An Optimized Polymorphic Hybrid Multicast Routing Protocol (OPHMR) for Ad Hoc Networks

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***Abstract*— We propose in this paper, an optimized, polymorphic, hybrid multicast routing protocol for MANET. The protocol proposed is based on the principle of adaptability and multi-behavioral modes of operations. It is able to change behavior in different situations in order to improve certain metrics like maximizing battery life, reducing communication delays, improving deliverability, etc. This new polymorphic protocol attempts to benefit of the high efficiency of proactive behavior and the low cost of network traffic of the reactive behavior, while being power, mobility and vicinity density aware. The protocol is augmented by an optimization scheme, adapted from the one proposed for the optimized link state routing protocol (OLSR) in which only selected neighbor nodes propagate control packets to reduce the amount of control overhead. Extensive simulations and comparison to peer protocols demonstrated the effectiveness of the proposed protocol in improving performance and in extending battery power longevity.**

I. Introduction

Wireless ad hoc networks are known not to rely on any fixed infrastructure, where the Mobile Nodes (MNs) are self-organizing and cooperating to ensure routing of packets amongst themselves. Routing protocols for ad hoc networks can be classified broadly as either proactive, reactive or hybrid.

Proactive protocols continuously exchange network topology information so that nodes could constantly monitor topology changes and use that knowledge for efficient, low latency data transmission.

Common proactive routing protocols include the Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) [12], which is a well-known distance vector routing protocol that uses a destination sequence to help find a route to destination. The Optimized Link State Routing (OLSR) is a link state routing protocol that uses the multipoint relay mechanism to reduce the amount of the period update packets [2]. The Multicast Optimized Link State Routing (MOLSR) [6] is a multicast extension of the OLSR protocol.

Since ad hoc networks have no fixed infrastructure, topology updates occurs more frequently than static networks, thus, most of the topology stored by the nodes may get stale and useless very quickly. Moreover, with the limitation of the traffic channel capacity and limited battery life of MNs, pure proactive protocols generate the large amount of control packets required by the proactive behavior that affects the battery longevity of the MNs and restricts the throughput on the channel.

Hence, reactive protocols were introduced to remedy to the above shortcomings. Reactive protocols adopt a *lazy* approach to communication requirements where nodes react only on-demand to data transmission requests and perform path finding operations only when needed.

The most common reactive protocols include the Ad hoc On-Demand Distance Vector Routing (AODV) [11] which uses the Request-Reply method to determine the path to destination. The Dynamic Source Routing (DSR) [1] is another one that uses a source based routing mechanism to determine path and send data. The On-Demand Multicast Routing protocol (ODMRP) [16] is an efficient Multicast routing protocol that uses a mesh strategy for fast building of the multicast tree to react better to transmission requests.

It is a well-known fact now that pure proactive or reactive protocols are known to perform well only in a limited range of a wide operational conditions and network configurations. Since different protocols are suited for different regions of the ad hoc network design space, combining them into a single framework constitutes a useful approach to capitalize on each protocol's strengths. The challenge in protocol behavior *hybridization* [14] is the ability to define proactive and reactive behaviors to suit an ever wider range. An elegant illustration of such protocols consists in the Multicast Zone Routing Protocol (MZR) that is based on Zone Routing concept [3]. The MZR builds up a zone around each MN to delimit the range of its proactive behavior. It performs periodic updates within the defined zone. Other proposed hybrid protocols include the Shared Tree MZR [13], and the Independent Zone Routing (IZR) [14], recently proposed, to name only a few.

Beside protocol hybridity, another no less sensitive issue to consider in the design of routing protocols for Mobile Wireless Ad hoc Networks (MANETs), is power efficiency with regards to the MNs' power usage. Most of the power efficient protocols proposed in the literature [7] [15] [9], were focused on controlling the construction of the forwarding path so that it includes nodes that have the highest residual battery power among different possible paths or to consume the least energy along the path. In many of these papers, the min-max algorithm was used as a mean to find the best path with maximum residual power.

