Ad hoc routing protocols with multipoint relaying

Géraud Allard, Philippe Jacquet and Laurent Viennot

Institut National de Recherche en Informatique et en Automatique
Unit de recherche INRIA Rocquencourt
Domaine de Voluceau - B.P.105
78153 Le Chesnay Cedex, FRANCE

Multipoint relays have been introduced in the proactive protocol OLSR in order to optimize the flooding overhead of control traffic. In this paper we show that multipoint relaying can be used as well in reactive protocols in order to save overhead in route discovery. To this end we specify a very simple reactive protocol called MPRDV (Multipoint Relay Distance Vector protocol). In MPRDV route requests and route replies are all flooded via Multipoint Relays (MPR). They both open routes to their originators. Route repairs are performed by new route request flooding.
We show with simulation that the use of MPR flooding does not lead to the control traffic explosion that we experience with basic reactive protocol in presence of frequent route discovery and failure.
MPR provide also another optimization since it tends to offer optimal routes to data packets and so increases the protocol performances.

---

1 Introduction

Mobile ad hoc networks are emerging as a very hot issue in telecommunication. They have numerous applications in several fields, including both military and civilian use. Since the effective range of high capacity radio link are limited (IEEE 802.11a, g), the capacity of packet relaying inside the network is a key component of such network. Mobile ad hoc routing has received tremendous quantity of intention since the opening of the IETF working group MANET. The main difficulty in ad hoc routing, compared to classic routing in wired environment, is that wireless networks must support much more mobility for much less channel capacity. In this case it is very important to limit the control traffic overhead of the routing protocols. The four routing protocols proposed for standardization are dispatched in two classes:

1. Proactive protocols: based on periodic exchanges that proactively update the routing tables to all possible destination, even if no traffic goes through. The two proactive protocols are OLSR [ACJ+03] and TBRPF [OTL03].

2. Reactive protocols: based on on-demand route discoveries that update routing table only for the destination that have traffic going through. The two reactive protocols are AODV [PBRD03] and DSR [JMH03].

A priori one may think that the proactive approach may generate much more control traffic than the reactive approach. This is not true since the proactive protocols have proposed several optimization to limit their overhead in order to fit the requirement for mobile wireless networks. Among these feature, the OLSR protocol proposes an optimised flooding mechanism based on MPR [LQV02][JLMV01] that minimize the number of retransmissions. In the reactive protocols such as AODV and DSR, the route discovery is based on the classical flooding of a route request originated by the source. In the classical flooding every node

retransmit once the message after having received it. This procedure is particularly heavy in a dense network where the number of redundant receptions may be excessive. In OLSR, the flooding is optimized such that only a subset of the nodes retransmits the message. So that the number of retransmissions is limited even when the network is dense.

If we consider a typical network with 10,000 nodes, each of them having 1,000 neighbors, the classical flooding would lead to 10,000 retransmissions, and the optimized flooding may limit this number to 100. One unexpected consequence of classical flooding on dense network is that the abondance of retransmissions concentred on a short period of time may actually put the network in such a stress that it may litteraly ruin the quality of the existing link. In such situation a single route discovery in a reactive protocol may kill several active routes and generate more route discovery for route repair. If the 10,000 nodes network working with a reactive protocol, breaks 10,000 active routes per update period, then the route re-discovery procedure would generate 10,000 flooding and causes the transmission of 10^8 messages at least per update periods.

In this paper we present an alternative to reactive protocols, called MPRDV, that uses an optimized flooding mechanism for route discovery. In order to use this optimized mechanism, the nodes must perform a proactive control in order to know their two-hop neighborhood. This can be done via the reception of hello messages generating by the nodes and containing their neighbors list. Since two nodes are neighbors when they can see each other address in their respective hellos, this is a very straightforward procedure. The cost of the proactive neighbors control is not negligible but is far less important than the cost of classical flooding, in particular when the condition of traffic and mobility causes too many route discovery procedure.

This work is organized as follow. In section 2 we describe the multipoint relaying process and how it is applied in OLSR protocol, in Section 3 we depict the MPRDV protocol and in section 4 simulation results are exhibited and discussed.

