DESIGNING ROUTING PROTOCOL FOR MOBILE AD HOC NETWORKS

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Abstract—**This paper presents a classification of routing design issues for mobile ad hoc networks, and their impact on routing protocol performance. This classification shows a need for a multimode routing protocol in order to satisfy both application requirements and network properties. An alternative simple loop-free bandwidth-efficient distributed routing algorithm, denoted as distributed dynamic routing (DDR), is also presented which can provide a multimode routing infrastructure for routing protocols in mobile ad hoc networks. Using simulation, we study the performance of DDR in terms of packet delivery ratio, average end-to-end delay, and routing overhead under the various load and pause time.**

Keywords—**Mobile ad hoc networks, ad hoc routing, simulation.**

I. INTRODUCTION

The growth of wireless communications coupled with high-speed broadband technology has led to a new era in telecommunications. Actually, in third generation mobile networks, efforts are undertaken to merge many technologies and systems to support a wide range of traffic types with various quality-of-service requirements. As wireless communication channels are highly affected by unpredictable temporal/spatial factors like co-channel interference, adjacent channel interference, propagation path loss and multipath fading, it is necessary to embed various adaptive mechanisms making these systems self-adaptive and more efficient, satisfying application best requirements and mitigating bad effects of wireless channels. However, there are some applications where the fixed infrastructure may not be present or is too expensive to maintain. So in this case, it is better to apply infrastructureless architecture for the desired system. Globally, future mobile networks can be classified in two main types: infrastructure and infrastructureless mobile networks, known as mobile ad-hoc networks. Many critical issues have to be addressed in the both systems. This paper focuses on the routing issue of mobile ad-hoc networks.

A Mobile ad hoc network (Manet) [1] is a set of wireless mobile nodes (MNs) forming dynamic autonomous network. MNs communicate with each other without the intervention of a centralized access point or base station. Due to the limited transmission range of wireless network interface, multiple *hops* may be needed to exchange data between nodes in the network. MNs act both as router and as associated host. No infrastructure is required. Routes between two nodes consist of hops through other nodes in the network. Therefore, each MN takes part in discovery and maintenance of routes to other nodes. The main characteristics of Manet strictly depend on both wireless link nature and node mobility features. Basically, they include dynamic topology, bandwidth and energy constraints, security problems, self-operated (stand-alone) and lack of infrastructure [2]. Manets are viewed as suitable systems which can support some specific applications [3]:

- Virtual classrooms,
- Military communications,
- Emergency search and rescue-operation,
- Data acquisition in hostile environments,
- Communication set-up in exhibitions, conferences, presentations, meetings, lectures, etc.

Because mobile ad hoc networks constitute a distributed multi-hop network characterized by a time-varying topology, limited bandwidth and limited power, conventional routing protocols are not appropriate to use. Therefore, it is necessary to develop new protocols able to ensure a correct reception of transmitted information on radio links and to determine efficiently routes to reach the desired destinations. In fact, to reach the challenge of responding to time and space variations of mobile environments, efficient powerful adaptive routing protocols must be designed with an aim of enhancing the overall system performance. Some of the main characteristics of routing protocols in mobile ad hoc networks are: dynamic, scalable, loop-free, convergent and distributed. In view of these characteristics, other desirable features of ad hoc routing protocol includes: fast route establishment, multiple routes selection, energy/bandwidth efficiency, and fast adaptability to link changes.

In this paper, we suggest a classification of routing design issues for mobile ad hoc networks, and their impact on routing protocol performance. A comparison of different class of routing protocols is also stated. We highlight the trade-off which can be found among the routing design issues through the example of a multimode *DDR - Distributed Dynamic Routing* infrastructure. The DDR can be tuned in order to satisfy both application requirements and network properties[1]. We consider three metrics: *packet delivery ratio, average end-to-end delay, routing overhead* in order to evaluate the impact of DDR on the routing protocol performance.

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[1] Some of network properties include rate of mobility, rate of the network connection/disconnection, scale of the network, node density, type of traffic.

