A New Scheme for Improving Route Discovery and Route Maintenance for Mobile Ad Hoc Networks (MANET)

Majid Jafri[a], Syed Rizvi[a,*], Laiali Almazaydeh[a], Aasia Riasat[b]

[a]*Computer Science and Engineering Department University of Bridgeport Bridgeport, CT 06601, USA*
[b]*Department of Computer Science Institute of Business Management Karachi, Pakistan 78100*

Abstract– **This paper presents a new scheme for the Distance Source Routing (DSR) protocol which shows the improvement over the two major metrics of the DSR protocol: Route Discovery and Route Maintenance. In addition, we present a mathematical model that includes probability density function for these two observed metrics. Our simulation results demonstrate a significant improvement in the route discovery, transmission time, and the overall network utilization. As an interesting side result, our analysis also shows that the proposed model can be used to effectively reduce the packet losses.**

Keyword: DS-CDMA, bit error rate, data throughput, multiuser communications.

1. Introduction

The Dynamic Source Routing (DSR) protocol is dealt under On-Demand Routing (ODR) protocol which is just an exact opposite to the Table-Driven Routing (TDR) [1, 2]. Generally, there are two main phases use in the DSR protocol. One is the Route Discovery (RD) phase which discovers all the possible paths for the packets to be transferred from a particular source to a destination. It is essential to properly maintain the RD phase since maintaining a separate table for storing routing details involves cost issues. The second phase of the DSP protocol is the Route Maintenance (RM) phase which fixes all the possible paths from one particular source to a destination [3]. In DSR, the packets are transmitted only one time for each node. If the node does not receive the packet, the previous node is responsible to make attempts in order to transmit the packet. On the other hand, if the destination node receives the packet successfully, an acknowledgment is transmitted back to the source node for the received packet. Since the use of the DSR protocol does not require the maintenance of a cache table, it allows us to avoid unnecessary updating works which results space and time saving advantages.

In the existing DSR scheme, the malfunctioning of one or more links along a certain route requires the retransmission of all packets back to the originating source node. This unnecessary amount of retransmission results a significant transmission overhead that can severely degrade the overall network performance by increasing the average time delay.

In order to minimize the transmission overhead and maximize the network throughput, we present an alternative scheme that can be used to optimize the performance of DSR protocol. Specifically, our proposed scheme suggests improvement in the RD and the RM metrics of the DSR protocol. Based on the proposed optimization, we derive a mathematical model which proves the correctness of the proposed scheme.

2. Related Work

Mobile ad hoc networks (MANETs) have received considerable research attention over last few decades because of their ease of deployment without the need of any fixed infrastructure [4]. Due to this ease of deployment, the typical applications of MANET are rescue/emergency operations in natural or environmental disaster areas, military operations, mobile conference, and home networking [4]. Due to its highly dynamic nature and network topology, one of the fundament challenges in MANET is the design of efficient dynamic routing protocols that can deliver the data packets between mobile nodes while at the same time maintain a consistent performance in terms of low transmission overhead and end-to-end delay.

Several routing protocols have been suggested for MANETs over the past few years [5, 6, 7, 8]. To name a few, Destination-Sequenced Distance Vector (DSDV) [5], Dynamic Source Routing (DSR) [6], Ad hoc On Demand Distance Vector (AODV) [7], Temporally-Ordered Routing Algorithm (TORA) [8], and their variations. These routing protocols route packets based on the assumption that the sender mobile node has the knowledge of the current location of the receiving mobile node using the routing information. The routing information is acquired and analyzed by each mobile node using the route discovery or route maintenance algorithm. In general, these routing protocols can also be divided into two categories [9]: proactive and reactive (or on-demand). Proactive routing protocols, such as DSDV [5] attempts to maintain consistent and up-to-date routing information from each node to every other node in the network. In the

*Corresponding author:
Email address: srizvi@bridgeport.edu, Ph: +1 107575760928

on-demand routing protocols, such as AODV [7] and DSR [6], routes are discovered only when they are needed.