2 Neighbor sensing Multipoint selection and relaying

2.1 Neighbor sensing

Mobile nodes perform neighbor sensing by periodically transmitting hello messages on all their interfaces. The hello messages contain the list of the neighbor nodes heard by the originator of the hellos. The heard neighbor nodes of a given node consists of the originators of the hellos received by this given node within a certain interval of time. If the number of heard neighbor nodes is too large to fit a single hello message, then several hellos will be used per period with the rule that all heard neighbor nodes must have been notified at least once per update period.

By comparing the heard nodes in a hello with its own address a node can determine whether or not it has a symmetrical link with the originator of the hello and build a neighbor table. A neighbor node with symmetric link is called symmetric neighbor. Further we will call it a neighbor node, assuming implicitly that non-symmetric links have been rejected by the neighbor sensing. Many wireless Medium Access Control (MAC) as in IEEE 802.11 need symmetric links in order to transfer data (acknowledged on a per packet basis).

2.2 Multipoint relay selection and relaying

The originator indicates in its hello the nodes with which it has symmetric links. Therefore all nodes are informed of the neighbor nodes of their neighbor and consequently can build two-hop neighbor tables.

Each node must select a Multipoint Relay (MPR) set among its neighbors. The MPR set must cover the two hop neighborhood of the node. The smaller is the MPR set the better it is. Although the optimal MPR set is an NP hard problem, there exist simple heuristics that approach optimality with a good factor [LQV02]. In some network models the number of multipoint relay for a given is $O(\log M)$, where M is the neighbor size of the node [JLMV01].

The multipoint relays of node are indicated in the hello message originated by the node. Therefore each node can build a multipoint relay selector list, *i.e.* the list of neighbors that have selected this node as multipoint relay.

Only MPR are allowed to retransmit a broadcast message. This feature considerably reduces the overhead of packet flooding. The MPR flooding works as follows:

> *A node retransmits the broadcast message only if it has received its first copy from a multipoint relay selector neighbor.*

Notice that the condition *to receive first from a multipoint relay selector neighbor* implies that not all nodes that are MPR of some neighbor will retransmit. In fact in some dense networks nodes has always an non-empty multipoint relay selector set, and without the "first reception" rule, all nodes would retransmit. The first reception rule greatly reduces the number of retransmitter. In some network model the number of retransmitter is $O(\log N)$, when N is the network size [JLMV01].

In OLSR the optimized flooding is used to disseminate the information on local topology. Each node generate a TC message that contains a partial list of neighbor nodes. The TC is forwarded to all nodes via the optimized flooding. Limiting the overhead of link state information dissemination. Another optimization is in the fact that the list of neighbor only contains the neighbors which have selected the node as MPR. OLSR must transmit 10^6 messages per update period, to be compared with the potential of 10^8 with a reactive protocol or with a classical link state protocol. OSPF would need 10^{11} since LSA message must be sent one by one to each neighbor nodes. Of course this example of a 10,000 nodes mobile ad hoc network can be considered to be extremal. But experience shows that the improvement is very significative even for reasonably sized mobile ad hoc networks.

3 Description of MPRDV

The main aim of this protocol is to provide an optimized flooding mechanism to the reactive route discovery messages. MPRDV protocol is divided into two parts :

- neighbor sensing which is carried out apart from any data communication period (proactive approach)
- route discovery which is performed when a source node needs a route to an unknown destination node (on-demand mechanism)

Due to nodes mobility, addition and deletion of wireless links frequently occur and we will see how this issue is addressed in MPRDV and how the links failures can be optimized using link layer notification.
In MPRDV, two packet types have been defined to provide these functionalities : HELLO and ROUTE messages. MPRDV packets share a common header format in which are specified, among other things, message type (HELLO or ROUTE), Time To Live, Hop Count and the Originator address of the message.