II. Routing Design Issues

Several routing protocols have been proposed for mobile ad hoc network as exposed in section III regarding application requirements and network properties. A comparison of different existing approaches and examining the main strengths of each tendency can be found in [3][4][5]. We propose a classification of routing design issues for mobile ad hoc network according to three criteria (see Fig. 1):

1. *Routing Philosophy:* Table-driven versus on-demand versus hybrid approach,
2. *Routing Architecture:* Flat versus hierarchical versus aggregate architecture,
3. *Routing Information:* Global Position versus Global Position-Less based protocols.

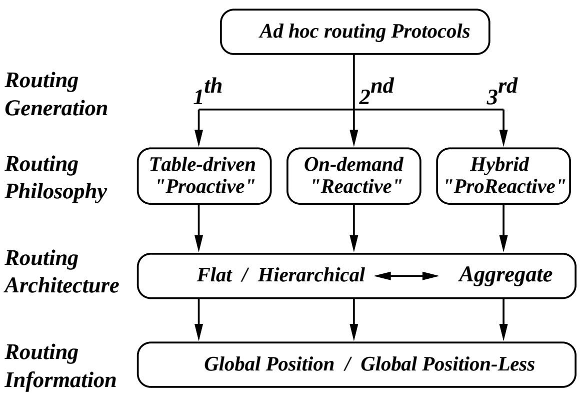


Fig. 1. A Classification of Ad Hoc Routing Protocols

A. Routing Philosophy

In *proactive* or *table-driven* routing protocols, each node continuously maintains up-to-date routes to every other node in the network. Routing information is periodically transmitted throughout the network in order to maintain routing table consistency. Thus, if a route has already existed before traffic arrives, transmission occurs without delay. Otherwise, traffic packets should wait in queue until the node receives routing information corresponding to its destination. However, for highly dynamic network topology, the proactive schemes require a significant amount of resources to keep routing information up-to-date and reliable. In contrast to proactive approach, in *reactive* or *on-demand* protocols, a node initiates a route discovery throughout the network, only when it wants to send packets to its destination. For this purpose, a node initiates a *route discovery* process through the network. This process is completed once a route is determined or all possible permutations have been examined. Once a route has been established, it is maintained by a *route maintenance* process until either the destination becomes inaccessible along every path from the source or until the route is no longer desired. In reactive schemes, nodes maintain the routes to active destinations. A route search is needed for every unknown destination. *Therefore, theoretically the communication overhead is reduced at expense of delay due to route research.* Furthermore, the rapidly changing topology may break an active route and cause subsequent route searches [6]. Finally in *hybrid* protocols, each node maintains both the topology information within its zone, and the information regarding neighboring zones. That is, proactive behavior within a zone and reactive behavior among zones. Thus, a route to each destination within a zone is established without delay, while a route discovery procedure is needed for every other destination.

B. Routing Architecture

In *flat* architecture, all nodes carry the same responsibility. Flat architectures do not optimize bandwidth resource utilization in large networks because control messages have to be transmitted globally throughout the network, but they are appropriate for highly dynamic network topology. The scalability decreases when the number of nodes increases significantly. On the contrary, in *hierarchical* architectures, aggregating nodes into clusters and clusters into super-clusters conceals the details of the network topology. Some nodes, such as cluster heads and gateway nodes have a higher computation communication load than other nodes. Hence, the mobility management becomes complex. The network reliability may also be affected due to single points of failure associated with the defined critical nodes. However, control messages may only have to be propagated within a cluster. Thus, the multilevel hierarchy reduces the storage requirement and the communication overhead of large wireless networks by providing a mechanism for localizing each node [6] [7]. In addition, hierarchical architectures are more suitable for low mobility case. *Although flat architectures are more flexible and simpler than hierarchical one, hierarchical architectures provide more scalable approach.* Finally, *aggregate* architectures aggregate a set of nodes into zones. Therefore, the network is partitioned into a set of zones. Each node belongs to two levels topology: low level (node level) topology and high level (zone level) topology. Also, each node may be characterized by two ID number: node ID number and zone ID number. Normally, aggregate architectures are related to the notion of *zone*. In aggregate architecture, we find both intra-zone and inter-zone architecture which in turn can either support flat or hierarchical architecture.

