Design, Implementation and Evaluation of Distance Vector Routing Protocols in Ad Hoc Networks

Abstract

Ad hoc networks are characterized by a lack of infrastructure and a high dynamic topology; hence, it is required a new kind of routing protocols able to adapt to this kind of networks in constant change. Many routing algorithms have appeared to cover this necessity, they can easily targeted in two main groups: ***proactive*** *and* ***reactive*** *protocols. Last, a new generation of protocols, joining characteristics of both and based on the definition of routing zones, has appeared into the target of* ***hybrid protocols****. This paper presents a detailed comparison of two distance vector protocols: DSDV as proactive candidate; and AODV, as reactive representative, in different scenarios of mobility, scalability, power and traffic load. It is also presented a new distance vector hybrid proposal derivate from the previous algorithms,* ***HRP****,. Finally, our new proposal is accurately compared with its predecessors, getting promising results.*

The simulations were made in OMNeT++, adding a clustering module to implement MAC layer based on TDMA policy.

Keywords: Ad Hoc networks, routing protocols, distance vector protocols, DSDV, AODV, hybrid, HRP,TDMA.

1.Introduction

An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any network infrastructure. In this kind of networks, the nodes are free to move randomly and organize themselves arbitrary; thus, the network's wireless topology may change rapidly and unpredictably.

The network nodes agree to relay each other's packets toward their ultimate destination, and the nodes, which will work as routers, automatically form their own cooperative infrastructure.

Such networks need a new generation of routing protocols, able to adapt to a dynamc network topology. A variety of new routing protocols specially designed for these networks has appeared in the recent years. They can be grouped in two main kinds: proactive and reactive protocols.

Proactive schemes attempt to keep an up-to-date topological map of the entire network. The nodes need to send periodic information of their view of the network in order to maintain routing tables including all nodes in the network.

On the other hand, *reactive protocols* does not attempt to continuously determine the whole network topology. Instead, a route is searched when it is required with the consequent saving on bandwidth.

Last, a new kind of protocols, with characteristics of both and based on the definition of routing zones, have appeared into the target of *hybrid protocols*.

On the other side, distance vector routing protocols are well-known as efficient but also simple, characteristic which made them critical in the deployment of wired networks. This fact seems to indicate that they will also play a main role in the development of this new network generation, conferring special interest to the study of this kind of protocols.

This paper presents the results of a detailed simulation, comparing two distance vector protocols for ad hoc networks: DSDV, as proactive candidate and AODV as reactive representative, in different scenarios of high scalability, mobility, power and traffic load.

Last, a new distance vector hybrid proposal,HRP, derivate from the previous protocols, is presented and compared with its predecessors. The hybrid proposal is based on the definition of routing zones, in order to limit the control overhead without renouncing good packet delivery ratios or latency values.

Every node marks a routing zone centered in itself and defined attending to the number of hops. The traffic within the zone is routed by the proactive scheme; the traffic beyond the zone is forwarded by the reactive scheme.

Our scheme, in contrast to ZRP (Zone Routing Protocol), can be distance vector because it uses flooding with query detection instead of bordercasting to transmit the reactive queries.

Finally, this new hybrid proposal is compared with its predecessors DSDV and AODV in detailed simulations.

2.Simulation Environment

OMNeT++ is an object-oriented modular discrete event simulator, created by András Vargas from University of Budapest. Its flexibility allowed us to create an ad hoc network model following an ISO layer model, adding a clustering module to provide TDMA policy and a mobility model, as shows Figure 1.

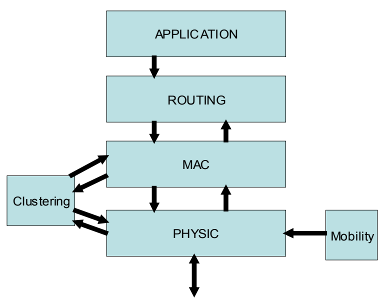


Figure 1. Layer model of the Simulation Environment

2.1 Physical Layer

Physical Layer tasks includes the connection with the direct neighbors in the network.

Each host has a transmission power that determines the range ,within which a communication is feasible. The signal power degradation is modeled by the Free Space Propagation Model in which the received signal power is inversely proportional to the node distance square ($1/r^2$).

2.2 Medium Access Control Layer (MAC)

MAC layer regulates the flow of messages between physical and routing layer. It is responsible for the correct share of the channel between connected nodes. In our case, this share is made through TDMA via time slots.

When MAC layer receives a message from the routing layer, it inserts it automatically the message into a buffer which regulates the output messages towards the physic layer. This buffer can only be empty when the node receives the right of a slot through the reception of a SLOTMESSAGE from the clustering module.

One time slot is 6 seconds and it allows the sending of 4096 bits.

2.3 Routing Layer

Routing Layer is the core of our analysis. It is responsible for the search of proper routes for the destination of the data messages generated in the nodes.

We implemented a DSDV module and modified the AODV module provided by [5].

To create the hybrid scheme, both modules had to be modified to create a complete new architecture which will be explained in detail later.