Although a route discovery operation captures the current network topology and related information, it has to be executed whenever a mobile node needs to transmit a data item [10]. In order to minimize the execution of route discovery phase, a cache technique was proposed that could store the previous route information. Significant amount of research has recently done on the cache technique to improve the performance of route discovery or route maintenance algorithms. There are number of caching techniques such as a cooperative caching scheme [11], summary/proxy cache scheme [12], and semantic caching scheme [13]. For instance, in cooperative caching scheme, unified caches are implemented to store the copies of routing information. These individual caches interact with each other to identify the duplicate copies to improve the cache utilization.

Almost all these cache techniques have proven to improve the performance of routing in MANET by minimizing the execution of route discovery phase. However, this advantage comes at the expense of a large cache that each node has to maintain. The implementation of such techniques not only demand large memory at each node but also increases the complexity that is involved in maintaining such sophisticated caches.

Recently, Mohammed et. al. [9] introduced a hybrid route discovery approach, called probabilistic counter-based route discovery (or PCBR for short) which combine the advantages of fixed probability and counter-based broadcast schemes to address the broadcast storm problem associated with existing on-demand routing protocols.

3. Proposed Optimization for the DSR Protocol

Our main goal is to maintain the original underlying architecture of the DSR protocol. Therefore, we consider the DSR scheme as a black box. The DSR protocol fails to maintain route consistency in the presence of broken links. When one of the links goes down, the DSR protocol locates an alternate route and transmits back the packet to the source node where the packet was originated. On contrary to the actual scheme of the DSR protocol, our proposed scheme uses a reserve direction search method. In our proposed scheme, the packets would be transmitted to the immediate prior node where the actual error was occurred. The proposed scheme then finds one or more alternative routes from the current location to the destination. This implies that the whole searching procedure of the proposed scheme will be done in the opposite direction starting from the destination node. Our simulation results demonstrate that the proposed scheme considerably increases the chance of finding a valid route for salvage packets that are typically stored in the send buffer.

For instance, in cooperative caching scheme, unified caches are For instance, consider an example for locating a route based on the reverse direction search scheme as shown in Fig. 1. It can be observed that the route finds by the RD procedure from node A (source node) to L would be: $A \rightarrow D \rightarrow E \rightarrow I \rightarrow L$. During transmission of the packets, it is detected at run time that the shortest link between node E and I goes down. Consequently, the proposed scheme immediately starts searching the best available alternate routes. In order to reach the destination node, the proposed scheme locates the neighboring nodes (i.e., node B, D, and
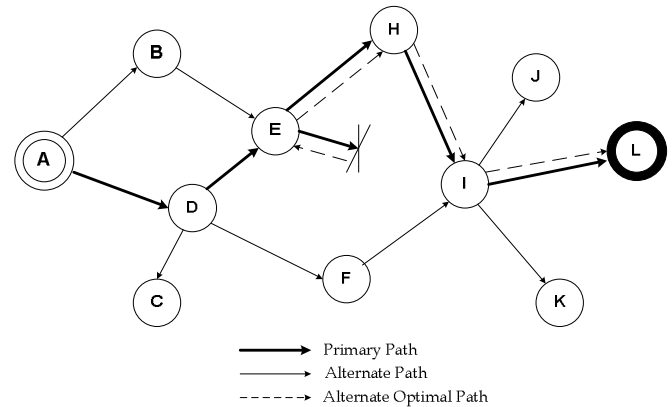

Fig. 1. Finding the alternate path in DSR protocol according to the proposed scheme.

H from node E).

This process of finding the alternate route from the location of error results an optimal alternate route: $A \rightarrow D \rightarrow E \rightarrow I \rightarrow H \rightarrow L$. This implies that our proposed scheme neither send any feedback to the destination node A nor it initiates the route discovery from the source point. Therefore, repeating this search in the reverse direction from the current location of error to the neighboring nodes results a significant increase in the chance of finding a valid optimized route.

3.1. Reverse Direction Search Scheme

In order to formulate the proposed scheme, we present a model that shows simple steps that need to be implemented for finding a valid and optimize route in the presence of link failures. The model is presented in Fig. 2. The model is typically divided into two parts. The upper part of the model represents the RD procedure where as the lower part represents the RM procedure. The RD procedure is based on an exhaustive search of an internal cache. During the transmission of a packet, if one of the links goes down, the proposed scheme mentions that the packet will be immediately forwarded to the next available node and starts transmitting from the new location. Unlike the DSR protocol, the proposed scheme minimizes the transmission overhead by avoiding the unnecessary transmission of data to the source node in the presence of a faulty link. In other words, the proposed scheme does not provide any feedback to the source node that leads to a significant improvement in the network throughput. Since the RD can be done on the current node, we do not need to focus on the source node. This implies that the proposed scheme suggests the best delivery of the packets even in the presence of link failure. In addition, the repetition of the packets due to the flooding will be cut down.

