MMDV: **M**ultipath and **M**PR based AO**DV** routing protocol

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Abstract— **The problem of routing in mobile ad hoc networks is considered as an important issue. In fact, these networks are characterized by multi hop wireless connectivity, node mobility, limited power and memory resources. In this paper we study several possible modifications of AODV[1] routing protocol based on selected features available in other routing protocols. Simulation results allowed us to select the two most relevant ones. MMDV is an amelioration of AODV protocol providing for multipath and MPR based flooding. This protocol consists of both proactive and reactive components. In a proactive phase, nodes compute their MPR lists and compute paths to their two hop neighbors. In a reactive phase, nodes compute two paths for each destination. Simulation results show that MMDV enhance the packet delivery performance and reduce the overhead.**

Keywords: ad hoc, routing protocols, node mobility, AODV.

I. INTRODUCTION

A mobile ad hoc network is a multi-hop wireless network without any infrastructure. Ad hoc networks are characterized by frequent changes and mobile nodes may join the network, disconnect or move at any time. These problems make the routing problem in ad hoc networks more difficult than traditional wired networks.

In this paper we study several possible modifications of AODV[1] routing protocol based on selected features available in other routing protocols. Simulation results allowed us to select the two most relevant ones. Moreover, we propose their combination called Multipath and MPR based AODV (MMDV).

The rest of this paper is organized as follows: In the second section, we present routing protocols in ad hoc networks. In the third section, we briefly review the AODV protocol and present related works which attempt to improve AODV. Section four describes specification and design of our variants. In section five, we present the simulation results followed by their interpretations. Finally, we describe MMDV and analyze its simulation results.

II. ROUTING IN AD HOC NETWORKS

The IETF MANET Working Group developed a number of protocols, which were described in [1], [2], [3], [4], [5], [17] and [6]. These protocols belong generally to two groups: proactive and reactive protocols.

A. *Proactive protocols*

Proactive or table-driven protocols are similar to the ones used in the wired networks. Routes to all destinations are updated periodically. The family of proactive protocols includes basically Destination Sequenced Distance Vector Routing (DSDV) [4], Optimized Link State Routing Protocol (OLSR) [5] and Topology Broadcast Based on Reverse Path Forwarding (TBRPF) [6].

DSDV is based on a Distance Vector approach. It associates to each route entry a sequence number indicating its freshness. Routes for each destination are preferred if they have: :

- a newer sequence number, or
- a best cost metric, in the case that two routes have a same sequence number.

OLSR [5], a proactive link state protocol, uses the concept of Multipoint Relays (MPR) to reduce broadcasting overhead. Each node chooses a subset of nodes in its neighborhood as its MPRs which forward his broadcast messages during the flooding process. In OLSR, topology information messages are generated only by nodes elected as MPRs. Only MPR nodes are allowed to forward broadcast messages.

TBRPF[6] is another proactive link state protocol. Each node running TBRPF[6] computes the shortest path tree based on partial topology information. To minimize overhead, TBRPF nodes use periodic and differential updates to flood only part of their source trees.

In order to maintain changing network graph due to incoming, moving or failing nodes, proactive protocols require continuous updates, which may consume large amounts of bandwidth. Moreover, some routes are never used, but they exist in the routing table.

B. On-demand protocols

In contrast, reactive (On-demand) protocols determine the route to a destination only when it is required. Thus, a node floods the network with a route request and waits for the route reply message to establish a route to the destination node. This reduces the routing load as compared to the proactive protocols. This technique does not require constant broadcast messages, but causes additional delay since the routes are not usually available. Ad hoc On demand Distance Vector Protocol (AODV) [1] and Distributed Source Routing Protocol (DSR) [2] are the two most popular reactive routing protocols for Ad hoc networks. AODV and DSR include the same two routing phases (route discovery and route maintenance). AODV uses sequence numbers for every node, in order to ensure that the selected paths will not include loops and the routing information is still valid.

DSR employs source routing: the sender of a packet determines the list of nodes which will be traversed by the packet. The sender adds this path in the packet header. Each node in the path should transmit the packet to the next node in this path until it reaches the destination node.

The Dynamic MANET On-demand (DYMO) [3] routing protocol is another reactive protocol. DYMO similar to AODV protocol but it uses a path accumulation mechanism: each node appends its own IP address to the control packets.

