IJARCCE

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
ISO 3297:2007 Certified
Vol. 6, Issue 4, April 2017

A New Efficient Multi-path Routing Protocol for Mobile Ad hoc Networks

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Abstract: A Mobile Ad hoc NETwork (MANET) is a network that does not require any presence of infrastructure. Mobile nodes can move at any time and cannot predict beforehand. Each node acts as a router to communicate with other nodes in the network. The movement of nodes is a big challenge for routing. Another challenge is interference. Interference in the network is one of the most important problems to study. Some interference-aware multi-path protocols were proposed to minimize the impact of interference. However, these protocols are not highly efficient or have a very high computational complexity (NP-hard).
In this paper, we propose 1) a definition of interference, 2) a formula of interference and 3) develop a novel Link-disjoint Interference-Aware Multipath protocol (LIA-MPOLSR) for mobile ad hoc networks. LIA-MPOLSR finds paths only in polynomial time. From our simulation results, we show that LIA-MPOLSR significantly improves performance in terms of packet delivery fraction, end-to-end delay, routing overhead and normalized routing load compared to the prominent protocol Ad hoc On-demand Multipath Distance Vector (AOMDV).

Keywords: Mobile Ad Hoc Networks; Multipath; Routing Protocol; OLSR

I. Introduction

Wireless networks can be divided into two types: infrastructured wireless networks and infrastructureless wireless networks. Infrastructured wireless networks have a wire backbone including stationary base stations (access points). Each access point (AP) has a coverage range. Nodes within this coverage range can directly exchange signals with the AP. In general, mobile nodes do not communicate directly with each other. In contrary to infrastructured wireless networks, infrastructureless wireless networks (ad hoc networks) are the networks without any pre-existing communication infrastructure. Wireless mobile nodes can freely and dynamically self-organize into arbitrary and temporary network topologies. Because of their unique characteristics, ad hoc networks have various applications such as disaster recovery, emergency services, defense, healthcare, education, corporate conventions/meetings, indoor and personal networks, as well as sensor networks. However, ad hoc networks are also faced with many challenges, for example, limited bandwidth, low battery, high loss rate, frequent link breakage, etc.

Routing is one of the most important problems in a network. Routing in ad hoc networks includes three catalogs of protocols: Proactive (table-driven), reactive (on-demand), and hybrid.
Proactive (table-driven) routing protocols reduce delay by maintaining and updating the routing table and the network topology information at each node. However, this approach has high traffic overhead.
On-demand routing protocols only calculate paths when the source node needs to transmit packets. Thus, on-demand protocols reduce routing overhead but the delay is high.
Hybrid protocols are designed to take advantages of both proactive and on-demand routing protocols.
In ad hoc networks, topology is very dynamic and route is frequently broken. There exist some first protocols for ad hoc networks such as on-demand protocols Ad hoc On-Demand Distance Vector (AODV) [2], Dynamic Source Routing (DSR) [3] and proactive protocols Destination Sequenced Distance-Vector (DSDV) [4], The Optimized Link State Routing (OLSR) [1]. Because single path protocol is not stable, high loss rate, and high traffic overhead, many multipath protocols have been proposed to increase the network performance. Multipath is the technique that uses multiple routes to send packets. Therefore, they can reduce packet loss rate, delay and increase stability.

Multi-path can be divide into three categories:
- Node-disjoint multi-path: the paths have only common source and destination.
- Link-disjoint multi-path: the paths can share a few common nodes but not links.
- Hybrid multi-path: the paths may be some common links and nodes.

In node-disjoint multi-path when nodes in a path move, they do not affect the other paths. This is different from link-disjoint and hybrid multi-path in the sense that in link-disjoint and hybrid multipath if common nodes in a path move, they impact on the other paths. In a dense network, node-disjoint multi-path is easier to be formed. Therefore, node-disjoint multi-path has many advantages compared to link-disjoint and hybrid multipath.
However, in a quite sparse network, node-disjoint multi-paths are difficult to be established.
In contrary, Link-disjoint multi-path can be formed in a dense and quite sparse network. In a quite sparse network, the

