AM-AOMDV: Adaptive Multi-metric Ad-Hoc On-Demand Multipath Distance Vector Routing

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Abstract. This paper proposes AM-AOMDV, a novel multi-metric and multipath reactive routing scheme for wireless ad hoc networks. The AM-AOMDV extends the AOMDV scheme by including a multiple route metrics, a novel local route update and route maintenance algorithm. The algorithm uses the one-hop information exchange between neighboring nodes to increase the packet throughput and route longevity, decrease the end-to-end latency, route discovery frequency and route overhead under high mobility environments. The multiple metrics (i.e., node-to-end latency, node-to-end RSSI, and node occupancy) allow the routing scheme to converge to the most efficient route during the data transmission period and hence avoid the creation of hotspots under heavy traffic conditions. Simulations are carried out in ns-2 and the results are compared to the AOMDV protocol. The results show that the AM-AOMDV outperforms the AOMDV protocol in terms of the above discussed performance metrics.

Keywords: routing, distance vector routing, reactive routing, multipath routing, AODV, AOMDV, multi-hop, wireless ad hoc networks.

1 Introduction

Mobile ad hoc wireless networks (MANETs) are usually characterized by limited bandwidth and unreliable channel conditions due to node mobility and multiple hops. These characteristics pose a serious challenge in designing efficient routing layer schemes due to short route lifetime. Though many reactive routing protocols have been proposed in the past for MANETs where the route setup is carried out only when required for data transmission [1, 2, 3], the issue of frequent route breakages due to high mobility surfaces time and again. This problem could be addressed in two ways: (*i*) by discovering multiple routes for reducing the frequency of route discovery, and (*ii*) by using a pre-emptive mechanism of frequent link updates all along the route. However most of the routing approaches follow only one of the above in order to improve their route set up mechanism [3, 4, 5, 6]. One such protocol Ad hoc

J. Zheng et al. (Eds.): ADHOCNETS 2009, LNICST 28, pp. 884–895, 2010.

On-demand Multipath Distance Vector (AOMDV) routing [3] is an extension of the single route AODV protocol [1].

The AOMDV scheme provides better performance in the dynamic MANET environment. It uses the information available in the routing messages of the AODV protocol to find multiple disjoint and loop-free routes during the route discovery phase. The link disjoint feature of this protocol ensures that no two parallel routes between a source-destination pair will have a common link. If the currently used route fails, the source chooses the next available route in order to continue packet transmission to the destination. In AOMDV, every node broadcasts the HELLO messages for the purpose of local link connectivity. However, the HELLO messages often interfere with the data transmission on the same or other closely spaced routes. AOMDV uses the minimum hop-count as the link metric in the route setup stage for choosing the shortest path from the source to destination. This does not necessarily support data transmission in high speed environments since minimum hop-count based metric does not consider the RSSI (received signal strength indication) degradation on multihop links (due to interference). Our investigation also shows that the AOMDV scheme still needs high frequency of route rediscovery for high node mobility.

Unlike using the multiple routes in AOMDV, the LHAOR (Link Heterogeneity Aware On-demand Routing) scheme strengthens the main route by using a local update scheme for generating surrogate routes. This scheme uses a path information exchange mechanism between neighboring nodes and introduces RSSI as a new routing metric [7]. However the single route concept could cause significant end-to-end latency in data transmission when a significant number of links fail.

In this paper, we propose the AM-AOMDV scheme, which adopts the local route update concept of LHOAR in the multipath AOMDV scheme. The AM-AOMDV scheme strengthens the route being actively used and also maintains the alternative routes through periodic unicast packets transmitted from the source to the destination. The use of multiple metrics (including RSSI, node-to-end latency and node occupancy, in addition to minimum hop-count) enables the proposed scheme to select the most efficient route from the source to destination. The multiple metrics also help in avoiding the hot spots under heavy traffic conditions.

Rest of the paper is organized as follows. Section 2 discusses the features of the AM-AOMDV. Section 3 discusses the simulation results and the performance improvements in the AM-AOMDV scheme compared to AOMDV. Finally Section 4 concludes the paper by summarizing the achievements of AM-AOMDV.

2 Adaptive Multi-metric AOMDV Routing Scheme

We describe below the major features of our AM-AOMDV routing scheme.