C. Routing Information

In *global position (GP)* based protocols, the network relies on another system which can provide the physical information of the current position of MNs. Such physical locations can be obtained by using the Global Position System (GPS) [8]. This involves the indoor problem[2], as well as increases in energy consumption, cost of the network maintenance and hardware requirements. Generally, satellites are used to deliver this physical information. Any problem in one of the used satellites will surely affect the efficiency of the network and in some cases can easily make this latter blocked. In *global position-less (GPL)*

[2] This problem arises when a MN can not correctly decode the satellite signals in an indoor (close) situation.

based protocols, the network is stand-alone in the sense that it operates independently of any infrastructure. However, there are some situations where the physical location remains useful such as emergency disaster relief after a hurricane or earthquake.

D. Synthesis

Table-driven approaches are the first generation of routing in mobile ad hoc networks, and they are mainly influenced by *Internet* routing protocols. They attempt to maintain consistent and up-to-date routing information from each node to every other node in the network. The areas in which they differ are the number of necessary routing-related tables and the methods by which changes of network topology are broadcast [3]. Second generation of routing ”on-demand” protocols are designed in order to decrease high communication overhead in table-driven approach due to maintain up-to-date routing information. While on-demand routing protocols decrease communication overhead, there are doubts as to its scalability and delay. On-demand routing protocol are different in the way they *construct* and *maintain* a route to the destination and the *metrics* they use to differentiate the discovered routes, as well as the mechanism to avoid a loop. To sum up two approaches, path finding differs from reactive to proactive approach in the sense that reactive approach apply an explicit route request that follows an explicit route reply while proactive one use implicit route reply. Third generation of routing, hybrid approach, is introduced to provide a better compromise between communication overhead and delay as well as better scalability. One of the main difference of hybrid approaches is related to the way of zone constructing. Other dissimilarities inherit from reactive and proactive approaches. Routing architecture is another issue that impacts the routing performance. Since flat or hierarchical architectures alone is not sufficient to satisfy both application requirements and network properties, aggregate or 2-level hierarchical architecture is considered as a hybrid architecture with the aim of being a better trade-off between flexibility and simplicity at one side and scalability at the other side.

Fig. 2 shows another way of representing the classification stated in Fig. 1 according to the distance between the reactive/flat/GPL or *simple* approaches and proactive/hierarchical/GP or *complex*[3] ones. As far as both simple and complex approach alone are not sufficient to satisfy both application requirements and network properties, hybrid/aggregate or *simplex* (simple + complex) approach is introduced with the aim of providing a better trade-off between simple and complex approach. Simplex approach can vary from simple to complex approach. This variation is also called *hybridization degree*, and provides a large flexibility in design choices. Thus, the question of *where to place a new routing protocol* simply returns to both application needs and network properties. This does not necessarily mean having an one-to-one function from application needs to routing protocol, but it can take the meaning of having a multimode routing protocol. Multimode routing protocol means a protocol with a tunable hybridization degree (HD).

[3] Complexity in terms of algorithm, computation, messaging and hardware.