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ISSN (Print) 2319 5940

International Journal of Advanced Research in Computer and Communication Engineering
ISO 3297:2007 Certified
Vol. 6, Issue 4, April 2017

link-disjoint multi-path is easier to be formed than the node-disjoint multi-path.
However, Link-disjoint paths are affected if a node of the common nodes moves.
Currently, there have been many proposed multi-path routing protocols, on-demand protocols such as Ad hoc On-demand Multipath Distance Vector (AOMDV) [7], Split Multipath Routing Protocol (SMR)[9] or proactive protocols such as SR-MPOLSR [8], Multipath OLSR (MP-OLSR) [10], to name a few.
In a MANET, the influence of interference is very significant for the network performance such as data loss, conflict, retransmission and so on. Therefore, interference is one of the factors that has the greatest impact to network performance. Reducing interference on the path is a critical problem in order to increase network performance.
Many single path protocols, for example, [11],[12],[13], etc. have been proposed to reduce impact of interference.
To improve the network performance and reliability, a few interference-aware multi-path protocols such as [14],[17],[20] were developed for mobile ad hoc networks. However, they are not high efficient or have a computational complexity of NP-hard that was not practical in reality.
In this paper, we present a new interference-aware multi-path protocol named the Link-disjoint Interference-Aware Multi-path Routing protocol (LIA-MPOLSR). LIA-MPOLSR has following features:
- LIA-MPOLSR uses alternate path mechanism (other path is used if the first path is broken): This mechanism helps to avoid interference between paths.
- Paths are link-disjoint: It works well with dense and quite sparse networks.
- This solution is easily understood, polynomial time for computational complexity while achieving a very high efficiency for mobile ad hoc networks.
To realize these works, we first specify an interference area of a link including all nodes that can interfere with the link. Then, we evaluate the interference level of a link based on the number of nodes impacting on the link and the geographic distance between nodes. By considering a MANET as a weighted directed graph that the weight of each arc is the link interference level, we can find the minimum interference paths based on the Dijkstra's algorithm with the computational complexity of O(n2).
The paper is organized as follows. Section II is the related works. We draw The Optimized Link State Routing Protocol (OLSR) protocol in Section III. Section IV introduces the detail structure of the LIA-MPOLSR protocol. In section V, we compare the LIA-MPOLSR protocol with the Ad hoc On-demand Multipath Distance Vector (AOMDV). A short conclusion is given in section VI.

II. RELATED WORKS

In ad hoc networks, nodes move freely thus, protocols developed for static networks are not suitable for ad hoc networks.
Some typical protocols such as Ad hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR), Destination Sequenced Distance-Vector Routing Protocol (DSDV), and the Optimized Link State Routing Protocol (OLSR) were proposed for ad hoc networks. These protocols find the route with minimum hop count. The disadvantage of the protocols using hop-count is that they can choose poor links (high data loss).
AODV is a typical reactive protocol. AODV conducts main processes: Path Discovery, Reverse Path, Path Forward and Path Maintenance.
In Path Discovery, the source node discovers the path by broadcasting a route request (RREQ) to its neighbors. To form a Reverse Path, a node keeps the address of the neighbor from which it received the first copy of the RREQ. Path Maintenance process is set up based on the information in RREQ. In Path Maintenance, if the movement of a source node occurs during an active session, it can reinitiate the route discovery procedure to find a new route to the destination.
DSR is another well-known reactive protocol for mobile ad hoc networks developed by David B. Johnson et al. The DSR protocol uses two mechanisms to discover and maintain source routes in the ad hoc network. In Route Discovery process, a node puts a source route with the sequence of hops into the header of the packet. The packet can come to destination based on this sequence of hops. DSR uses ROUTE ERROR message to maintain path. If a node does not receive confirmation information it will send a ROUTE ERROR message to the original sender of the packet, specifying the link over which the packet could not be forwarded.
DSDV is the proactive protocol developed by Charles Perkins and Pravin Bhagwat.

Each node in DSDV is also required to advertise to each of its current neighbors its routing table. The route table is used to transmit packets between the nodes in the network. Each route table, at each of the nodes, and shows all available destinations and the distance (hop) to each destination. To maintain the consistency of route tables in a dynamic topology, each node periodically sends updates. Updates are immediately transmitted when new information is available.
The Optimized Link State Routing Protocol (OLSR) proposed by P.Jacquet et al. The OLSR is based on the Link State Algorithm. The OLSR uses message to detect their neighbors. A HELLO message in OLSR contains the information about a node's neighbors and the current link status of the node. Nodes periodically broadcast HELLO message. To

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ISSN (Print) 2319 5940
International Journal of Advanced Research in Computer and Communication Engineering
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Vol. 6, Issue 4, April 2017

reduce routing overhead, the OLSR uses Multipoint Relay (MPR- a subset of 1-hop neighbors which covers all the 2-hop neighbors). Nodes build the topology table based on the information from Topology Control (TC) messages. Each node periodically sends a TC message in the network. The routing table is calculated based on the information in the neighbor table and the topology table. The shortest-path algorithm is used to find the path from the source to the destination.
Numerous multipath protocols are the extensions of single-path protocols. For instance, AOMDV, SMR, and (MP-OLSR) are extended from AODV, DSR, and OLSR, respectively. However, these protocols still use hop count.