The main idea of this paper is to modify AODV taking into account the most interesting and promising features used in the above mentioned routing protocol such as MPR and Multipath. It is an attempt to achieve protocol convergence.

III. AODV AND RELATED WORK

AODV is a reactive routing protocol. This protocol initiates route discovery only when a route is needed and maintains active routes only while they are not stale.

A. Route Discovery

When a new route is needed, the source node broadcasts a Route Request message (RREQ). Each node which maintains a route to the destination responds by sending a Route Reply message (RREP) to the source node. If an intermediate node does not have a route to the requested destination, it relays the RREQ. If the source node receives a RREP, the route is established and the source uses this route to transmit data packets. AODV collects only a limited amount of routing information. Source calculates only a route to a destination. Thus a new route discovery process is necessary to send data to another destination node. This usually forces AODV to flood packets more often, which may carry a significant network overhead.

B. Local Connectivity

A node broadcasts Hello messages periodically to determine the connectivity to its neighbors. When a Hello message is received, a route to the neighbor is added to the routing table if it does not already exist. If the route exists, its lifetime is increased. When the topology of the ad hoc network changes, lifetime of the route expires and the route is deleted from the routing table.

C. Route maintenance

A broken link between two nodes affects only active paths using this link: if this link is not used by any active path, AODV does not trigger any process action. When a node involved in an active session moves, the upstream node that detects the movement broadcasts a “Route Error” packet in order to inform its precursor nodes about the broken link. This information is propagated backwards until it reaches the source node. Each intermediate node receiving this route error, updates its routing table. Then the source re-initiates the route discovery process, if the route is still required.

To minimize the impact of RREQ flooding several protocols ([11], [12], etc.) use multipath mechanism. AOMDV [11] enhances the AODV protocol to attempt to find multiple paths between the source and the destination in every route discovery. These multiple paths are guaranteed to be disjoint. Indeed, AOMDV can find link or node disjoint paths. In [12] authors propose an extension of AODV to support multipath routing protocol. The proposed protocol finds pairs of disjoint paths by selecting a route which has a small number of common nodes on its path.

IV. SELECTED ROUTING FEATURES

Many researches proposed more efficient broadcasting techniques ([7], [8], [9], etc.) to minimize the number of retransmissions in order to ensure that a packet reaches all nodes in the network. Authors in [9] classify existing broadcasting schemes and compare these techniques. They conclude that Neighbor Knowledge methods (SBA, MPR, AHBF, LENWB, etc.) are the best broadcast protocol types. OLSR [5] uses the MPR flooding mechanism to minimize its broadcast messages. This mechanism represents the OLSR innovation. It minimizes the flooding overhead by reducing redundant messages. Hence, each node selects a set of its neighbors to cover all its two hop neighbors.

Fast-OLSR [13] is an extension of OLSR that addresses the issue of fast mobility. It maintains connectivity with fast moving nodes; while quickly discover a list of neighbors. Fast-OLSR detects the node mobility by observing the neighborhood changes. We propose to integrate this mechanism to AODV protocol to reduce the impact of RREQ flooding.

In [14] AODV-PA as in DSR protocol, nodes support a path accumulation to store several routes during the same route discovery process. This protocol is not a source routing protocol: in fact, each node appends its own address to the control packets. However, each node does not use this path to route packets.

In summarize, we retain 4 important routing features:

- MPR flooding
- Dynamic MPR flooding (DynMPR) like Fast-OLSR[13]
- Path Accumulation (PA)
- Multipath

We propose to implement these features. First, we propose to integrate in AODV the three features one at time in order to evaluate the impact of each of these features on AODV performances. Then, we selected the appropriate ones to be introduced in our proposed protocol MMDV.