MPRDV relies on OLSR techniques of neighbor sensing and Multipoint Relays selection to provide flooding optimization. Neighbor discovery is the keypoint of Multipoint relaying mechanism. Each node *n* periodically broadcasts HELLO messages (every `HELLO_INTERVAL` seconds) describing its immediate neighbors and the status of the links. More precisely, a link to node *m* may be "symmetric" if the link between *n* and *m* is bi-directional, "asymmetric" if *m* can be heard but it is not confirmed that *m* is able to hear *n*, "mpr" if *n* has elected *m* as MPR and "lost" if *n* doesn't receive any informations from *m*. Upon receiving HELLO messages, a node should update its neighbors informations maintained in topology tables. There are four types of topology tables :

- 1-hop table, this table stores informations about one-hop neighbors
- 2-hop table, this table stores informations about two-hop neighbors
- MPR table, this table stores nodes addresses which are elected as MPRs by the node
- MPRS table, this table stores nodes addresses which have elected the node as MPR

When an asymmetric link is discovered its lifetime is set to `CURRENT_TIME + NB_HOLD_TIME`. When a link becomes symmetric, we consider that this link will be symmetric for `NB_HOLD_TIME` seconds and asymmetric for $2\times$ `NB_HOLD_TIME` seconds.

Considering these neighborhood informations, a node *n* is able to compute its Multipoint Relays set [LQV02] which will be the only nodes allowed to retransmit broadcast messages from *n*. Thus, neighbor sensing and MPR calculation provide us an efficient flooding mechanism which is a significant optimization of the pure flooding technique. Since TTL field of HELLO messages is set to 1, they are not retransmitted by the recipients.

In common reactive protocols, pure flooding is used and multiple retransmissions of broadcast messages lead to control traffic explosion. The idea of MPRDV is to take advantage of Multipoint Relays mechanism for route discovery messages flooding. We use ROUTE packets to perform route requests and route repairs. A ROUTE packet basically contains addresses of nodes for which a route should be created.
A node maintain a routing table which contains informations about the known destination nodes (next hop, hop count, etc...). Lifetime of these informations is specified as a protocol parameter (`ROUTE_HOLD_TIME`) and is refreshed every time a data packets are transmitted along this path. Each node also maintains a Sequence Number which is incremented every time a ROUTE message needs to be sent. Including this Sequence Number in ROUTE messages is a common way to provide loop free route creation and to only consider the most recent messages.

Upon receiving data packets, a node *n* checks its routing table for an entry for the destination node. If such an entry exists, data packet is transmitted to the specified next hop. On the other hand, if destination is unknown, *n* broadcasts a ROUTE packet containing the address of the requested destination. Data packets are buffered until a route is created for this destination.
When a node *n* receives a ROUTE message, it first creates or updates a reverse route to the Originator node. Next hop is set to the node from which the ROUTE message have been received (last hop). Routes lifetime is initially set with the parameter `ROUTE_HOLD_TIME`. Then, *n* checks the message to determine if the packet contains its address. If *n* finds its address in the message, it broadcasts an empty ROUTE message (*i.e.* a ROUTE message containing no requested addresses) and then erased its address from the message.
After this phase of addresses processing the message is broadcasted if the following two conditions are satisfied :

- the list of addresses is not empty
- the node *m*, from which the message has been received, has elected *n* as MPR (*i.e. m* is in *n* MPRS table)

Route repairs are also performed by ROUTE messages. MPRDV takes advantage of the proactive neighbor sensing to determine whether a link is valid or not. A symmetric link between *n* and *m* is considered to be broken either if :

- *n* does not receive any informations from *m*
- or the link is explicitly declared as broken in HELLO messages

When a node *n* detects the loss of a neighbor *m*, it sends a ROUTE message containing the addresses of all the nodes n_i for which *n* has a valid route AND *m* is the next hop on this route. The reply and broadcast mechanisms are the same as described above.
We also introduced a link layer detection as AODV-LL in [BMJ+98] which permits to quickly handle route failures. This is a complementary way to provide link failure detection since breakage can only be detected, on link layer, during data packets transmission. We will show in section 3 that this detection increases the protocol performances.

Number of nodes	50
Simulation time	900s
Flat space size	1,500m×300m
Pause time	0s, 30s, 60s, 120s, 300s, 600s, 900s
Number of CBR sources	10, 20, 30, 40
Maximum node speed	$20m.s^{-1}$

Fig. 1: *Simulations parameters*

HELLO_INTERVAL	2s
NB_HOLD_TIME	8s
ROUTE_HOLD_TIME	3s

Fig. 2: *Protocol parameters*

4 Simulation results

We performed several simulations using Network Simulator (NS-2) to compare MPRDV with a reactive protocol using full flooding (AODV) in presence of frequent route discovery and failure (high mobility). We used AODV simulations results exhibited in [BMJ+98] and we took the same simulations parameters for MPRDV simulations as shown on figure 1.

