ON-DEMAND LINK STATE HYBRID ROUTING PROTOCOL FOR MOBILE AD HOC NETWORKS

Muhammad Umar FAROOQ[1], Nicolae ŢĂPUŞ[2]

Generally, mobile ad hoc network (MANET) routing protocols employ a proactive or reactive routing approach to facilitate multi-hop routes between different nodes. Hybrid protocols benefit from both schemes to fit-in diverse network scenarios. In this article, a hybrid zone routing protocol (ZRP) is tailored to contain optimized link state routing (OLSR) protocol as intra-zone and ad hoc on-demand distance vector (AODV) routing protocol as inter-zone routing component. Certain modifications and optimizations are also introduced to enable coordination between intra-zone and inter-zone routing components, and to minimize the control traffic. Simulation results indicate that the attained protocol performs well under different mobility and traffic patterns.

Keywords: ad hoc network; AODV; hybrid routing; OLSR; routing protocol; ZRP

1. Introduction

Conventionally, wireless networks offer last-hop wireless connectivity with help from pre-constructed backbone infrastructure, e.g. cellular phone networks. MANETs take wireless communications to a level of maturity, where no backbone infrastructure is needed. All multi-hop communication among such networks are carried out through cooperative communications, i.e. nodes not in direct communication ranges of their intended destinations communicate with help from intermediate nodes. This liberty takes ad hoc networks to a level of maturity and failure resilience, not available to conventional communication networks. As a result, ad hoc networks become a suitable choice for diverse scenarios like battlefield communications, rescue operations in disaster areas and vehicular communications etc. However, constraints like frequent node mobility and wireless channel behavior make it difficult for a MANET routing protocol to locate and persistently maintain multi-hop routes between different nodes. During the recent years, many sophisticated routing protocols have been proposed to address the routing needs for MANETS. Some of these protocols [1, 2, 3, 4]

[1] PhD student, Faculty of Automatic Control and Computers, University POLITEHNICA of Bucharest, Romania, e-mail: umar@ieee.org
[2] Prof., Faculty of Automatic Control and Computers, University POLITEHNICA of Bucharest, Romania, e-mail: nicolae.tapus@cs.pub.ro

proactively learn and maintain routes to every destination. This eliminates the need for any route setup latency and facilitates quicker convergence to topology changes, on cost of perpetual topology broadcasts needed to build and maintain routing tables at each node. These broadcasts increase with the network size, which limits scalability. Reactive protocols [5, 6, 7, 8] address this problem by locating and maintaining a route only when it is needed. But, an on demand route discovery requires the route search messages to be disseminated to the entire network. These network wide broadcasts increase significantly with the network size, and number of transmitters. As a result, no proactive or reactive routing protocol is well-suited for diverse network scenarios. Hybrid protocols [9, 10, 11] address this problem by finding a balance between both approaches. But, hybrid protocols do not benefit from the recent optimizations introduced to proactive and reactive routing protocols. As a result, recent proactive and reactive routing protocols outperform the hybrid routing protocols [12, 13]. This article contributes in two folds. First, it tailors a hybrid zone routing protocol (ZRP) [9, 14] to accommodate more sophisticated optimized link state routing (OLSR) [2, 3] and ad hoc on-demand distance vector (AODV) [5, 6] routing protocols. Secondly, AODV and OLSR protocols are modified and enhanced to better coordinate, and to benefit from each other's optimizations. This further reduces the topology information messages and route discovery broadcasts. Simulation results indicate that the attained protocol performs well for a wide range of mobility and traffic patterns.

The rest of the article is organized as follows: Section 2 provides a literature overview to deliver necessary background of the area. Section 3 explains the proposed routing protocol. Section 4 evaluates the proposed protocol against different mobility and traffic patterns; whereas, Section 5 concludes the article.

2. Background

Context of work is provided in this section. First, a brief overview of AODV and OLSR routing protocols is given. Then, hybrid routing paradigm is described by discussing the functioning of ZRP routing protocol.