Split Multipath Routing (SMR) is an on-demand multi-path protocol for ad hoc networks proposed by Lee & Gerla. SMR discovers root by flooding the ROUTE REQUEST (RREQ) (including source id and sequence number) message to the entire network. When an intermediate node that is not duplicated receives the message, it puts its id in the RREQ and rebroadcasts the packet.

SMR chooses the route with maximally disjoint. If there is more than one route that is maximally disjoint with the first route, the route with the shortest hop distance is selected. If the remain multiple routes also satisfy the condition, the path that most rapidily delivered the RREQ to the destination between them is chosen.
In Root Maintenance process, when a node cannot transmit the packet to the next hop, it sends a ROUTE ERROR (RERR) packet to the upstream direction of the route.
Ad hoc On-demand Multi-path Distance Vector routing (AOMDV) is a multi-path extension to a well-studied single path routing protocol known as Ad hoc On-demand Distance Vector (AODV). It is a protocol with loop freedom and uses alternate disjoint paths. In AOMDV, a RREQ packet is sent from the source to the destination establishing multiple reverse paths both at intermediate nodes and the destination. Multiple RREPs come back from these reverse paths to form multiple forward paths to the destination at the source and intermediate nodes. AOMDV also provides intermediate nodes with alternate paths as they are found to be useful in reducing route discovery frequency.

Route Maintenance is realized by sending route error (RERR) packets. When an intermediate node finds a Link failure it creates a RERR packet. The RERR is sent towards sources that have a route via the failed link, and all broken routes are deleted. When a source receives the RERR, it initiates a new route discovery.
The MultiPath Optimized Link State Routing (MP-OLSR) is a multi-path routing protocol based on OLSR. MP-OLSR uses HELLO messages and Topology Control messages to update the network topology, like OLSR. The main functioning of MP-OLSR includes topology sensing and route computation. The topology sensing is to get the topology information of the network including link sensing, neighbor detection and topology discovery.

To get the network topology (the neighbors, 2-hop neighbors and other links), the nodes periodically broadcast the routing control messages. The routing computation (the multiple paths) is based on the information from the topology sensing and use the Multipath Dijkstra Algorithm. The hops of the route are put in the header of the data packets. The intermediate hops just read the packet header and forward the packet to the next hop.
To enhance link quality, interference-aware protocols have been studied in recent years.

One of these protocols is the Dynamic Interference Aware Routing Protocol (DIAR) proposed by Liran Ma et al.[19].

The authors of the DIAR built an Interference Aware metric named Network Allocation Vector Count (NAVC) to predicate the possible delay and the available bandwidth.
First, they studied the channel contending mechanism in IEEE 802.11 protocol by using Network Allocation Vector (NAV). Once a node hears other nodes transmission, its NAV is set to busy.

$$\text{NAVC} = \frac{\text{The total time that the NAV is set}}{\text{Observation period}}$$

DIAR does three phases:
Route Request phase:
When a source node wants to find a route to a destiantion without any existing path, it broadcasts a route request (RREQ) packet to all nodes in the network. Once received the RREQ packet, an intermediate node has three following options before continuing to broadcast this message.
Route Reply phase:
When the destination node receives a valid and non-duplicated RREQ message, it immediately sends the route reply (RREP) message. If an intermediate node already has a valid route to the destination, it also creates the RREP.
Route Update and Maintenance phase:
The route update process will be processed at the source, the destination or intermediate nodes if any of the following conditions is satisfied: a route renew message received, a route failure message received, another RREQ message received for getting a better route.
The weak points of DIAR are one path only and the available bandwidth prediction limited within transmission range of a node.

