Reducing End-to-End Delay in Multi-path Routing Algorithms for Mobile Ad Hoc Networks

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Abstract. Some of the routing algorithms in mobile ad hoc networks use multiple paths simultaneously. These algorithms can attempt to find node-disjoint paths to achieve higher fault tolerance capability. By using node-disjoint paths, it is expected that the end-to-end delay in each path should be independent of each other. However, because of natural properties of wireless media and medium access mechanisms in ad hoc networks, the end-to-end delay between any source and destination depends on the pattern of communication in the neighborhood region. In this case some of the intermediate nodes should be silent to reverence their neighbors and this matter increases the average of end-to-end delay. To avoid this problem, multi-path routing algorithms can use zone-disjoint paths instead of node-disjoint paths. Two routes with no pair of neighbor nodes are called zone-disjoint paths. In this paper we propose a new multi-path routing algorithm that selects zone-disjoint paths, using omni-directional antenna. We evaluate our algorithm in several different scenarios. The simulation results show that the proposed approach is very effective in decreasing delay and packet loss.

Keywords: MANET; Routing Algorithms; Multi-Path Routing; Zone-Disjoint Paths.

1 Introduction

Mobile Ad hoc Networks (MANETs) are characterized by dynamic topology, high node mobility, low channel bandwidth and limited battery power. To provide end-to-end communication throughout the network, each mobile node acts as an intermediate router forwarding messages received by other nodes.

Designing efficient routing protocols is the central challenge in such dynamic wireless networks. However, many ad hoc routing algorithms have been proposed, such as AODV [1], DSR [4]. Routing protocols for MANETs can be broadly classified into reactive (on-demand) and proactive algorithms [1]. In reactive protocols, nodes build and maintain routes as they are needed but proactive routing algorithms usually constantly update routing table among nodes.

In on-demand protocols, nodes only compute routes when they are needed. Therefore, on-demand protocols are suitable for dynamic large networks. When a

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node needs a route to another node, it initiates a route discovery process to find a route. On-demand protocols consist of the following two main phases.

Route discovery is the process of finding a route between two nodes. Route maintenance is the process of repairing a broken route or finding a new route in the presence of a route failure.

Among the on-demand protocols, multi-path protocols have relatively greater ability to reduce the route discovery frequency than single path protocols. On-demand multi-path protocols discover multiple paths between the source and the destination in a single route discovery. Therefore, a new route discovery is needed only when all these paths fail. In contrast, a single path protocol has to invoke new route discovery whenever the only path from the source to the destination fails. Therefore, on-demand multi-path protocols cause fewer interruptions to the application data traffic when routes fail. They also have lower control overhead because of fewer route discovery operations.

Multi-path Routing can provide some benefits, such as load balancing, fault-tolerance capability, and higher aggregation of available bandwidth. Load balancing can be achieved by spreading the traffic along multiple routes; this can alleviate congestion and bottlenecks. From fault tolerance perspective, multi-path routing can provide route resiliency. Since bandwidth may be limited in a wireless network, routing along a single path may not provide enough bandwidth for a connection. However, if multiple paths used simultaneously to route the traffic, the aggregation of the paths may satisfy the bandwidth requirement of the application and a lower end-to-end delay may be achieved. Moreover, the frequency of route discovery is much lower if a node maintains multiple paths to destination.

After recognizing several paths between the source and the destination in route discovery process in multi-path routing algorithms, data transferring can be started through several routes. By using these mechanisms we can distribute the traffic to several paths in order to balance the traffic, and increase the bandwidth and as a result decaling the delay.

Choosing the suitable paths to the destination for transferring data traffic is the most important issue. Choosing disjoint paths between the source and the destination is one of the ideas. This increases the fault tolerance noticeably. If there isn’t any common node in the paths chosen for transferring the data, it may break down and also the route may spoil.