A. Dynamic MPR flooding

This feature is an extension of MPR flooding feature specified in [5]. This extension consists in varying the Hello period according to node mobility. That supposes that each node maintains both a Neighbor Set and a 2-hop Neighbor Set to calculate Multipoint Relay list (MPR), thus the resulting protocol is *hybrid*. Each node observes the neighborhood changes to detect its mobility. It calculates periodically entity *changes* after reception of all Hello messages (as described in eq.1 where neighbor(t) is the number of neighbors at time t). Node switches to the fast mode, if it detects that it is moving fast (the *changes* entity exceeds the threshold). In this case, it sends Hello messages more frequently.

$$changes = \frac{neighbor(t) - neighbor(t-1)}{neighbor(t-1)} \quad (1)$$

Based on many simulation tests, we chose the *changes* threshold value to 1/5 (i.e. one neighbor out of 5 changes): This threshold appears to achieve a good balance between packet delivery and routing overhead metrics. Implementation of this feature results in the AODV+DynMPR protocol. We propose comparing this protocol with AODV+MPR (which implements only MPR flooding mechanism) to show the improvement of this mechanism. AODV+MPR uses uses the same MPR heuristic as specified in [5]. To implement this mechanism, we have modified the structure of AODV Hello messages.

B. Path accumulation

Path accumulation feature enables to append all discovered paths between source and destination nodes to the control messages. Hence, at any intermediate node the RREQ packet contains a list of all nodes traversed. Each node receiving these control messages, updates its routing table. It adds paths to each node contained in these messages. Authors in [14] proposed an enhanced AODV based on path accumulation: AODV-PA. AODV-PA uses a path accumulation feature with both RREQ and RREP messages. When the RREQ and RREP messages are generated or forwarded by the nodes in the network, each node appends its own IP address on these control messages. We implement this protocol [14] called thereafter AODV+PA.

C. Multipath

Multipath AODV reduces the route discovery frequency as compared to a single path AODV protocol. It finds multiple paths between a source and a destination in a single route discovery. Single path protocol like AODV initiates a new route discovery when it detects one path failure to the destination. In contrast, Multipath AODV initiates a new route discovery when all these paths fail or are obsolete. AODV-multipath [12] minimizes the number of common links between a source and a destination. A path with more common nodes shows that there are many possibilities to obtain common links. To count the number of common nodes on the path, authors in [12] proposed to add a new field called JointCount to RREP messages. Each node, receiving a RREP message and that already has multiple reverse routes to the source node, is considered as a common node. Hence, it increments the JointCount field of the RREP message by one. To find a pair of link “disjoint” paths, each intermediate node selects a route that has a smaller number of common nodes. This protocol computes multiple paths from source to destination but not in the reverse path: each node can maintain the same paths to the source node. To avoid this problem, we propose that each node discard the second RREQ from the same upstream node. This mechanism minimizes common nodes on the two paths. Moreover, we propose using a *JointCount threshold* to avoid using unnecessary second paths. Each intermediate node receiving another RREP message, rejects this packet if the RREP JointCount value exceeds a *JointCount threshold* value. Otherwise, it stores a route with a lowest JointCount value.

V. Performance evaluation

We evaluate the 4 proposed AODV modifications (AODV+MPR, AODV+DynMPR, AODV+PA and Multipath AODV) using simulations and compare them with AODV protocol. We implemented these routing protocols using NS-2 [15].

A. Traffic and network models

Scenarios used in the simulation are summarized in Table.I. The mobility model uses the random waypoint model [16] in rectangular fields. We have kept the pause time constant at 30 seconds for all our simulation experiments. In the first scenario we consider 50 nodes in a rectangular field. We vary the mean speeds from 0 to 20 m/s. In the second scenario, we maintain the node density constant, but we consider 100 nodes. Third scenario consists of 100 nodes in a 700 m * 700 m area. thus, we modify the node density and we vary the number of connections from 10 to 100 sources.

Constant bit rate (CBR) traffic sources with 512 byte data packets are used. The number of sources is varied in the simulations. The packet sending rate is set to 4 packets / second. Each node has a radio range of 250 m and the channel capacity is 2 Mb/sec. We used the IEEE 802.11 Distributed Coordination Function. Nodes maintain a send buffer of 64 packets. Each node stores all data packets while waiting for a route. Routing packets are given higher priority than data packets in the interface queues.

B. Performance Metrics

1) Packet delivery fraction (PDF): The average ratio of the number of data packets received by destination nodes to those sent by the source nodes.

2) End-to-end delay: The average delay between the time at which the data packet was originated at the source and the time it reaches the destination. Lost packets are not considered. Delays due to route discovery, queueing and retransmissions are included in the delay metric.