2.1 Multiple Routing Metrics

We use a novel multiple metric approach for converging to the most efficient route while discovering multiple routes in the route setup stage. These metric values are introduced in the routing table for each node and their corresponding paths. The enhanced routing table contains three additional metrics: (a) *node-to-end RSSI* metric,

(b) *node-to-end latency* metric, and (c) *node occupancy metric*. The node to-end RSSI metric is defined as the RSSI value of the path from any node to the destination. We use average value of RSSI. The RSSI value of each forward link is fed back to the nodes through the ACK packets. The node-to-end latency metric consists of two parameters (*i*) delay from the node to the source computed from the timestamp of the RREQ packet, and (*ii*) the delay from the destination to the node computed from the RREP packet. The node occupancy metric is defined as the total number of data packets that any node processes per second and plays an important role under heavy traffic conditions where hot spots are likely to be created in the network. The AM-AOMDV scheme uses these metrics along with the hop-count metric to find the new paths and select the best one intelligently.

2.2 Route Setup Stage

Every node maintains a routing table which is updated whenever it receives a RREQ (Routing REQuest), RREP (Routing REPly) or a local update HELLO packet. When the application layer sends a packet to the routing queue, the source looks for a route to that destination in its routing table. If a valid route is available the node enters the *data forwarding* state and forwards the packet to the first hop node of the appropriate route. However, if no route is available and the node is the source of the data packet, it enters the *route discovery state*, which is similar to the AOMDV scheme [3]. In this state, the node broadcasts RREQs for finding the routes to destination. Each intermediate node re-broadcasts the received RREQs and sets up a backward route towards the source. During this phase, each intermediate node discards multiple RREQ packets from the same former relay node to avoid looping and the same sequence number to guarantee link disjoint routes. Moreover the next hop and last hop information are also used for checking node disjoint routes. Finally, when one of the RREQ packets reaches the destination node it sends an RREP back to the source node using the backward routes (appropriate to that RREQ packet) stored in each intermediate node in the reverse direction. The destination floods RREP's in the reverse direction similar to the number of multiple RREQ's received from the source. The RREQ-RREP pairs form multiple routes from source to destination [3].

After receiving the first RREP from destination, the source starts forwarding data packets. If a new reply arrives after the source has entered data forwarding state with a better routing metrics (discussed in Section A), the source will switch to the new route. This is because our proposed scheme is inherently adaptive and chooses the best available route, unlike AOMDV. In the event of a link breakage the intermediate node enters into a *route maintenance state* after a repeated number of unsuccessful attempts made by it to forward the data packet. It interprets the situation as a route error and transmits an RERR (Route ERRor) packet in a unicast manner on the backward route to the source. This process causes all the nodes to delete the next hop to the destination in their routing tables along that route.

2.3 Data Transmission Using Local Path Update

The number of routes from the source to destination is restricted to a heuristic upper bound and the source begins data transmission on the route identified by the first received RREP packet. This route is labeled as the *primary route* whereas the other routes are labeled as *secondary routes*. All the nodes through which the RREP packet(s) travels from the destination to the source are marked as Forward Route (FR) nodes. When the first FR node on the *primary route* receives a data packet, it starts participating in the *local path update* process by broadcasting a HELLO message to its 1-hop neighbors. The HELLO packet contains path information from its routing table. A flag in the HELLO message identifies the originator of the packet, which enables the neighboring FR nodes to discard this HELLO broadcast. The 1-hop neighboring non-FR nodes, which hear this local update HELLO message, either add a new route entry or update the existing routing information. These 1-hop neighbors of the FR nodes are labeled as Surrogate Route (SR) nodes. These SR nodes help in setting up alternate routes to the destination by receiving periodic local updates from their 1-hop FR neighbors. The SR nodes respond to the local update HELLO messages received from an FR node, by broadcasting another local update HELLO but with the flag reset inside it. This enables other FR nodes to accept this HELLO broadcast from the SR nodes and add new paths in their routing table or update existing paths, if they are found to be better in terms of the multiple metrics described in Section IIA. This causes the *primary* route to converge to a more efficient route and thus prolong the route life-time. After receiving the first data packet, the SR nodes label themselves as FR nodes and begin the local path update process again.

2.4 Enhanced Link Layer Failure Handling

When the MAC layer does not receive a CTS (clear to send) packet even after retransmitting the RTS (request to send) packet for a short retry limit, the situation is interpreted as a link failure. The MAC layer reports this to the routing layer through a callback mechanism and a packet salvage process is initiated by finding alternate routes to the destination in its routing table. If no route is available to the destination, the data is dropped and an RERR packet is transmitted in a unicast manner on the backward route to the source. Due to the lack of local route update, the AOMDV scheme cannot always salvage the packets and drops them which results in large packet loss and routing overhead when node mobility is large. On the other hand, our proposed routing approach periodically updates the route to the destination using the local update algorithm. It not only strengthens the path locally and ensures longer route life-time but also delivers more packets to the destination.