As we know there are two problems in wireless networks, known as "hidden station" and "exposed station". For handling these problems, CSMA/CA [11] protocol has been suggested. In 802.11 standards, this protocol is used for accessing the channel. Due to transferring RTS and CTS packets between nodes in this protocol, some of the nodes do not transfer the data and as a result the delay is increased.

As an example, consider figure 1 that shows an imaginary LAN with ten nodes. In this figure radio range of every node is illustrated and the dotted line shows the relation between nodes. In other words, the dotted lines between any two nodes show that they are located in the radio range of each other.

There are two node-disjoint paths, S-I1-I2-I3-I4-D and S-I5-I6-I7-I8-D, between S and D, which transferring the data in one path is not completely separated from the other path. In this case, the delay of every path is related to the traffic of the other path, because of transferring RTS and CTS packets between the nodes of the network in order to avoid the collision and solve hidden station and exposed station problems. As a result some of the stations in a path in order to receive CTS from a node in the opposite path should postpone their sending.

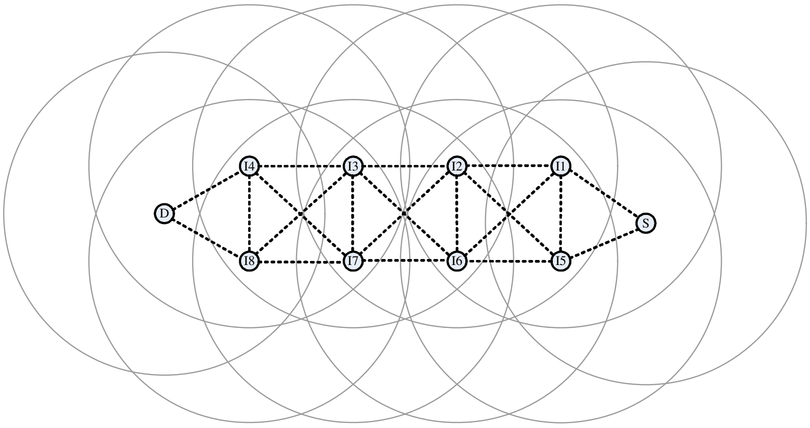

Fig. 1. Node-Disjoin paths

To solve this problem, we can use zone-disjoint paths instead of node-disjoint paths. Two routes with no pair of neighbor nodes are called zone-disjoint. In [7, 8], the authors proposed a method for distinguishing the zone-disjoint paths in the networks equipped with the directional antennas. However most of the present equipments are not equipped with directional antenna. In this paper a multi-path routing algorithm is proposed. In this approach, by using omni-directional antennas, the zone-disjoint paths are recognizable and these paths can be used for sending the data traffic simultaneously.

The rest of this paper is organized as follows. The following section deals with the related works. Section 3 describes the proposed protocol in detail. Performance evaluation by simulation is presented in section 4, and the concluding remarks are made in section 5.

2 Related Works

Multi-path routing and its applications have been well studied in wireless ad hoc networks.

The goal of SMR [6] is finding maximally disjoint multiple paths. SMR is an on-demand multi-path source routing algorithm that is similar to DSR [4]. To discovery the routing paths, the source, at first, broadcasts the RREQ to every neighbor. When the RREQ is delivered to a node, the intermediate node's ID is included into packet. Then the node, receiving RREQ, re-broadcasts it to every outgoing path. In this algorithm, the destination sends a RREP for the first RREQ it receives, which represents the shortest delay path. The destination then waits to receive more RREQs. From the received RREQs, the path that is maximally disjoint from the shortest path is selected and the destination sends a RREP for the selected RREQ. In SMR, the intermediate nodes do not reply to RREQs, this is to allow the destination to receive RREQs from all of the routes, so that it can select the maximally disjoint paths.