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Another interference protocol is the Expected Transmission Count (ETX). The ETX finds paths that deliver a packet to its destination with the lowest expected number of transmissions (including retransmissions) required. The metric uses per-link measurements of packet loss ratios in both directions of each wireless link to predict the number of retransmissions. The ETX metric can obtain high throughput in static networks.

However, the authors of [21] demonstrated that these metrics do not perform well in mobile ad hoc networks because they do not rapidly adapt to the change of topology. Some protocols such as [14], and [15] are based on the Expected Transmission Count (ETX) metric, thus they are not efficient for mobile ad hoc networks.

The authors of [13] considered the interference region within two-hop range and estimated the interference level by hop distance. In [12], Zhang et al. measured a link's interference degree by an average interference degree of two nodes forming the link. The authors of [19] proposed a metric to predict the available bandwidth in transmission range of a node.

In order to overcome the above mentioned weakness, a few interference-aware multi-path protocols were proposed for mobile ad hoc networks.

W. Wei et al. [20] proposed a heuristic approach that applied the technique of [11] to measure packet loss of a link. In Centralized implementation, the authors assume that flow rate and packet loss probability of broadcast packets of each link, are periodically distributed over the whole network. Thus, the sender knows the topology of the network and the characteristics of each link. In this case, the sender can calculate the Packet Drop Probability (PDP) of any two paths in the network. To calculate PDP of each link, they use two techniques of De Couto et al. [11] and Jiang et al [18]. With contention and wireless channel error, the technique of the broadcast packet technique of De Couto et al. is chosen. In the case of mobility nodes, the technique of link availability prediction [18] is applied.

Viewing the PDP over link lij as the cost assigned to link lij, the first path can be found by using the Dijsktra's algorithm. To find the second path, the node-disjoint path with the first path and with minimum PDP is chosen.
In Distributed implementation, first, the sender performs a route discovery process by sending a Route Query (RREQ) message. The RREQ message consists of the cost of the path traversed by the message. When a node receives a non-duplicate RREQ message, it updates the path cost before forwarding it. The receiver chooses the path with the least path cost and sends a Route Reply (RREP) with the path to the sender. When the sender receives the RREP carrying the first path, it sends another RREQ with a different sequence number. RREQ has an odd sequence number representing the first path and even sequence number representing the second path. If the path_cost value in RREQ is smaller, an intermediate node records this path_cost value and sends RREQ. Thus, the path with smaller cost has a better chance to arrive at the receiver. This way, the receiver has a better chance of choosing the best path.
The disadvantage of this protocol is that it is only suitable for static network or network with slow moving nodes.
One more protocol, IMRP [17] is also an interference-aware multipath protocol. IMRP assumes that any mobile device in the ad hoc network can evaluate its available bandwidth. Available bandwidth of a path is the minimum available bandwidth of all links of the path. The available bandwidth of multiple paths is the total available bandwidth of all paths. The throughput of a path is the total throughput of all links of the path. The interference between multiple paths is quotient of throughput of multiple paths and available bandwidth of multiple paths.
In Route Discovery, the source broadcasts Route Discovery Packet (RDP) including <request ID, source ID, destination ID, intermediate nodes, QoS metric, QoS constraint, Time-To-Live (TTL), and Path-Stable-Time>.
With Route Reply phase, if the destination node receives a RDP, it records the intermediate nodes and sends a “Route Reply Packet” (RRP) to the source along the original routing path. The destination node also records the available bandwidth recorded in the <QoS metric> of RDP. The RRP packet includes <request ID, source ID, destination ID, intermediate nodes, QoS metric, QoS constraint, Time-To-Live (TTL) and Path- Stable-Time> information. If an intermediate node receives a RRP, it clears the “Pre-Reservation Timeout”, records the bandwidth and forwards this packet to the next node.
IMRP does Route maintenance process as follows:

If a node detects packet loss when transmitting packet to next node, a “Route Failure Packet” (RFP) is sent back to the source node. When the source node receives RFP, the source node initiates Path Discovery Phase.
Based on the results we can see the protocol does not obtain a high efficiency.
Kamal Jain et al. [16] used the conflict graph to find paths. Computational complexity is NP-hard.