2.5 Route Maintenance

AOMDV does not maintain or locally repair the secondary routes. As a result, the secondary route may also fail and may not be available for data transmission after the primary route has failed, especially when node mobility is high. Consequently, the route discovery frequency increases in AOMDV in the presence of high node mobility. Our scheme uses the *keep alive* packets to monitor the secondary routes and heal any link breakages. If any FR node does not find a valid next hop it initiates a local one hop repair query, asking its neighbors for a route via the same last hop. Non FR neighbors having paths to the destination via the required last hop reply to this query.

Thus the FR node immediately adds one of these neighbors as a new next hop in its routing table. When the *keep alive* packet reaches the destination, it retransmits the same on the reverse route to the source via that *secondary path* and updates the multiple metrics in both the forward and reverse directions. This mechanism thus periodically updates the secondary routes and reduces the route discovery frequency.

3 Simulation and Discussion

We simulated the AM-AOMDV and AOMDV schemes using the discrete event network simulator ns-2.32, which supports multihop wireless scenarios [8]. The objective is to evaluate (i) *packet loss ratio*, (ii) *average end-to-end delay*, (iii) *average route discovery delay*, (iv) *average route discovery frequency*, and (v) *routing overhead* in AM-AOMDV against that of AOMDV in the presence of mobility-related route failures. Scenarios with large number of source destination pairs or connections, varying packet rates and increasing node speeds were considered.

3.1 Simulation Scenario

Table 1 summarizes the parameters used in our simulation setup. The original results of AOMDV are available in the literature [3]. It is important to note that the nodes can serve as source as well as destination in the network. Table II provides the set of constant parameters used during the simulation of various scenarios. We run each simulation for 1000 seconds and ignore the initial 250 seconds as done in AOMDV protocol, which is considered as a warm-up period. Each simulation is run 5 times and the results are an average of the 5 observations. Therefore each point represents a simulation of five unique traffic movement patterns. We repeat the simulations for different traffic (connections and packet rate) variations and mobility models (mean node speed).

Table 1. Simulation Parameters

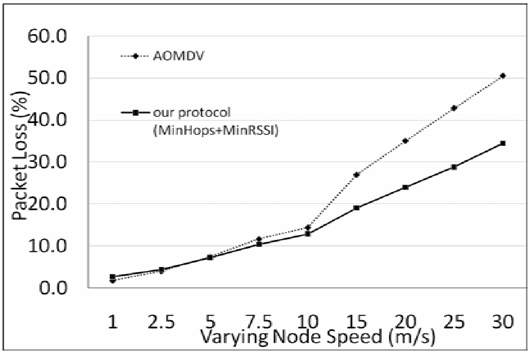
Parameters	**Values**
Network size	100m X100m
Number of nodes	100
Propagation model	Two ray ground
Transmission range	250m
Simulation time	1000 seconds
Traffic type	Constant bit rate (512bytes)
MAC protocol	IEEE 802.11 b
Link bandwidth	2Mbps
Interface queue length	Drop/Tail PriQueue of 50
Mobility model	Random way point

Table 2. Scenario Variations

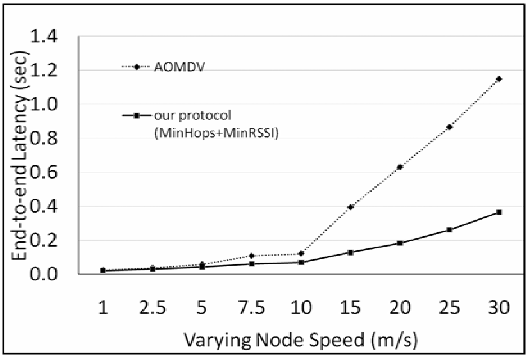
Varying parameters	Constant parameters
Speed (1m/s to 30m/s)	Connection:50 pkt rate:1pkt/s
Connection/flow (10 to 70)	Speed:5m/s pkt rate:1pkt/s
Packet rate (0.25 to 3 pkt/s)	Speed:5m/s connections:50