In the proposed model, we mainly focus on the RD and the RM. During the RD process, if the entries are found in the internal cache of the next node, the proposed scheme determines the optimal path that will be used to forward all the packets to the next node. At that current node location, the same procedure for searching the optimal path will be repeated over the passage of time in order to find the best path towards the destination. An empty entry in the internal cache represents that there is no valid route exist for a particular destination. In such a scenario, the proposed scheme will lookup into the next neighbor's cache and de-
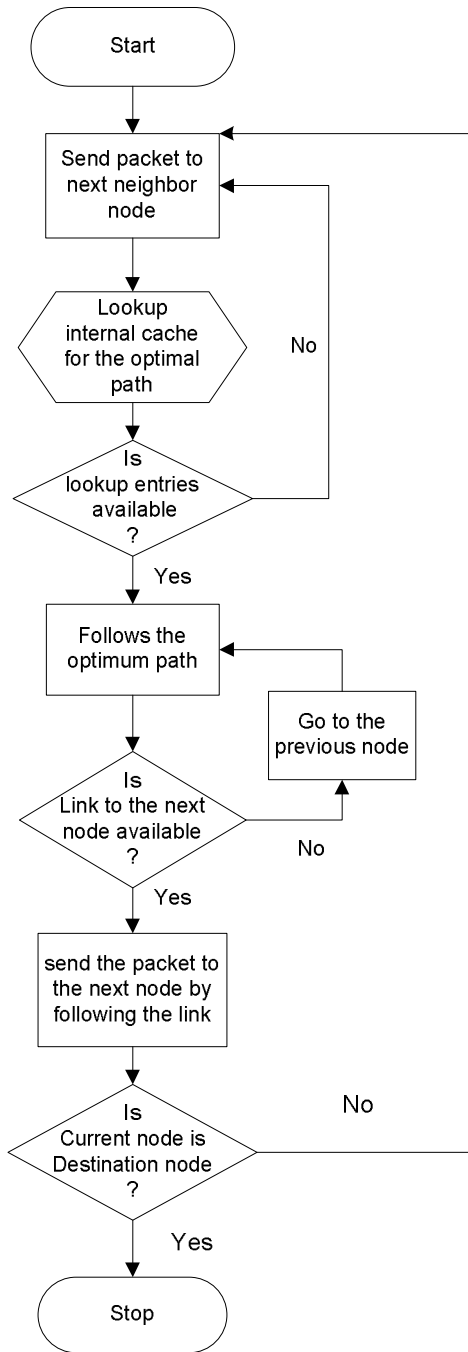
Fig. 2. Flow chart showing proposed model of DSR algorithm.

Table 1. System parameters and definitions.

Parameters	Description
P_i	This represents the ith link in a primary path.
S_i	This represents the ith link in a secondary path.
X_{P_i}	Life time of the ith primary route.
X_{S_i}	Life time of the ith secondary route.
X_R	Minimum life time for the collection of all values in the primary path links
T	Intervals for route discovery
E_o	An event that shows any of the given link fails
$f_T(t)$	Frequency of route discovery
Z_i	Maximum life time among all available values.
$\bar{P}_i$	Represents the faulty primary link due to an event E
$\bar{S}_i$	Represents the faulty secondary link due to an event E

as compared to transmitting packets from the source node using a primary route. This is especially true in the presence of error. All system variables, along with their definition, are listed in Table 1.

The accuracy of the proposed scheme is essentially dependent on how efficiently we can discover the alternate routes in the presence of faulty links. In general, the accuracy is partially related to a certain interval by which we perform the RD procedure for a specific type of network traffic such as a stream of packets. In particular, we first need to derive an expression for a random variable, *x*, that can be used to characterize the behavior of RD process with respect to time. Therefore, in order to implement the proposed scheme, one must measure the frequency of route discoveries. In order to determine the interval between the route discoveries, the following mathematical expression can be derived for a random variable, *x*:

$$\int_{-\infty}^{+\infty} xf(x)dx \qquad (1)$$

It should be noted that equation (1) is based on the PDF which is used to find the frequency of route discovery for a particular pair of source and destination.

