

Interference-Aware Multipath routing protocols for Mobile Ad hoc Networks

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Abstract: Routing plays a major role in determining the overall throughput and the delivery ratio in mobile networks, and is an area of active research for mobile ad hoc networks (MANets). This paper presents two routing protocols: (1) Least delay, Interference Aware Multipath Routing protocol (LIMR) and (2) Shortest path, Interference Aware Multipath Routing protocol (SIMR). Both proposed protocols are designed to reduce the influence of interference between the selected node-disjoint multipath schemes, by selecting node-disjoint routes with the minimal interference between them. In both protocols, we use a new technique in order to reduce the control packets overhead, while enabling the destination node of collecting the required information. The main difference between the two proposed routing protocols is the path selection criteria; it mainly affects the Average End-to-End delay. LIMR arranges the routes according to their Latency, while SIMR arranges them in ascending order according to the number of hop count.

As in all routing protocols for MANETs, both proposed routing protocols have four main phases, Route Request, Route Reply (RREP), Data relay, and Route maintenance phase. The route request phase is fired by the source node when there is a need to communicate with any destination node with no known routing information. Thus, it broadcasts a route request packet. Each intermediate node is allowed to receive the request packet only from different incoming links. The intermediate node stops receiving the request packets after a certain pre-specified duration of time. In the route reply phase, the destination node is responsible for replying to the first received RREQ packet (least delay route), waiting a specific period of time to collect more routing information, arranging routes in an ascending order according to their path selection criteria, selecting the first route as the main route and finding other disjoint routes set with the main route, adding a flag to the main route, deriving the interference nodes set for each selected route, prior to sending back the RREP packets. Each RREP packet contains the entire route information and the set of addresses for the interfering nodes with that route. In the data relay phase, the source node distributes the traffic load on the main route and the least interfering route with that route. The route maintenance phase is fired when an intermediate node detects a link break. The RERR packet is sent back to the source node, and the source node try to find another route that is considered as the least interfering routes with the main route.

Our simulation results show that LIMR performs better than SIMR in decreasing average End-to-End delay. Results show that the proposed routing protocols have a higher delivery rate and higher throughput compared with the ones in Split multipath routing protocol (SMR). LIMR improves the delivery ratio of the SMR by 37.41 %, while SIMR improves the delivery ratio of the SMR by 32.8 %. LIMR improves the throughput of the SMR by up to 28.1%. The developed routing protocols reduce the average frequency of control packet by 74%.

The significant improvement in packet delivery ratio results mainly from reducing the impact of hidden terminal problem. Increasing the number of available channels between the selected disjoint routes is the main reason for the dramatic improvement in throughput. The efficiency of the proposed protocols and SMR protocol is evaluated by GloMoSim simulator.

Keywords: MANETs, Interference, Multipath, Routing.

1. INTRODUCTION

Mobile ad hoc networks (MANETs) are a multi-hop temporary autonomous system of mobile nodes with wireless transmitters and receivers without the aid of pre-established network infrastructure. Due to the dynamic nature of the network structure as well as limited resources, the efficiency of the existing routing protocols is a critical and challenging issue and their performance would have a great impact on the network's overall performance (Chun *et al.*, 2000).

The literature suggested several attempts to handle different routing scenarios that focused on developing multipath routing protocols to distribute the traffic load on multiple node-disjoint routes. These studies generally aimed to enhance the existing routing protocols. Such protocols vary in their enhancements criteria such as load balancing, power saving or increasing the delivery ratio and throughput such as LS-AOMDV (Lu *et al.*, 2008) and NDM _ AODV (Ding and Liu, 2010). However, the existence of interference between the multiple node-disjoint paths significantly affects the overall performance of MANETs (e.g. in terms of data loss, conflict, retransmission, and channel share) (Le *et al.*, 2011). Therefore, interference is one of the most important factors that need to be taken into consideration when developing a multiple path disjoint scheme.

Quality of the selected paths is an important issue to be considered when developing a new routing protocol. The choice of the selected path can affect End-to End delay, as well as throughput and delivery ratio. Various studies had used hop count criteria as path selection criteria in their design. However, it has been shown that the shortest hop-count path may not be the least delay path (Le *et al.*, 2011). For example, any movement of the nodes between the source and destination nodes may result in the short hop-count path being broken (see Figure 1). In addition, when the network has a high traffic load, nodes on the selected shortest path may be part of another path at the same time. Consequently, congestion occurs, especially if the particular node is located in the middle of the network or if it is during the rush hour for this network. Hence, the shortest hop-count path in this situation may cause a higher End-to End delay with lower throughput and delivery ratio compared to other routes which are least delay routes. On the other hand, least delay path is another path selection criteria, which depends mainly on RREQ latency. Arranging routes according to their latency gives a real indication for the network state. This paper developed two routing protocols with different path selection criteria, where SIMR uses hop-count while LIMR uses path latency selection criteria.