2.1. Ad hoc On-demand Distance Vector (AODV) Routing Protocol

AODV introduces an on-demand route discovery and maintenance mechanism, i.e. routes are searched and maintained only when they are needed. These routes are stored in routing tables carrying up-to-date information about every active route. An AODV route entry carries destination ID, next hop node ID, route length etc. In addition to this information, destination specific sequence number (a monotonically increasing number maintained by each node) is also stored. This number is embedded in route discovery messages to assert information freshness and to avoid stale routes. When an AODV node needs to communicate with some destination, it consults its routing table for a route towards that destination. If a valid route is not found, it initiates the route discovery process by broadcasting a route request (RREQ) message to its neighbors. Destination’s last known sequence number is also embedded in the RREQ message. On receiving this RREQ, every node learns or updates its route towards originator (reverse path) and consults its routing table to see if it has a fresher route towards destination (higher sequence number indicates a fresher route). If a valid route is found, it sends back a route reply (RREP) message to the originator. Otherwise, it rebroadcasts the RREQ message to its neighbors. This process continues till the message reaches the destination or to a node having fresher route towards destination. On receiving this RREQ, the destination creates a RREP message, increments and embeds its sequence number in the RREP header, and sends it to the originator. As the RREP traverses the reverse path, the intermediate nodes learn about their route towards destination (forward path). If multiple routes towards same node are found, route with the highest sequence number is chosen (among routes with same sequence number, route with the minimum hop-count is selected). Once a route is setup, nodes monitor their neighbors for link failures via some neighbor sensing mechanism like hello messages or link layer feedback etc. On identifying a link break, a node informs its affected precursors (neighbors using the broken link for their communications) via route error (RERR) message. This RERR travels back to the respective source nodes which may reinitiate the route discovery process.

2.2. Optimized Link State Routing (OLSR) Protocol

OLSR introduces a proactive routing solution for MANETs by optimizing the conventional link state routing mechanism for ad hoc networks. It first designates only a fraction of nodes to disseminate topology broadcasts (link-state information) to the network, and then minimizes the number of broadcasts by obliging only a fraction of nodes to relay these messages, while still preserving the network-wide reachability of topology broadcasts. For this purpose, OLSR nodes periodically broadcast hello messages to their neighbors. Node IDs and link status (unidirectional, bidirectional etc.) of known neighbors are also embedded in the message header. Hello messages enable each node to learn about its one-hop as well as two-hop neighborhood, which allows it to select a subset of its one-hop neighbors, having reachability to all of its two-hop neighbors. This subset is named as Multipoint Relay (MPR) set and announced via subsequent hello broadcasts. On listening to these messages, every announced MPR node records the hello message transmitter as its MPR selector. Like other link-state routing protocols, OLSR nodes perpetually disseminate their link state information to the network. However, OLSR significantly minimizes topology broadcasts by obliging only the MPR nodes to generate topology control (TC) messages to the network. TC messages only contain the link-state information of the MPR node with its MPR selectors. Any node listening to a TC message relays it only if it was received from its MPR selector. OLSR nodes use the information learnt via TC messages to build and maintain topology tables. Each topology table entry consists of a destination (MPR selector), last hop towards destination (TC message originator) and MPR selector set sequence number. Topology tables are traversed in reverse order to build routing tables. For instance, a node S discovers its path towards destination D by finding the connected pair (X, D), then (Y, X) and so on until it finds a link in its one-hop neighborhood. Only the connected pairs along minimal paths are considered to assure shortest routes.