2.4 Application Layer

This layer is described as a simple traffic generator. The traffic is modeled by generating a packet burst of 64 messages sent to a destination that stays the same for all the burst length. The time elapsed between two consecutive data burst is defined by a truncnormal variable of mean 2 seconds. The time between two packets within the same burst is 0.25 seconds.

2.5 Clustering module

Clustering module gives the network the ability of self creating clusters or small subnetworks to contribute to a better behavior and efficiency of the global network.

The clustering formation consists of two phases. First, all the nodes in the network perform the lowest-ID cluster algorithm, after which the node with lowest ID (node address) will become clusterhead of its 1-hop neighborhood. After that, clusterheads send INFO messages in order to allow other nodes to add to the clusters.

Clustering module is also responsible for the calculation of the slots. Since every node owns a list of the nodes in its cluster , and this list has the same order in all the nodes; nodes are able to calculate the time in which medium will be free for their broadcast (slot).

2.2 Mobility module

Nodes' movement is described by a *Random Direction* mobility model. Each node chooses a speed and a direction distributed uniformly and goes on until it reaches a map border. Here the node waits a *pause time* and then chooses a new direction and speed.

3. Proactive and Reactive Studied Schemes

3.1 Proactive Protocols

Proactive protocols attempt to maintain consistent, up-to-date routing information for each node in the network. These protocols require each node to maintain one or more tables to store routing information.

3.1.1 Destination-Sequenced Distance Vector (DSDV)

DSDV[2] is a table-driven algorithm based on the classical Bellman-Ford routing mechanism, but guaranteeing loop-freedom via sequence numbers.

Every mobile node in the network maintains a routing table in which all of the possible destination within the network and the number of hops to each destination are recorded. Each entry is marked with a sequence number assigned by the destination node. The sequence numbers enable the mobile nodes to distinguish stale routes from newer ones, avoiding the formation of routing loops.

Two different updates are defined: the first is known as a *full dump*, it carries all available routing information of the node and, attending to the size of the network, it can require multiple network protocol data units (NPDUs). It is sent periodically. The second kind of update packets are named *incremental* and they are sent by a node when it detects a decisive change in the network.

Update messages contain the address of the destination, the number of hops to reach the destination and the sequence number of the advertised route.

Routes labeled with the most recent sequence number are always preferred. In the event that two updates have the same sequence number, the route with the smaller metric is used.

Mobiles also keep track of the settling time of routes, or the weighted average time that routes to a destination will fluctuate before the route with the best metric is received. By delaying the broadcast of a routing update by the length of the settling time, mobiles can reduce network traffic by eliminating those broadcasts that would occur if a better route were discovered in the very near future.

Implementation Decisions

The absence of a standard makes some parameters of the algorithm be without clear definition. The constants and parameters which were used in the implementation of the algorithm are shown in Table 1.

Periodic route update interval	1 s
Time without news to declare a link broken	3 s
Time after the link break to remove the entry from the routing table	4 s
Size of control packets	Full dump -> 4096 bits incremental-> 512 bits
Maximal number of entries fitting in a full dump packet	32 entries

Table 1. Constants used in DSDV simulation

3.2 Reactive Protocols

This type of routing creates routes only when desired by the source node. When a node requires a route to a destination, it initiates a route discovery process within the network. This process is completed once a route is found or all possible route permutations have been examined.

3.2.1Ad Hoc On-Demand Distance Vector Routing (AODV)

AODV is a reactive protocol built on the DSDV algorithm previously described.

Every node in the network sends periodically "HELLO" messages to have information about its 1-hop neighborhood.

When a source node desires to send a message to some destination and has not already a valid route, it initiates a *path discovery* process.

It broadcasts a route request (RREQ)packet to its neighbors, which then forward the request to their neighbors and so on, until either the destination or an intermediate node with a "fresh enough" route to the destination is located. Figure 2 shows the propagation of the RREQ across the network.

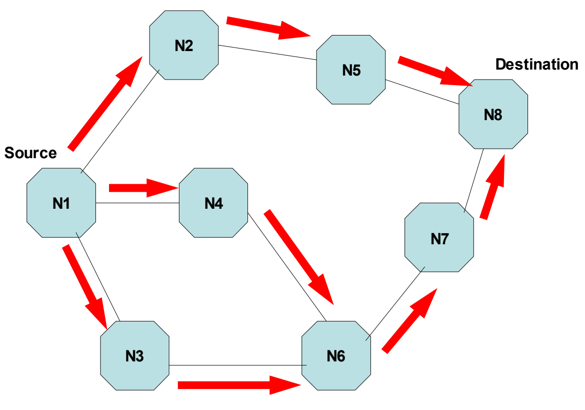


Figure2. Propagation of RREQ across the network

AODV utilizes destination sequence number to ensure all routes are loop-free and contain the most recent route information. Each node maintains its own sequence number and every entry in the routing table must contain also the sequence number of the destination. Every time a node initiates a discovery process, it includes in the RREQ message the sequence number it has for the destination. Intermediate nodes can reply to the RREQ only if they have a route to the destination whose sequence number is greater or equal to that contained in the query.

