Extended Disjoint Multipath Routing Protocol for the Ad Hoc Wireless Network

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Abstract
The ad hoc network consists of mobile hosts which communicate with each other by radio media. The mobile host must route data to the host within the radio range by hopping to the destination host. Since the hosts are mobile and the network topology is variable, routing protocols have been an important research issue in the network area. On-demand routing protocol is an efficient protocol in the ad hoc network. The routing path discovery and data resend operator are the major overheads of the on-demand routing protocol. Disjoint multipath routing reduces the frequency of routing path discovery and data resent. In this paper, we extend the disjoint multipath routing to increase the alternate routes and reduce the frequency of the route discovery. The simulation results show that our proposal outperforms the on-demand and disjoint multipath protocols.

Keywork: ad hoc network, routing, multipath, disjoint path, on-demand protocol.

1. Introduction

The deployment of computer technology and wireless communication has been grooving rapidly over the last few years. Mobile communication and computing have been became the important issues in the field of the computer communication technology. We can categorize the mobile network configurations into the infrastructure network and the infrastructureless network. In the infrastructure networks, the mobile host communicates with the nearest base station which is within the communication radio radius, and connects to the wired network through this nearest base station by a single hop. The base station is a fixed and wired gateway between the wired and wireless networks. The infrastructureless networks, such as the mobile ad-hoc networks [7][8], have no fixed routers. In other words, there is no static infrastructure (e.g. the base station) in the infrastructureless networks. Each mobile host acts as a router, forwards data packets for the other mobile hosts with radio media. In practice, the mobile hosts can move to anywhere with no limitation, the network topology is forced to change dynamically. As a result, the mobile ad hoc network (MANET) is a representative model in the infrastructureless networks. There
are many applications in the MANET, especially in military, emergency rescue, and exploration missions. Examples include home-area wireless networking [11], on-the-fly conferencing applications, networking intelligent devices or sensors, communication between mobile robots, etc. In particular, MANET is suitable for the remote districts without network services.

Many works corresponding to the MANET routing protocols have been done when the U.S. Defense Research Agency, DARPA, supported the Packet Radio Network (PRNET) and Survivable Adaptive Networks (SURAN) projects [14]. An MANET working group has also been formed within the Internet Engineering Task Force (IETF) to develop a routing framework for IP-based protocols in the ad hoc networks [7]. The specifications of IEEE 802.11b of the wireless LAN include the transmission of the ad hoc networks. The practical application of the MANET can be implemented in IEEE802.11b.

Unlike the traditional wired networks, the MANET topology is drastically and unpredictably changed for the high degree of node mobility. Therefore, finding and maintaining an efficient routing path between source nodes and destination nodes are important issues in the MANET. However, the MANET does not have static fixed devices to route the communications. There are many challenges core raised in the network design [4]. The MANET lacks the centralized management devices, including base station, mobile switch center, HLR, and VLR, to communicate. Every node acts as a router and communication intermedium. Therefore, it needs a more sophisticated algorithm to route the communication. The mobile node in the MANET is free to move around randomly. Consequently, mobility changes the network topology. All the communications are carried on the unstable wireless medium which is easily interfered, and do not guarantee the connectivity of mobile nodes. Hence, stable connectivity is a quite important problem. The functionality of the mobile node is limited. For more detailed description of the effective power consumption can be referred to [2][6].

An obvious approach for trying to provide routing in the MANET is to designate each mobile node as a router and to run the routing protocol. Due to the mobile nodes move around randomly, the network topology is not fixed in the MANET. Therefore, the conventional routing protocols are not suitable for the MANET. Many routing protocols have been proposed for the MANET. The routing protocols are generally categorized as the table-driven routing protocols [9][12] and the on-demand routing protocols [5][13]. The table-driven routing protocols maintain the routing table in
every mobile node and periodically update the tables. The on-demand routing protocols find a routing path between the source mobile node and the destination mobile node while data is transmitting. They should re-find a routing path when the routing path is not valid to transmit data, because the network topology has been changed.

Concerning the table-driven routing protocols, every mobile node must maintain the routing information all the time in the table-driven routing protocols. These protocols need every node to maintain one or more tables to store routing information. The mobile nodes need to update the routing information when the network topology has been changed. Every mobile node periodically broadcasts beacons and the routing information to its neighbor nodes. By comparing the signal strengths from the neighbors, the mobile node can determine the next transmission node on the shortest path toward the destination. The Destination-Sequenced Distance-Vector Routing protocol (DSDV) is the famous routing protocol. It updates the routing table by periodically transmitting throughout the network in order to maintain table consistency [12]. The serious disadvantage of the table-driven routing protocols is the heavy routing load of the routing table maintaining. High routing load usually has a significant performance impact in low-bandwidth wireless links. The Clusterhead Gateway Switch Routing (CGSR) and Wireless Routing Protocol (WRP) have been designed to overcome the shortcoming of the DSDV [1][9].