Figure 3 represents the proposed scheme with the primary and the secondary paths along with their corresponding links. It can be seen in Fig. 3 that the node *P* represents the primary route whereas the node S represents the secondary route. If an error occurs in the primary route, the proposed scheme will immediately discover an alternate route S_1 rather than going back to the source node *A*. In other words, in the presence of faulty links, the proposed scheme searches the internal cache and determines the alternative route S1 which is typically stored in the local cache.

For this particular scenario, the success of the proposed scheme is heavily dependent on the rate at which one may need to execute the RD procedure. In addition, the success of the proposed scheme is not only dependent on the rate at which the RD procedure will be performed but also dependent on the accuracy and the efficiency by which the alternate routes will be determined. In order to find the frequency of an alternative RD, we assume that an event *E* might occur at a discrete point in time
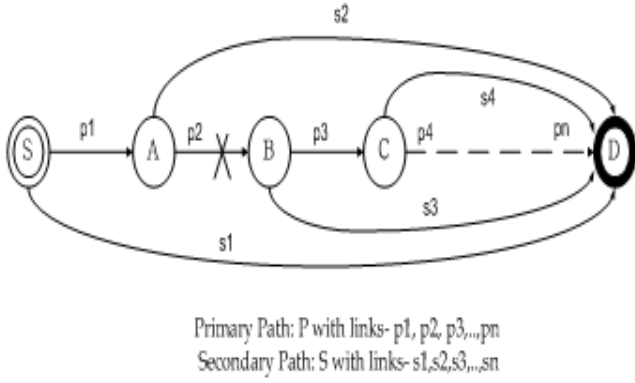
termine the best available route for the desired destination. Once the optimal route is discovered, the packet can then be transmitted. In the RM process, whenever there is a link failure along the path, the packet would not go further at the point of error and there is no need to send any feedback to the original source node. Instead, the proposed scheme determines and performs the RM process on the best available alternate path.

4. Proposed Analytical Model

We derive our mathematical model based on the proposed reverse direction scheme. In our mathematical model, we show that the transmission of packets via an alternate route is more efficient

Primary Path: P with links- p1, p2, p3,..,pn
Secondary Path: S with links- s1,s2,s3,..,sn

Fig. 3. Proposed scheme with primary and secondary path and their links.

in the network which causes an error in one of the two types of routes (i.e., the primary P and the secondary S routes). Thus the transmission of an event can be mathematically described as:

$$E = \bar{P}_1\bar{S}_1 + (\bar{P}_2(\bar{P}_1 + \bar{S}_2)\bar{S}_1) + (\bar{P}_3(\bar{P}_1(\bar{P}_2 + \bar{S}_3)\bar{S}_2)\bar{S}_1) + \cdots \quad (2)$$

where $\bar{P}_i$ represents the faulty primary-link where as $\bar{S}_i$ represents the faulty secondary-link which caused due to the occurrence of an event E at discrete point in time within a network.

Equation (2) represents a generic equation that shows how the occurrence of an event in the network may cause an error in the alternate routes. Equation (2) can be further extended for the maximum K number of forwarding links within the available primary paths. It should be noted that the occurrence of an event E is representing a cause of malfunctioning in the currently used valid route. Taking these factors into account, one may write the following mathematical expression:

$$E = \langle \bar{P}_1\bar{S}_1 \rangle + \langle \bar{P}_2\bar{S}_2\bar{S}_1 \rangle + \langle \bar{P}_3\bar{S}_3\bar{S}_2\bar{S}_1 \rangle + \cdots + \langle \bar{P}_k\bar{S}_k\bar{S}_{k-1}\bar{S}_1 \rangle \quad (3)$$

where $\bar{P}_i$ and $\bar{S}_i$ in (3) represent the faulty primary and secondary links, respectively.

Both of these faulty links are caused due to the occurrence of an event E at a discrete point in time within a network. It should be noted that we only consider the values of the most forwarding links that one may find within the primary path links from the generic equation (2).