During the process of forwarding the RREQ, intermediate nodes record in their tables the address of the neighbor from which the first copy of the broadcast packet is received thereby establishing a reverse path. If additional copies of the same RREQ are later received, they are discarded.

Once the RREQ reaches the destination or an intermediate node with a fresh enough route, this node responds by unicasting a route reply (RREP) packet back to the neighbor from which it received the RREQ packet. The path which follows the RREP message is shown in Figure 3:

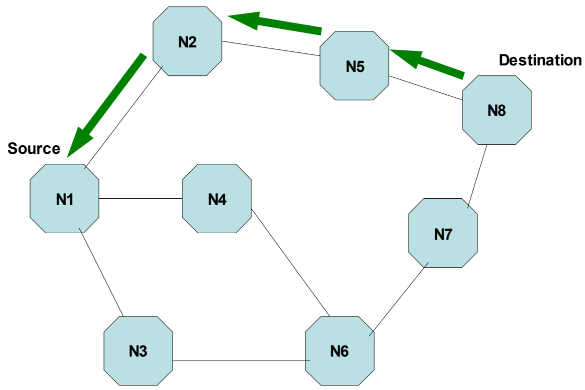


Figure3. Path of the RREP to the source

Associated with each route entry is a route timer which will cause the deletion of the entry if it is not used within a specified lifetime.

If a node along the route moves, its upstream neighbor notices the move and propagates a RERR message to each of its active upstream neighbors to inform them of the erasure of that part of the route. These neighbors repropagate the RERR message to their upstream neighbors, and so on until the source node is reached. The source node may reinitiate route discovery for that destination if a route is still desired.

Implementation Decisions

HELLO interval	1 second
Time without news to declare a link broken	3 seconds
Time after link break declaration to remove the entry from the table	4 seconds
RREQ sent without replay arrival at time	3
Times a RREP is resent without ACK arrival	2

Table 2. Constants used in AODV simulation

4. Simulations

4.1 Scenarios

Our protocol evaluations of DSDV and AODV are based on a model of an ad hoc network with a parameterizable number of nodes, moving over a rectangular area of 1000m x 1000m.

We created 4 different scenarios changing the number of nodes in a range from 50 to 100 nodes; the percentage of active nodes from 20% to 100% and the average speed in a range from 0 to 40 Km/h. Thus, we could accurate compare the effects of number of nodes, traffic load and mobility over the analyzed protocols.

In order to enable direct, fair comparisons between the protocols, it was critical to challenge the protocols with identical loads and environmental conditions. Each run of the simulator accepts an input scenario file which describes the exact motion of each node. Since both protocols were challenged with the same scenario file and during the same time (60 seconds), we can directly compare the performance results of both protocols.

4.2 Ratios measured

In order to compare the protocols, we chose to evaluate them according to the following metrics:

- *Packet delivery ratio*: The ratio between the number of packet originated by the application layer and the number of packets received correctly in the nodes at the final of the simulation.
- *Latency*: Time between the generation of the packet in the application layer and the arrival of the packet in the destination.
- *Control Overhead*: Bits per second invested in control packets.

Packet delivery ratio is important as it describes the loss rate that will be seen by the transport protocols. This metric characterizes both the completeness and correctness of the routing protocol.

Latency measures the efficiency of the routing protocol in conjunction with the medium share policy, in our case TDMA.

Routing overhead is an important metric for comparison of protocols because it measures the scalability and its efficiency in terms of consuming node battery power.

4.3 On the density

To see the effect of the density, we created a scenario of 1000m x 1000m with a variable number of nodes from 50 to 100 nodes, with a transmission power of 300 m in range, a speed of 15 Km/h and only a 20% of them are active (generate data traffic).

The packet delivery obtained for both protocols is shown in Figure 4. As the figure shows, both protocols maintain stable their performance, showing DSDV higher rates of delivery packets.

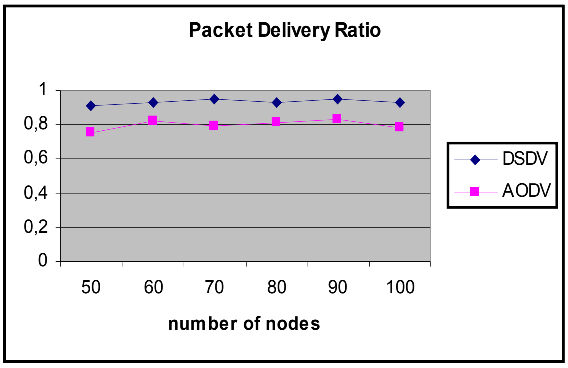


Figure4 Comparison of the packet delivery ratio for a scenario with a variable number of nodes .

When we analyze where these lost packets are in AODV, we notice that AODV has not only more packets in buffers waiting for a route; but also more packets are lost because they were sent following old routes. So AODV, suffers in part from its lack of periodic update information but maintaining reasonable good delivery ratios.