Several protocol parameters in keeping with time must also be defined. Some of them are shown on figure 2. Jitters are added to messages transmission time to cope with synchronization phenomenon and so avoid collisions.

In the following sections, we analyse simulation results concerning routing overhead, data packet delivery, route length and link layer detection influence.

4.1 Routing overhead

Simulation results for MPRDV routing overhead are illustrated on figure 4. We consider all ROUTE and HELLO messages transmissions (including ROUTE messages retransmissions). Each node transmits a HELLO message every 2 seconds and the simulation runs for 900s. Thus, the constant overhead generated by HELLO messages is : $50 \times \frac{900}{2} = 22,500$ *packets*. This value is a limit for global routing overhead when nodes mobility decreases. Since link failures less frequently occur in case of low mobility, the number of ROUTE messages transmissions for route repairs decreases.
But the most important point is the optimization provide by Multipoint Relays. Figure 3 shows simulation results for AODV. The version of AODV implemented in [BMJ+98] uses link layer notification instead of using periodic HELLO messages for link breakage detection. This is the reason why routing overhead tends to 0 for AODV. But for high mobility scenarios we can see a significant decrease of routing overhead for MPRDV, due to MPR optimization. For example with 30 sources and a pause time of 0s AODV reaches 160,000 control packets whereas MPRDV generates only 55,000. We also ran simulations for 40 sources which were not performed in [BMJ+98].

4.2 Data packets delivery

One of the most important parameter is the number of data packets successfully delivered. Results for MPRDV and AODV are presented on figures 5 and 6. We can see that results are quiet similar : for 10, 20 and 30 sources MPRDV and AODV present a fraction of data packets greater than 0.95 tending to 1 while mobility decreases. We do not have any simulation results for AODV with 40 traffic sources but we can see that the data traffic generated implies a heavy concentration of packets which causes collisions and then numerous link breakages. This phenomenon especially occurs in presence of high mobility (*i.e.* pause time is lower than 300s). In case of low mobility, the fraction of data packets becomes normal again.