Thus, in this piece of work we propose a novel routing protocol that attempts to combine the three above design dimensions, namely, *hybridization*, *adaptability* and *power*

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efficiency. To illustrate the above claim our proposed protocol was empowered with different modes of operation that are either proactive (to a certain extent) or reactive. The protocol dictates that a MN chooses a mode of operation depending on different considerations of power residue, mobility level and/or vicinity density level. Thus, it combines the issue of power efficiency with that of better performability (with regards to lower latency and reduced overhead) in an adaptive manner.

The backbone of the protocol is based on the ODMRP protocol [16] that is used to drive its reactive behavior. In addition, the ZRP protocol [5] was chosen as the driver of its proactive behavior. The protocol belongs to the class of hybrid and adaptive protocols that we tag as *polymorphic* protocols [10].

Furthermore, the protocol is augmented by an optimizing scheme, that was adapted from the Optimized link State Routing (OLSR) protocol to fit in the ODMRP in order to help decrease the amount of control overhead that it produces. The protocol is named as the Optimized Polymorphic Hybrid Multicast Routing (OPHMR) Protocol.

In the remainder of this paper, Section II introduces formally the polymorphic algorithm driving the protocol's behavior. A simulation based performance evaluation is given in Section III. Section IV concludes the paper.

II. Protocol Description

A. The Polymorphic Algorithm

The polymorphic concept governing this was proposed in [10]. It is based on defining four different behavioral modes of operation, two power level thresholds, one mobility level threshold and one vicinity density threshold.

The different threshold values for power are denoted (P_TH1 and P_TH2, where $P\_TH1 > P\_TH2$). The mobility speed threshold is denoted as (M_TH) and the vicinity density threshold is denoted as (V_TH). These will dictate the choice of the right behavioral mode that an MN can select and engage into.

The four behavioral modes of operation are:

1) Proactive Mode 1 (*PM1*): when an MN is in *PM1*, it periodically updates its neighborhood topology and multicast information by sending out an update packet with the Zone Radius R set as the Time-To-Live (TTL) and the update interval is set to a tunable parameter value i.
2) Proactive Mode 2 (*PM2*): the behavior of an MN in *PM2*, is similar to the one of an MN in *PM1*, however, the update interval is set to $2 \times i$ (a less proactive state).
3) Proactive Ready Mode (*PRM*): a MN in *PRM* does not send out update packets but maintains the NRT table using information stored in the received packets.
4) Reactive Mode (RM): a MN in *RM* does not send out update packets, and discards any received update packets.

The Polymorphic algorithm driving the OPHMR protocol includes two parts: the main algorithm and the mobility Speed Routine.

The main algorithm is mainly concerning the behavior of the node under different power thresholds. In OPHMR when a node's power level is high ($> P\_TH1$), the node is set to *PM1* mode, so that it can be able react faster to topology changes.

On the other hand, when the node's power level is quite low ($< P\_TH2$), the node is forced into the *RM* mode in order to extend its battery life.

When a node's power level is within P_TH1 and P_TH2, the mobility routine is performed to help determining the node's behavior.

When the mobility speed level of the MN gets high ($> M\_TH$), the node is required to behave proactively in order to maintain better connectivity and awareness of the topology changes. On the other hand, the mobility speed level of the MN is quite low, the MN could in *RM* to save battery life.

When the mobility speed is high, we also need to consider the node's vicinity density level. When it is high ($> V\_TH$), it means that there are many nodes within the power range of the node and more update packets would consume the channel capacity and jam the network with higher probability within proactive modes. Thus, the node is forced into PRM (semi-proactive) behavior. The PRM state is more conservative with regards to proactiveness. And when the vicinity level is low, the MN are in *PM2* since the mobility speed is high.

When an MN switches its behavior, it generates a notification packet and broadcasts the packet to all of its one hop neighbors. When a node receives a notification that indicates the source node has switched to *PM1*, the lifetime of its corresponding entry is set to $2 \times i$. When a node receives a notification that indicates the source node has switched to *PM2*, the lifetime of its corresponding entry is set to $3 \times i$. When a node receives a notification that indicates the source node has switched *PRM* or *RM*, the lifetime of the corresponding entry is set to $4 \times i$.