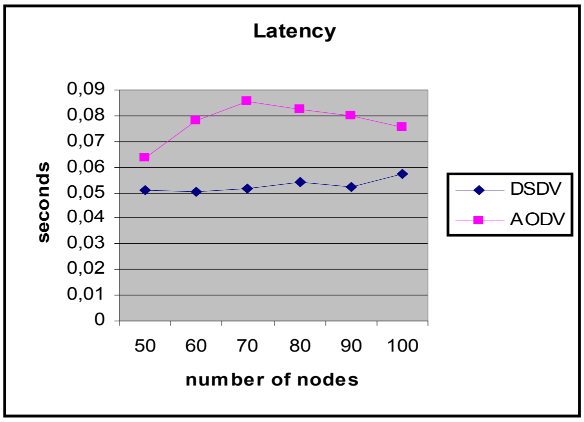


Figure5 Comparison of the latency for a scenario with a variable number of nodes

Figure 5 shows the latency tendency for both schemes. As it could be expected, the reactive scheme, AODV presents considerably higher latency due to the discovery process and the absence of a constant up-to-date information interchange between the nodes.

However, AODV presents a more limited control overhead in contrast with the unsustainable growth of the overhead in the proactive scheme DSDV (Figure 6).

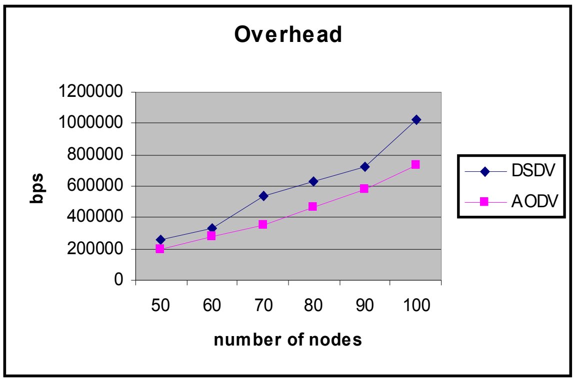


Figure6. Comparison of the control overhead for a scenario with a variable number of nodes.

In fact, in DSDV the control overhead grows as the number of nodes in the networks grows; on the other side in AODV and, in general, in any reactive scheme, it grows with the number of required destinations. These variables are close related, in fact the number of required destinations will be a proportion of the number of nodes in the network with a random traffic generator like the one from our model , that is why they have parallel tendencies but with considerably lower rates for the reactive scheme.

4.4 On the mobility

To see the effect of the mobility, we created a scenario of 1000m x 1000m with 80 nodes, with a transmission power of 300 m in range, a speed of 15 Km/h and only a 20% of them are active (generate data traffic).

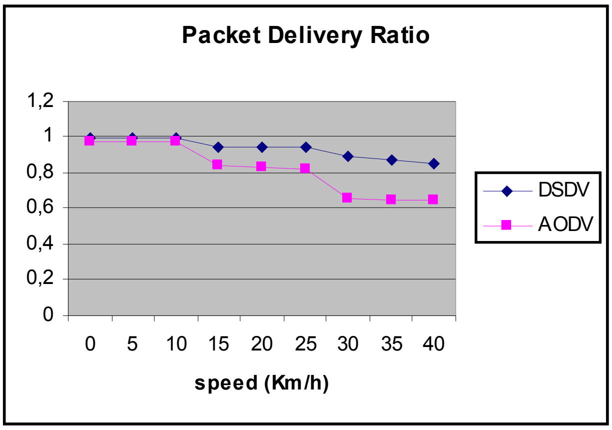


Figure7.Comparison of packet delivery ratio for a scenario with a variable node speed.

As shows Figure 7, both protocols follow similar decremental tendencies with the speed. AODV seems however to be more sensible to the effects of the mobility in the nodes . Once more AODV suffers from not always up-to-date information but with ratios of overhead much lower that its proactive predecessor (Figure 8).

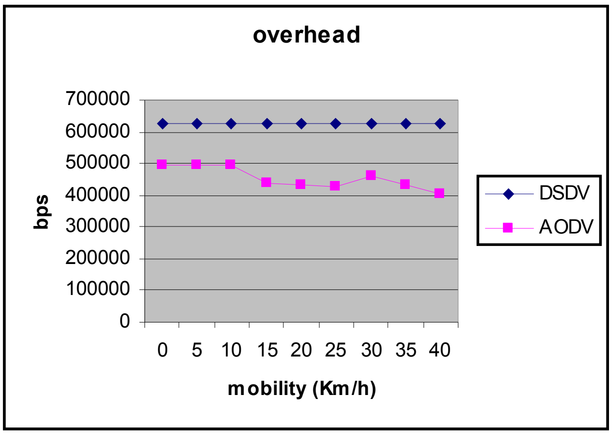


Figure8. Comparison of control overhead for a scenario with a variable node speed.