2.3. Zone Routing Protocol (ZRP)

ZRP takes advantage of both, proactive and reactive routing approaches to form a flexible hybrid routing mechanism. For this purpose, the network is divided into node specific routing zones, i.e. all neighbors of node X at a distance of at-most R hops from X, will be the part of X's routing zone. An intra-zone routing protocol (IARP) is run to proactively learn about network topology within the routing zone. An example IARP component requires each ZRP node to periodically broadcast an IARP packet to its neighbors. On receiving this packet, every neighbor updates its routing table, embeds its ID to the IARP header, and rebroadcasts the IARP packet to its neighbors. This process continues until the hop limit (zone radius) is reached. Depending upon this information, every node discovers its peripherals (nodes lying at zone border) and constructs a Bordercast tree (spanning all of its peripheral nodes) rooted at itself. When a ZRP node needs to communicate with a node outside the proactive zone, an on-demand inter-zone routing protocol (IERP) is invoked. The node first consults its routing table for a path to that destination. If a path is not found, it Bordercasts a route query message to its peripherals. If any of the peripherals has a route towards destination, it sends back a reply message to the originator. Otherwise, it embeds its ID in the message header (Path Accumulation) and Bordercasts the message to its peripherals. This process continues till the message reaches the destination or to a node having route to the destination. The node in return, sends back a route reply through the path accumulated in the query message.

Having larger zone radius can simultaneously put ZRP nodes in many zones, which significantly increases proactive topology broadcasts. Whereas, smaller zones reduce proactively reachable destinations, which may increase route discovery broadcasts. Therefore, zone radius and optimality of the proactive routing component are of utmost importance for zone based hybrid routing protocols. Zone radii can be user-defined or learnt by the protocol itself, as demonstrated [15].

3. Proposed routing mechanism

We comprehend the notion of zone based routing from ZRP, i.e. every node builds and maintains a proactive routing zone around itself. This enables each node to persistently have an up-to-date view of the network topology within its R-hop (zone radius) neighborhood. For larger zone radius, a node might simultaneously fall in multiple routing zones, which solicits more topology information broadcasts. Therefore, an optimal proactive routing protocol OLSR is used as IARP component. OLSR benefits from MPR optimizations to significantly minimize the proactive topology broadcasts. To make it more suitable and fitting for hybrid routing, certain optimizations and enhancements are introduced to OLSR's routing mechanism. These enhancements also enable the running of on-demand routing protocol AODV as IERP routing component. The IERP component also benefits from the MPR optimizations to minimize route discovery broadcasts, forming an optimized link state hybrid routing (OLSHR) protocol. Fig. 1 presents major components of the OLSHR routing protocol.

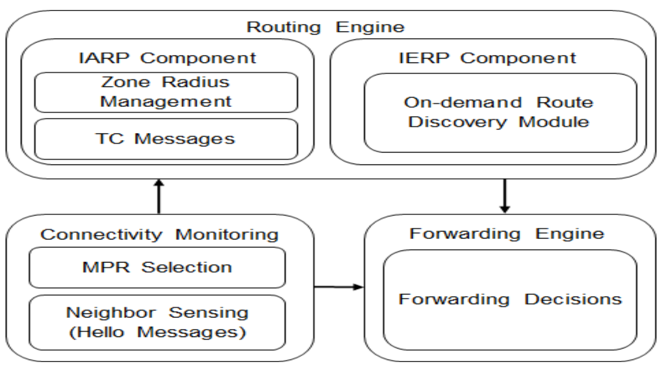

Fig. 1. Major OLSHR components

3.1. Intra-zone routing (IARP) component

Intra-zone routing is mainly influenced by the zone radius (R). Each OLSHR node proactively builds and maintains a routing table, carrying up to date route information about all nodes within R-hop neighborhood. OLSR routing protocol is used as an IARPP component, to build routing tables at each node. However, a few modifications and optimizations are introduced to enable coordination between IARP and IERP components, and to minimize the dissemination of proactive control traffic. Salient features of intra-zone routing are discussed in subsequent subsections.