AOMDV [3] is an extension to AODV [1] protocol for computing multiple loop-free and link-disjoint paths. In AOMDV through a modified route discovery process multiple link-disjoint paths are computed. The destination responds to only those unique neighbors from which it receives a route request. Each node in the network maintains a list of alternate next hops that are stored based on the hop count. If during routing, one of the links between any two nodes breaks, then the immediate upstream node switches to the next node in its list of next hops. In this algorithm, the source node initiates a route request when all of its alternate paths fail. The main drawback of this protocol is that the alternate paths that are computed during route discovery are not maintained during the course of data transfer.

Multi-path Source Routing (MSR) [9] is an extension of DSR [4] protocol. It consists of a scheme to distribute traffic among multiple routes in a network. MSR uses the same route discovery process as DSR with the exception that multiple paths can be returned, instead of only one (as with DSR). When a source requires a route to a destination but no route is known (in the cache), it will initiate a route discovery by flooding a RREQ packet throughout the network. A route record will be contained in header of each RREQ in which the sequence of hops that the packet passes through is recorded. An intermediate node contributes to the route discovery by appending its own address to the route record. Once the RREQ reaches the destination, a RREP will reverse the route in the route record of the RREQ and traverse back through this route. Each route is given a unique index and stored in the cache, so it is easy to pick multiple paths from there. Independence of the paths is very important in multi-path routing. Therefore, disjoint paths are preferred in MSR. As MSR uses the same route discovery process as DSR, where the complete routes are in the packet headers, looping will not occur. When a loop is detected it will be immediately eliminated.

Since source routing approach is used in MSR, intermediate nodes do nothing but forward the packets according to the route indicated in the packet-header. The routes are all calculated at the source. A multiple-path table is used for the information of each different route to a destination. This table contains the following items for each route to the destination: the index of the path in the route cache, the destination ID, the delay (based on estimated RTT), and the calculated load distribution weight of a route. The traffic to a destination is distributed among multiple routes; the weight of a route simply represents the number of packets sent consecutively on that path.

In [7, 8] multi-path routing with directional antenna is proposed. In this protocol directional antenna is used for finding zone-disjoint paths between a source and a destination. Due to low transmission zone of directional antenna, it is easier to get two physically close paths that may not interfere with each other during communication.

3 The Proposed Algorithm

The proposed algorithm can be used in all on-demand routing protocols. In on-demand protocols when the source has data packets to send but does not have the route information to the destination, it floods the RREQ packet to search and discover a route to the destination.

We can say generally the destination in the proposed algorithm tries to choose the zone-disjoint paths from received RREQs and send the RREPs to the source for these RREQs. For recognizing zone-disjoint paths between the source and the destination, a new field is added in RREQ packet, which is called *ActiveNeighborCount* and it is initialized to zero. As a matter of fact this field shows the number of active neighbors for the nodes on a path. Active neighbor is a node received this RREQ, and the source and the destination may choose another path which has this node on it, and in this case sending the data from selected paths, is related to each other. In order to set the proposed algorithm working, the entire nodes should keep a table which is called RREQ_Seen. This table records the characteristics of received RREQs by every node.

Finally for the last important change in on-demand algorithms, the intermediate node should not send RREP to any source and in fact should let the destination receive all RREQs and choose the best paths and send RREPs to the source. In other words, in the proposed algorithm, the intermediate nodes do not need using Route Cache.

In this algorithm, like other on-demand algorithms, the source node floods a RREQ packet in order to recognize a route to the destination. As mentioned before, initial value of *ActiveNeighborCount* in this packet is zero. In this case every intermediate nodes which received the RREQ, records it's characteristics in RREQ_Seen table, but before sending this packet, asks its neighbors "Have you ever seen this RREQ with this characteristics before?" and sends a packet which is called RREQ_Query to its neighbors and waits for their reply for a specified time distinguished by a timer. In this case the neighbors have to reply the answer by searching in their RREQ_Seen table. When the time is over, this node increases the value of *ActiveNeighborCount* in RREQ packet with the number of neighbors that send positive answer, and then it floods RREQ packet to its neighbors.