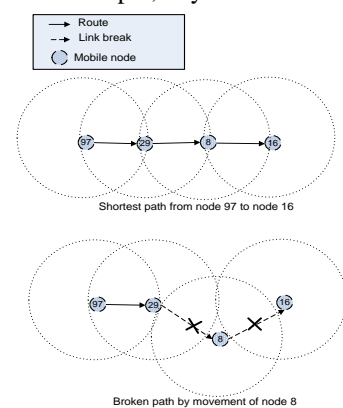


Figure 1 Easy breaking on shortest path

2. RELATED WORK

Lee and Gerla (2001) developed SMR protocol for MANET, which is a node disjoint multipath routing protocol based on the DSR (Johnson and Maltz, 1996) routing protocol. In the SMR protocol, the connection establishment process starts with the flooding of route request (RREQ) packets from source node to the destination node over the entire network. In this scheme, instead of dropping a duplicate request packet, each intermediate node forwards only the request packets in a different incoming link other than the links from which the previous requests were received and if the incoming route is shorter in its hop-count from all the previously incoming request.

The destination node replies to the first received request packet and waits a certain time interval to receive more routing information. The destination node then arranges the routes according to their hop-count and selects a route from one of the alternative paths, which is maximally disjoint with the shortest path. In other words, selecting the path with the minimum intersection nodes for distribution of the traffic load (Tarique *et al.*, 2009).

A number of studies examined the effects of interference between disjoint multipath routes in MANETs. Yang *et al.* (2010), for example, presented the Greedy-based Interference Avoidance Multipath Routing (GIMR) protocol. With the aid of geographic information, two least-interference paths between a source and destination pair is established with low overhead. Le *et al.* (2011b) proposed the node-disjoint Interference-Aware Multi-Path OLSR routing protocol (IA-MPOLSR) to increase the stability and reliability of MANETs. IA-MPOLSR divides the interference area of the node into three zones to calculate the interference of a node. IA-MPOLSR then selects the route with the minimum interference as the main route,

and finds another low interference route with Dijkstra algorithm. Interference is calculated by taking into account of the geographic distance between nodes instead of hop-by-hop. In (Das NIRUPOM, 2012), authors developed another inter-path interference aware multipath routing protocol for MANETs, it mainly depends on the location information for the source and the destination node, the first constructed route divides the area in two parts. The interference aware routing scheme is constructed by building route in each area, by considering that each node that belong to each route far away from the first constructed route by distance with $R/2$, where R is the transmission range of the source node.

3. MOTIVATIONS OF PAPER

Interference is the possibility of any node to be positioned in the range for any other node's carrier sensing range in the same network. Carrier sensing range for any node is the range in which a node can receive signals but cannot appropriately decode them. For instance, when a node gets an access to the channel and start to transmit data, all other nodes that are located within its carrier sensing range will be interfered as shown in Figure.2.

Theoretically speaking, the use of multiple disjoint paths to transfer data in parallel should lead to a significant increase in data rate and throughput. However, the presence of interference between the nodes on the selected node-disjoint paths affects the efficiency of multi-path routing by decreasing the total packet delivery ratio and throughput to be nearly equal to the possibility of sending the traffic load on single route. This is mainly due to the existence of the hidden terminal problem (Tsertou and Laurenson, 2008) between the selected routes (affecting the packet delivery ratio) in addition to single shared channel problem (affecting the overall throughput for the selected disjoint routing scheme).

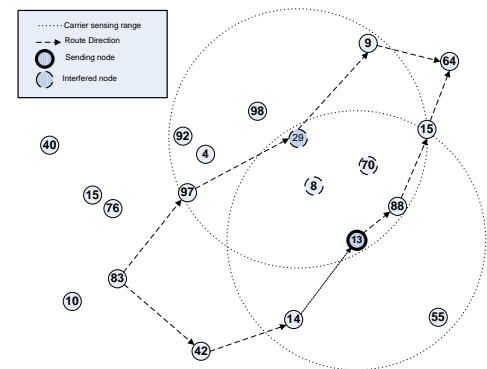


Figure 2 Interference between nodes

Channel sharing seems to be a logical solution in MAC protocols to reduce the impacts of collision (CSMA/CA) by organizing the channel gain between the interfered nodes. Consequently, in multiple node-disjoint routing scheme, this could prevents a node belonging to a route from starting to send data where the channel is gained by another node in its transmission range and belongs to another disjoint route. That waiting period experienced by the node to gain channel results in the cancelation of a parallel data transmission. This can also result in a single path routing scheme and reduces the overall throughput.