B. Routing Issues

As stated above the OPHMR is built using the proactive behavior of the MZR and the reactive behavior of the ODMRP. In addition, the protocol was augmented with the Multipoint Relay (MPR) based optimization mechanism of the OLSR [2] so as to reduce the amount of control packets forwarded.

Proactive Behavior:

When a node is in *PM1* or *PM2* it sends out periodically update packets which has a TTL set to the Zone Radius. When a node receives an update packet, if it is in *PM1*, in *PM2* or in *PRM*, it saves the information in the packet into the one hop Neighborhood Table (NTable), reduces the TTL by 1 and forwards the packet.

Reactive Behavior:

When a node have packets to send to a multicast group or wants to join a multicast group, it sends out a *Join_Request* packet and waits for its *Join_Reply* from a destination node. Only nodes that are within the destination multicast group can send out *Join_Replies*, and such nodes need to update their Multicast Routing Table (MRTable) to maintain the multicast group information. If an intermediate node (including the source node) has entries in its NTable that belongs to the destination multicast group, it unicasts the *Join_Request* to the nodes registered in those entries. When the source node receives a *Join_Reply*, it updates its MRTable and begins data transmission.

C. Optimized Forwarding Mechanism

The multipoint relay (MPR) based mechanism of the OLSR [2] is used to perform an optimized forwarding Mechanism.

In our protocol each node maintains a two hop Neighborhood Table (*2NTable*). The 2NTable is used to calculate the MPR information. When a node receives an update packet, it uses the neighborhood information in the packet to calculate the two hop neighborhood and updates the corresponding entries in the 2NTable.

MPR nodes are selected to forward broadcast messages during the flooding process. Each node has its MPR set and will broadcast its MPR information in the periodic update packets. When propagating the periodic update packets only the MPRs forward the update packets.

We use the heuristic algorithm proposed for the OLSR to compute the MPR.

MPR Computation [2]: We give the following definitions.

N: represents the subset of neighbors of the node.

N2: represents the set of two hop neighbors of the node.

D(y): The degree of a one hop neighbor node *y* (where *y* is a member of *N*). It is defined as the number of symmetric neighbors of node *y*, excluding all the members of *N* and excluding the node performing the computation.

The proposed heuristic is as follows:

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1) *Start with an MPR set made of all members of* N.
2) *Calculate* D(y), *where* y *is a member of* N, *for all nodes in* N.
3) *Add to the MPR set in* N, *the nodes that provide reachability to a node in* N2. *Remove the nodes from* N2 *which are now covered by node in the MPR set.*
4) *While there exist nodes in N2 which are not covered by at least one node in the MPR set:*
   a) *For each node in* N, *calculate the reachability to* N2*;*
   b) *Select as a MPR the node which provides reachability to the maximum number of nodes in* N2. *In case of multiple nodes providing the same amount of reachability, select the node whose* D(y) *is greatest as the MPR. Remove the nodes from* N2 *which are now covered by node in the MPR set.*
5) *A node's MPR set is generated from the union of the MPR sets for each interface. If all nodes in* N2 *are still covered by at least one node in the MPR set excluding node* y, *then node* y *may be removed from the MPR set.*

III. Simulation and Sensitivity Analysis

A. Simulation Scenarios

We have performed a simulation based comparison of the OPHMR against the P_ZODMRP [10], the ODMRP and the MOLSR. The simulation of these protocols was implemented using the GloMoSim library [8]. The two parameters, R and i, were pre-configured for OPHMR, where R denotes the Zone Radius and i is the tuning factor used for determining the update interval and table entries' lifetime.

Nodes are placed randomly within a 2000m by 2000m area. The radio propagation range for each node was set at 225m, and the channel capacity was set at 2Mbps. The IEEE 802.11 MAC was used as the MAC protocol. The traffic type generated is a constant bit rate (CBR), and the size of the data packet is set to 512 bytes. The random waypoint mobility model was used. For power consumption, L.F. Feeney's model [4] was adopted and implemented in Glomosim. We have performed two sets of simulations. In the first set, the initial power level of all the nodes was set to the full power.