A). Hello messages

Every OLSHR node periodically broadcasts hello messages to inform its neighbors about its presence. Node IDs of known neighbors are also embedded in these messages. This enable each listener to learn about its one-hop and two-hop neighborhood, forming a two-hop proactive routing zone around each node. Using this information, every node discovers a subset of its one-hop neighbors (MPR nodes), having reachability to all of its two-hop neighbors. The MPR set is announced via subsequent hello messages. On listening to these messages, the MPR nodes select the hello message transmitter as their MPR selector. Afterwards, any broadcast messages transmitted by a node X will only be relayed by its MPR nodes. But, increase in node density can significantly increase hello message sizes and broadcasts. To address this problem, OLSHR nodes maximize the use of promiscuous listening (a node doesn't broadcast a hello message if it has transmitted some data during the last hello Interval and no neighbor changes are recorded since last hello message broadcast), and differential hellos. Differential hellos are considerably small hello messages, advertising only the differences recorded in neighborhood or MPR list, since last hello message broadcast. Small sizes can even facilitate airing of differential hellos at higher frequency. However, airing of a complete hello message is necessary on identification of new neighbors, and once after every FULL_HELLO_INTERVAL. Fig. 2 presents the differential hello message format used by the OLSHR nodes. Differential_List carries IDs of all advertised neighbors. In Differential_List, first IN_MPR nodes are newly designated MPR nodes, next OUT_MPR nodes are the denounced MPR nodes, and remaining OUT_NBRS correspond to the lost neighbors.

