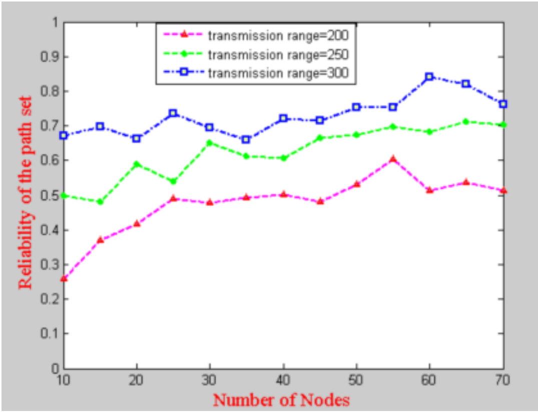


Figure08. the path set reliability changes with respect to the node numbers.

## 6. Predicting the reliability of links using a neural network

In another experiment, we save the LET of entire links in the ad-hoc network during a specific time period, then use them as a data base for predicting the probability of proper operation of links. In this scenario links reliability obtains from LET. Prediction is done by using a Multi-Layer Perceptron (MLP) network which is trained with back propagation error algorithm. The MLP model consists of three layers: input, hidden and output. Our MLP neural network is shown in figure09.

The very general nature of the back propagation training method means that a back propagation net can be used to solve problems in many scenarios in an ad hoc network. The pattern of the MLP network for predictions is the input vector and output vector, where the input vector is the coordinate of mobile hosts, angle of them and Euclidean distance between nodes and the output vector is the reliability of links between mobile nodes which is obtained from LET. The aim is to train the network to achieve a balance between the ability to response correctly to the input vectors that are used for training and the ability to give reasonable responses to input that is similar to that used in training. The training is done by using back propagation in two passes. The forward pass is used to evaluate the output of the neural network for the given input in the existing weights. In the reverse pass, the difference in the neural network output with the desired output is compared and fed back to the neural network as an error to change the weights of the neural network. Train set is the set of input-output patterns that are used to train the network, and test set is the set of input-output patterns which MLP net predict proper LET. Figure10 illustrates the neural network training model for predictions. The actual predicted output $(o)$ is compared to the desired output $(d)$ and the error values are used to calculate new weights of connections between neurons of all input, output and hidden layers thereby reducing the error in the output.

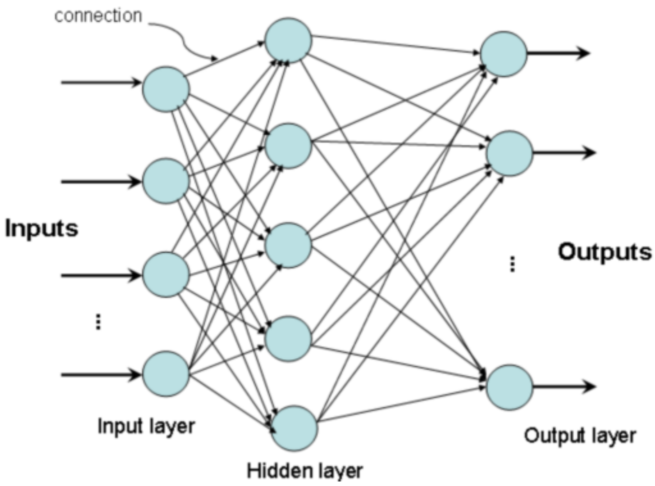


Figure09. The MLP neural network architecture for predicting the reliability of links

This training procedure is iterated over all the entries of the train set for several times until the mean square error between neural network output $(o)$ and the desired output $(d)$ reaches some specified threshold. The mean square error is obtained:

$$Error = \frac{1}{n}\sum_{n}\sum_{outputs}(d-o)^2 \qquad , (10)$$

Where $n$ denotes to number of test set and $outputs$ are the number of output vectors. This neural network algorithm essentially minimizes the mean square error between the MLP output and the desired output using gradient descent approach.