In the second set, variable power levels were assigned to the nodes. This setting is done to validate the effect of the proposed protocol when in the course of the simulation some nodes will die off due to lack of battery power. We have set 20% of the nodes to have 100% power, 20% of the nodes have 90% power, 20% of the nodes have 80% power, and 40% of the nodes have 75% power. The simulation time was set to 1000s. Several metrics were used in the performance evaluation, which include, the packet delivery ratio, the average end-to-end packet transmission delay, and the average percentage of power conservation.

The above metrics were evaluated against mobility speed, network traffic load and the total number of nodes.

B. Sensitivity Analysis

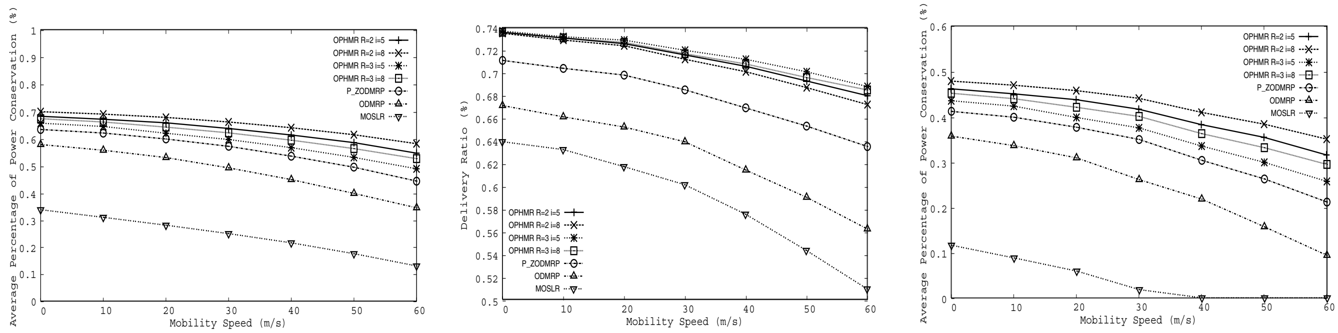
1) Mobility Speed:

Experimental Scenario:

In this scenario, 150 nodes were spread within the defined area. Node mobility speed was varied from 0m/s to 60m/s. The traffic load was set to 20 packets per second, and 40 multicast members and 10 source nodes were considered.

Fig. 1(a) shows the average percentage of power conservation against mobility speed, where nodes are initialized with full power. Because of its embedded MPR mechanism, the OPHMR could save up more power. With their polymorphic behavior, the OPHMR and the P_ZODMRP protocols were able to achieve better performance than non-polymorphic ones. When the speed is at 60m/s, the OPHMR was able to save about 20% more of power usage than the ODMRP. In addition, for the OPHMR the least proactive behavior (with $R = 2$ and $i = 8$) was beneficial for power conservation, and the most proactive (with $R = 3$ and $i = 5$) one resulted in less power savings.

Fig. 1(b) shows the performance of protocols with varied initial power level setting. We can see that again, the OPHMR has the best performance among all four protocols. When the



(a) Average percentage of power conservation vs. mobility speed with full initial power

(b) Delivery ratio vs. mobility speed with variable initial power

(c) Average percentage of power conservation vs. mobility speed with variable initial power

Fig. 1. Performance against mobility speed

speed reaches 60m/s, the OPHMR could score 13% advantage over the ODMRP's performance.

Fig. 1(c) shows the average percentage of power conservation. Since the OPHMR could adaptively change its behavior to meet network conditions, nodes in the OPHMR could have a longer battery life and could have around 25% increase over the ODMRP when the mobility speed is at 60m/s.

2) Nodes' Vicinity Density:

Experimental Scenario:

The total number of nodes within the defined area was varied from 50 to 500. Each node moves constantly with a predefined speed of 20m/s. The traffic load is 20 packets per second. Again in this scenario, we had 40 multicast members (forming a single multicast group) and 10 source nodes.

