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Comparative Analysis of Routing Protocols for Mobile Adhoc Networks

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Abstract - Mobile ad-hoc networks (MANETs) are self-configuring networks of nodes connected via wireless. This kind of networks is currently one of the most important research subjects, due to the huge variety of applications (emergency, military, etc...). In MANETs, each node acts both as host and as router, thus, it must be capable of forwarding packets to other nodes. Topologies of these networks change frequently. To solve this problem, special routing protocols for MANETs are needed because traditional routing protocols for wired networks cannot work efficiently in MANETs.

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Comparative Analysis of Routing Protocols for Mobile Adhoc Networks

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Abstract - Mobile ad-hoc networks (MANETs) are self-configuring networks of nodes connected via wireless. This kind of networks is currently one of the most important research subjects, due to the huge variety of applications (emergency, military, etc...). In MANETs, each node acts both as host and as router, thus, it must be capable of forwarding packets to other nodes. Topologies of these networks change frequently. To solve this problem, special routing protocols for MANETs are needed because traditional routing protocols for wired networks cannot work efficiently in MANETs.

I. INTRODUCTION

Mobile Ad-Hoc networks or MANET networks are mobile wireless networks, capable of autonomous operation. Such networks operate without a base station infrastructure. The nodes cooperate to provide connectivity. Also, a MANET operates without centralized administration and the nodes cooperate to provide services. Figure 1.1 illustrates an example of Mobile Ad-Hoc network.

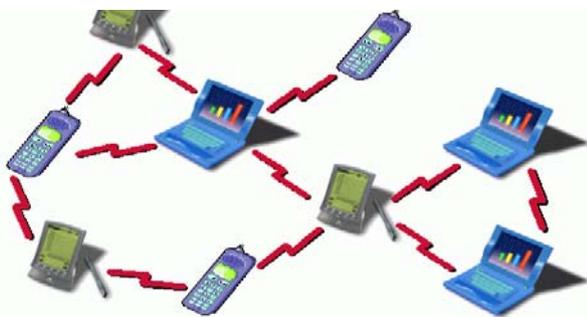


Figure 1.1 : Mobile Adhoc Networks

II. ROUTING PROTOCOLS FOR MOBILE ADHOC NETWORKS

MANETs are necessary to have different routing protocols from the wired networks. There are three types of routing protocols for MANETS:

- **Table-driven (Proactive):** OLSR, TBRPF, DSDV (Dynamic Destination Sequenced Distance Vector), CGSR (Cluster head Gateway Switch Routing

protocol), WRP (Wireless Routing Protocol), OSPF (Open Shortest Path First) MANET, etc.

- **Demand-driven (Reactive):** AODV, DSR, TORA (Temporally Ordered Routing Algorithm), etc.
- **Hybrids:** ZRP (Zone Routing Protocol), HSLs (Hazy Sighted Link State), etc.

In the proactive protocols, each node has a routing table, updated periodically, even when the nodes don't need to forward any message.

In the reactive protocols, the routes are calculated only when required. When a source wants to send information to some destination, it calls on route discover mechanisms to find the best route to this destination.

The hybrids protocols try to use a combination of both to improve them.

a) Reactive Routing Protocols

These protocols find the route on demand by flooding the network with Route Request packets. The main characteristics of these protocols are:

- Path-finding process only on demand.
- Information exchange only when required.
- For route establishment, the network is flooded with requests and replies.

i. The Dynamic Source Routing (DSR)

DSR is a reactive routing protocol. It uses source routing. The source node must determine the path of the packet. The path is attached in the packet header and it allows to update the information stored in the nodes from the path. There are no periodical updates. Hence, when a node needs a path to another one, it determines the route with its stored information and with a discovery route protocol. This protocol has 2 parts:

- Route Discovery
- Route Maintenance

a. Route Discovery

When a node sends a packet to a destination, firstly it looks at its Route Cache the routes previously learned. If no route is found in its cache, then the node begins the route discovery process with a Route Request Packet (RREQ) broadcast. This packet includes the destination address, the source address and an identification number (request id). Each node receiving the RREQ, looks for the destination in its cache. If it does not know the route to the destination, it adds its

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address to the 'route record' in the RREQ and propagates it by transmitting it as a local broadcast packet (with the same request id). To limit the number of RREQ's, if one node receiving the RREQ has recently seen another RREQ from the same source, with the

same request id, or if it finds its own address in the route record, then it discards the RREQ. In Figure 1.2 the development of the route record while the RREQ is spreading through the network is shown.