3.2 Varying Average Node Speed

Fig. 1(a) shows the packet loss ratio of the AM-AOMDV and AOMDV schemes with varying average node speeds. The proposed AM-AOMDV scheme has a much lower packet loss ratio as compared to the AOMDV scheme at high node speeds of >10m/s. This is because the probability of link breakage increases with increasing node speeds. Though an RERR message travels to the source in AOMDV causing it to switch to another route, the packets already queued in the nodes of the broken route

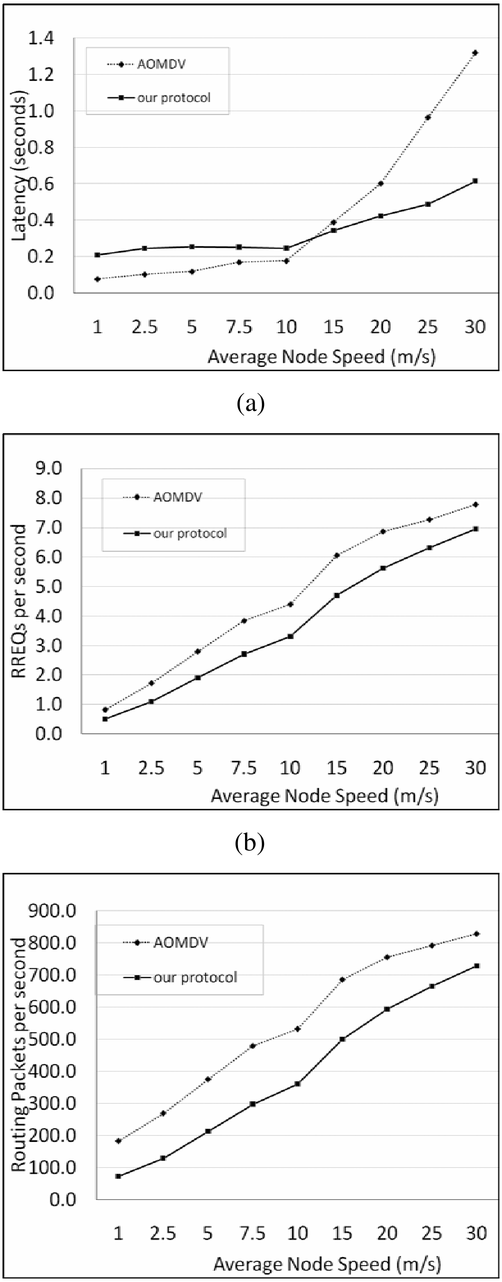


(a)



(b)

Fig. 1. Performance with varying average node speed. (a) %packet loss ratio, and (b) end-to-end latency.



(c)

Fig. 2. Performance with varying average node speed. (a) Route discovery latency, (b) route discovery frequency, and (c) route packet overhead.

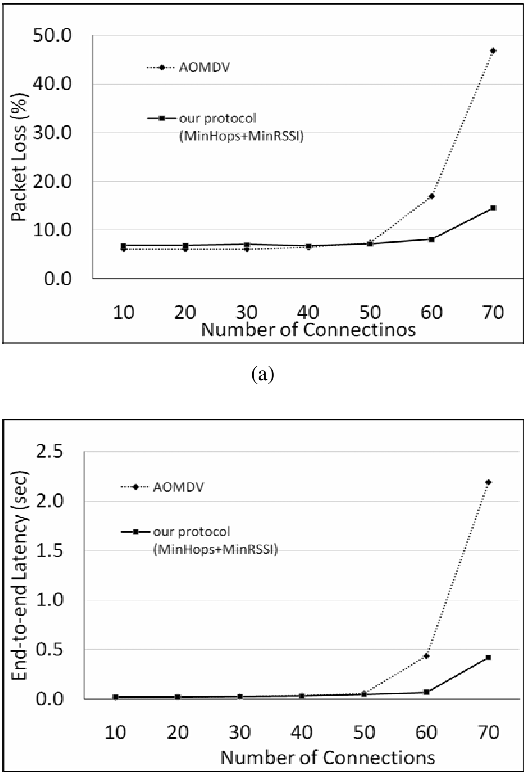
are dropped. Moreover, the source node sometimes finds that all the secondary routes are also broken at high node speeds by the time the primary route fails. This is a major problem in AOMDV and also contributes to the delay overhead. The periodic broadcasts of HELLO messages in AOMDV to maintain the link connectivity increases the collisions of data packets leading to the MAC layer back-offs. On the other hand, the local path updates in AM-AOMDV increase the route longevity. Similarly, the use of keep-alive messages also updates the secondary routes in AM-AOMDV. This enables the AM-AOMDV scheme to deliver more packets in comparison to AOMDV. Figure 1(b) show that the end-to-end latency at higher node speeds is much lower in our scheme as compared to the AOMDV. The primary path update avoids the large queuing delays in our scheme, whereas the packets in AOMDV experience large queue delay before being salvaged on another route.