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 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      | Neighbor_Count|     IN_MPR    |    OUT_MPR    |
+---------------------------------------------------------------+
|                     Originator_IP_address                     |
+---------------------------------------------------------------+
|                                                               |
|                                                               |
|                       Differential_List                       |
|                            ......                             |
|                            ......                             |
|                                                               |
+---------------------------------------------------------------+
```

Fig. 2. Differential hello message format

B). Multi-hop proactive zones

Hello messages enable each node to learn about two-hop topology information around itself, forming a two-hop proactive routing zone around it. In

OLSR protocol, MPR nodes periodically broadcast TC messages (advertising their MPR selectors) to the entire network. This information is used by all nodes to learn multi-hop routes. OLSHR minimizes TC message broadcasts in two folds. First, it benefits from the two-hop topology information maintained at each node; i.e. the MPR nodes generate TC messages on behalf of their MPR selectors, which are also the designated MPR nodes. This saves a TC message broadcast for each MPR node through every TC message interval. Second, TC message dissemination radius (TTL) is also controlled by the zone radius (R); i.e. the TTL for TC messages is set to R-2 (two-hop information is already learnt via hello messages). This significantly minimizes the number of topology broadcasts; as, R is generally much smaller than the network diameter.

3.2. Inter-Zone Routing (IERP) Component

OLSHR makes use of on-demand route discovery mechanism to find destinations outside the proactive zone. If an OLSHR node needs to communicate with some destination, it consults its routing table to see if it has a valid route to that destination. If a valid route is not found (destination unavailable or outside the proactive routing zone), it invokes an on-demand route discovery process by broadcasting a RREQ message to its neighbors. On receiving the RREQ message, every intermediate node learns or updates its route towards originator. If RREQ is received from an MPR selector, the node embeds its ID in RREQ header (path accumulation) and rebroadcasts the RREQ to its neighbors. This process continues till the RREQ reaches the destination, or hop limit is reached. On receiving this RREQ, the destination sends back a RREP message to the originator. This RREP traverses the path accumulated in the RREQ header. MPR optimization significantly enhance IERP's performance by curtailing the number of retransmissions, while still preserving the network wide reachability of route search messages. Whereas, path accumulation helps dissemination of additional topology information during the route discovery broadcasts. This minimizes the number of on-demand route discoveries by enhancing the number of proactively known destinations [16].