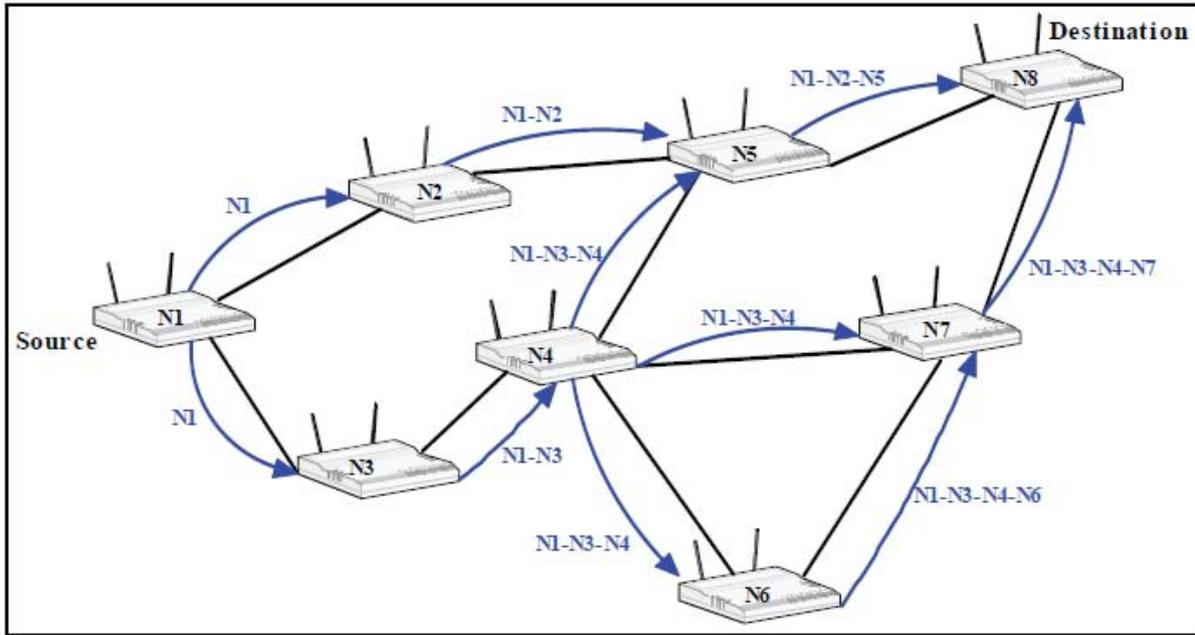


Figure 1.2 : Construction of the route record in the route discovery

b. Route Maintenance

The maintenance of the routes is useful to check the operation of a route and to report any routing error to the source. This check is made between consecutive nodes. When there is a problem in the transmission found by the link level, the RERR (Route Error) packets are sent by the node. This RERR has the

addresses of both nodes in which the link failed. For example, in the situation illustrated in Figure 1.3 N1 has originated a packet for N8 using a source route through intermediate nodes N2 and N5. In this case, N1 is responsible for the reception of the packet at N2, N2 is responsible for the reception at N5, and N5 is responsible for the reception at the final destination N8.

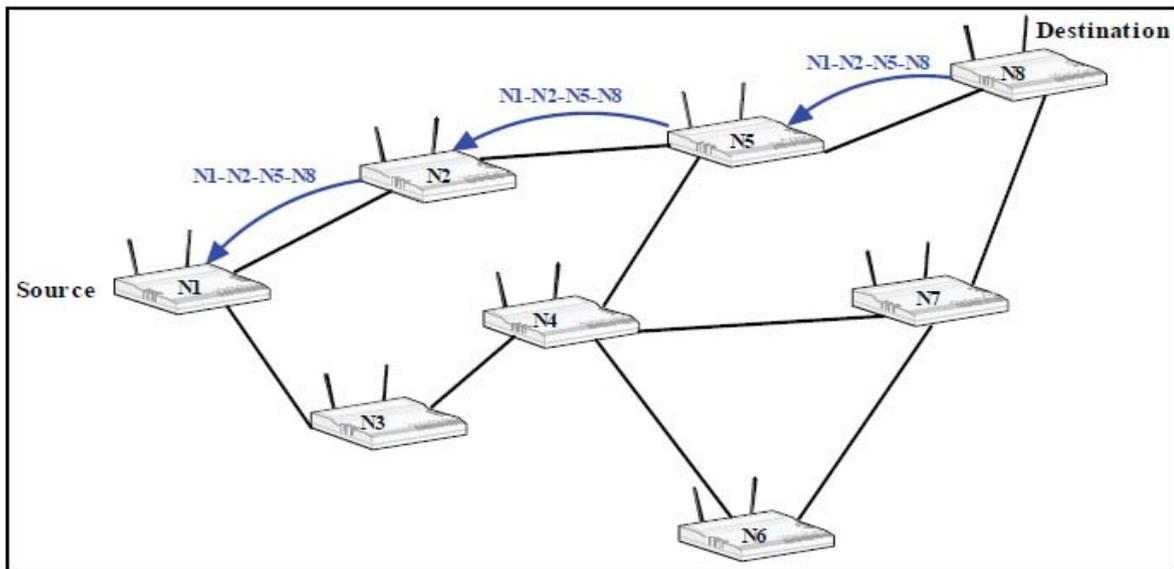


Figure 1.3 : Forwarding of the RREP with the route record

As N5 is unable to deliver the packet to N8, N5 returns a Route Error to N1 stating that the link from N5 to N8 is currently 'broken'. N1 then removes this broken link from its cache. In other words, when a node receives a RERR, it deletes the link failed in its routes list, and all the routes that have this link are cut at this point. Besides the RERRs, ACKs (acknowledgements) can be used to verify the links availability.