Another approach is the on-demand protocol. The approach creates the routing path only on the demand of the source node. The routing paths are required to connect source/destination pairs. When the routing information has been established, it is maintained by a route maintenance procedure until the destination nodes do not access the routed data from the source nodes. The Ad Hoc On-Demand Distance Vector (AODV) routing protocol tries to minimize the number of required broadcasts by creating routes on a demand basis [12]. When a source node sends a data to the destination node, it initiates a path discovery process to find a routing path to the destination node. If a node moves along the routing path, its upstream neighbor notices the move behavior and propagates a path fail message to inform the source node to rebuild the routing path. The Dynamic Source Routing (DSR) protocol presented in [5] is another famous on-demand protocol. The key difference between the DSR and AODV is the use of source routing in DSR. The source of the DSR keeps trace of the complete hop-by-hop route to the destination. These routes are stored in a route cache. The transmission data packets carry the full routing path in the packet header.
The disjoint multipath routing protocol is an on-demand protocol [3][10]. The protocol determines the primary source route first. Primary source route is the first path queried by the source node. It always defines the shortest path between the source and destination nodes. Other backup routing paths are chosen for only disjoint routes. When the primary source route is fail during connection, an alternate path in the backup routing paths for the broken path is chosen to be the primary source route. The process continues until all routes break or the data transmission is finished. If the data transmission is not over, a new route discovery is initiated.

Our goal of this paper is to propose an extended disjoint multipath routing protocol (EDMR) to improve the performance of the disjoint multipath routing protocol (DMR). In DMR, if the number of the hops of the primary source route is small, the number of the alternate routes is small as well, even none. When the number of the alternate routes is small, the frequency of route discovery should be high. Our algorithm increases the backup routing paths to improve the performance of the DMR. The remainder of the paper is organized as follows: Section 2 provides an overview of the Dynamic Source Routing (DSR) and DMR protocols. Section 3 describes the detailed algorithm of the EDMR protocol. The performance of our protocol is evaluated in section 4. Finally, section 5 concludes the paper.

2. Overview of DSR and DMR

Dynamic Source Routing (DSR) is an on-demand protocol [5]. The source node records the routing information from source node to destination node. The routing information is also packed in the transmission data packet. Every node in the routing path checks the routing information of the transmission data. Sequentially, the node makes use of the routing information to realize which is the next node to be sent. The data is sent to the destination node by the means of the routing information. To get the routing information, route discovery and route maintenance are two main procedures in the DSR.

When a source node (represented as S) attempts to send data to a destination node (represented as D), the source node S needs to invoke a route discovery when the source node did not have any routing information about the destination node D. The route discovery finds the routing information with the flooding technique. That is, if the node received the request message, it then broadcast the request to the surrounding nodes within the radio range. The broadcasting keeps on working until
either the destination or an intermediate node with a route to the destination is located. The example is illustrated in Figure 1. The source node S broadcasts a route request (RREQ) packet to its neighbors. The RREQ associates a unique identity number to distinguish from the old message. The nodes, A and B, receive the RREQs and broadcast them to nodes, E and C, respectively. Every intermediate node only processes the RREQ at a time. Therefore, the node F receives the RREQ from the node C and broadcast the RREQ to D. Later, the node F receives the RREQ from the node E and ignores the message. When the first copy of the RREQ message is received by the destination node D, the destination node D will respond by unicasting a route reply (RREP) message. If additional copies of the same RREQ are later received, these messages are discarded. Figure 2 shows the route of the RREP. In addition, the reverse path is established.

![Figure 1: Route request.](image1)

![Figure 2: Route reply.](image2)

If a node moves along the route path and the data transmission is failed, its upstream neighbor notices the move and propagates the route error (RERR) packet to the active upstream neighbors. The propagation continues in the reverse path until the
source node is reached. The source node $S$ receives the RERR and realizes the route path is failed. It is able to reinitiate the route discovery protocol to find a new route to the destination when a route is still desired. The procedure of the propagation of the link failure message and the re-initiation of the route discovery is referred to as the route maintenance. The route information is used for data packets as a source route. Every node maintains a route cache to record the complete routes to various destination nodes.