As discussed earlier, OLSHR nodes make use of hello messages to proactively learn about their neighborhood. A certain number (MAX_HELLO_LOSS) of missing hellos from any neighbor indicates a link break to that neighbor. In addition, other neighbor sensing mechanisms like link layer feedback (available with DCF based MAC layers) can also be used for quicker identification of link failure. On identification of a link failure, any node X sends a RERR message to its precursors (neighbors using X as next hop node for any on-demand route through the broken link). On receiving this RERR, every node informs its precursors about the broken route. On receiving this information, the originator can reinitiate the on-demand route discovery process. Fig. 3 presents flow of events for the proposed IERP component.

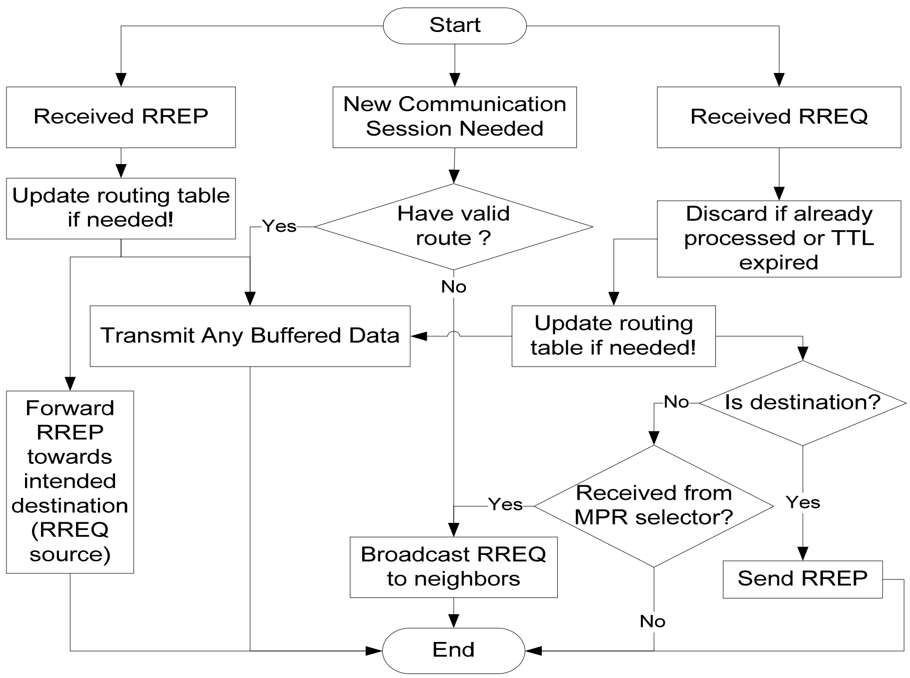


Fig. 3. Flow of events for the proposed IERP component

4. Results and analysis

In this section, performance evaluation of OLSHR is intended against AODV and OLSR routing protocols. Each protocol is evaluated for its Packet Delivery Ratio (PDR) and Normalized Routing Load (NRL). PDR is the ratio of data packets received at destination to the number of data packets transmitted; whereas, NRL is the ratio of control packets transmitted to the number of data packets received at destination.

4.1. Simulation environment

The simulations are performed on open source NS-2 [17] simulator. All simulations are carried out in a flat rectangular area of 1200m*500m and each simulation is run for 400 seconds. All results are averaged on at-least five simulation runs. The node movements in all simulation scenarios are modeled using random waypoint mobility model. At start of every simulation, each node starts its movement from a random startup position to a randomly chosen destination. After reaching the destination, it waits for a given pause time and starts moving towards some other destination. All the nodes communicate using IEEE 802.11 DCF (Distributed Coordination Function) MAC layer. A CBR application is run to transmit 2 packets (512 bytes each) per second, making a constant data rate of 8Kbps per transmitter. The traffic patterns are generated using NS-2's traffic generation utility and all protocols are evaluated against the same mobility and traffic pattern files. Protocol implementations UM-OLSR [18] and NS-2 AODV are chosen for OLSR and AODV respectively. Protocol specific simulation parameters are presented in Table 1.

Table 1

Protocol specific simulation parameters

Parameter	Value
Hello message interval (OLSR & OLSHR)	2 seconds
TC message interval (OLSR & OLSHR)	5 seconds
Connectivity monitoring (AODV & OLSHR)	Link layer feedback
OLSHR proactive zone radius	3 hops