ii. *The Adhoc On Demand Distance Vector (AODV)*

The AODV protocol is a reactive routing protocol. It is a Single Scope protocol and it is based on DSDV. The improvement consists of minimizing the

number of broadcasts required to create routes. Since it is an on demand routing protocol, the nodes who are not in the selected path need not maintain the route neither participate in the exchange of tables.

When a node wants to transmit to a destination and it does not have the valid route, it must begin the Path Discovery process. Firstly, it sends a broadcast of the Route Request (RREQ) packet to its neighbours, and they relay the packet to their neighbours and so on until they reach the destination or any intermediate node which has a 'fresh' route to the destination (Figure 1.4). Just like in DSDV sequence numbers are used to identify the most recent routes and to solve the loops.

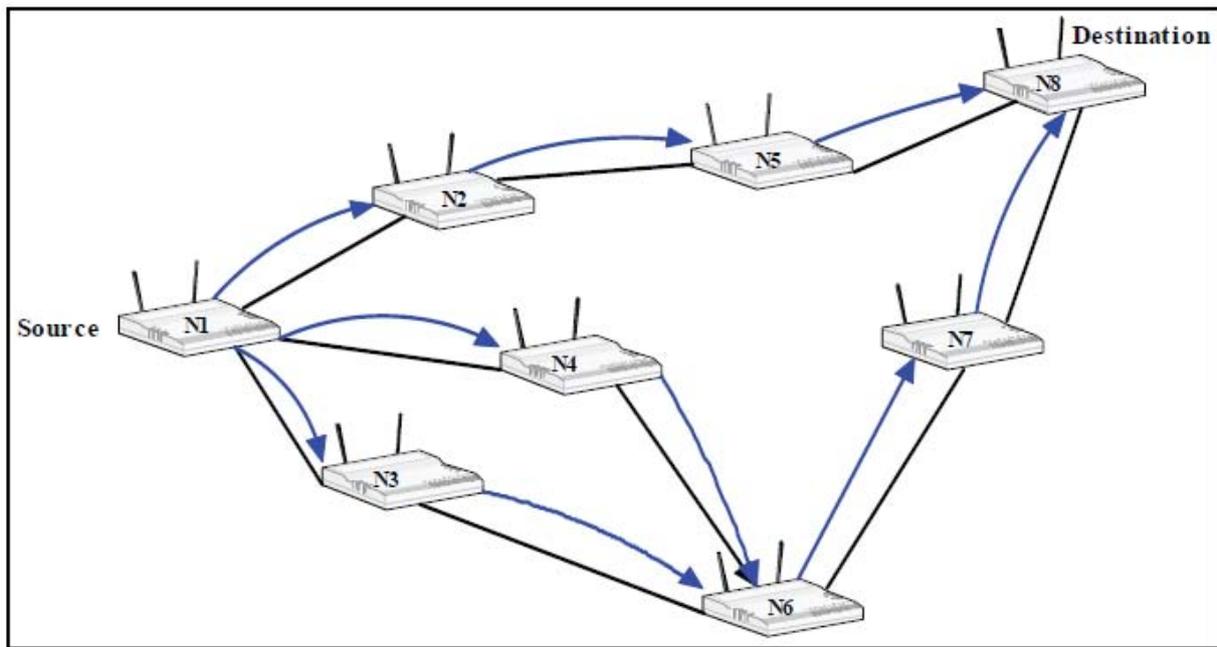


Figure 1.4 : Propagation of RREQ

Each node maintains two counters: the sequence number of the node (to solve the loops) and the broadcast ID which is incremented when a broadcast is started in the node. To identify only one RREQ (see Figure 1.6) it is used the broadcast ID and the IP (Internet Protocol) address of the source node. The RREQ has the following fields: Source address, Source sequence number, Broadcast_id, Destination address, Destination sequence number, and the number of hops to the destination.

The intermediate nodes only answer to the RREQ if they have a path to the destination with a sequence number greater or equal to the sequence number of the RREQ. Hence, only if they have paths equal (in age) or more recent. While the RREQ is sent, the intermediate nodes increase the field 'number of hops to the destination' and, also store in its routing table the address of the neighbour from whom they first received the message, in order to establish a 'Reverse

Path' (Figure 1.6). The copies of the same RREQ received later which are coming from the other neighbours are deleted.