Fig. 2 shows the performance of the protocols against vicinity density. Fig. 2(a) shows the delivery ratio, and Fig. 2(b) shows the average end-to-end delay versus nodes vicinity density with full initial power. We can see that when the total number of nodes is low, the proactive behavior in the polymorphic protocols could increase the performance with the knowledge of the neighbor nodes. When node vicinity density is high, the reactive behavior of the polymorphic protocols could reduce the amount of the control packets while guaranteeing a good performance. In addition, for higher vicinity density the OPHMR superiority over both the P_ZODMRP and the ODMRP was clear. This is mainly due to the MPR based optimization scheme.

Another general observation related to effect of node density, is that (which is also intuitive that) there is an optimal number of nodes per area that guarantees the best performance. This can be used as a guideline for setting the vicinity density threshold value.

Fig. 2(c) shows the average power conservation against nodes vicinity density with full initial power. The power usage of all the protocols increases with the increase of the total number of nodes. Since the polymorphic protocols usually change their behavior based on node vicinity density, the performance of the polymorphic protocols are better than other protocols. The OPHMR could save up about 15% power usage than ODMRP when the total number of nodes is 300.

Fig. 2(d) shows the delivery ratio, and Fig. 2(e) shows the average end-to-end delay as a function of nodes vicinity density with variable initial power. We can observe that with the nodes vicinity density increases, the performance of the pure reactive protocol to decrease sharply, especially with varied initial power level. In Fig. 2(e), again the superiority of the OPHMR over both the P_ZODMRP and the ODMRP for higher vicinity density is again confirmed. Again the gain can be attributed to the MPR based optimization scheme adopted.

Fig. 2(f) shows the average power conservation against nodes vicinity density with variable initial power. From the plots, we can see that due to the polymorphic behavior of the OPHMR, it could save up more power usage and extends the battery life of the nodes. When the total number of nodes is 200, the average power level of the MOLSR reaches zero. When the total number of nodes is 400, the average power level of the ODMRP and the P_ZODMRP reaches zero, but the OPHMR could still prolong the battery life of some nodes up to a vicinity density of 500 nodes.

3) Network Traffic Load:

Experimental Scenario:

There are 150 nodes spread within the defined area and the number of packets the sources send was varied from 1 to 70 packets per second. Each node moves constantly with a predefined speed of 20m/s. The same setting of 40 multicast members and 10 source nodes was maintained in this scenario as well.

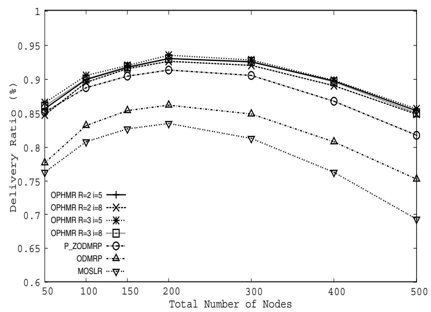
Fig. 3(a) plots the average power conservation against traffic load with full initial power. As we can see, higher update intervals and lower zone radius do benefit power conservation. Furthermore, the OPHMR clearly outperformed the P_ZODMRP and the ODMRP, and the gain in performance is clearer at heavy load. The MOLSR was great loser in all the simulations.

Further plots shown in Fig. 3(b) and 3(c) have also highlighted the performance advantages of OPHMR in other considered situations.