	Scenario 1	**Scenario 2**	**Scenario 3**
Number of nodes	50	100	100
Area (m2)	1000*750	1500*1000	700*700
Node density (nodes per m^2)	1/15000	1/15000	1/4900
Mobility model	Random waypoint	Random waypoint	Random waypoint
Pause time (s)	30	30	30
Max speeds (m/s)	0-20	0-20	10
Channel capacity	2Mb/s	2Mb/s	2Mb/s
Number of CBR connections	20	20	10-100
Data rate	4 packets/s	4 packets/s	4 packets/s

TABLE I
SIMULATION SCENARIOS

3) Normalized routing load: The average number of routing packets transmitted per data packet delivered at destination node. Normalized routing load gives a measure of the overhead of the routing protocol.

C. Simulation results

Simulations are run for 2800 seconds. We use batch means method to obtain confidence intervals. The method of batch means splits a simulation run into several sub-runs. It records the means of each sub-run. Confidence intervals (95%) are shown with vertical bars in the graphs.

1) Packet delivery fraction (PDF): Figure 1, 2 and 3 compare the packet delivery metric of each of the five protocols in terms of mobility and number of connections.

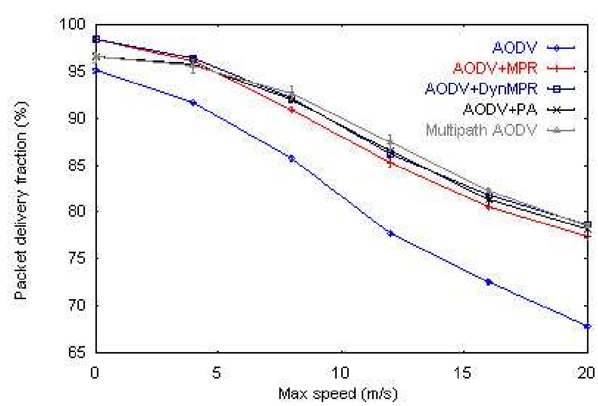


Fig. 1. PDF vs max speeds (scenario1)

In Figure 1, we consider scenario 1 (see Table.I). We note that AODV exhibits the smallest Packet delivery fraction. We note that the four proposed protocols enhance AODV performances especially at higher speeds. In Figure 2, where scenario 2 is considered, we note that AODV+MPR performs worse than AODV at high speeds

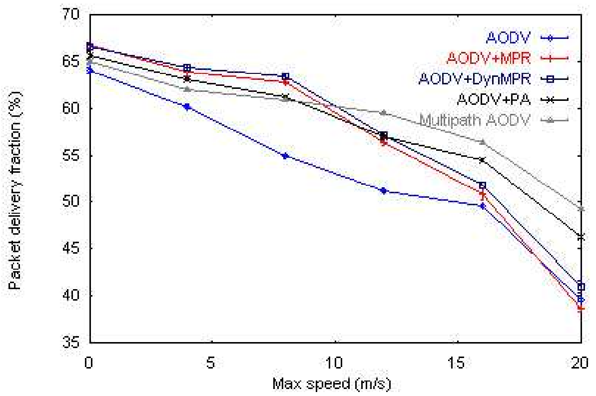


Fig. 2. PDF vs max speeds (scenario2)

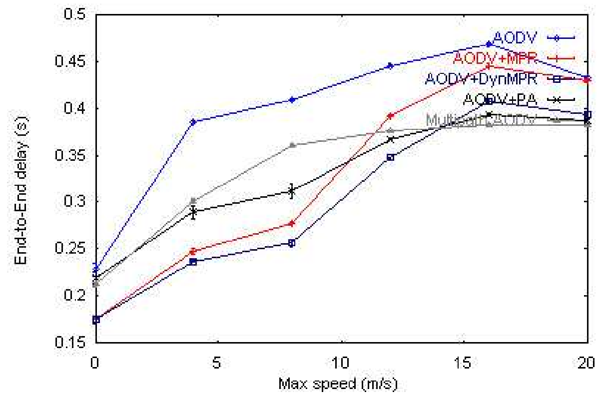


Fig. 4. End-to-End delay vs max speeds (scenario2)