III. THE OPTIMIZED LINK STATE ROUTING PROTOCOL

A. Neighbor sensing

A HELLO message in OLSR contains information about its neighbors and the current link status of the node. The link status can be symmetric (communication with two directions), asymmetric (communication with only one direction) or

 DOI10.17148/IJARCCE.2017.6454

Multipoint relay (MPR). The link status as MPR means that the connection between the local node and the neighbor is symmetric and the neighbor is a multipoint relay of the local node. Each node detects the neighbor nodes with which it has a direct and symmetric link by checking all links in both directions to be considered valid. To process this, each node periodically broadcasts HELLO messages. This HELLO message allows a node to learn 1-hop neighbor and 2-hop neighbor (the node has a link to 1-hop neighbor). From the received HELLO messages, each node can build its MPR set.

1) Neighbor Set

A node records the main address of a neighbor, the status of the node, and the willingness of node (N_willingness). The status of the node is symmetric or asymmetric.

The N_willingness is an integer between 0(WILL_NEVER) and 7(WILL_ ALWAYS), and specifies the willingness of a node to carry traffic on behalf of other nodes.

2) 2-hop Neighbor Set

A node records a tuple including the main address of the neighbor node, the address of the 2-hop neighbor node that has a symmetric link to the neighbor node, and the time at which the tuple expires and must be removed.

To reduce the number of retransmissions when a node floods control messages from that node into the network, Multipoint Relays (MPRs) are used. Each node in the network chooses its own set of MPR from its neighbors. Only nodes in its set of MPR are retransmitted. The other nodes only read and process.

B.Multipoint relay selection

Each node calculates its MPR set by the way such that it can reach all 2-hop neighbors through the neighbors in the MPR set. This means that the MPRs connect the entire 2-hop neighbor set. It is important that all 2-hop neighbors can be reached through the selected MPR nodes. A node that has chosen its 1-hop neighbor, node Y, as its MPR node, is called a multipoint relay selector of node Y. The optimization of MPR sets is not essential. However, the smaller a MPR-set, the more optimizations are obtained.

C.MPR information declaration

Each node in the network maintains the network topology information.

Each node selected as MPR broadcasts Topology Control (TC) messages to all nodes in the network. It takes advantage of MPRs to reduce routing overhead. Each node in the network sends a TC message to declare its MPR Selector set. The TC message includes the list of neighbors that have selected the sender node as a MPR.

In the OLSR protocol, the link sensing and neighbor detection are performed by "Hello" message. Each node periodically broadcasts "Hello" message containing information about neighbor nodes and the node'current link status.

Each node in the network broadcasts the "Topology Control" (TC) message about the network topology. The information of network topology is recorded by every node. The OLSR minimizes the overhead from flooding of control traffic by using only selected nodes, called Multipoint Relays (MPRs), to retransmit control messages.

IV. LINK DISJOINT INTERFERENCE-AWARE MULTI-PATH ROUTING PROTOCOL

A. Topology discovery

We assume that a node's position is known by using GPS.

The LIA-MPOLSR consists of all components in OLSR's HELLO and Topology Control (TC) messages. It also performs the following tasks:

Node's carrier sensing range and its position are added to HELLO message to record the HELLO message's information.

A node creating TC messages adds the information including its neighbor information, carrier sensing range, position, the neighbor information, the carrier sensing range and the position of nodes in MPR selector set to TC messages. When a node receives a TC message, it records the message's information to estimate the link's interference level.

Like OLSR, nodes periodically send HELLO messages to their neighbors while TC messages are transmited to all nodes of network.

B. Definition and estimation of link interference

We introduced the definition and evaluation of interference in my previous papers [22, 23,24].

ISSN (Online) 2278-1021
ISSN (Print) 2319 5940

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C. LIA-MPOLSR protocol design

1) Specifying n1, n2, n3, n4

Acceding to the formula (3), a link's interference of e = (u,v) in a MANET is

$$I(e) = n1 + 0.25n2 + 0.11n3 + 0.06n4$$

In reality, to specify co-ordinate of a node we can use GPS. In NS-2, the co-ordinate of a node is defined by a written program. Supposed that in a MANET, each node has a co-ordinate (x,y). If u and v have the co-ordinate (x_1,y_1), (x_2,y_2), respectively, the distance between u and v is

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{4}$$

In a MANET, the distances between u and all other nodes are specified by the formula (4). To have the number of nodes in zone(1), zone(2), zone(3), and zone(4) of the link e, we compare those distances to R_{1u}, R_{1v}, R_{2u}, R_{2v}, R_{3u}, R_{3v}, R_{4u}, R_{4v}.