4.5 On the traffic load

To analyze the effect of the increment of the traffic load in the protocols, we created a scenario of 1000m x 1000m with 80 nodes, with a transmission power of 450m and a speed of 15 Km/h. The traffic load is incremented by increasing the number of nodes which generate traffic in the network. In a network of 80 nodes, we made 4 simulations with 20, 40, 60 and 80 of the nodes active.

The results in packet delivery ratio, shown in Figure 9, demonstrate once more the more sensibility shown by the reactive schemes to all the factors which can stress the routing algorithm.

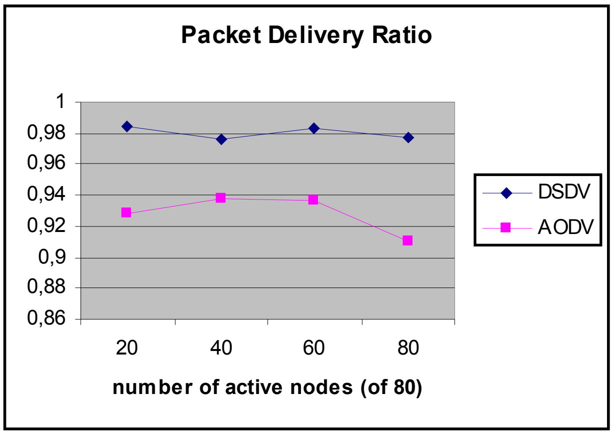


Figure9. Comparison of packet delivery ratio for a scenario with variable traffic load.

Figure 10 highlights the importance of the data traffic load for the behavior in latency of the reactive protocol (Figure 10).

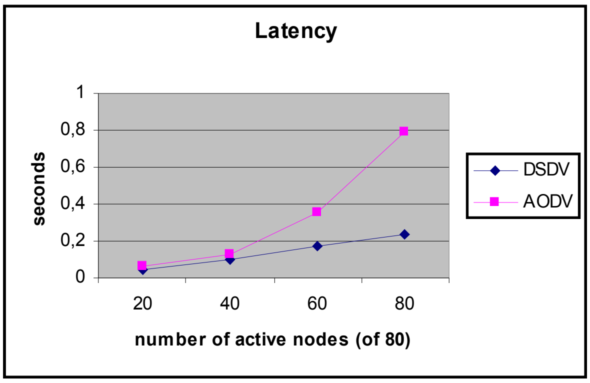


Figure10. Comparison of latency for a scenario with variable traffic load.

When the percentage of traffic load grows, the number of discovery processes triggered also grows, the buffers are fulfilled and the latency grows unsustainable. This general delay has a big impact on the control overhead (Figure 11) because the growing number of route requests do not receive replay at time, so the discoveries processes restart and restart, producing an unsustainable growth of the control overhead, exceeding even the proactive scheme.

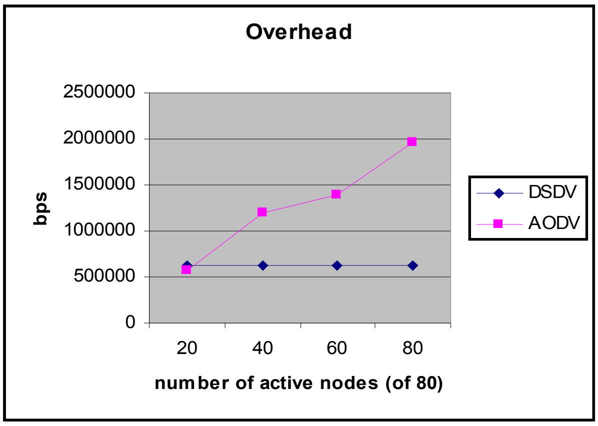


Figure 11. Comparison of control overhead for a scenario with variable traffic load.

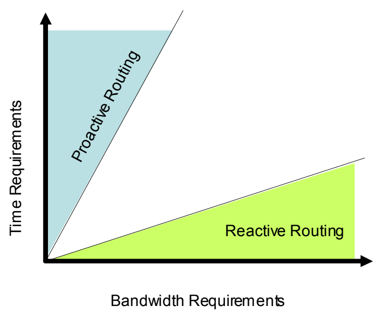
4.6 Conclusions

After the study, we can conclude that the proactive scheme (DSDV) presents a more stable behavior in all circumstances but with a dramatic increment in control overhead. On the other side, the reactive scheme (AODV) presents a more adaptable behavior on the network topology with the consequent limitation of control overhead. It is also true that AODV suffers sometimes too much from its lack of periodical updates, especially in environments of high traffic load.

5. A Hybrid Proposal

5.1 Motivation

As we could see in the previous section, both proactive and reactive schemes have specific advantages and disadvantages that make them suitable for certain types of scenario.



Since proactive routing maintains information that is immediately available, the delay before sending a packet is minimal in cost of an increasing control overhead.

On the other hand, reactive protocols must first determine the route, which may result in considerable delay; moreover, the reactive route search procedure may involve significant control traffic due to the global flooding.

It is therefore necessary to find a intermediate solution, able to adapt to the topology and traffic characteristics of the network traffic to assure scalability in ad hoc networking problem.