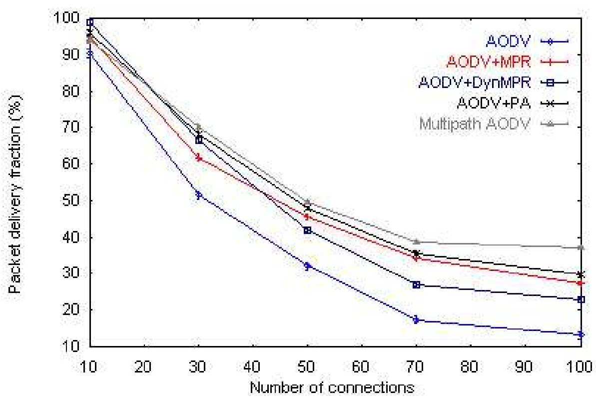


Fig. 3. PDF vs CBR connections (scenario3)

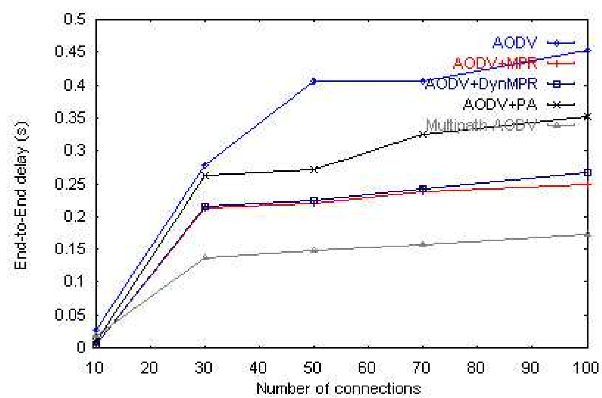


Fig. 5. End-to-End delay vs CBR connections (scenario3)

(from max speed 18m/s). As a matter of fact, at high speeds, AODV+MPR could maintain obsolete MPR lists: the two hop topology, maintained by each node, may change frequently, so these nodes could use an incorrect MPR lists to forward packets. But, AODV+DynMPR performs better than AODV because it uses a variable period to send its Hello messages and hence catching up better the topology changes.

We show (in Figure 3) that PDF degrades with increasing number of connections. For a smaller number of connections, the difference between all protocols is not quite noticeable. However, with the increasing number of connections, multipath AODV tends to perform relatively better . This shows that Multipath AODV, thanks to finding multiple paths, has a better ability to handle broken link problems.

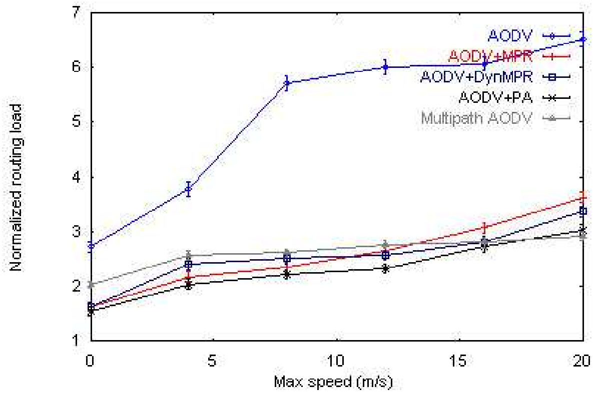
2) End-to-end delay: As regards the end-to-end delay we note in Figure 4 (where scenario 2 is considered) that AODV incurs the largest delay. AODV with Dynamic MPR exhibits the smallest end-to-end delay at low speeds; in fact, all packets destined for the one or two hop neighbors are routed directly. However at high speeds, Multipath AODV offers the best end-to-end delay performance because it is able to react quickly following broken link detects.

We show in Figure 5 that the difference between delays of all protocols is visible at high number of CBR sources. Multipath AODV offers a smallest delay (0,17s at 100 CBR connections).