Figure 2(a), (b) and (c) illustrate route discovery latency, route discovery frequency and routing packet overhead, respectively, under varying average node speeds. As shown in Figure 2(a), the route discovery latency is much lower for AM-AOMDV at node speeds of >10m/s. At low mobility (<10 m/s), the RREP messages generated by the destination travel quickly back to the source thus bringing in the faster response path. However, for node speeds >10 m/s, the HELLO messages in AOMDV start saturating the network and gradually increase the collisions in the network. As a result, the RREP packets cannot reach the source as quickly as before causing a considerable increase in the route discovery delay.

The AM-AOMDV scheme suffers initially due to the lack of HELLO messages to maintain the link connectivity and relies only on the reverse paths built by the RREQs. This explains the greater initial route discovery delay. But AM-AOMDV is more tolerant to path loss due to link failure as illustrated in terms of the lower route discovery frequency in Figure 2(b). The AM-AOMDV scheme has a much lower routing overhead (almost half as compared to AOMDV) and hence it is more reliable than AOMDV. This is due to limiting the total number of HELLO broadcasts through controlled local updates along the primary routes and ‘keep alive’ (route maintenance) mechanism to ensure that the alternate routes are available in case of considerable link breakages.

3.3 Varying Number of Connections

Fig. 3(a) shows packet loss performance for varying number of connections. The packet loss ratio in AM-AOMDV is substantially lower than in AOMDV, in heavy traffic conditions (>50 connections). The network saturation threshold for AOMDV is 50 connections, after which it starts experiencing heavy packet losses of >10%. However, the AM-AOMDV scheme does not reach network saturation even up to 70 connections. The local update process in AM-AOMDV controls the propagation of HELLO messages and makes a large number of SR routes available for different connections. This limits the packet loss in heavy traffic conditions due to the large number of connections. But this has a weakness in sparse networks since they would not have enough number of nodes to exchange the local updates and create more surrogate paths. Similarly, Fig. 3(b) shows that AM-AOMDV has a superior end-to-end latency performance as compared to AOMDV.



(a)

(b)

Fig. 3. Performance with varying number of connections. (a) %Packet loss ratio, (b) end to end latency.

Fig. 4 shows the route discovery delay performance of both schemes for varying number of connections. In a sparse network (i.e., lower number of connections), the AM-AOMDV scheme shows higher route discovery delay than AOMDV. This is due to the fact that the number of local updates is low in AM-AOMDV scheme in addition to the absence of HELLO messages to maintain link connectivity. Also RREPs do not come back to the source as quickly. However AOMDV has much better link connectivity maintenance (especially in the reverse paths) because of the abundance of HELLO messages. Thus the RREP takes the fastest reverse path to reach the destination. However, the route discovery delay increases considerably in AOMDV for heavy traffic (>50 connections), whereas AM-AOMDV has much lower route discovery delay than AOMDV (almost half). This can be attributed to availability of surrogate paths that guarantee packet delivery by locally updating the primary route leading to much longer route longevity. As a result, the frequency of route discovery is much smaller than AOMDV. AM-AOMDV also maintains the secondary paths by healing them using the '*keep alive*' packets. When the main path has to be switched, the chances of the secondary path being stale are almost half as compared to AOMDV. This again reduces the need for re-initiating the route discovery by source nodes. Conversely, since AOMDV is always using the first path (fastest response path) in the list and not maintaining the other paths, it ends up exhausting all the paths and thus has to rediscover the routes more frequently.