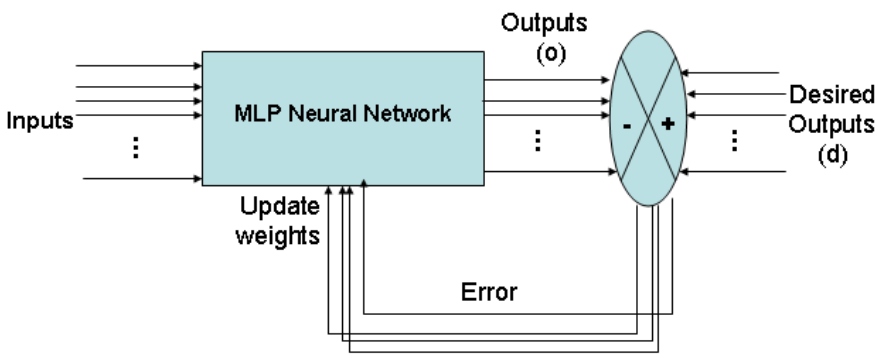


Figure 10. Neural network training model for predicting the probabilityof proper operation of links

Figure11 shows learning error versus number of iterations carried out during the training of MLP network. It is observed that learning error falls dramatically almost .005. Therefore MLP

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could be a good choice to predict the reliability of the links between the mobile nodes with more accuracy.

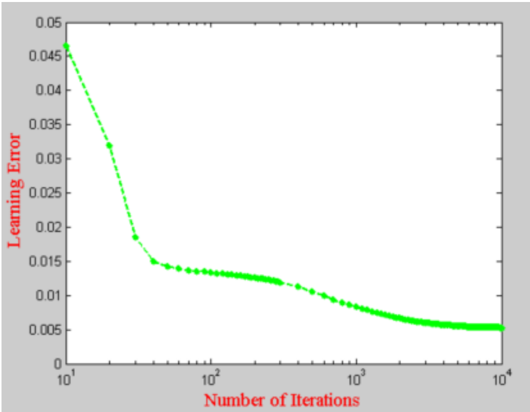


Figure 11. learning error with respect to number of iteration

If the hidden layer numbers of our MLP net increase its performance will be increased. In figure12 we can see the rate of neural net performance changes as a function of its hidden layer numbers.

The performance defines as fallowing step:

At first the output vector of neural network is obtained for each problem, and it subtracted with its desired output and produced the error vector. Then each entry in the error vector compare to the threshold $\theta$. If the result greater than $\theta$, the prediction is successful. Otherwise, it is unsuccessful. In this paper we assume it as .2. Therefore the performance calculates as follows:

$$performance = \frac{1}{k} \sum_{patterns} \sum_{outputs} successful.solved.problem$$

Where k is the sum of total outputs in the whole test set $(k = patterns \times outputs)$. As shown in this figure, if the hidden layer numbers is selected as 6, the performance will be maximized.

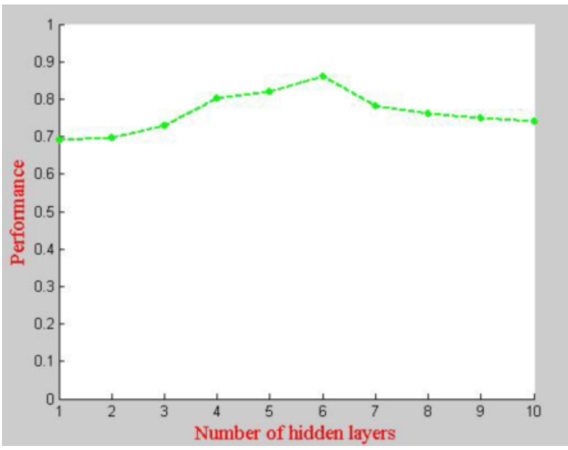


Figure12. the rate of net performance with respect to number of hidden layers.

## 7. 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, and no message exchange overhead. 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.

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. In addition we introduce an approach for predicting the probability of proper operation of links using MLP neural network. The method predicts the future reliability of links between nodes in ad hoc networks. This MLP net use the back propagation error algorithm for updating its weights. In this paper We showed the rate of mean square error changes versus number of iterations carried out during the training of MLP network. In addition we evaluate the performance of MLP with respect to number of hidden layers. Therefore MLP could be a good choice to predict the reliability of the links between the mobile nodes with more accuracy.

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