5.2 A new hybrid proposal

ZRP proposes an open architecture to adapt proactive and reactive protocols to a hybrid scheme based on routing zones. Every node defines a routing zone limited by parameterizable number or hops. The data traffic within the zone is routed by a proactive scheme generically named IARP; the traffic beyond the zone is forwarded by a reactive scheme, IERP, whose queries are sent by bordercasting.

In ZRP, protocol candidates for IARP and IERP are proposed link-state in order to bordercast the queries to the bordercast nodes in the zone. However, in [9] it is demonstrated that ZRP's response time in single channel environments is comparable to that of flood searching only with a small reduction in control overhead.

Besides, AODV includes an “already processed query detection”, which limits considerably the flooding process with an effect similar to the Early Termination (ET) [8]. So the idea of creating a new distance vector hybrid proposal, that we will name from now HRP, based on routing zones which joins simplicity and adaptability seems to have viability.

5.3 Architecture

ZRP defines four main modules which compound the general routing framework: IARP as routing scheme within the zone, IERP as routing scheme beyond the zone, NDP as neighbor detection protocol and BRP to provide bordercasting service.

In HRP, IARP task will be taken by DSDV. As DSDV includes neighbor detection procedure, it will not be necessary to include NDP. The routing outside the zones (IERP) will be lead by AODV. BRP is not necessary since we will use flooding instead bordercasting techniques.

The DSDV & AODV modified versions used for the hybrid scheme will be named from now HDSDV and HAODV.

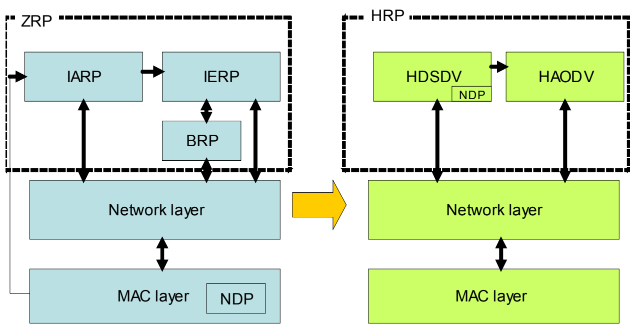


Figure 13. From ZRP architecture to HRP architecture.

5.4 DSDV and AODV Modifications

Some small modifications had to be done to adapt the original algorithms DSDV and AODV to our hybrid proposal.

HDSDV needed to reduce its scope to the neighborhood limited by RADIUS, **ρ**. Besides, it will have to redirection the DATA packet to HAODV instead of discarding it, when the destination is unknown.

In HAODV, the HELLO messages will be avoided because the neighbor detection task is already done by HDSDV.

When HAODV receives a RREQ message, it can now use the exact knowledge of its zone provided by HDSDV to answer before to a Request message. Thus, it will look first in HDSDV(IARP) routing table to know if the destination is within its area.

5.5 Routing Operation

When a packet comes from the application layer, the message is always received by HDSDV(IARP). HDSDV looks up the destination in its routing table to forward properly the message. In case it finds the next hop for the destination, it forwards the packet following the information included in its routing table; otherwise it sends internally the message to HAODV(IERP).

When HAODV receives the message, it looks up also in its routing table a route to forward the message. If it has a proper route for the destination, it includes the suitable next hop and forward the message through the MAC layer. If it has not a route, it keeps the packet in a buffer and starts a discovery process, flooding the query.

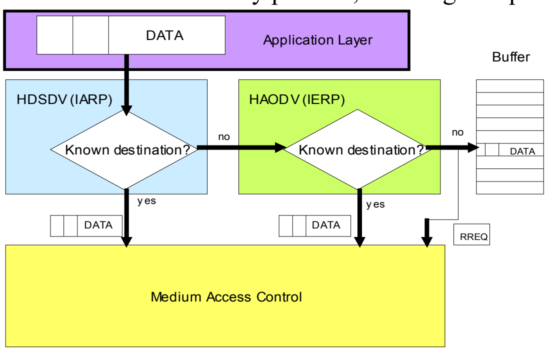


Figure 14. Data message arquitecture in HRP

When a node receives a Request Packet (RREQ), it checks if it has a route not only in its HAODV Routing Table but also in its HDSDV Routing Table. This way, the discovery process shortens because the RREQ is answered, as latest, by the bordecaster nodes of the destination.

In the path were the RREQ is sent, all the nodes along the path learn the routes for the previous hop and the originator of the RREQ in order to be able to reroute the replay of the discovery process (RREP).

When the originator node receives the replay for the discovery process initiated, it sends finally the packets which were waiting for the route for this destination in the buffer.

5.6 Operation Example

Let's consider the network of Figure 15, where Node A wants to send a packet to Node F. The RADIUS zone is supposed to be 2 hops.