The disadvantage of the DSR is the heavy load of the route maintenance for the high speed mobility of the mobile node. The straightforward improvement is to provide the multipath routing. The disjoint multipath routing (DMR) protocol is proposed to provide an effective multipath routing [10]. The source node selects a primary source route and other alternate routes. The primary source route is the route taken by the first query reaching the destination node. This usually indicates the shortest route between the source and the destination. The other alternate routes are chosen only for the disjoint routes. When the primary source route breaks, the shortest alternate route is chosen to use. The procedure continues until all routes breaks. A new route discovery is initiated if the data transmission is not finished.

The advantage of the DMR protocol is the low cost of data retransmission. When the data packet finds that the primary source route breaks down, the data packet rolls back to the nearest alternate route to continue the data transmission. The data packet needs not roll back to the source node. Therefore, the transmission cost is decreased.

Take a look at the example in Figure 3. L1-L2-L3-L4-L5 is the primary source route. If the data packet arrives at the node n3 and finds the path L3 has been broken, the new alternate route P3 is selected to be as the primary source route, and the data packet continues to be sent via the new primary source route. If the route P3 is broken after the path L3 is broken, the data packet rolls back to n2 to select the alternate route P2 as the primary source route. If the alternate route P2 is also broken, the data packet is back to the source node n1 and selects the alternate route P1 as the primary source route. If we find the alternate route P1 that has been broken, the route discovery is invoked. This protocol decreases the probability of route re-discovery. Moreover, the cost of the route maintenance is decreased.
Figure 3: The multipaths of the DMR protocol.

There is a main drawback for the DMR. It is not easy for every intermediate node to find the disjoint alternate route. Therefore, the number of the alternate routes may not be plenty. Since the number of the alternate routes is limited in the condition of “disjoint”. This circumstance may be occurred when the number of the neighbors of the destination is few. Accordingly, the number of the alternate routes to the destination is few. Another drawback of the DMR is about the length of the alternate route. That is, the number of the hops of the alternate route may be large. The broken probability of the long alternate route is larger than that of the short alternate route.

3. The EDMR Protocol

To improve the DMR, we propose the extended disjoint multipath routing (EDMR) protocol. We define two parameters, N1 and N2, for the EDMR protocol. N1 is the minimal number of the alternate routes. This parameter can ensure the number of the multipath is plenty enough. If the number of the multipath is enormous, the shorter routes should be selected. Consequently, we can select the first, second, ..., N2th short routes as the alternate routes. The parameter, N2, is used to prevent from selecting the long alternate route to decrease the route broken probability.

In comparison with the DSR, the EDMR protocol finds routes with source routing. The source node S records all routes from the source node to the destination node D. The transmission route should be packed in the data packet. When the data packet is transferred, the intermediate node will unpack the routing information and route the data packet to the next node. The process continues until the data packet reaches the destination node. The difference between the EDMR and DSR protocol is that the intermediate node records the alternate routes to the destination node. Therefore, if the data packet arrives at the intermediate node and the path to the next
node is broken, it will select the nearest alternate route to route the data packet. The procedure of the EDMR is similar with the DSR. It includes the route discovery and route maintenance.

The objective of the route discovery is to find all routes from the source to the destination. When the data packet needs the routing information, the source node propagates the RREQ message to its neighbors. The RREQ message is transmitted by means of the flooding. When the first RREQ message arrives at the destination, the route recorded by this RREQ message is the shortest route. The shortest route is referred to as the primary source route. The destination collects all the intermediate nodes of the primary source route. When the other RREQ messages arrive at the destination, the destination chooses the alternate routes from the collected intermediate nodes in the primary source route. Each link of the chosen alternate routes is not identical. The links of the alternate route and the primary source route can not be overlaid. If the number of the disjoint alternate routes is less than \( N_1 \), we may ignore the selected primary source route and disjoint alternate nodes, and reposit them in a temporary space. The second shortest route is selected as the primary source route. The process continues until the \( N_2 \)th shortest primary source route is selected. If the number of the alternate routes is more than or equal to \( N_1 \) before processing the \( N_2 \)th shortest primary source route, the process will be stopped. The primary source route and disjoint alternate routes are our selection. After the selection, the destination acknowledges the RREP messages to the source node and the intermediate nodes of the disjoint alternate routes. After the process, if the number of the alternate routes for the \( N_2 \)th shortest route is smaller than \( N_1 \), all the primary source routes and disjoint alternate routes are the target multipath routes. The number of the disjoint alternate routes is sufficient to further operate.