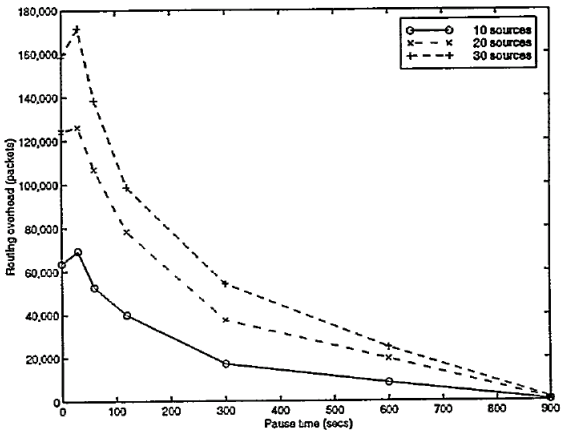

Fig. 3: *Routing overhead as a function of pause time for AODV*

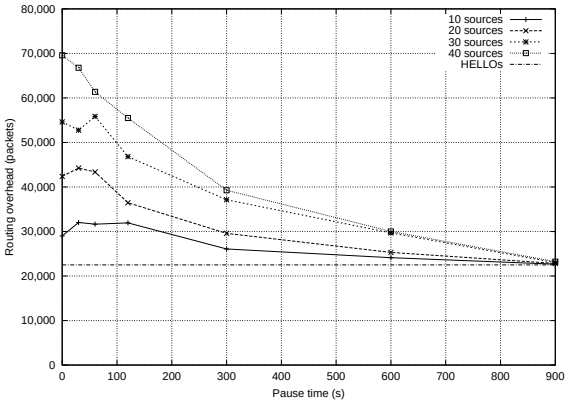

Fig. 4: *Routing overhead as a function of pause time for MPRDV*

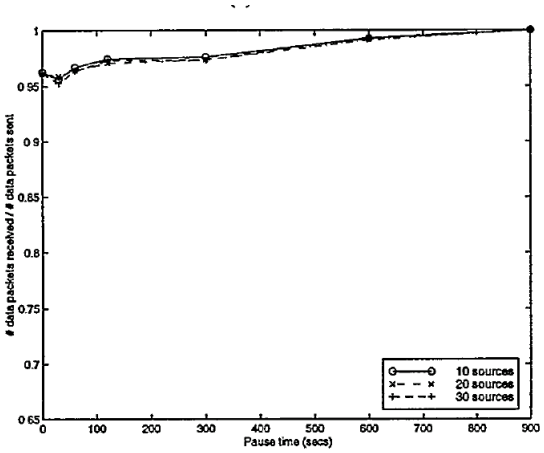

Fig. 5: *Fraction of data packets successfully delivered for AODV*

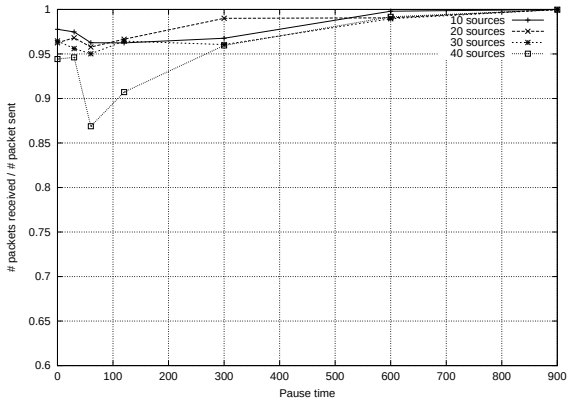

Fig. 6: *Fraction of data packets successfully delivered for MPRDV*

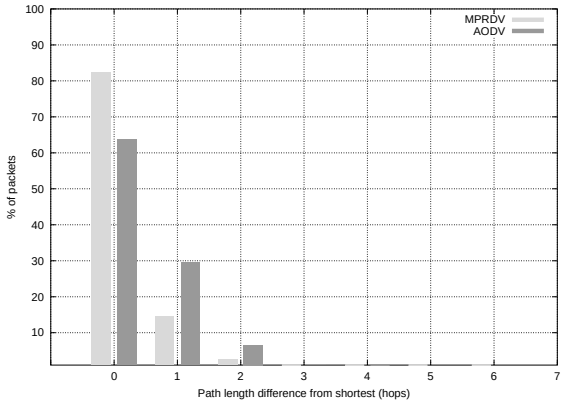

Fig. 7: *Difference between the number of hops taken by data packets and optimal number of hops for 20 sources*

4.3 Routes length

In this section we compare difference between the number of hops each data packet took to reach a destination for MPRDV and AODV. When a route is created it is not confirmed that this route is the optimal path. Thus, packets may be sent along this route before a shorter route is discovered. As shown on figure 8 more than 82% of data packets take an optimal path for MPRDV and 63% for AODV. This is due to MPR mechanism which tends to offer optimal routes. Consequently more data packets take longer routes in AODV protocol : 30% of data packets take a route with a difference of one hop from the optimal path and only 13% for MPRDV.
Figure 8 shows the evolution of routes length for MPRDV as a function of pause time. We can see that the number of packets which take the optimal path increases as the mobility decreases. And we can also point out that the number of packets transmitted along non-optimal routes tends to 0 in case of low mobility.

4.4 Influence of link layer detection

We described in section 2 how MPRDV detects route breakages using HELLO messages and link layer detection. We ran simulations with 10 sources of traffic without link layer detection in order to show the influence of this mechanism on routing overhead and data packets delivery.
Figure 9 represents routing overhead for MPRDV with and without link layer notification. We see that the control traffic slightly decrease in case of high mobility since less ROUTE messages are sent to perform route repairs when mobility becomes lower.
But the most important result is again data packets delivery. We can see on figure 10 that data packet

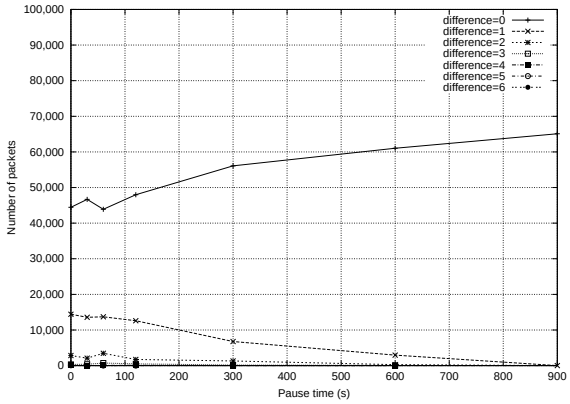

Fig. 8: *Difference between the number of hops taken by data packets and optimal number of hops as a function of pause time with 20 sources for MPRDV*