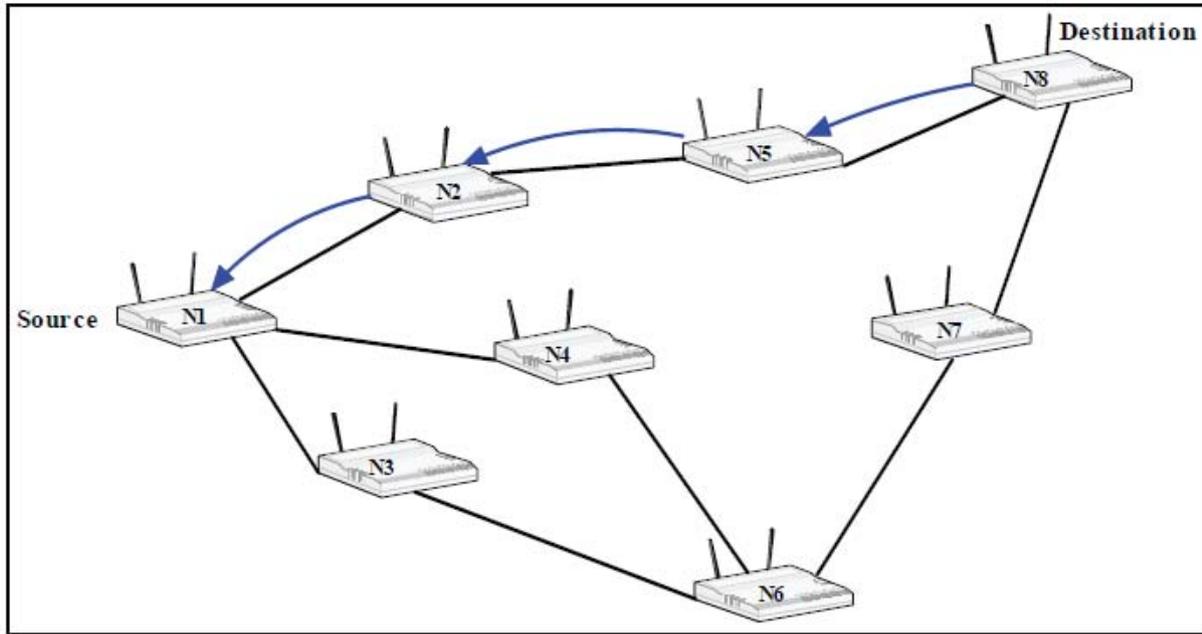


Figure 1.6 : Path of the RREP to the source

When the 'destination node/intermediate node with the fresh route' has been found, it answers with a Route Reply (RREP) to the neighbour from which it received the first RREQ. The RREP has the following fields: Source address, Destination address, Number of Hops to the destination, Sequence number of the destination, Expiration time for the Reverse Path (Figure 1.8). Then, the RREP uses the return path established to the source node. In its path, every node forwarding the RREP sets the reverse path as the freshest path to the destination node. Therefore, AODV can only use bidirectional links.

If a source node moves, it is capable of restarting the discovery protocol to find a new path to the destination. If an intermediate node moves, its previous neighbour (in source-destination way) must

forward a RREP not requested with a fresh sequence number (greater than the known sequence number) and with a number of hops to destination infinite to the source node. In this way, the source node restarts the path discovery process if it is still needed.

Hello messages (periodic broadcasts) are used to inform mobile node about all the neighbourhood nodes. These are a special type of RREP not solicited, of which sequence number is equal to the sequence number of the last RREP sent and which has a TTL=1 (Time To Life) to not flood the network. They can be used to maintain the network connectivity, although other methods used more often exist for this function, like for example, to listen to the neighbour nodes transmissions.



Figure 1.7 : RREQ Packet



Figure 1.8 : RREP Packet

b) *Proactive Routing Protocols*

These algorithms maintain a fresh list of destinations and their routes by distributing routing tables in the network periodically. The main characteristics are:

- These protocols are extensions of wired network routing protocols.
- Every node keeps one or more tables.
- Every node maintains the network topology information.
- Tables need to be updated frequently.

i. *Optimized Link State Routing (OLSR)*

OLSR is a proactive link state routing protocol. It is a point to point routing protocol based in the link state algorithm.

Each node maintains a route to the rest of the nodes of the ad hoc network. The nodes of the ad hoc network periodically exchange messages about the link state, but it uses the 'multipoint replaying' OLSR strategy to minimize the messages quantity and the number of nodes that send in broadcast mode the routing messages. The strategy MPR (Multipoint Relay) [MANET lies in that each node uses 'Hello' messages to discover what nodes are in a one hop distance and makes a list. Each node selects a group of neighbours of that list that are able to reach all the nodes in a distance of two hops with regard to the node that is making the selection. For example, in Figure 1.9 the node A selects the nodes B, C, K and N as the MPR nodes, because they are capable of reaching all the nodes at two hops distance with regard to the node A.