Therefore, to address the above highlighted issues, this paper presents two on-demand multipath routing protocols LIMR and SIMR.

In LIMR, the destination node selects the least delay route to be the main route and other set of node-disjoint routes with the main route, which are also considered the set of least interference routes with the main route. The data is sent on the main route and the least interference route with the main route of that chosen set. SIMR is based on the same idea but SIMR uses the criteria of shortest hop-count route instead of the latency criteria. Both protocols use a previously unpublished technique in the Route Request phase to reduce the routing overhead, which prevents the continuous relay of late control packets after the destination node selects the disjoint route set. This process reduces the routing overhead significantly compared with Split Multipath Routing Protocol (SMR)(Lee and Gerla, 2001).

The rest of the paper is organized as follows. Section 4 and 5 explain the proposed routing protocols. Section 6 presents the performance factors in the developed protocols and analyzes the results. The last section concludes the paper.

4. LEAST DELAY, INTERFERENCE AWARE, MULTIPATH ROUTING PROTOCOL FOR MANETS (LIMR)

4.1. Route Request phase

The basic route discovery mechanism of SMR protocol is used in LIMR, in which the intermediate node is not allowed to reply from its route cache and RREQ packet carries the total routing information from the

source to destination node. LIMR introduces a route request forwarding scheme that is similar to the one in the SMR, but with some modifications that allow the intermediate nodes to pass more request packets with a lower routing overhead.

In LIMR, each intermediate node receives the RREQ packet, appends its address and rebroadcasts the RREQ packet. In this scheme, instead of dropping a duplicate request packet, an intermediate node forwards only the request packets in a different incoming link other than the links from which the previous requests were received. This process is designed to give the destination node the required information about the neighbor nodes of that intermediate node which passed the request packets. This information enables the destination node to derive the group of interference nodes for each selected route. To reduce routing overhead, each intermediate node has a specific period of time to pass RREQ packets in order to decrease the routing overhead by preventing the late request packets from travelling through the network. This period of time (t) is determined as a function of the number of hops that the RREQ is travelled until it reaches the destination node as seen in Equation 1

$$t = \frac{\alpha * RREQhopcount}{MaxRREQDest} \quad (1),$$

Where α is a constant period of time. In the GloMoSim simulation environment, α is assigned to 10 milliseconds in $RREQhopcount$ denotes the number of hops that the RREQ packet travelled, and $MAXRREQDest$ denotes the maximum distance that the RREQ message can travel in the network. This enables the nodes that are near the destination node to gain more routing information, which increases the number of available routes in the destination node.

The destination node replies to the first RREQ packet and waits a period of time to get more requests. The first RREP packet is designated only for the shortest delay route. This route is temporary until the source node receives the set of elected routes.

4.2. Route Reply phase

The route reply phase is fired when a destination node receives the first RREQ packet. Route Reply phase is responsible for sending the required complete routing information to the source node. In LIMR, the intermediate nodes don't need to record a route to a destination, because they are not allowed to send ROUTE REPLY (RREP) packet back to the source. The destination node is responsible for replying to the first received RREQ packet, arranging the other routes according to their latency, selecting the main route, selecting the node disjoint routes with the main route, deriving the group of interfering nodes for each selected route and finally sending the RREP packets to the source node.

- **Disjoint Route selection method**

In the Route Reply phase, the destination node replies for the first RREQ packets, and waits Route request time interval to receive the maximum number of the RREQ packets. It arranges the received routing information in its routing table in ascending order according to their latency, before selecting the first route as the main route and finding the other routes that are disjoint with that main route. The destination node adds a flag for the main route. The time interval denotes to a pre-specified period of time, this time interval is restricted to be less than re-try route request period.

- **Deriving interfering nodes set**

This process aims to guide the route discovery to select a route with the highest number of available channels with the main route.

The main idea in deriving the interfering nodes for each selected route is by comparing each of the selected routes with the rest of the routing information. The goal of that comparison process is to gather the addresses of all the neighbor nodes for that route. Interfering nodes set for a route can be defined as a set of nodes addresses that are considered as neighbor nodes for that route.