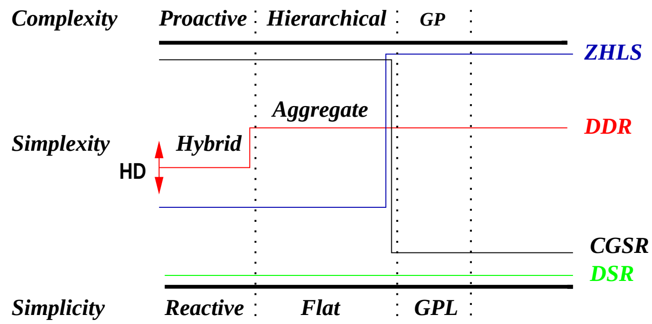


Fig. 2. Hybridization Degree: Simplexity

III. Related Work

Node mobility can cause frequent unpredictable topology changes. Hence finding and maintaining routes in Manets are non trivial task. Many protocols have been proposed for mobile ad hoc networks with the goal of achieving efficient routing. Several table-driven protocols have been proposed such as highly dynamic destination-sequenced distance-vector (DSDV) [9], wireless routing protocol (WRP) [10], global state routing (GSR) [11], clusterhead gateway switch routing (CGSR) [12], fisheye state routing (FSR) and hierarchical state routing (HSR) [13]. Routing performed in DSDV and WRP is based on flat architecture while in HSR, FSH and CGSR, it is based on hierarchical architecture. Among the developed on-demand protocols, we can find cluster based routing protocol (CBRP) [14], ad hoc on demand distance vector (AODV) [15], dynamic source routing (DSR) [16], temporally ordered routing algorithm (TORA) [17], associativity based routing (ABR) [18], signal stability routing (SSR) [19], location-aided routing (LAR) [20], and distributed spanning trees (DST) based routing protocol [21]. These latter protocols except CBRP, maintain flat architectures. The LAR protocol needs physical location information. Hybrid protocols combine proactive and reactive features, we can find zone routing protocol (ZRP) [22][23] and zone-based hierarchical LSR protocol (ZHLS) [6]. Like LAR, ZHLS requires physical location information. Both ZRP and ZHLS support 2-level aggregate architecture.

IV. Distributed Dynamic Routing Algorithm

A. Basic Idea

We propose a *global position-less aggregate with intra-zone hierarchical hybrid* routing algorithm, denoted as DDR - distributed dynamic routing protocol [24]. The main idea of DDR is to construct a forest from a network topology, where each tree of the constructed forest has to be optimal. Then, each tree forms a zone. After that, the network is partitioned into a set of non over-lapping dynamic zones. Each node computes periodically its zone ID independently. Each zone is connected via the nodes that are not in the same tree but they are in the direct transmission range of each other. So, the whole network can be seen as a set of connected zones. Thus, each node from zone z_i can communicate with another node from zone z_j. The size of zone increases and decreases dynamically depending on some network features such as node density, rate of network connection/disconnection, node mobility and transmission power. Mobile nodes can either be in a router mode or non-router mode regarding its position in its tree. This allows a more efficient energy consumption strategy. Each node is assumed to maintain routing information *only to those nodes that are within its zone*, and information regarding *only its neighboring zones*.

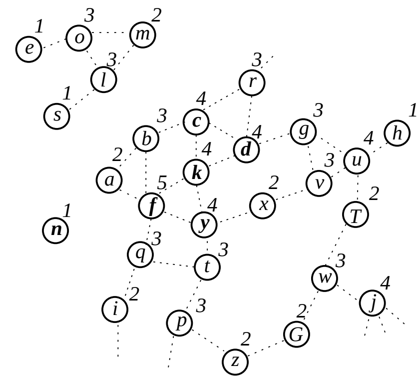
B. *General Description*

DDR combines two classical notions *forest* and *zone*. Forest is previously used in DST - distributed spanning tress for routing in mobile ad hoc networks [21]. Also zone is used in zone routing protocol (ZRP) [23] [22], and zone-based hierarchical link state (ZHLS) routing protocol [6]. Although DDR benefits from classical concepts like zone and forest, unlike previous solutions it achieves several goals at the same time. Firstly, it provides different mechanisms to drastically reduce routing complexity and improve delay performance. Secondly, it is an infrastructureless in a strong sense: it does not even require a physical location information. Finally, zone naming is performed dynamically and broadcast is reduced noticeably. The combination of these two classical notions provides us with an appropriate structure which in turn can give us better trade-off between delay and communication overheads.