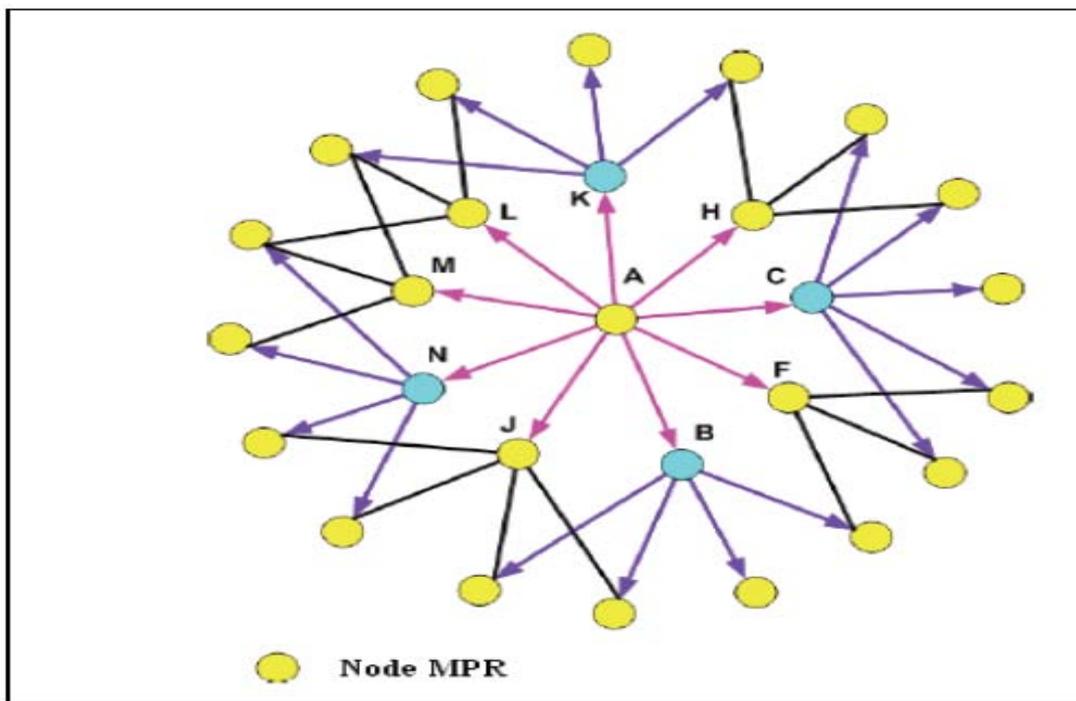


Figure 1.9 : Multipoint Relays

These neighbours selected are the only nodes in charge to relay the routing packets and are called MPRs (Multipoint Relays). The rest of the neighbourhood process the routing packets that they receive, but they can not relay them. Each node decides an optimum path (in number of hops) to each destination using the stored information (in its topology routing table and in of their neighbours ones). Besides each node stores that information in a routing table for usage when a node wants to sent data. This protocol selects bidirectional links to send packets, and does not use unidirectional links. The OLSR protocol is more efficient in networks with high density and highly sporadic traffic. The quality metrics are easy to expand to the current protocol. OLSR requires that it

continuously has some bandwidth in order to receive the topology updates messages.

ii. *The Destination Sequenced Distance Vector (DSDV)*

The DSDV is a distance vector, proactive routing protocol. It is based in the Bellman-Ford algorithm, but improved to solve the routing loop problem. It uses the distance vector algorithm to find the shortest path to the destination.

Each node within the ad hoc network maintains a routing table with the following information to each destination.

- Destination IP address.
- Destination sequence number.
- Next hop (IP address).

- Cost (in number of hops).
- Install time: used to delete old routes.

Each node sends periodically broadcasts with the routing table updated to its neighbours:

- Each node adds its sequence number when it sends its routing table.
- When the other nodes receive this information, they update its routing tables.

The routing tables also can be sent if there are topology changes (link creation or breakage). In this case, the update information travelling in the routing messages is:

- Destination IP address.
- Number of hops.
- Sequence number.

The nodes use the sequence numbers to distinguish between old and new routes to a destination. A node increases its sequence number when there is a topology change (a new link is created or deleted). The route to a destination with the biggest sequence number (the more current) is the valid one. If there are two routes with the same sequence number, the valid is the one which number of hops is smaller. Two types of route update are used

- **Full dump:** This packet carries the whole routing table. It is unusual to send this packet.
- **Incremental:** This packet carries only the routing table information of a node that has changed since the last full dump sent. These packets are sent more frequently. Hence, the control overhead and the bandwidth consumption are smaller.

c) Hybrid Routing Protocols

These protocols are a combination of reactive and proactive routing protocols, trying to solve the limitations of each one.