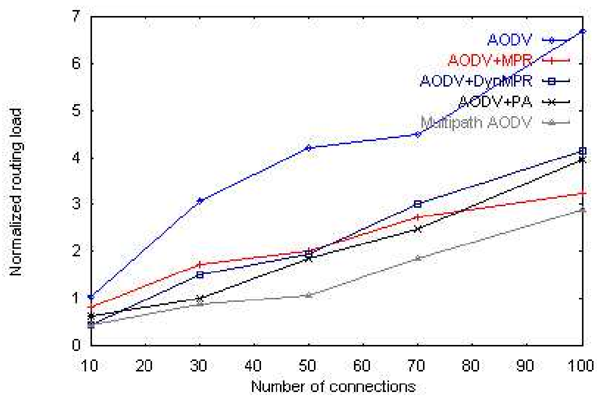
3) Routing Overhead: Figure 6 represents variation of routing overhead with varying mobility or number of CBR connections. AODV provides much higher routing overhead for all scenarios: for example, at 12 m/s AODV sends 6 routing messages (on the average) to receive one data packet. However, AODV+DynMPR provides the lowest routing overhead at lower speeds and number of connections. AODV+DynMPR sends directly all packets destined for neighbors within a 2 hop zone without sending any RREQ or other control messages. Multipath AODV performs the best at high speeds and for large number of connections.

D. Synthesis

At this stage we summarize the main results of our simulations in Table. II (where A and C are respectively



(a) Normalized routing load vs max speeds (scenario2)



(b) Normalized routing load vs CBR connections (scenario3)

Fig. 6. Routing overhead metrics

	Low speeds	Low loads	High speeds	High loads
AODV	D	D	D	D
AODV+MPR	B	B	C	C
AODV+DynMPR	A	A	B	B
AODV+PA	C	C	C	C
Multipath AODV	C	C	A	A

TABLE II
SYNTHESIS

the highest and the lowest score of improvement of AODV).

At lower speeds and/or lower number of CBR connections, AODV+DynMPR performs the best ("A"). Dynamic MPR feature reduces considerably the routing overhead; some routes are immediately available when needed. But, at higher speeds nodes maintain obsolete topology graph. Thus nodes may establish erroneous routes.

Multipath AODV enhances the performances of AODV protocol mainly at high speeds and/or high loads (Best performances "A"). At higher link failure frequency, some protocols initiate another route discovery process to reach destination node. This process adds an additional delay and routing overhead. However, Multipath AODV initiates a new route discovery when all paths, available in a routing table, fail. At lower speeds, Multipath AODV adds unnecessary routes because, in this case, there are a fewer number of broken links.

AODV with path accumulation enhances the AODV performances but it cannot exceed those of Multipath AODV or AODV+DynMPR (poor improvements "C"). In fact, path accumulation enables to maintain additional routing information in node routing table, so it can respond to RREQ messages without initiates any routes discoveries process. But, at dynamic topology frequency and/or high loads, path accumulation does not have any processes that handle frequently broken links.

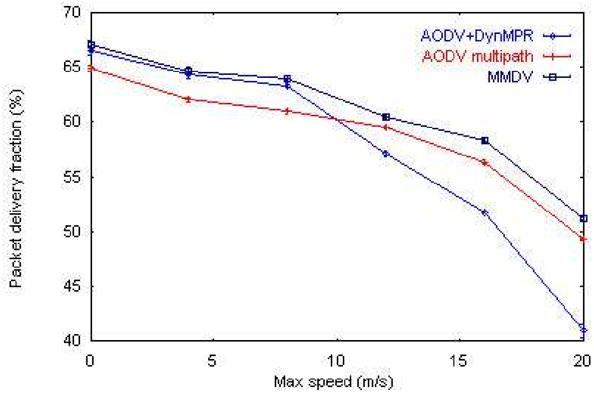
We note that the two added mechanisms Dynamic MPR and Multipath are extremely important. They exhibit overall better results under various conditions. Hence, the main idea of our proposer is the integration of these two features in a unique routing protocol, which will be called thereafter Multipath and MPR based AODV (MMDV).