The route maintenance is invoked when the transmission route is broken. The data packet does not need to resend from the source node. When the data packet arrives at an intermediate node and the next hop is broken, the data packet will search the alternate route in the intermediate node. If there is an alternate route in the intermediate node, the primary source route is replaced by the alternate route. The data packet is sent in the new primary source route. The intermediate node also sends a route error message back to the source node. The information about the broken route and the selected alternate route is packed into the route error message. When the source node receives the route error message, it immediately updates the routing table for the new primary source route. If there is not an alternate route in the intermediate node, the data packet will be rolled back to the preceding hop and look for an
alternate route in the intermediate node. The process continues until an alternate route is found. If the data packet is sent back to the source node without any alternate route, the source node will invoke a new route discovery. Hence, the data packet is sent in the new primary source route.

The illustration with $N_1=3$ and $N_2=3$ is given in Figure 4. In Figure 4 (a), all alternate routes found in the shortest route are route $P_1$ and $P_2$. The number of the alternate routes is less than 3. Therefore, the second shortest route is selected as shown in Figure 4 (b). The four alternate routes, $P_3$, $P_4$, $P_5$, and $P_6$, can be found. The number of the alternate routes is more than 3. The destination node $D$ sends RREP messages to the source node $S$, $n_5$, $n_7$, and $n_8$ respectively. Note that the RREP messages contain the routing information. Node $S$, $n_5$, $n_7$, and $n_8$ receive the RREP messages and save the routing information respectively. Consider another example in Figure 5. The parameters $N_1$ and $N_2$ are also equal to 3. The numbers of the alternate routes for the first, second, and third shortest routes are all less than 3. Hence, the first, second, third shortest routes, alternate routes $P_1$, $P_2$, $P_3$, $P_4$, and $P_5$ are the selected multipath routes. The first, second, and third shortest routes are kept in the source node. The routes $P_1$, $P_2$, $P_3$, $P_4$, and $P_5$ are recorded in the individual intermediate nodes. The shortest route is referred to as the primary source route. The other routes are all alternate routes. Consequently, in our protocol, the number of the alternate routes is large enough to reduce the overhead of the route maintenance.

Figure 4: An example of the EDMR protocol with $N_1=3$ and $N_2=3$. 
Figure 5: Another example of the EDMR protocol with N1=3 and N2=3.

4. The Simulation and Numerical Results

In this section, we provide the simulations to evaluate the efficiency of the EDMR and DMR. The storage space of the mobile node is created large enough to accommodate the routing information, the control messages, and the data packets of the route discovery. In terms of the simulations, we only take the operation of the network layer into account. The MAC protocol and link errors are neglected. We assume the data packets can be transmitted successfully between the mobile nodes within the radio range. The problems about the collisions, congestions, data packets loss for unreliable networks are ignored in our simulations.

In our simulation programs, all mobile nodes roam in a 1000m x 1000m square area. The moving directions of the mobile nodes are the east, west, south, and north. We adopt the uniform distribution to determine the moving directions. If the mobile node moves to the boundary of the area, the counter direction is selected. The mean velocity of the mobile nodes is 16 m/s in uniform distributions. The radio range of the mobile node is fixed in 250m. The transmission time of the data packet is 300 ms in average with exponential distributions. The transmission pair is the source node and the destination node. The transmission pair is chosen randomly with uniform distributions. That is, the probability of the selection for all transmission pairs is
identical. The simulation time is 2000 seconds. The number of the transmitted data packets is four. After finishing the transmission of all data packets between the transmission pair, a new transmission pair is selected by the simulation programs. The value of parameters N1 and N2 are all assigned to three.

There are two major parameters to evaluate the performance of the EDMR in the simulations:

1. Route Discoveries: The number of invoking the route discovery in a simulation.

2. Data Resends: The number of data packets resent from the source node.

If the number of the route discoveries is large, the radio link should be sent more control messages (RREQ, RREP, and RRER) to find the route. The more the control messages are sent, the heavier the network load is. The probability of network collisions, congestions, data packets loss, and delay is increased. Therefore, the routing overhead of the protocol is decreased as the route discoveries are decreased. Data resend is the number of data packets resent from the source node. It occurs when the radio link of the transmission route failed. The successful probability of the data packet transmission is increased as the number of the data resends is decreased.