Hybrid routing protocols have the potential to provide higher scalability than pure reactive or proactive protocols. This is because they attempt to minimise the number of rebroadcasting nodes by defining a structure (or some sort of a backbone), which allows the nodes to work together in order to organise how routing is to be performed. By working together the best or the most suitable nodes can be used to perform route discovery.

i. The Zone Routing Protocol (ZRP)

The Zone Routing Protocol (ZRP) is a hybrid routing protocol. It combines the advantages from reactive and proactive routing protocols. This protocol divides its network in different zones. These zones are the nodes local neighbourhood. Each node has its own zone. Each node can be into multiple overlapping zones, and each zone can be of a different size. The size of a zone is given by a radius of length, where the number of hops is the perimeter of the zone. Within each zone it is used a proactive routing protocol.

Therefore, each node into the zone knows how to reach its neighbours. However, if the packets are sent to a node outside of the zone, it is used a reactive routing protocol.

ZRP runs three routing protocols:

- Intrazone Routing Protocol (IARP)
- Interzone Routing Protocol (IERP)
- Bordercast Resolution Protocol (BRP)

IARP is a link state routing protocol. It operates within a zone and learns the routes proactively. Hence, each node has a routing table to reach the nodes within its zone.

IERP uses the border nodes to find a route to a destination node outside of the zone. IERP uses the BRP.

BRP is responsible for the forwarding of a route request.

When the Route Discovery process begins, the source node asks to its routing table and if necessary, it starts a route search between different zones to reach a destination. If a route is broken by a node's mobility into the same zone where the node was, the routing tables used for the proactive routing protocol must be updated. If the node's mobility is from one zone to another one, then it is necessary to execute a query between zones.

To use a reactive routing protocol to find a route from a source node to a destination node placed in another zone reduces the control overhead (in comparison with the proactive ones) and the delays in the Route Discovery (in comparison with the pure reactive ones), since these routes are discovered much faster. The reason is because to find a route to a node placed outside the routing zone, the route request is send only to the border router within the zone where the destination is. This border router can answer to the request since it has a routing table to do the proactive routing and knows how to reach the destination.

The disadvantage of ZRP is that it becomes a proactive routing protocol if the radius is big. Otherwise, if the radius is small, it becomes a reactive routing protocol.

In Figure 1.10 a Route Discovery process is shown; the node S sends information to the node X, and by IARP decides X is not in the same zone that S. The search travels through the border nodes to find the zone where X is. Finally, the border node G discovers that X is in its zone and sends a route response to S.

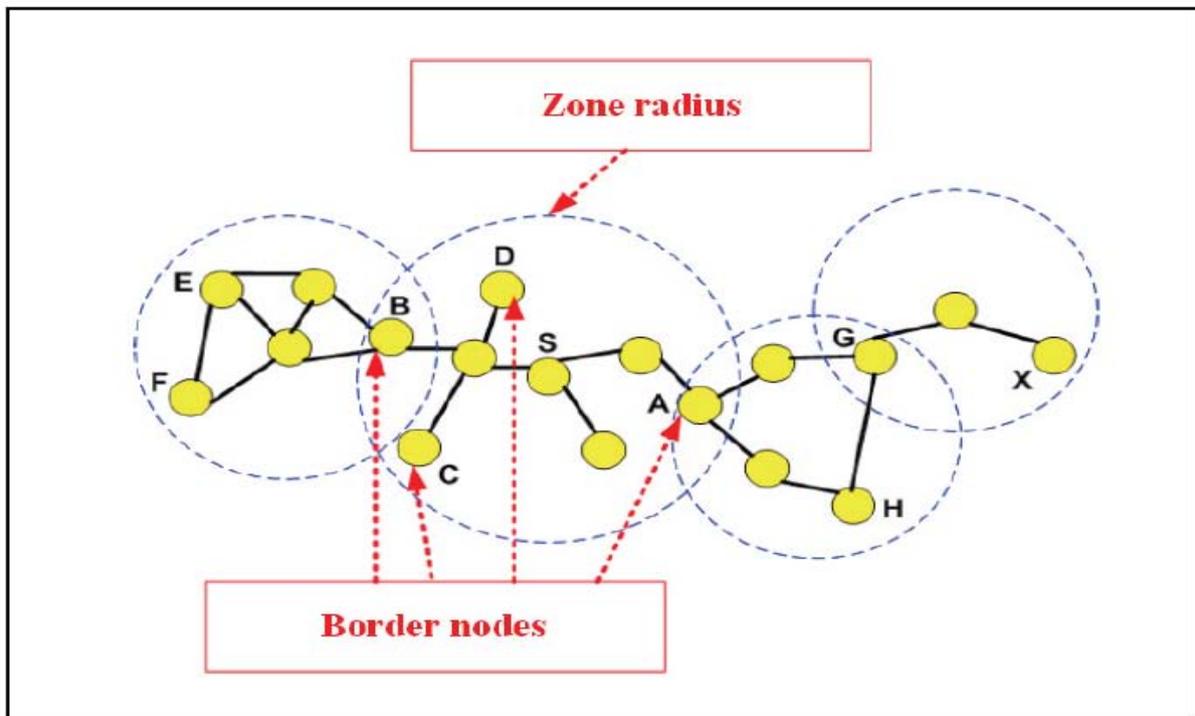


Figure 1.10 : Example of a Route Discovery in an ad hoc network using the routing protocol ZRP