VI. MULTIPATH AND MPR BASED AODV (MMDV)

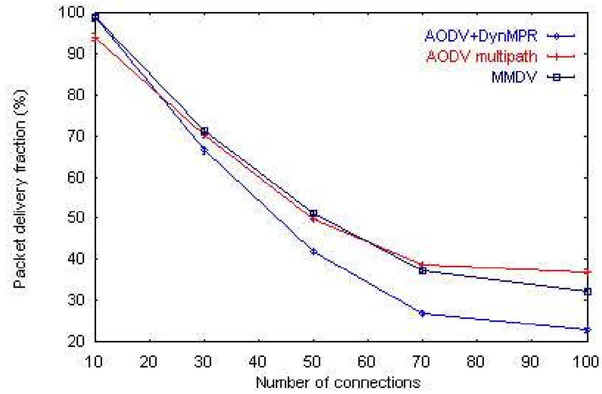
MMDV integrates dynamic MPR and multipath to AODV protocol. MMDV is a hybrid routing protocol: it sends proactively Hello messages to store routes for two hop neighbor nodes and compute MPR lists. It computes all other routes only when needed (reactively). Moreover, MMDV finds multiple and "disjoint" paths between a source and a destination in a single route discovery process. To evaluate MMDV performances, we implemented and simulated this protocol using previous scenarios (Table.I). We compare our protocol with the two previously proposed "single feature improvement": AODV+DynMPR and Multipath AODV. Figure 7 compares the packet delivery fraction and the end-to-end delay metrics of the three protocols with varying mobility and connections. MMDV offers the best PDF for all speeds (Figure 7 (a)). Higher packet delivery fraction with MMDV is achieved because:

- availability of routes to all destinations in the two hop zones.
- availability of alternate routes to send packets when one route fails.

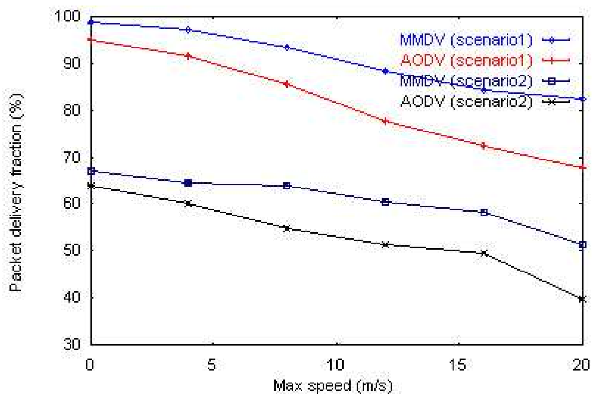
However the delivery performance of three protocols degrades with increasing node mobility. With regards to the traffic MMDV (Figure 7 (b)) behaves practically better most of the time except at large number of CBR connections it is slightly outperformed (32%) by Multipath AODV (36%). In Figure 7 (d) and (e) we



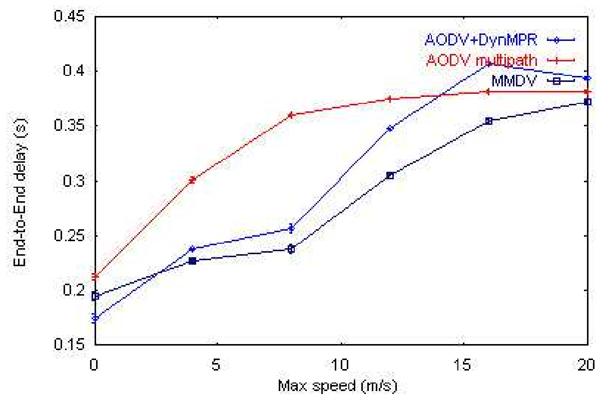
(a) PDF vs max speeds (scenario2)



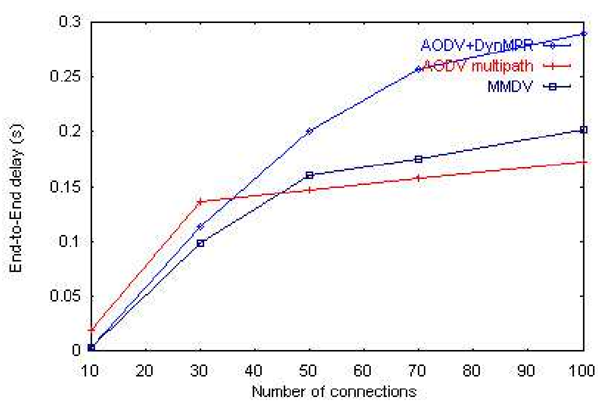
(b) PDF vs CBR connections (scenario3))