2)Modelling a MANET as a weighted directed graph

A MANET can be considered as a weighted directed graph (Figure 2) where the nodes of a MANET are vertices of the graph and the arcs of the graph are any connection between two nodes. The status of each arc is defined by the information in HELLO and TC messages. The weight of each arc is the interference level of the corresponding link.

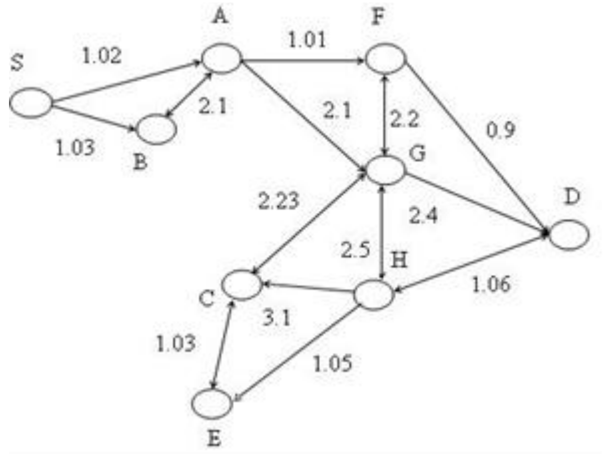

Fig 2. Illustration of LIA-MPOLSR

3)Algorithm of link-disjoint multi-path

To build the link-disjoint multi-path algorithm for OLSR, we perform the following steps.
- Step 1: Over a topology, find the single path with minimum interference based on the IA-OLSR algorithm.
- Step 2: Use the Dijkstra's algorithm one more time while avoiding any link between the source and the destination along the path found in the step 1. We then get the second minimum interference path from the source to the destination.
- Step 3: Repeat the Dijkstra's algorithm for a number of times k (k=3,...,n) while avoiding any link between the source and the destination along the paths found in the previous steps to find k-minimum interference path.

In the Figure 2, we illustrate an example for a MANET which is considered as a weighted graph.

When applying the Dijsktra's algorithm at the first time for this weighted graph with the source S and the destination D, we get the link-disjoint multi-path S-A-F-D as the minimum interference with the value of 3.02.

The second minimum interference path S-B-A-G-D is found by employing the Dijsktra's algorithm once again. This path has the value of 7.63. This graph has not the third link-disjoint path.

4)Check status of next hop

When a node wants to forward packets to the next node in the path that found, one more check has been conducted by the sending node to confirm the received node. The packet will be transmitted without any problem on the path. Otherwise, the node will immediately use a different path to transmit the packet. When there have been no available paths, all paths will be recomputed. This mechanism could help to enhance the stability and reliability of the network. It is a modification of [10].

IJARCCE

ISSN (Online) 2278-1021
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ISO 3297:2007 Certified
Vol. 6, Issue 4, April 2017

V. PERFORMANCE EVALUATION

A.Simulation Environment

Our protocol is implemented in NS2. We use an area of 550m x 550m to randomly place 40 nodes that have a carrier sensing range of 400 meters, and a transmission range of 160 meters. The nodes move with their speed from 1m/s to 30 m/s. The pause time of a node is 5s. We use the distributed coordination function (DCF) of IEEE 802.11 as the MAC layer. Traffic source is CBR and channel capacity is 11 Mbps. Constant Bit Rate (CBR) is kept at 100 Kbps. The Two-Ray Ground and the Random Waypoint models are also used in our simulations. The simulation time is 120 seconds. Each data column represents an average of two runs with different random mobility scenarios. The RTS/CTS mechanism is turned on and turned off alternatively.

B.Simulation results

We compare three protocols LIA-MPOLSR, AOMDV in terms of i) Packet delivery fraction (PDF)-the ratio of the number of delivered data packet to the destination; ii) Average end-to-end delay-the average time taken by a data packet to arrive in the destination; iii) Routing overhead- the average number of packets sent at each node.

We can observe in Figure 3 that the Packet delivery fraction (PDF) of LIA-MPOLSR outperforms AOMDV about 28% with 10 source-destination pairs (connections) and using RTS/CTS because the paths of LIA-MPOLSR were only influenced by lower interference. When RTS/CTS is disabled, all protocols have higher PDFs. The PDFs of LIA-MPOLSR achieve from 90% to 98% and they are from 29% to 33% better than AOMDV (Figure 4).