Even though the hybrid nature of the ZRP seems to indicate that it is a hierarchical protocol, it is important to point out that the ZRP is in fact a flat protocol. ZRP is more efficient for large networks.

d) Reactive Vs Proactive

Proactive routing protocols lose more time updating their routing tables. Therefore when the topology changes frequently, most of the current routes in the tables can be wrong. Hence, these protocols are recommended for ad-hoc networks semi dynamics.

Reactive routing protocols have delay in route determination, because of the flooding mechanism. They are recommended for networks with nodes moving constantly.

Intuitively, we can think in the advantages and disadvantages of both looking the table 1.1:

Parameters	Proactive/Table-driven	Reactive/On Demand driven
Route availability	Always available	Available when required
Latency	Minimum	Long delays when there is not an available route
Route updating periodically	Yes	No
Movement	Advertises to other nodes to update the routing tables.	Only advertises if affect to the source node. Uses alternative routes.
Control traffic	Greater than On Demand driven	Increase if mobility of the active routers increase.
Energy consumption	Greater	Depends of the nodes mobility

Table 1.1 : Comparison between proactive and reactive routing protocols

e) *Quality of Service*

Quality of service can be used as a measurement of how good the routes in the network are. The routes should guarantee a set of pre specified service attributes, such as delivery, bandwidth and delay variance (jitter). It also involves the specification of latency, loss, availability etc...

For a protocol to provide good QoS it must determine new routes rapidly and with minimal bandwidth consumption. There are several metrics that directly affect the QoS of every protocol, for example: Packet delivery ratio, control packet overhead (packets and total bytes), average hop count, end-to-end latency and power consumption to mention a few. Using a protocol that provides good quality of service will greatly affect the MANETs performance.

f) *Comparing the Protocols*

As a proactive routing protocol, OLSR inserts high control traffic overhead on the network. To maintain and to update the routing table for the entire network it needs a lot of communication between the nodes, as well as periodic updates flooding the network. The use of MPR's reduces this control traffic overhead, but for small networks the improvement is minimal. The traffic overhead also consumes bandwidth.

The behaviour of reactive protocols AODV and DSR is different. The main part of control traffic is emitted during route discovery. Therefore, a lot of the resource and bandwidth consumption is related to actual data traffic.

Protocol Property	OLSR	AODV	DSR	ZRP
Routing Structure	Flat	Flat	Flat	Flat
Loop Free	Yes	Yes	Yes	Yes
Multiple Routes	No	No	Yes	No
Distributed	Yes	Yes	Yes	Yes
Reactive	No	Yes	Yes	Hybrid
Unidirectional Link Support	No	No	Yes	No
Qos Support	Yes	No	No	No
Multicast	Possible	Yes	No	No
Security	No	No	No	No
Power Efficiency	No	No	No	No
Periodic Broadcasts	Yes	Yes	No	Yes

Table 1.2 : Comparison between the Protocols

III. RESULTS

In Figure 1.11, the Control Overhead curve for the Node Density experiments is shown. The control overhead measurements are normalized. The horizontal axis represents the distance between neighbouring nodes in the grid. The sparse networks have higher paths lengths. Thus, in these networks there are more

rebroadcasts of route requests, and more route reply packets. For that reason DSR increases its control overhead when the density is smaller. However, AODV begins with a high overload when the node density is high, but uses fewer control packets as the density is smaller.