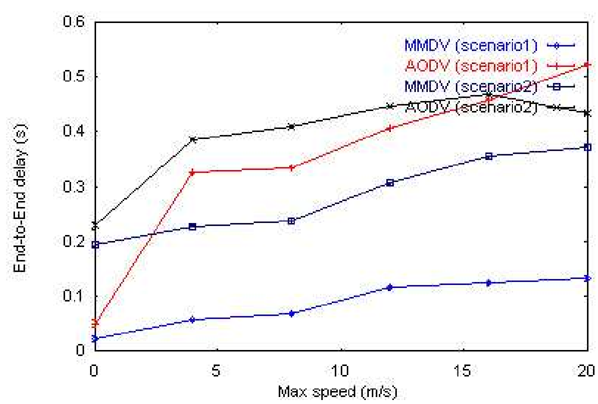
(c) MMDV vs AODV delivery performance



(d) End-to-End delay vs max speeds (scenario2)



(e) End-to-End delay vs CBR connections (scenario3)

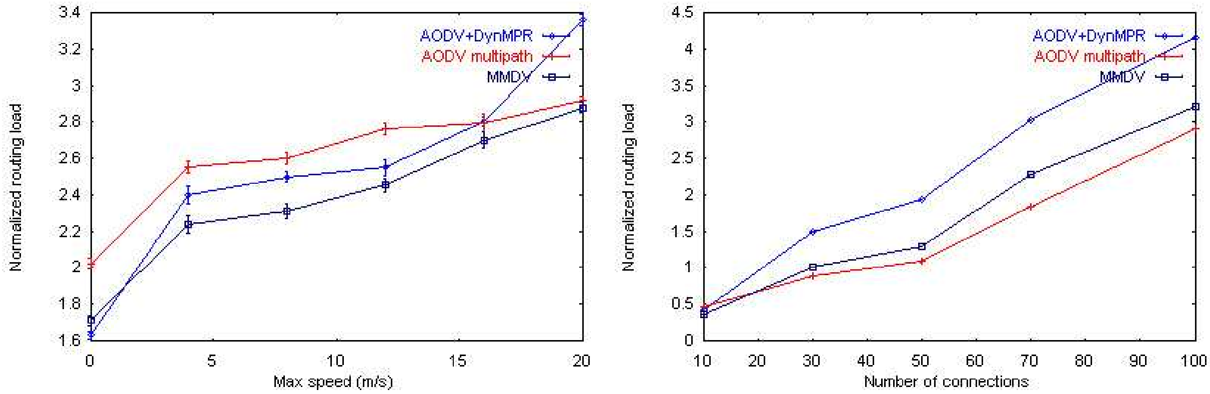


(f) MMDV vs AODV delay performance

Fig. 7. Packet delivery and end-to-end metrics

show the end-to-end delay performance respectively as a function of node mobility and of the number of connections. The performance of the three protocols degrades with increasing node speeds or number of connections. Moreover, with smaller speeds and/or smaller number of connections, the difference between these protocols is not noticeable. However, with the increase number of connections, MMDV tends to perform relatively better . This demonstrates that MMDV, by combining both features Dynamic MPR and multipath, has a better ability to handle overload with large number of connections. Moreover, in Figure 7(c) and (f), we note that MMDV performs better than AODV: with increasing node speeds, the improvements are quite noticeable for both network scenarios.

Figure 8 demonstrates that MMDV significantly reduces the routing overhead since it reduces the number of route discovery and the RREQ flooding. Note that MMDV has many mechanisms to reduce congestion at high loads.



(a) Routing load vs max speed (scenario2)

(b) Routing load vs CBR connections (scenario3)

Fig. 8. Routing overhead metrics

VII. CONCLUSION & PERSPECTIVES

In this paper, we have proposed a hybrid protocol called MMDV. It extends the AODV protocol with a dynamic MPR and multiple paths. We have studied the performance of MMDV as compared to the 4 single feature adaptations of AODV (AODV+MPR, AODV+DynMPR, AODV+PA, Multipath AODV) using NS-2 simulations under varying mobility and traffic scenarios. Merging DynMPR and multipath optimisation offers a significant reduction in delay and improve the packet delivery fraction. It also improves the routing overhead by reducing the frequency of route discovery processes. However, this protocol cannot mitigate congestion and collisions at high loads and high node density. Several additional issues of the MMDV protocol require further investigation. We propose to study the influence of node density on MMDV performances. We propose, also, to limit exchanges of network topology control messages by using a prediction model of node displacements. In this study, we only evaluated protocols using random waypoint mobility model and CBR/UDP traffic. We propose, also, to use other mobility models and TCP traffic to evaluate the performance of MMDV.

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