4.2. Simulation scenarios

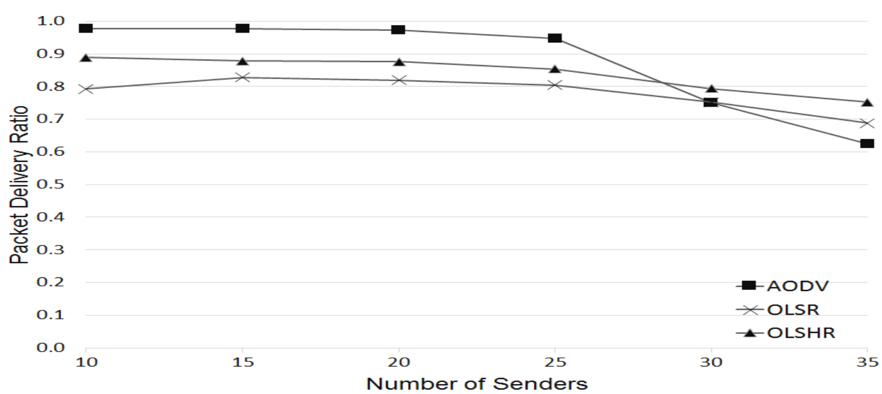
Three simulation scenarios are defined. First, number of nodes is kept constant and number of senders is increased to see how each protocol behaves when more nodes start to transmit. In second scenario, number of senders is kept constant and number of nodes is increased to visualize the impact of increasing node density on each protocol's performance. In third scenario, average node speeds are increased to visualize the impact of changing mobility levels. Table 2 presents scenario specific simulation parameters.

Table 2

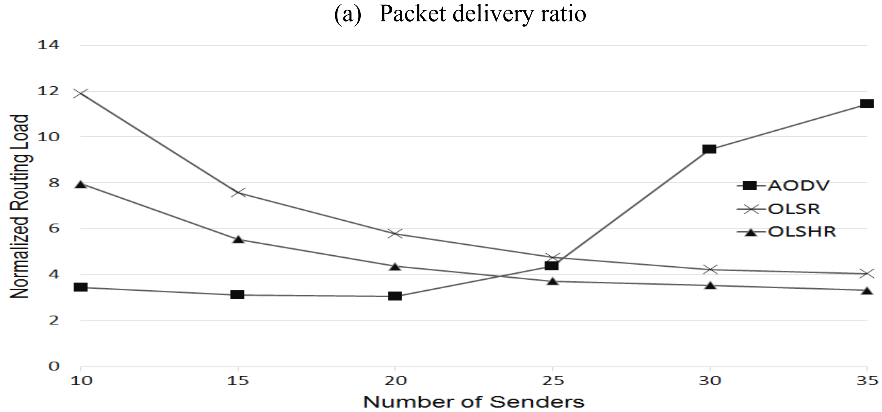
Simulation scenarios

Parameters	Scenario1	Scenario 2	Scenario 3
Number of nodes	100	50, 75, 100, 125, 150, 175	100
Number of senders	10, 15, 20, 25, 30, 35	20	20
Pause time (m/s)	10	10	10
Max node speeds (m/s)	15	15	5, 10, 15, 20, 25
Traffic type	CBR (2*512 Bytes/sec)	CBR (2*512 Bytes/sec)	CBR (2*512 Bytes/sec)

Fig. 4 (Scenario 1) presents PDR and NRL of the protocols against increasing number of senders. Initially, AODV shows the highest PDR and the lowest NRL. On the other hand, OLSHR and OLSR maintain reasonably comparative PDR; but, higher NRL (owing to proactive topology broadcasts). However, all protocols' PDR start to decrease with the increasing number of senders, as more traffic is introduced to the network. A steep decline in AODV's PDR is seen when more than 25% nodes start to transmit. This happens because increasing number of transmitters add to the route discovery broadcasts. It is also evident from the sharp rise in AODV's NRL; whereas, OLSHR and OLSR's NRL lowers. On the other hand, proactive routing and MPR optimizations enable OLSHR and OLSR to maintain a somewhat steady PDR. OLSHR shows even steadier PDR and lower NRL, since proactive topology broadcasts are only confined to proactive routing zones. This indicates that proactive and well-engineered hybrid routing protocols are more suitable for networks requiring higher number of transmitters.



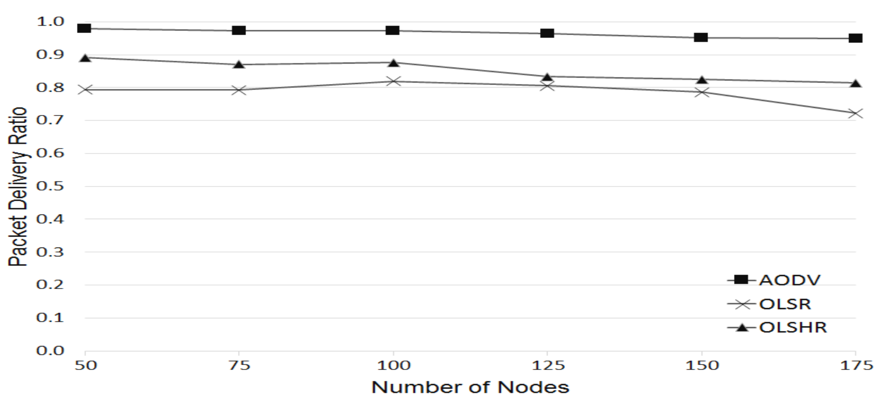
(a) Packet delivery ratio



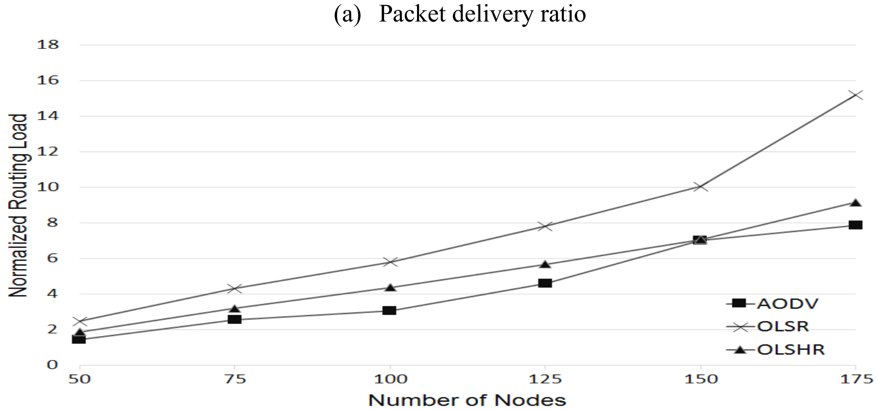
(b) Normalized routing load

Fig. 4. Performance comparison against increasing number of senders

Fig. 5. (Scenario 2) presents PDR and NRL of the selected protocols against increasing node density. Initially, all protocols depict high PDR and low NRL. However, the protocol's PDR lowers with the increase in node density. This happens because increase in node density also increases topology or route discovery broadcasts. That is why, an increase in all protocol's NRL is seen with the growth in node density, which indicates certain limits on each protocol's scalability. Now, a smooth rise in AODV and OLSHR's NRL is seen; whereas, OLSR's NRL increases noticeably when network size approaches beyond 150 nodes. As a result, a noticeable decrease in OLSR's PDR is also seen. This indicates that AODV and OLSHR can scale to relatively larger networks. This is also interesting to see that AODV and OLSHR manage to maintain very similar NRL. Moreover, major share of OLSHR's control traffic comes from non-congested nodes (periodic broadcasts within the routing zones), which implies that hybrid protocols can scale to relatively larger networks.