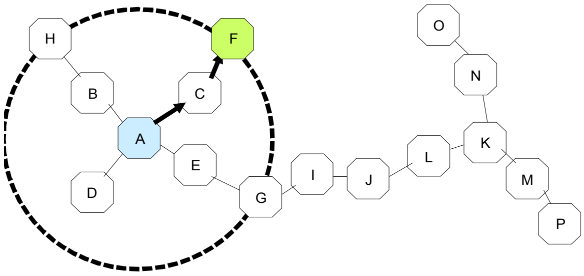


Figure 15. Node A wants to send a packet to Node F

As Node F is within the zone of Node A, A will have an entry of F in its HDSDV(IARP) table so the data packet will be properly forwarded using the proactive scheme, HDSDV.

Let's consider now that Node A wants to send a packet to Node K.

Node A initiates a discovery process sending a RREQ packet which will be rebroadcasted until a node finds an entry in its routing table for the destination. As it can be seen in Figure 16, the RREQ will be rebroadcasted by the correct way maximum only as far as a bordercaster node of the destination, in this case node J. It is sure that these bordercaster nodes of destination will have in IARP (HDSDV) a proper route to destination.

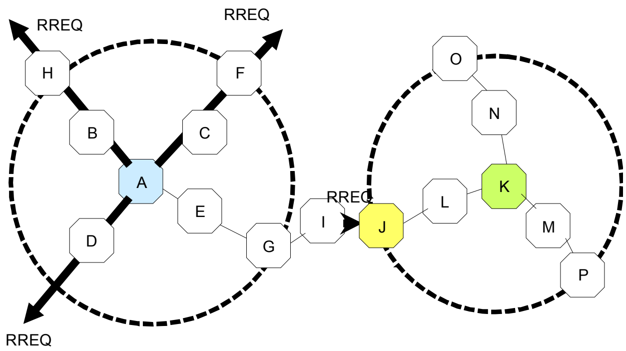


Figure 16 Request broadcasting from Node A

In the other cases (RREQ is broadcasted through erroneous paths), RREQ will be rebroadcasted a limited number of times limited by the TTL value of the RREQ packet.

As the RREQ packet is broadcasted, the nodes learn the routes for the previous hop and the originator of the RREQ packet. In this way, they are able to propagate properly the replay packet RREP.

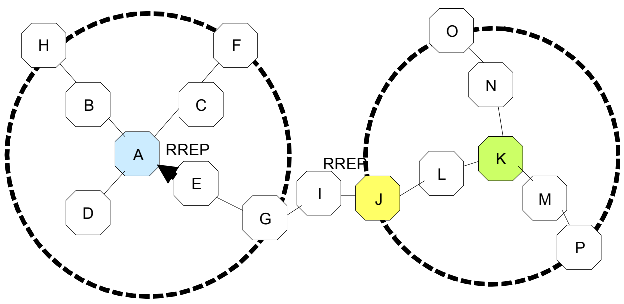


Figure 16. Replay message

Once Node A receives a replay message from the destination or an intermediary node (in our scheme it will always be, minimum, from a bordercaster node from destination), it can send properly the packet which waits in the buffer.

In this case, the packet will be sent by HAODV (IERP) until Node J, and from J to the destination will be routed by HDSDV (IARP), as shows Figure 17.

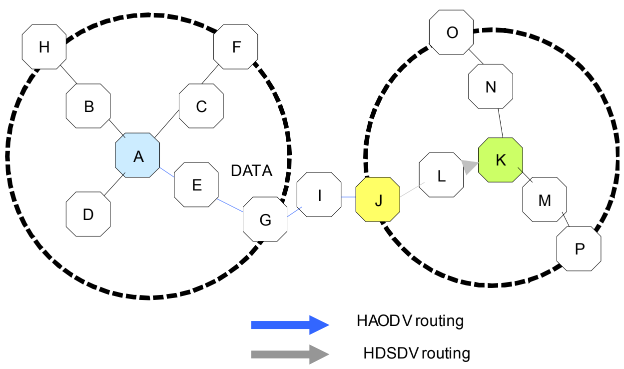


Figure 17. Sending of waiting DATA packet

6. HRP Performance Evaluation

For a first performance evaluation of the new proposal, we created a scenario of 1000m x 1000m with nodes whose antennae have a transmission power of 300 m in range and an average speed of 15 Km/h.

We compared the control overhead results for a network with 60, 100 and 180 nodes in order to analyze the scalability ability of the proposal. Only 20% of the nodes generated traffic. The simulations were of 120 seconds.

Figure 17 shows the overhead per node in the network for the different scenarios simulated.

As it can be seen in the figure, the control overhead presents a non lineal behavior with a minimum in RADIUS 2, for the scenario condition.

These results, really similar to the ones got by ZRP in [6], indicate the necessity of a previous RADIUS election according to the network characteristics.