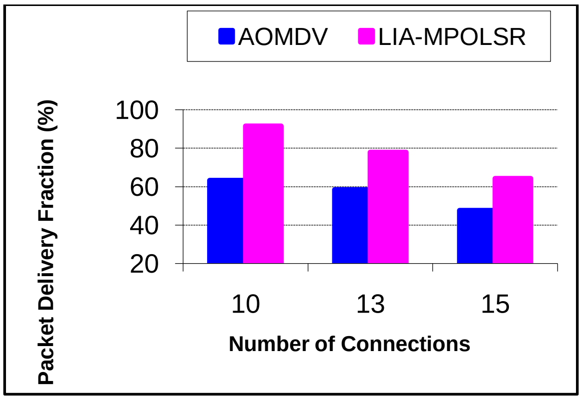

Fig 3. Packet delivery fraction with RTS/CTS

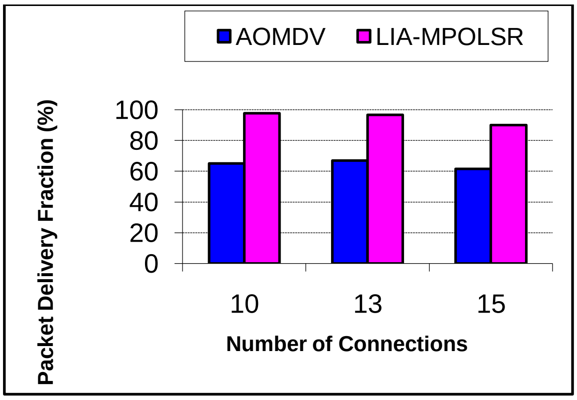

Fig 4. Packet delivery fraction without RTS/CTS

In terms of end-to-end delay, Figures 5 and 6 show that the LIA-MPOLSR has always small delays. At 10 connections and turning off RTS/CTS, end-to-end delay of LIA-MPOLSR is less than about 7.5 times that of AOMDV since LIA-MPOLSR has less contention.

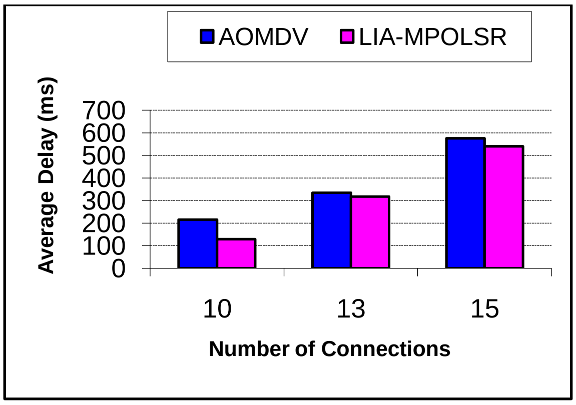

Fig 5. Average delay with RTS/CTS

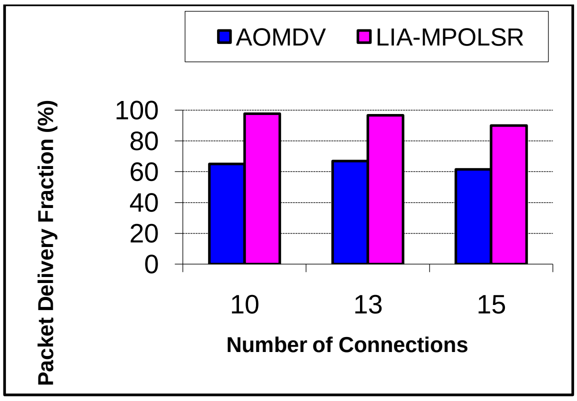

Fig 6. Average delay without RTS/CTS

Regarding routing overhead, when the RTS/CTS mechanism is enabled and disabled, our protocol demonstrate remarkably lower routing overhead than AOMDV (Figure 7 and 8). With increasing number of source-destination pairs,

IJARCCE
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routing overhead of AOMDV increases a lot while proactive protocol show only a little difference. This is because the high mobility environment leads to the increase of link breakages. Routing overhead of interference-aware protocol is much more stable and lower because of the characteristic of proactive protocol and the efficiency of Multipoint Relays (MPRs).