One of our observations about the two phases of the proposed scheme is the life time of the primary path which we use to transmit the packets to the desired destination in the presence of the faulty links. In other words, in order to effectively implement the proposed scheme, we must determine the minimum value of the life time for primary path links. This calculation is essential, since the ration of determining the accurate valid primary links is critically dependent on the knowledge of accurate values of lifetime. The minimum life time of primary path links is simply chosen from one of the primary links that has a smallest value for the life time. In other words, if one of the ith primary routes has the smallest life time value, this will be chosen as a minimum life time value for the primary path links. This hypothesis can be changed into a simple expression:

$$X_R = \text{Min}|X_{p1}, X_{p2}, \ldots, X_{pk}| \quad (4)$$

where X_R in (4) represents the minimum life time value for the collection of all values in the primary path links. The right hand side expression of (4) represents the life time of each individual primary route starting from X_{p1} to X_{pk}. These values are considered as a life time of the sub links in the primary path. Similar to (4), we can further extend our mathematical model for computing the interval of time for the RD procedure:

$$T = \text{Max}|X_{s1}, X_{s2}, \ldots, X_{sn}| \quad (5)$$

where T represents the intervals of time for the RD and X_{S_i} represents the life time of the *ith* secondary route.

Equation (5) gives an estimate of the time to be taken by the proposed scheme for the RD procedure. This value is evaluated from the maximum values of the collected time in the sub links of the secondary path. The right hand side expression of (5) represents the life time of each individual secondary route starting from X_{s1} to X_{sn}. For the sake of the simulation and the performance evaluation, we assume that the value of T will be measured in millisecond. Combining (4) with (5), we can compute the value of the alternative route discovery as follows:

$$T = \text{Min}\left\langle \begin{array}{c} \text{Max}(X_{p1}.X_{s1})\text{Max}(X_{p2}.X_{s2}.X_{s1}) \\ \cdots \text{Max}(X_{pk}, X_{sk}, X_{sk-1}, \ldots, X_{s1}) \end{array} \right\rangle \quad (6)$$

Equation (6) gives the value of the alternative RD. This can be considered as the optimum value which is determined from all the available maximum values for both the primary and the secondary links. Using (6), we can compute the values for the RD metrics which is one of the subparts of the proposed scheme.

$$Z_i = \text{Max}\langle X_{pi}, X_s, X_{si-1}, \ldots, X_{s1} \rangle \quad (7)$$

where Z_i represents the maximum life time among all available values for both primary and the secondary paths.

Recall (1), we can now derive an expression for the frequency of RD using equations (2) to (6).

$$f_T(t) = \sum_{i=1}^{N}\left(\lambda_i e^{-\lambda_i t}\prod_{k=1 k\neq i}^{N}(1 - e^{-\lambda_k t})\right) \quad (8)$$

where the right hand side of (8) represents the frequency of RD.

Equation (7) also has a significant impact on the RD for the alternate path. Implementing the results of (7) on (8), we can derive a new expression for the frequency of the RD which take into account the maximum life time among all available values for both primary and the secondary paths. In addition, this implementation describes the PDF in Z_i with respect to the RD metrics.

$$f_{Zi}(t) = \sum_{j=1}^{i+1}\left\langle \begin{array}{c} (\lambda_j(i)e^{-\lambda}j^{(i)}t) \\ \prod_{k=1, k\neq j}^{i+1}(1 - e^{-\lambda}k^{(i)}t) \end{array} \right\rangle \quad (9)$$

where $\lambda_j^{(i)} = ki/l \rightarrow$ for $j = 1, 2, \ldots, i$ and for $I/l \rightarrow j = j + 1$.

Equation (9) describes the summation of all the possible routes which can lead us to the desired destination. Equation (9) can be further extended for the following given expressions:

$$T = \text{Min}\left\langle \begin{array}{c} \text{Max}(X_{p1}.X_{s1}), \text{Max}(X_{p2}.X_{s2}.X_{s1}) \\ \cdots \text{Max}(X_{pk}, X_{sk}, X_{sk-1}, \ldots, X_{s1}) \end{array} \right\rangle \quad (10)$$

$$Z_i = \text{Max}(X_{pi}, X_{si}, X_{si-1}, \ldots, X_{s1}) \quad (11)$$

$$T = \text{Min}(Z_1, Z_2, Z_3, \ldots, Z_k) \quad (12)$$

Based on the above three expressions, we can approximate the PDF of T for the frequency of RD as follows:

$$f_T(t) = \lim_{dt \to 0} p[t \leq T \leq t + dt]/dt \qquad (13)$$

Equation (10) gives the value for the frequency of the RD in terms of a PDF function. Relating (8) and (9) with (10), we can derive the following mathematical expression

$$f_T(t) = \sum_{i=1}^{k} f_{Zi}(t) \prod_{j=1, j \neq 1}^{k} p[z_j > z_i]$$
$$f_T(t) = \sum_{i=1}^{k} f_{Zi}(t) \prod_{j=1, j \neq 1}^{k} (1 - F_{Z_i}(t)) \qquad (14)$$

where $F_{Z_i(t)}$ in (11) was introduced from (7) to make Z_i as a function of PDF.

Equation (11) shows that we derived the expected expression which can be used to compute the interval between the rout discoveries. In other words, one could use (11) to determine the frequency of the alternate RD process. The same frequency value can be used to measure the efficiency of the network. In addition, the final results show that the use of the proposed reverse direction scheme with the derived mathematical model can effectively minimize the transmission delay especially in the presence of collisions (links error) or faulty links due to the malfunctioning.

5. Simulation Results

We simulate our model based on the predicted data from the existing DSR model suggested in [14, 15]. For the sake of simulation and the performance evaluation, we consider two major metrics for RD and RM. These metrics are considered for the evaluation of the efficiency of a network.

For the sake of the first simulation (see Fig. 4), we characterize the behavior of the RD phase of the proposed scheme with respect to the number of nodes present in the network. The purpose of this experiment is to show the performance of the RD phase for discovering the alternate primary and the secondary path. During the simulation, we consider that as the number of nodes increases in the network, the more packets will be accumulated in the network that could affect the performance of the RD phase. It can be clearly evident in Fig. 4 that the RD phase of the proposed scheme performs better for the primary paths discoveries than for the secondary path. When we have small number of nodes, it can be seen in Fig. 4 that the performance of the RD phase for both primary and secondary path discoveries is overlapping. However, as network grows in terms of the number of nodes, the performance differences between the primary and the secondary path is obvious.

Fig. 5 shows the packet losses (in the fraction value) with respect to the number of nodes during the transmission using both primary and the secondary paths. In addition, Fig. 6 represents a comparison between the time delay (represents in seconds) and the number of nodes. It can be seen in Fig. 6 that the time required to discover the primary paths using the RD phase is very low as compared to the time required to discover the secondary paths.
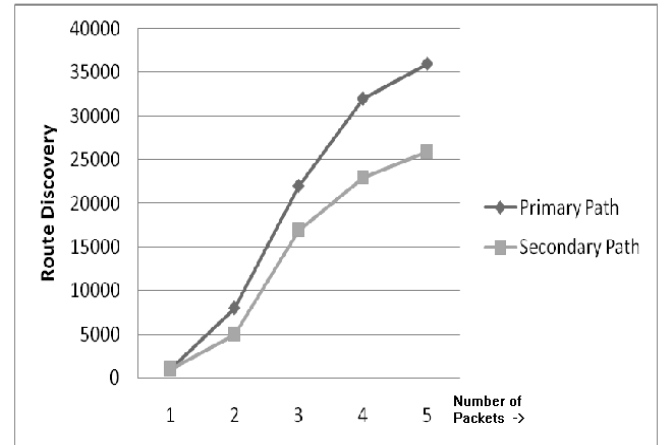

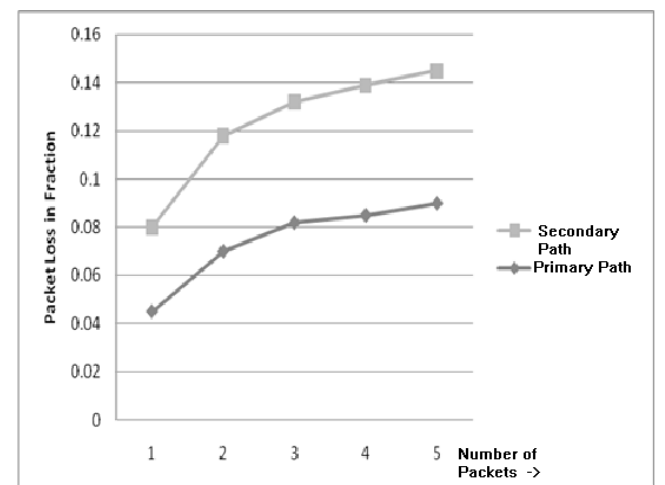**Fig. 4.** Number of nodes versus RD.