In this phase, the destination node compares each candidate route with all other received routes to get the interference nodes set. The intersection nodes are considered as the critical nodes to gain the interference information.

Figure 3 presents a candidate route and routes for comparison. Path No.1 is considered as a disjoint routes with the candidate route. Thus, any disjoint routing protocol can select them if they satisfy the other pre-specified criteria (shortest route, battery life time, etc...). However, path No.3 has an intersection node with the candidate route in node No.29. This intersection node guides LIMR to the interference node No.13. If node No.13 is located within the transmission range of node No.29, and both nodes are in sending mode, selecting path no.1 as a disjoint route will not increase the throughput due to the single channel share.

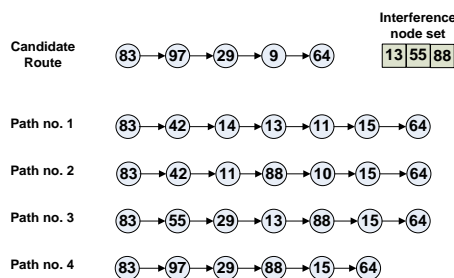


Figure 3. Example of routes set in the destination node

Another scenario can happen: If node No.13 is in the receiving mode, while nodes No.14 and 29 are in sending mode but out of each other’s transmission range, and node No.13 is in transmission range of both nodes No.13 and No.29 (hidden terminal problem), selecting both these routes will decrease the delivery ratio due to the packet collisions in node No.13.

After collecting the interference node set for each selected route, the route reply packets are generated and sent back to the destination node. Route reply packet contains the whole route and the interference nodes set for that route.

4.3. Data Relay phase

This section focus on the process of selecting the least interference routes set to send the data through them. The source node starts to send data on the shortest delay route until it receives the other routing information. The source node arranges the received routing information in an ascending order according to their latency. It selects the flagged route as the main route and assign another route with the least interference as alternative route. Finally, it sends the data on the selected routes with Round Robin fashion.

Least interference route selection algorithm

In LIMR, the source node is responsible for finding the least interference route with the main route. Figure.4 presents an example of a set of routes that the source node received, which indicates that the three routes are disjoint with the main route. The source node selects the least interference route by comparing the interference node set of the main route with the other disjoint routes (and vice versa) comparing the interference nodes set of the disjoint routes with the main route. Node address 13 belongs to path No.1 and interference set of nodes for the main route, and therefore, path No.1 creates interference with the main route. However, path No.2 is considered a candidate route with the main route, where there is no interference between them. Given path No.3, the interference nodes set for the path contains node address 9, and node No.9 is a member in the main route, and therefore, path No.3 leads to interference with the main route if it is selected. In LIMR, the source node selects the least interference route to participate with the main route in the data relay.

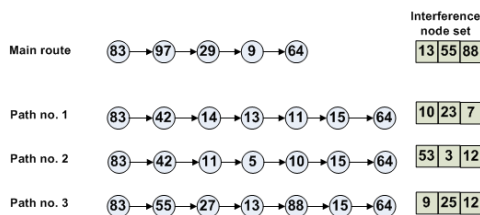


Figure 4 Adding interference set of addresses to disjoint routes and main route

4.4. Route maintenance phase

LIMR fires an error message (RERR) when it detects a link break. The RERR packet carrying the broken path is forwarded from the intermediate node that detects the link break toward the source node. The source node applies the least interference route selection algorithm to find another least interference route with the active route.

5. SHORTEST PATH, INTERFERENCE AWARE MULTIPATH ROUTING PROTOCOL FOR MANETS (SIMR)

SIMR is similar to the LIMR protocol, except that the shortest hop-count path selection criteria is used instead of the latency factor selection criteria. SIMR is developed to compare the effect of path selection

criteria on the overall performance of the routing protocols. In the scheme, the Route Request phase is fired when the source node needs to communicate with a destination node which has not known routing information. This phase is responsible for collecting the required routing information for all possible routes with a lower control overhead compared with SMR.

In the route reply phase, the destination node is responsible for replying to the first received RREQ packet, waiting a specific period of time to collect more routing information, arranging routes in ascending order according to their hop-count, selecting the first route as the main route and other disjoint routes set with the main route, adding a flag to the main route, deriving the interference nodes set for each selected route, and sending back RREP packets. Each RREP packet contains the whole route information and the set of addresses for the interfering nodes with that route. In the data relay phase, the source node distributes the traffic load on the main route and the least interfering route with that route. The route maintenance phase is fired when an intermediate node detects a link break, the RERR packet is sent back to the source node, the source node try to find another route which is considered as the least interfering routes with the main route.