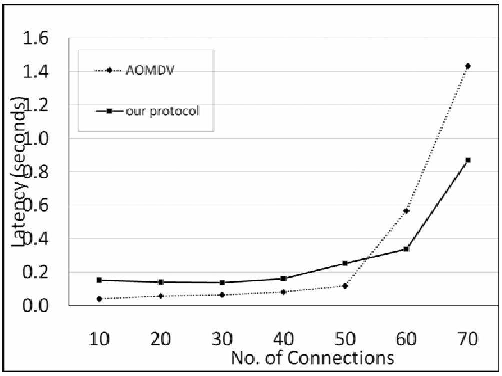
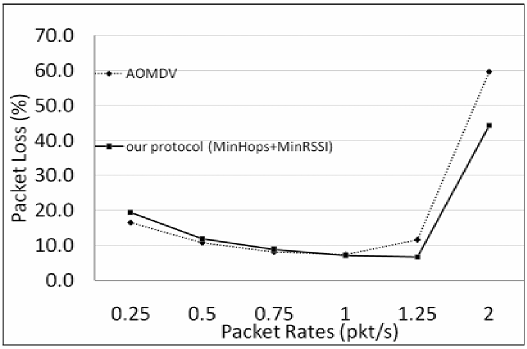


Fig. 4. Route Discovery delay performance for varying number of connections

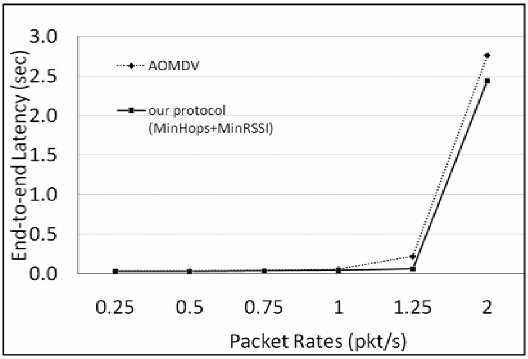
3.4 Varying Packet Rates

Fig. 5(a) shows that the AM-AOMDV scheme has lower % packet drop rate for packet rates of >1packet/second/node. Fig. 5(b) shows the performance in terms of the average end-to-end latency with varying packet generation rate. With varying packet rate, the end-to-end latency of AM-AOMDV is lower than AOMDV. The latency continues to increase with packet rate, but the disparity with respect to AOMDV becomes more apparent at 1.25packet/s, where AM-AOMDV shows a considerably lower latency of 67ms while AOMDV has a latency of 219ms. Fig. 5(c) shows the variation of route discovery delay with respect to the packet generation

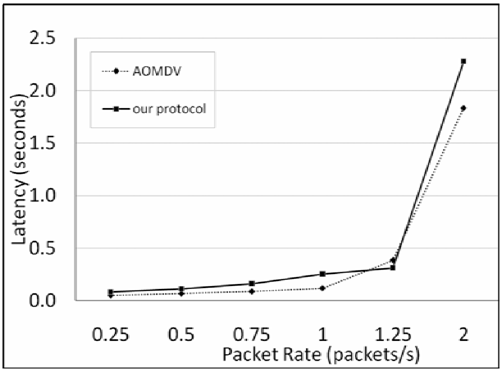


(a)

Fig. 5. Performance with varying packet rate. (a) %packet loss ratio, (b) Route discovery delay, and (c) End to end latency.



(b)



(c)

Fig. 5. (*continued*)

rate. AM-AOMDV shows 80 ms of route discovery delay initially as compared to 50 ms for AOMDV. However, it increases to 2.2s as compared to 1.8s for AOMDV at 2pkt/s. The reason for AM-AOMDV to show a consistently higher route discovery is obviously the lack of link connectivity maintenance. Additionally, the number of control packets (in our case the local update HELLOs) being dropped increases at higher packet rate. Moreover, the effective loss of HELLO packets by AOMDV is much less than AM-AOMDV, which enhances this effect. To summarize, AOMDV incurs a very high routing overhead for a slight improvement in the route discovery delay. AM-AOMDV trades off the route discovery delay for achieving a reduction in overhead of half of that of AOMDV.

4 Conclusion

In this paper, we designed and implemented a new AM-AOMDV scheme which extends the AOMDV scheme by including a multiple route metrics, a novel local route update and route maintenance algorithm. For enhancing the route reliability, we use new routing metrics, namely received signal strength (RSSI), path latency and node occupancy for intelligent path selection. These metrics are used as feedback to understand the route behavior. Besides, we implement the *local route update* algorithm, which strengthens the routes and also creates multiple surrogate routes by using the metric feedback mechanism. For maintaining the diversity of multiple routes, we propose a *keep alive* packet for updating the secondary paths in terms of their metrics. The simulation results demonstrate that the proposed AM-AOMDV scheme performs considerably better than the AOMDV routing scheme in terms of packet drops, latency and route discovery frequency, especially in high mobility and heavy traffic conditions.

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