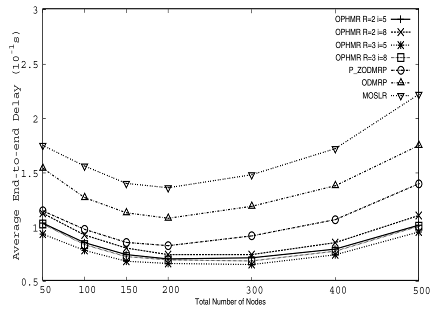
4) Performance Variation over Different Threshold Settings:

Experimental Scenario:

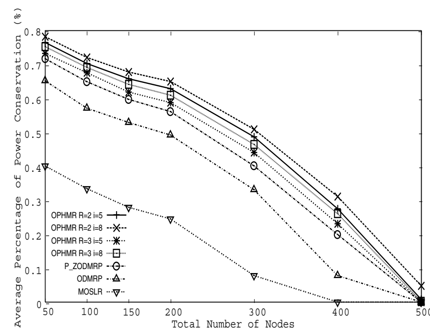
In the previous simulation, the threshold values are fixed, P_TH1 is 85%, P_TH2 is 50%, V_TH1 is 6 and M_TH is



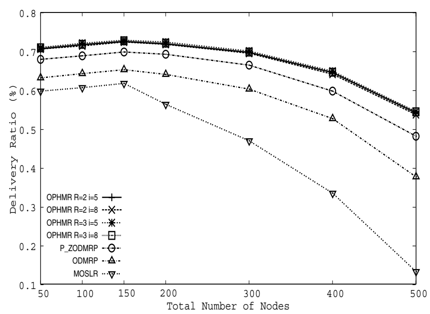
(a) Delivery ratio vs. nodes vicinity density with full initial power



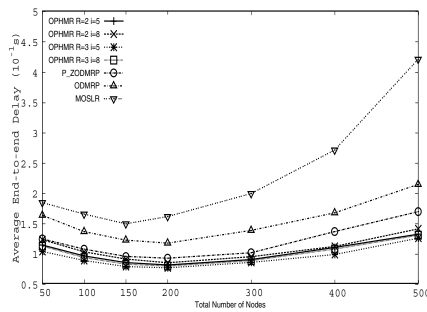
(b) Average end-to-end delay vs. nodes vicinity density with full initial power



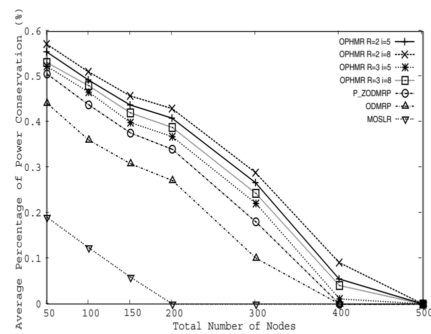
(c) Average percentage of power conservation vs. nodes vicinity density with full initial power



(d) Delivery ratio vs. nodes vicinity density with variable initial power

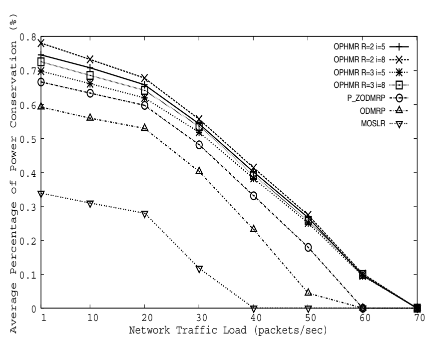


(e) Average end-to-end delay vs. nodes vicinity density with variable initial power

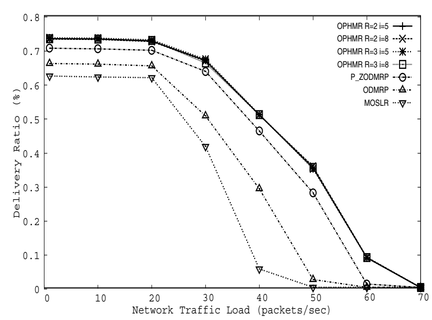


(f) Average percentage of power conservation vs. nodes vicinity density with variable initial power

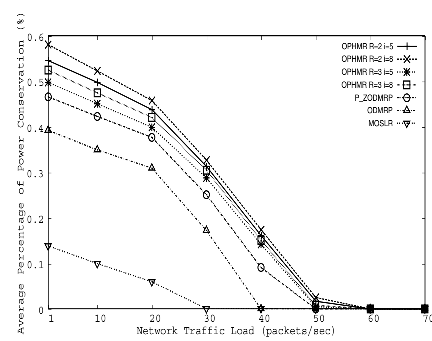
Fig. 2. Performance against nodes vicinity density