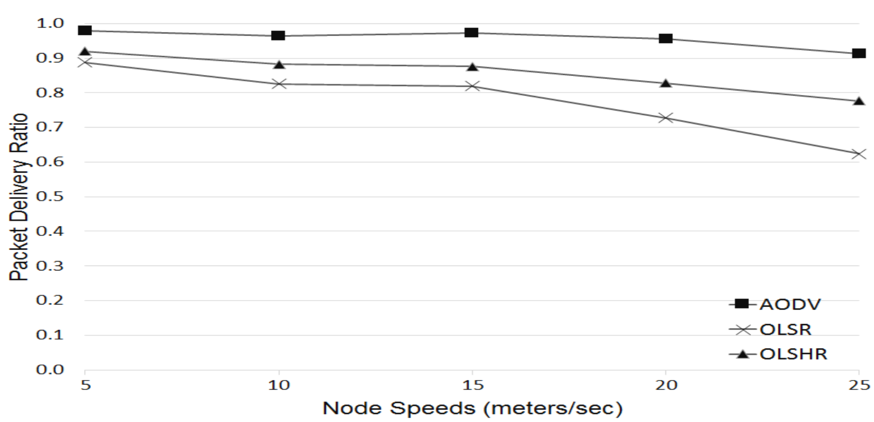
(a) Packet delivery ratio



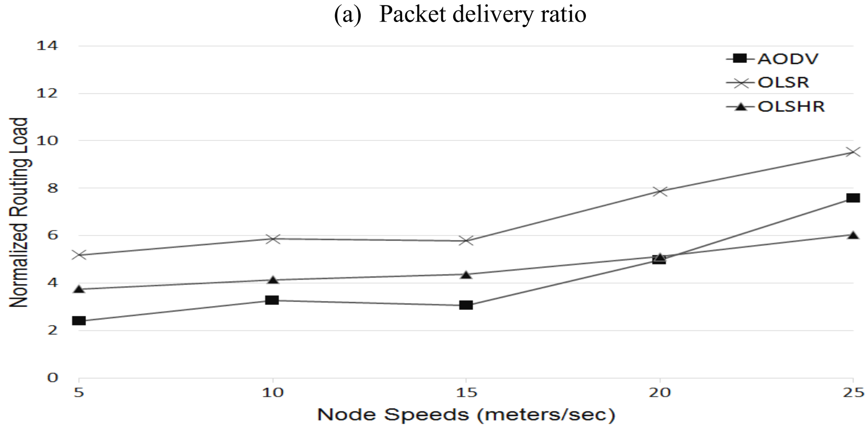
(b) Normalized routing load

Fig. 5. Performance comparison against increasing node density

Fig. 6. (Scenario 3) presents all protocols' PDR and NRL against increasing node speeds. At low node mobility, very high PDR is recorded for all protocols; however, it lowers with increase in node speeds. This happens because higher mobility causes more route breaks; as a results, more route searches are triggered for on-demand protocols. That is why, a sharp rise in AODV's NRL is seen for node speeds beyond 20m/s. A noticeable decrease in OLSR's PDR is seen because proactive protocols converge to topological changes with help from periodic topology broadcasts. Having higher frequency of topology broadcasts can increase the PDR on cost of increased control traffic, which compromises scalability. A slight decrease in OLSHR's PDR is also seen, but its hybrid nature and MPR optimizations have enabled OLSHR to maintain reasonably low control overhead. As a result, a steadier NRL is recorded for OLSHR. This indicates that on-demand and well-engineered routing hybrid protocols can better accommodate increasing node speeds.



(a) Packet delivery ratio



(b) Normalized routing load

Fig. 6. Performance comparison against increasing node speeds

5. Conclusions

A hybrid zone based routing protocol OLSHR is proposed. OLSHR optimizes and incorporates a well-appreciated proactive routing protocol (OLSR) to find routes within a confined scope (proactive routing zone). Whereas, a prominent on-demand routing protocol (AODV) is used to find destinations outside the proactive routing zone. The on-demand routing component is configured to benefit from the MPR optimizations introduced by the OLSR protocol. Proactive maintenance of intra-zone routes and MPR optimizations significantly minimize the impact of route discovery broadcasts; as, fewer route searches are initiated and broadcast messages are only relayed by the MPR nodes. Having a hybrid routing mechanism enables OLSHR to fit diverse network scenarios, where a single proactive or reactive routing protocol fails. Tuning the proactive zone radius between small and large values can make OLSHR to have more proactive-like or reactive-like behavior. We are aware of the fact that hello messages and TC messages (used by OLSR) introduce some overhead to the protocol. Therefore, optimizations like differential hellos and neighbor based TC message generation have proven useful. Simulation results confirm that OLSHR protocol performs well for wide range of mobility and traffic patterns.

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