6. PERFORMANCE EVALUATION

The performance of the three routing protocols (SMR, LIMR, and SIMR) is examined using the simulations outlined in Table 1.

A. Simulation environment

All three routing protocols were implemented using Global Mobile Simulation (GloMoSim) (Nuevo and INRS, 2004). The implementations are completely modular and designed in compliance with other MANET protocols specified for radio/wireless models.

B. Results and analysis

The performance of the routing protocols was measured using the following metrics:

- **Packet Delivery Ratio:** The ratio of data packets successfully delivered to the destinations to the total number of data packets actually sent by the sources.
- **Throughput:** The total number of data packets received by the destination node per second.
- **Average End-to-End delay:** The average delay between the sending of the data packets by the source and its receipt at the corresponding receiver.
- **Routing overhead:** The total number of routing packets which are transmitted during the simulation time. For packets sent over multiple hops, each transmission of the packet counts as one transmission. The performance metrics of the developed routing protocols has been evaluated in consideration of the speeds of the mobile nodes. Where, the behavior of the developed routing protocols is tested under different and random speeds of nodes that vary between 0 and 30 meter in second as seen in figure 5.

Table 1. Simulation Parameters

Parameter type	Parameter value
Simulation time	300 sec
Simulation terrain (m * m)	1000*1000
Seed values	From 0 to 10
Number of nodes	100
Mobility model	RANDOM-WAYPOINT
Mobility speed	Varying between 0 and 30 m/sec
Transport protocol	UDP
Radio Model	Accumulative noise (ACCNOISE)
Radio frequency	2.4e9 Hz
Propagation model	Free Space
Channel bandwidth	2Mbps
Mac protocol	IEEE 802.11, Distributed Coordination Function (DCF)
Transmission range	250 m
Traffic type	CBR (Constant bit rate)
CBR data rate	3 packet per second
Packet size	512byte
Number of data session	15

7. DISCUSSION AND SUMMARY

We proposed two on-demands, interference aware, node-disjoint multipath routing protocols for MANETs: LIMR and SIMR. Both routing protocols achieved their goals of distributing the traffic load on the selected main route and another node-disjoint route with that route, and the selected disjoint route is also considered as the minimal interference route with the main route.

The proposed routing protocols were implemented using different path selection criteria. LIMR orders routing information according to their latency, while SIMR orders them according to number of hop-count. Our simulation results suggested that LIMR performs better than SIMR in improving End-to-End delay. Both protocols were also successful in collecting the required routing information in the route request phase, with a significantly lower routing overhead compared to SMR (see Figure 5).

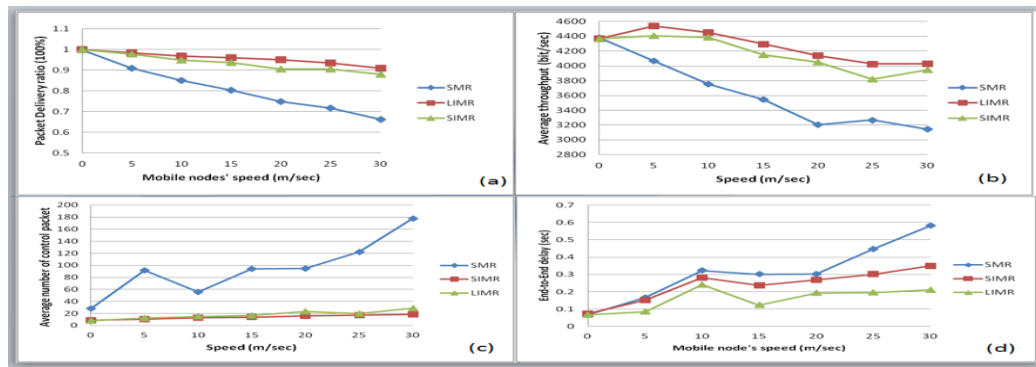


Figure 5. Results Analysis for the three routing protocols, LIMR, SIMR, SMR

This is due to our technique (Section 4) to prevent the late request messages from continuous transmission through the network. In summary, our simulation results demonstrated that both LIMR and SIMR have better performance than SMR in terms of increasing throughput and delivery ratio, and decreasing the routing overhead and End-to-End delay significantly. From Figure 5, LIMR improves the delivery ratio of the SMR by 37.41 %, while SIMR improves the delivery ratio of the SMR by 32.8 %. LIMR improves the throughput of the SMR by up to 28.1%. The developed routing protocols reduce the average frequency of control packet by 74%.

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