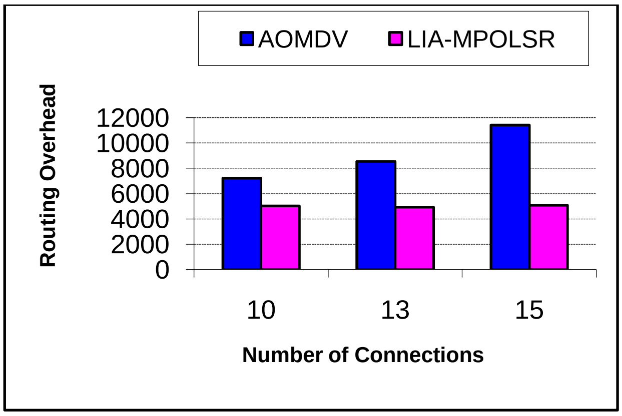

Fig 7. Routing overhead with RTS/CTS

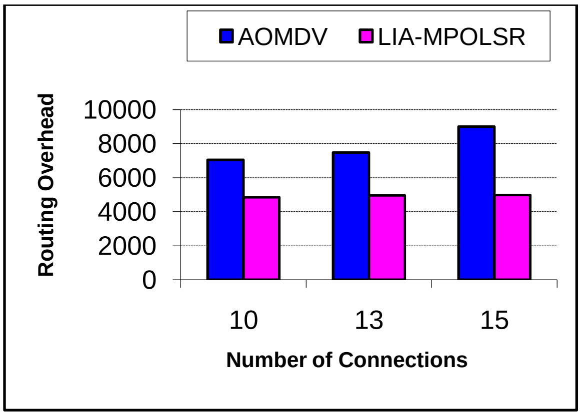

Fig 8. Routing overhead without RTS/CTS

As seen in Figure 9 and 10, without using RTC/CTS the Normalized routing load (NRL) of all protocols diminishes. Nevertheless, with 15 connections, NRL of LIA-MPOLSR reduces about 63% compared to that of AOMDV.

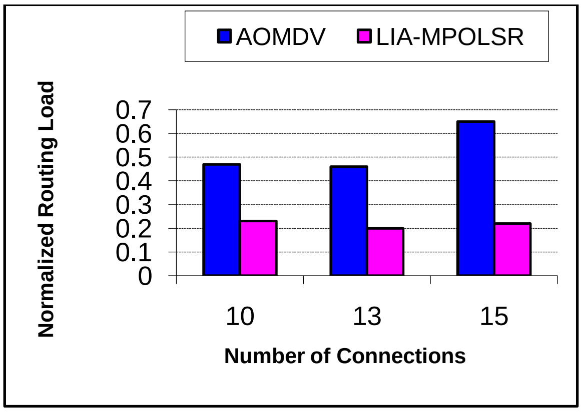

Fig9. Normalized routing load with RTS/CTS

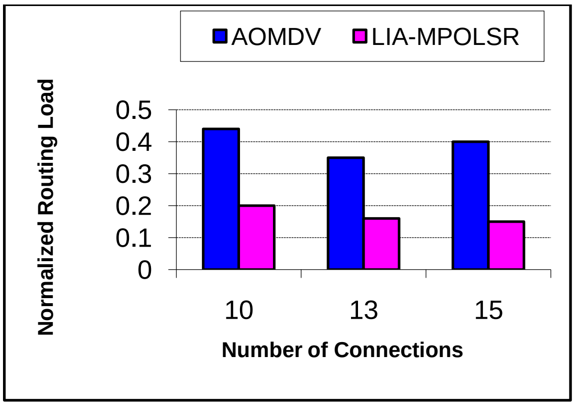

Fig 10. Normalized routing load without RTS/CTS

VI. CONCLUSION

Interference in a Manet is a big challenge to design efficient routing protocols.

In this paper, we proposed a definition of link interference, a formula of link interference and a novel Link-disjoint Interference-Aware Multi-path Routing protocol (LIA-MPOLSR) for mobile ad hoc. We showed that the LIA-MPOLSR can work fast and efficiently. We proved the significant performance improvement of LIA-MPOLSR compared to AOMDV in most key metrics such as packet delivery fraction, end-to-end delay, and routing overhead when RTS/CTS turning on or turning off alternatively.

Moreover, the paper showed that the RTS/CTS mechanism significantly decreases the network performance in mobile ad hoc networks.

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BIOGRAPHY

Phu Hung Le received the Ph.D degree in Computer Science from Pierre Marie Curie University (Paris 6), France. His research interests are ad hoc networks, wireless sensor network, routing, network performance. Phu Hung Le is the author of many articles in international conferences and journals and is a reviewer for international conferences and journals