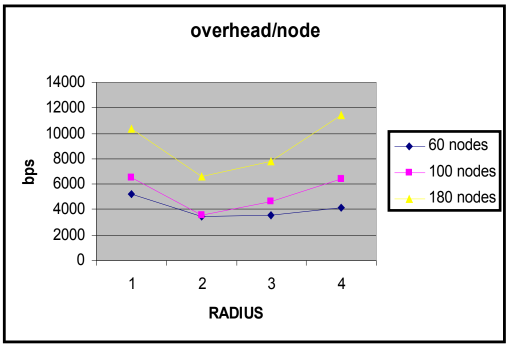


Figure 17. Overhead per node against RADIUS value

To analyze the scalability improvements got by the hybrid scheme HRP on its predecessors DSDV and AODV, we challenged the three protocols with same scenarios, changing the number of nodes from 60 to 160 nodes.

We also tested a HRP with traffic generation with selective destination choice. This traffic generator generates data traffic for nodes within the zone with a probability of 70%. Therefore, we will be able to measure the effect of the assumption of that most of the traffic in real networks is generated for nodes near the sources.

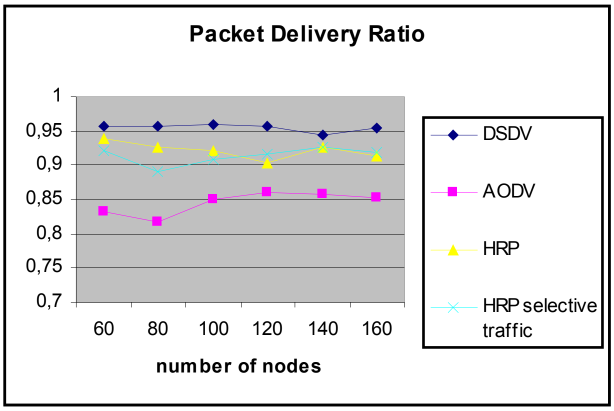


Figure 18. Packet Deliver Ratio against number of nodes

The delivery ratio and latency (figures 18 and 19) maintain between the borders of the proactive and reactive schemes. In the case of HRP with selective traffic, it becomes better results than even DSDV for the decrement of number of hops due to the selective destination choice.

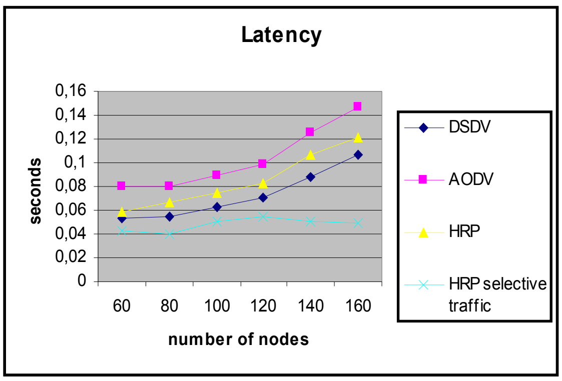


Figure 19 Latency against number of nodes

Finally, in the case of control overhead, main indicator of the scalability ability of a scheme, the improvements are notable (Figure 20).

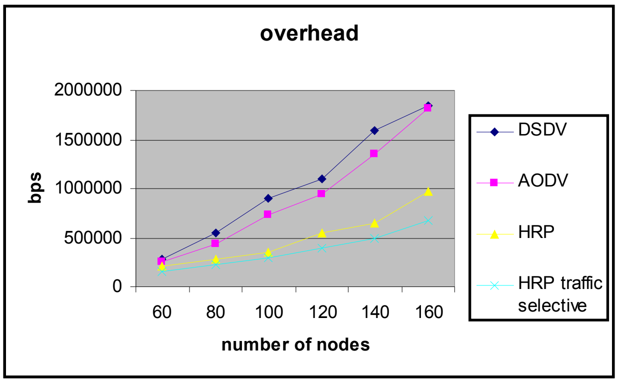


Figure 20 Control Overhead against number of nodes.

The limitation of the control overhead with a proper RADIUS selection follows a much more sustainable tendency than its predecessor for both cases, with and without selective traffic. Moreover, the difference between HRP and its predecessors is bigger as the number of nodes in the network increases.

The definition of routing zones with a suitable RADIUS value, reaches a compromise between proactive and reactive traffic. On the one hand, HDSDV limits its scope, reducing the number of control packets required for a periodical update; on the other hand, the traffic routed by HAODV is reduced, hence the delivery ratio and latency values are closer to the better results got by the proactive schemes.

7. Conclusions

The simulations of the two distance vector algorithms, DSDV and AODV, have proved that there is not a best solution for a general mobile ad hoc network. Meanwhile DSDV, maintains stable its rates of delivery ratio and latency in cost of an unsutainable growth of the control overhead; AODV adapts its behavior dynamically to the network topology suffering in some of its ratios, specially in scenarios of growing data rate.

A new proposal, following the Zone Routing Protocol philosophy was proposed, HRP defines a routing zone for each node limited by a number of hops (RADIUS). Within the zone, the traffic is routed proactively; beyond the zone, it is sent using the reactive scheme.

The simulations made to test the efficiency of HRP, show that HRP improves substantially the results got by its predecessors, DSDV and AODV. It is especially notable the results obtained in control overhead, with a proper RADIUS election, which solves the scalability problems which presented the previous proactive and reactive schemes.

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