In this case when the destination receives all of RREQs, it starts to choose disjoint paths and then between the chosen paths considers the values of *ActiveNeighborCount*s and chooses the paths which have less values of *ActiveNeighborCount*. In fact the destination by choosing the paths which have less values of *ActiveNeighborCount*, tries to select the zone-disjoint paths. Then the destination sends the RREP packets to the source through the chosen paths. As soon as the source receives the first RREP, it starts to transfer the data by this route and after receiving the next RREP, it divides the traffic into the present routes based on load balancing criteria.

To clarify the strategy of the proposed algorithm, consider the given network of figure 2. Suppose in this case the node S is going to send data to the node D and it intends to send these data through two routes simultaneously. By paying attention carefully at the figure, you will find out there are three node-disjoint paths between S and D: S-A-D, S-B-D, and S-C-D. Now if the source chooses S-A-D and S-B-D paths as an example, due to transferring RTS and CTS between A and B, we can say one of the nodes can be active in a given time. Although the data is transferring from two routes, but it seems that just one path is active in each time.

Now suppose the proposed algorithm has been used. On the first step, the source sends RREQ to its neighbors, i.e. A, B and C. However, these nodes before sending this packet to their neighbors should ask them about this RREQ. After doing this, the A and C nodes find out just one of their neighbors has seen this RREQ before. Therefore A and C add a unit to the *ActiveNeighborCount* field of their RREQ. However, B node finds out two of its neighbors have seen this RREQ before and adds two units to the *ActiveNeighborCount* field of its RREQ. Then these nodes send their RREQ to their neighbors.

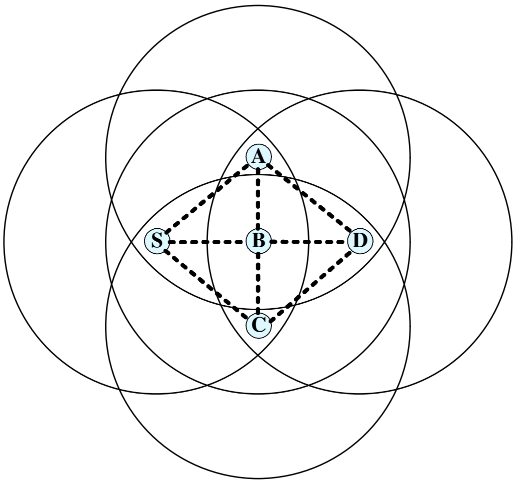

Fig. 2. Zone-Disjoint paths

Finally the destination receives several RREQs and finds out three paths between A and D: S-A-D, S-B-D and S-C-D which are node-disjoint paths. Then the destination considers the *ActiveNeighborCount* field in these RREQs and chooses two of them: S-A-D and S-C-D routes as the best paths and sends the RREP packets to the source by these two routes which are zone-disjoint.

In the existing algorithms, they just considered the node-disjoint routes and did not consider the negative effect of the neighbor routes in the performance of packet forwarding. However, by using the proposed idea the neighbor routes have the minimum effect on each other. It is very important to remember that the proposed idea just uses the omni-directional antenna in order to choose the zone-disjoint routes to send the data.

4 Performance Evaluation

In order to demonstrate the effectiveness of the proposed algorithm, we evaluated it and compare its performance to SMR. We implemented the proposed algorithm in DSR routing protocol, from now on we name this protocol as Proposed-DSR.

4.1 Simulation Environment

As simulation environment we use GloMoSim [10]. The simulated network is deployed in a flat square with 1000 meters on each side. The network was modeled with mobile nodes placed randomly and all nodes have the same transmission range of 250 meters. The radio model to transmit and receive packets is RADIO-ACCNOISE which is the standard radio model used. The IEEE 802.11 was used as the medium access control protocol. The random waypoint model was adopted as the mobility model. In the random waypoint model, a node randomly selects a destination from the physical terrain. It moves in the direction of the destination in a speed uniformly chosen between a minimum and maximum speed specified. After it reaches its destination, the node stays there for a time period specified as the pause time. In our simulation, minimum speed was set constant to zero. All data packets are 512 bytes and each simulation time is 300 seconds.