Fig. 5. Packet loss in fractions versus number of nodes.

Based on the simulation results of Fig. 6, we can observe that the time delay for primary paths is not only small but also linear with respect to the number of nodes. In other words, when we increase the number of nodes in the network, more packets will be accumulated that make a linear increase in the time delay for discovering the secondary paths which is not really desirable as far as the optimum performance of the DSR protocol is concerned.

6. Conclusion

In this paper, we presented a new scheme that improves the retransmission mechanism for the existing DSR protocol. In order to support our hypothesis, we provided a complete mathematical model that shows the formulation of the proposed scheme. In particular, we investigated the RD and the RM phases with respect to the proposed reverse direction scheme. We also showed that how effective the proposed scheme would be when we implement it with the reverse direction search for discovering the primary paths. Our analysis also suggested that the discovery of alternate primary paths from the current source of error significantly improves the network performance in terms of RD process, time delay, and the packet losses. Moreover, we have experimentally verified that both the RD and the RM metrics perform well with
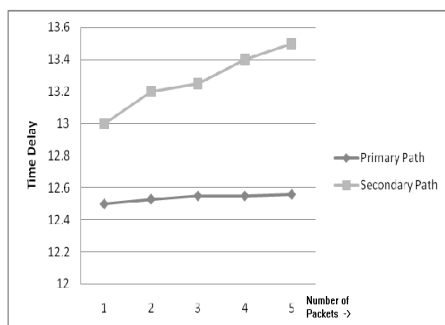
Fig. 6. Time delay versus number of nodes.

the proposed scheme than the existing infrastructure of the DSR protocol. Our performance evaluation is also well supported by the simulation results presented in this paper.

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Majid A. Jafri is pursuing M.S. in Computer Science and Engineering at University of Bridgeport, CT. For last one year, he is working on routing protocols for Mobile Adhoc Network (MANET). His current research focuses on the design and implementation of routing protocols for MANET and mesh networks.

Syed S. Risvi is a Ph.D. student of Computer Engineering at University of Bridgeport. He received a B.S. in Computer Engineering from Sir Syed University of Engineering and Technology and an M.S. in Computer Engineering from Old Dominion University in 2001 and 2005 respectively. In the past, he has done research on bioinformatics projects where he investigated the use of Linux based cluster search engines for finding the desired proteins in input and outputs sequences from multiple databases. For last one year, his research focused primarily on the modeling and simulation of wide range parallel/distributed systems and the web based training applications. Syed Rizvi is the author/co-authors of 75 scholarly publications in various areas. His current research focuses on the design, implementation and comparisons of algorithms in the areas of multiuser communications, multipath signals detection, multi-access interference estimation, computational complexity and combinatorial optimization of multiuser receivers, peer-to-peer networking, and reconfigurable coprocessor and FPGA based architectures.

Laiali Almazaydeh is a Ph.D. student of Computer Science and Engineering at the University of Bridgeport. She received her B.S. in Computer Science from Al Hussein Bin Talal University and an M.S. in Computer Information Systems from the Arab Academy for Banking and Financial in 2003 and 2007, respectively. Her current research focuses on the wireless sensor networks and human computer interaction.

Aasia Risfasat is an Assistant Professor of Computer Science at Institute of Business Management (IOBM) since May 2006. She received an M.S.C. in Computer Science from the University of Sindh, and an M.S in Computer Science from Old Dominion University in 1999, and 2005, respectively. For last one year, she is working as one of the active members of the wireless and mobile communications (WMC) lab research group of University of Bridgeport, Bridgeport CT. In WMC research group, she is mainly responsible for simulation design for all the research work. Aasia Riasat is the author or co-author of more than 30 scholarly research papers in various areas. Her research interests include modeling and simulation for parallel and distributed systems, web-based visualization, virtual reality, data compression, and algorithms optimization.