(a) Average percentage of power conservation vs. traffic load with full initial power



(b) Delivery ratio vs. traffic load with variable initial power



(c) Average percentage of power conservation vs. traffic load with variable initial power

Fig. 3. Performance against traffic load

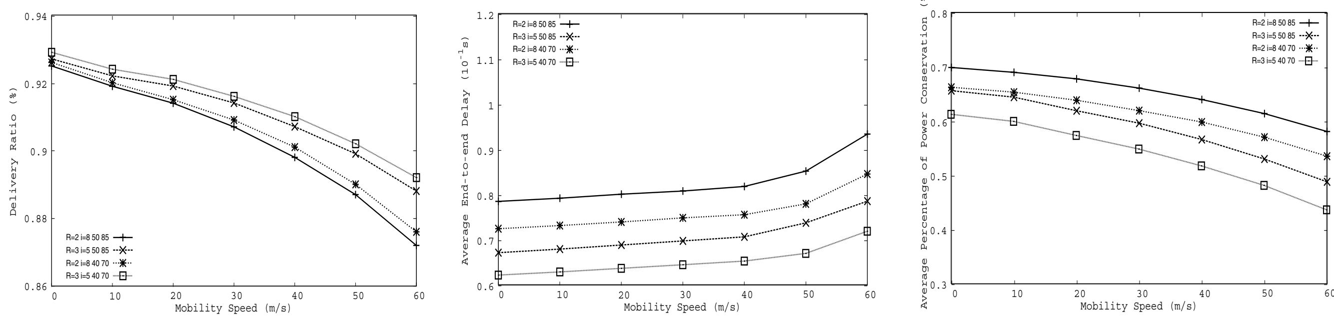
20m/s. In this scenario, we conducted a series of simulation with another settings and examined the effect of different threshold settings. In the new setting, P_TH1 is 70%, P_TH2 is 40% and the other two values are the same with previous one. In this scenario, 150 nodes were spread within the defined area. Node mobility speed was varied from 0m/s to 60m/s. The traffic load was set to 20 packets per second, and 40 multicast members and 10 source nodes were considered.

Fig. 4(a) shows the delivery ratio versus the mobility speed with different threshold values. Fig. 4(b) shows the average end-to-end delay versus mobility speed and the threshold values are different. Fig. 4(c) shows the average percentage of power conservation against mobility speed, where there are different threshold values.

IV. Conclusion

We have presented in this paper an optimized, polymorphic, hybrid multicast routing protocol for MANET. The protocol design is a novel way of combining three dimensions in protocol design, namely, *hybridity*, *adaptability* and *power awareness*. With regards to hybridity the protocol attempts to take benefit of the high efficiency of proactive routing in reducing response time to transmission requests, and of the reduced control overhead offered by reactive routing.

We have applied this concept to the P_ZODMRP protocol (proposed earlier) and enhanced it with an optimized forwarding mechanism borrowed from the OLSR protocol and thus were able to construct a better performing, polymorphic protocol named the OPHMR. When compared to the ODMRP,



(a) Delivery ratio vs. traffic load

(b) Average end-to-end delay vs. traffic load

(c) Average percentage of power conservation vs. traffic load

Fig. 4. Performance against mobility speed with different threshold values

the P_ZODMRP, and the MOLSR the OPHMR clearly outperformed them in most situations. The superiority lies in the fact that on the long run, the protocol was able to extend battery life and enhance survivability of the mobile Ad Hoc nodes. Hence, it has increased data deliverability ratio and decreased latency, while keeping the control packet overhead at acceptable levels.

The design approach we have adopted in this paper is generic in nature and the choice of the right protocol (proactive or reactive) to use will depends on its proven performance and on its applicability to the situation where the protocol is deployed.

We think that this new concept of polymorphic protocols constitutes the next trend in the design of efficient multi-behavioral routing protocols for wireless, power-constrained networks such as MANETs.

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