4.2 Performance Metrics

Three important performance metrics were evaluated: (i) The average of end-to-end delay of data packets – this includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission at the MAC, propagation and transfer times; (ii) Packet delivery ratio; (iii) Control overhead ratio - Ratio of the number of routing control packets to the total received packets.

4.3 Simulation Results

In the first scenario, to evaluate the capability of the protocols in different node mobility, we change node mobility by varying the maximum speed. The number of nodes and pause time was fixed at 100 nodes and 1 second, respectively.

In this scenario the proposed-DSR exhibits the lower end-to-end delay than the SMR (Fig. 3), and it also has greater packet delivery ratio than SMR (Fig. 4). However, in this case the proposed-DSR has greater control overhead ratio than SMR (Fig. 5).

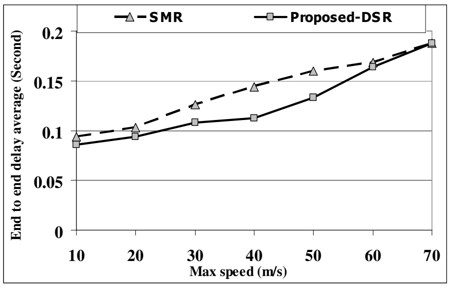

Fig. 3. The speed of the nodes vs. the average of end-to-end delay

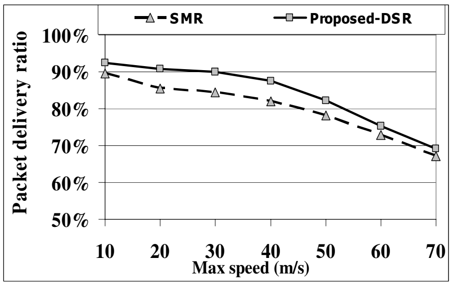

Fig. 4. The speed of the nodes vs. packet delivery ratio

In the second scenario, the effect of node mobility with different velocities on the performance of the routing protocols is evaluated. To achieve this, we change node mobility by varying the pause time. The number of nodes was fixed at 100 and the maximum speed was fixed at 25 m/s.

In this case, the proposed-DSR has lower end-to-end delay than SMR (Fig. 6), and it also exhibits greater packet delivery ratio than SMR (Fig. 7). The experimental results represent that if the pause time of the nodes increases, the amount of receiving data packets by destination nodes will be increase too. In this scenario, the proposed-DSR has greater control overhead than SMR (Fig. 8).