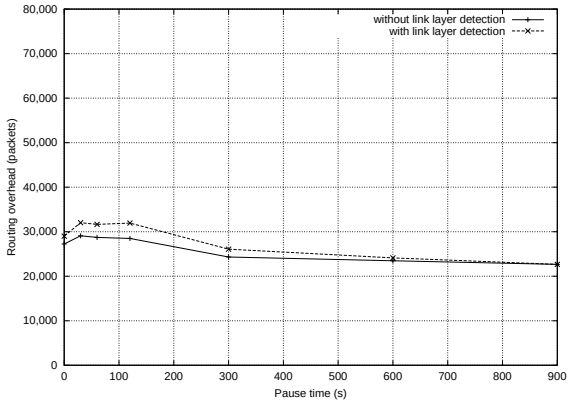

Fig. 9: *Influence of link layer detection on routing overhead for MPRDV*

delivery is affected by the absence of link layer detection. In case of high mobility the route failures detection only performed by HELLO messages is not sufficient and fraction of data packets decreases to 0.75. Performances become almost the same for pause time values greater than 600s.

5 Conclusions

In this paper we show with a simple example of reactive protocol how Multipoint Relays can be used to provide an optimized flooding mechanism. We shown that this optimization is especially significant in presence of high mobility. We also pointed out that Multipoint Relays tend to offer optimal routes which increases the protocol performances.
Route repairs are provide by new route request flooding using the same messages as routes discovery.
In this work, results were mainly based on mobility and it will be interesting now to compare protocols behaviour in presence of different traffic loads and especially in presence of heavy traffic load.

References

[ACJ+03] Cédric Adjih, Thomas Clausen, Philippe Jacquet, Anis Laouiti, Pascale Minet, Paul Muhlethaler, Amir Qayyum, and Laurent Viennot. Optimized Link State Routing Protocol. Internet draft, March 2003. IETF MANET Working Group.

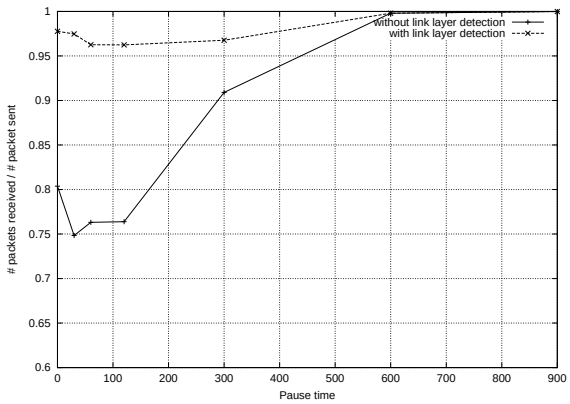

Fig. 10: *Influence of link layer detection on data delivery for MPRDV*

[BMJ+98] Josh Broch, David A. Maltz, David B. Johnson, Yih-Chun Hu, and Jorjeta Jetcheva. A Performance Comparison of Multi-Hop Ad Hoc Network Routing Protocols. October 1998.

[JLMV01] Philippe Jacquet, Anis Laouiti, Pascale Minet, and Laurent Viennot. Performance Analysis of OLSR Multipoint Relay Flooding in Two Ad Hoc Wireless Network Models. Research Report 4260, INRIA, September 2001.

[JMH03] David B. Johnson, David A. Maltz, and Yih-Chun Hu. The dynamic source routing protocol for mobile ad hoc networks. Internet draft, IETF MANET Working Group, March 2003.

[LQV02] Anis Laouti, Amir Qayyum, and Laurent Viennot. Multipoint Relaying : An Efficient Technique for Flooding in Mobile Wireless Networks. In *HICSS'2002*, 2002.

[OTL03] Richard Ogier, Fred Templin, and Mark Lewis. Topology Broadcast Based on Reverse-Path Forwarding. Internet draft, IETF MANET Working Group, March 2003.

[PBRD03] Charles E. Perkins, Elizabeth M. Belding-Royer, and Samir R. Das. Ad hoc On-Demand Distance Vector Routing. Internet draft, IETF MANET Working Group, March 2003.