The parameters, N1 and N2, affect the performance of the EDMR. Figure 6 shows the performance effect of the parameters, N1 and N2, in the EDMR. In Figure 6 (a), the number of the route discoveries is decreased as the value of the parameter, N1 or N2, is increased. This is because the increase of the parameters, N1 and N2, is to increase the number of the routes in routing information. The more the number of the routes is, the fewer the probability of invoking the route discovery is. Figure 6 (a) also shows that the improvement in route discovery is not great when the parameters, N1 and N2, are more than 3. That is, the utilization of the extra routes produced when N1 and N2 are larger than 3 is not high. Figure 6 (b) shows the results the number of data resends. It is obvious that increasing N1 and N2 decreases the number of data resends when N1 and N2 are larger than 3. Exceptions are occurred in N1=3, N2=4 and N1=4, N2=3, 4. The parameters, N1 and N2, are incremental and the number of data resends is incremental. It is because increasing the parameters, N1 and N2, may not increase the number of disjoint alternate route. A large N1 will lead to many independent primary source routes. The probability that the data packet is rolled back to the source node is incremental.
The length of a data transmission is represented by the number of data packets in a data transmission. If the number of data packets and the transmission time are large, then the probability of the route broken is high. It is obvious that increasing the number of data packets increases the number of route discoveries. Figure 7 (a) shows the results. Since the number of the alternate routes in the EDMR is larger than that in the DMR, the number of route discoveries in the EDMR is less than that in the DMR. Similarly, Figure 7 (b) shows that the large number of data packets results in the large number of data resends. The number of the data resends in the EDMR is fewer than that in the DMR. It is because that the larger probability for data packets can find a route to be sent to the destination node. The fewer number of the route discoveries also verifies reveals the same situation.

Figure 7: The number of the data packets in the EDMR and DMR.

The mobility of the mobile nodes affects the performance of the protocols. The number of the mobile nodes in the simulations is another factor to impact the
performance. The numbers of the mobile nodes in the simulation area are 30 and 50. Figure 8 (a) shows that the number of route discoveries with 30 mobile nodes is larger than that with 50 mobile nodes. Since the average number of routes resulted in the low density of mobile nodes is fewer that resulted in the high density of mobile nodes. Thus, more route discoveries are needed in the low density of mobile nodes. In the case of the average mobility, the high speed mobility brings the heavy load of route discoveries. In contrast the EDMR can reduce the load of route discoveries for the DMR. In particular, the route discoveries are working well at high speed mobility. The speed of mobile also has influence on the number of data resends and the results are shown in Figure 8 (b). It is similar that the high speed mobility brings the high frequency of data resends. The number of data resends for the EDMR is fewer than that for the DMR. It is because the number of the disjoint alternate routes for the EDMR is more than that for the DMR.

Figure 8: The performance evaluation with the mobility of the mobile nodes.

Figure 9 shows that the percentage of the Nth shortest path is the primary source route for the EDMR simulations. N1 and N2 are all assigned to 3. The bar of “1st” represents the percentage when the primary source route is selected from the first shortest route in the route discovery. The other chart bars represent that the numbers of the alternate routes of the first, second, and third shortest routes are all fewer than N1, and all the routes are selected. From the figure we can see that there is less than 50% to find the primary source route for the first shortest route. That is, almost 50% in route discovery must collect the routes found in the first, second, and third shortest routes to be the alternate routes. Therefore, the improvement of the EDMR protocol is great.
5. Conclusion

The DMR is a multipath protocol for the mobile ad hoc networks. It reduces the frequency of the route discoveries for the source nodes and the data resends for the disjoint alternate routes. But the number of the disjoint alternate routes would not large enough to improve the performance of the multipath protocol. This is due to the number of the disjoint alternate routes depends on the number of mobile nodes within the radio range of the destination node. The EDMR has been proposed to increase the number of the alternate routes. The protocol also filters the long alternate routes, since the long alternate routes result in the high probability of fail links. The parameter N1 is used to filter the long alternate routes, and the parameter N2 is used to determine the primary source route.

In our simulations, the numerical analysis shows that the number of the route discoveries in the EDMR is fewer than that in the DMR. The number of the control messages for searching routes is reduced for the sake of that the number of the route discoveries is few. Then, the load of the networks is reduced. It is the same results for the data resends. We also compare the values of the parameters N1 and N2. The results show that increasing the parameters, N1 and N2, decreases the number of the route discoveries and increases the number of data resends. For balancing the numbers of route discoveries and data resends, we all assign three to N1 and N2 in the experiments.

Recently, some papers employed QoS or the stability of the mobile nodes to search the shortest route in MANET. In the near future, we will make good use of these factors to elaborate our protocol.
Reference