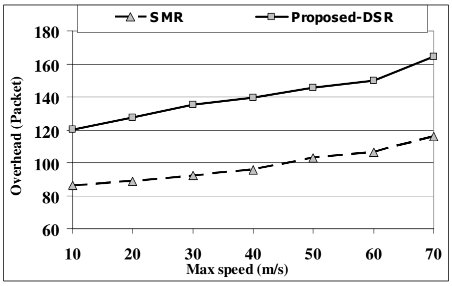

Fig. 5. The speed of the nodes vs. overhead

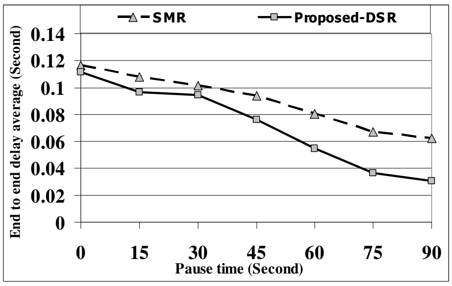

Fig. 6. Pause time vs. the average of end-to-end delay

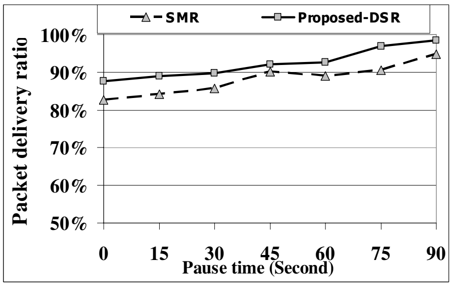

Fig. 7. Pause time vs. packet delivery ratio

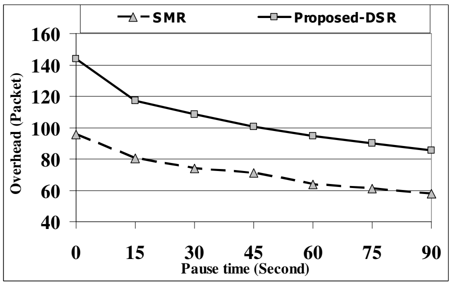

Fig. 8. Pause time vs. overhead

In the last scenario, we evaluate the proposed protocol by examining the effect of the density of nodes (the number of nodes) on the performance of proposed-DSR, and SMR protocols. To achieve this, we consider different number of nodes and in this case, the maximum speed and pause time were fixed at 25 m/s and 1 second, respectively.

In this scenario the proposed-DSR exhibits lower end-to-end delay than the SMR (Fig. 9), and it also has greater packet delivery ratio than SMR (Fig.10). Finally in this case the proposed-DSR has greater control overhead ratio than SMR (Fig. 11).

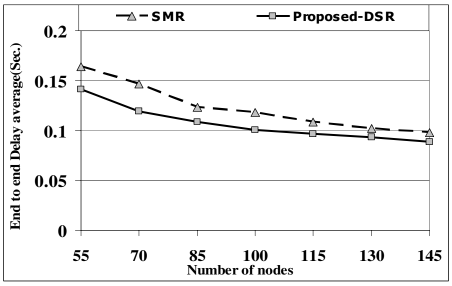

Fig. 9. The number of nodes vs. the average of end-to-end delay

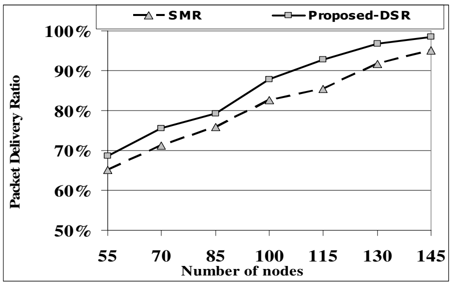

Fig. 10. The number of nodes vs. packet delivery ratio

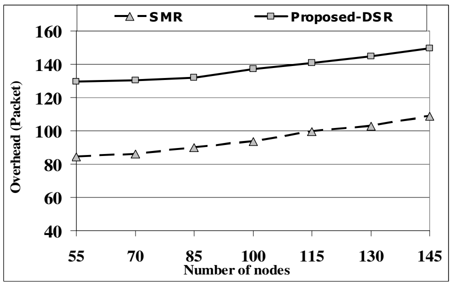

Fig. 11. The number of nodes vs. overhead

5 Conclusion

In some of the multi-path routing algorithms in MANETs, the source node spreads the data traffic to the destination node through several routes simultaneously. It seems that in these scenarios, the node-disjoint routes are the best option. However, the node-disjoint routes are not independent of each other and due to nature of MANET MAC Protocols (e.g. CSMA/CA), sending data by a route affects on the other routes. In this paper, a new multi-path routing algorithm is proposed in which by using common and omni-directional antennas we can recognize the zone-disjoint routes between any two nodes and use these routes for sending the data traffic. The simulation results show that the proposed algorithm is very effective in decreasing the packet loss ratio and also decreasing the average of end-to-end delay in MANETs.

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