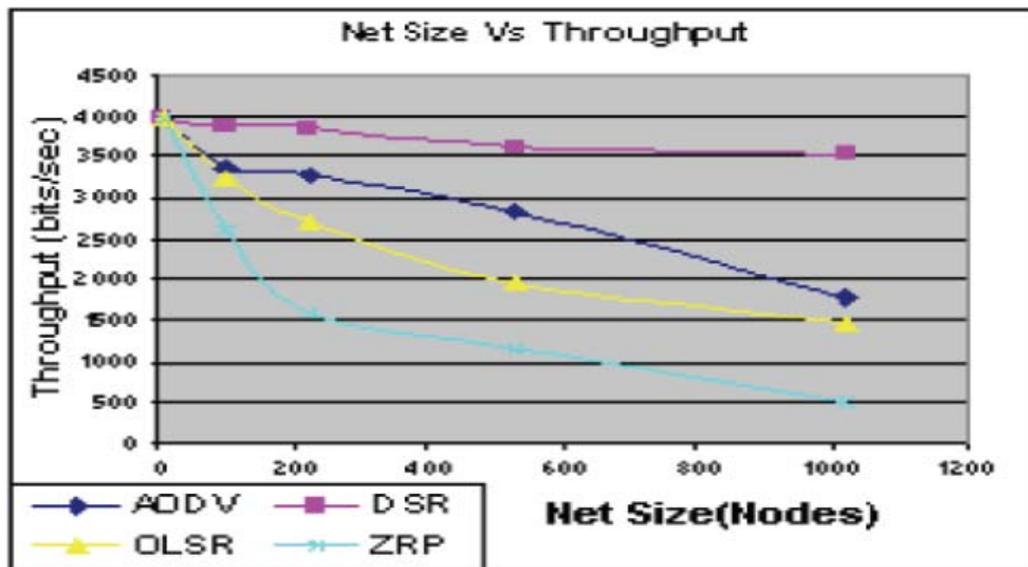


Figure 1.11 : Throughput for Network Size

ZRP performs similar to AODV. When the density is high, it performs better and this is because the original route acquisition process depends on neighbouring nodes overhearing and rebroadcasting route requests, and if router requests are lost, the entire process stalls. The hidden terminal problem can contribute to route request losses, and is more prevalent in sparse networks. These protocols have difficulty dealing with a network with few neighbours.

a) Number of Hops

The strangest result is to see that the latency for OLSR has the highest values from 1 to 10 hops, and

generally the highest slope. For OLSR to lose its innate advantage in latency, network route convergence would have to be slower than route acquisition, and given the high control overhead data that was collected for this experiment set, it is easy to see that this is the case. However, under normal circumstances the OLSR is supposed to be the best of the analyzed protocols since the point of view of the latency.

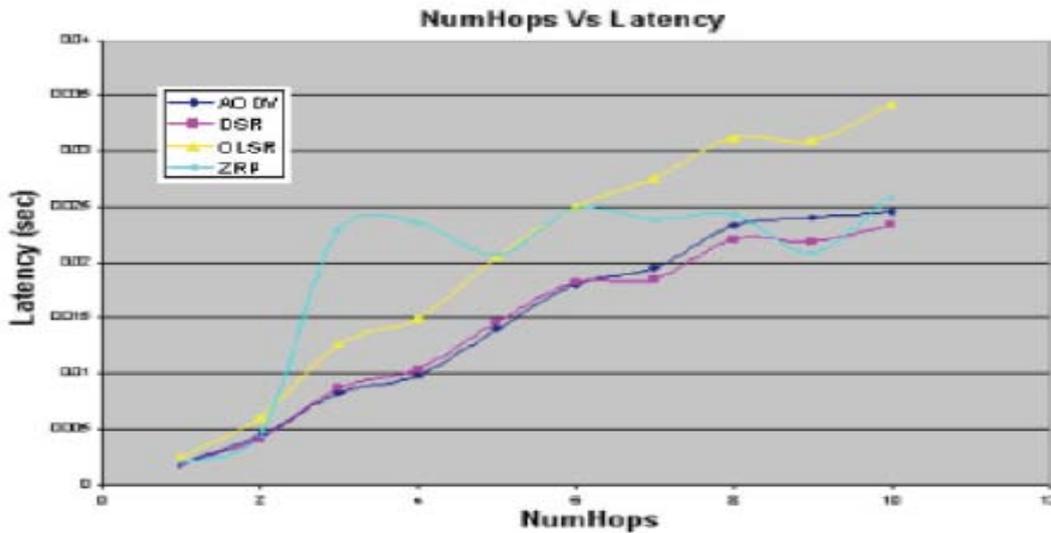


Figure 1.12 : Number of Hops Vs Latency

For ZRP at the 1 and 2 hop has better latency than OLSR. This is because the proactive zone of interest is much smaller. At 3 hops and beyond, this result is indicative of the interzone routing, and it shows a fairly flat graph from 3 to 10 hops, with some oscillation caused by random number seeds not being completely filtered out.

IV. CONCLUSION

For a network with a large number of nodes, which move with changing velocities and have different traffic patterns, a hybrid routing protocol is the best choice. The nodes moving slowly and with high traffic should run the proactive routing features, and the rest of nodes implement the reactive ones. Besides, the choice should be a hierarchical approach to achieve a big scalability. The AODV and DSR protocols will perform better in the networks with static traffic and with a number of source and destination pairs relatively small for each host. In this case, AODV and DSR use fewer resources than OLSR, because the control overhead is small. Also, they require less bandwidth to maintain the routes. Besides, the routing table is kept small reducing the computational complexity. Both reactive protocols can be used in resource critical environments.

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