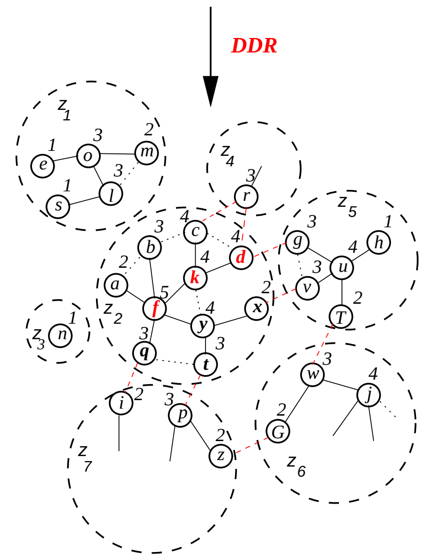
The DDR - algorithm consists of six cyclic time-ordered phases: *preferred neighbor election, forest construction, intra-tree clustering, inter-tree clustering, zone naming and zone partitioning* [24], which are executed based on information provided by beacon. Beacon is a periodic message that exchange *only* between a node and its neighboring nodes. The content of beacon is primitive at the beginning, and it will be enriched during each phase of the algorithm. At the beginning, each node in the network topology carries out the preferred neighbor election algorithm. Then, a forest is constructed by connecting each node to its preferred neighbor and vice versa. Next, the intra-tree clustering algorithm is carried out in order to give an appropriate structure to each tree, and build intra-zone routing table for each node. After that, inter-tree clustering algorithm provides a natural structure among trees which is kept in the inter-zone routing table of gateway nodes[4]. Each tree is assigned with a name by executing zone naming algorithm. Since the constructed forest contains a set of tree where each tree is assigned with a name, then the network is partitioned to a set of non-overlapping dynamic zones. Note that DDR only use beacon to construct a forest and to build both intra-zone routing table and inter-zone routing table as well as other phases of the algorithm. Therefore, it avoids global broadcast throughout the network cause a more efficient use of radio resources.

Fig. 3(a) represents an arbitrary network topology. Once DDR algorithm is executed on each mobile node, the network is partitioned into a set of non over-lapping dynamic zones, as it is illustrated in Fig. 3(b). Each node in the network maintains

[4]The nodes that are not in the same tree or zone, but they are in the direct transmission range of each other are called gateway nodes.



(a) Network Topology



(b) Network Topology under DDR

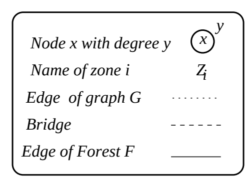


Fig. 3. DDR Infrastructure

two tables: intra-zone table and inter-zone table. Intra-zone table keeps the information within a zone, and it is filled during intra-tree clustering algorithm. It contains three fields: node ID number (NID), learned preferred neighbors (Learned_PN) and last update time (LUT). The field NID represents the ID number of a node that holds an edge of forest with the owner of the table directly. The field Learned_PN represents the nodes that are reachable indirectly by the owner of table via their associated NID in the intra-zone table. The field of LUT represents the last update time of the node NID, and it is used to remove a whole entry in the intra-zone table after a time-out. Table I (a) and I (b) depict the intra-zone table of node k and f belonging

TABLE I

INTRA-ZONE TABLE OF NODES k AND f REGARDING FIG. 3(B)

NID	$learned\_PN$	LUT
f	a, b, q, y, t, x	t_f
c	-	t_c
d	-	t_d

(a) Intra-zone table of node k : $Intra\_ZT_k$

NID	$learned\_PN$	LUT
y	x, t	t_y
k	c, d	t_k
b, a, q	-	t_b, t_a, t_q

(b) Intra-zone table of node f : $Intra\_ZT_f$

to the zone z_2 in Fig. 3(b), and they are denoted by $Intra\_ZT_k$ and $Intra\_ZT_f$ respectively. The intra-zone table gives the current view of a node concerning its tree, and it is updated upon receiving beacons.

In contrast to intra-zone table, inter-zone table keeps the information concerning neighboring zones. This table represents the bridges[5], which are detected during the execution of inter-tree clustering algorithm. Table II shows the inter-zone table of node d, and it is denoted by $Inter\_ZT_d$. Each entry in $Inter\_ZT_x$ contains the ID number of a gateway node (GNID), the zone ID of this gateway node, i.e. neighboring ZID (NZID), the stability of this neighboring zone regarding node x (Z_Stability), and the last update time (LUT) of this entry which is used as same as in intra-zone table.

TABLE II

INTER-ZONE TABLE OF NODE d

$GNID$	$NZID$	$Z\_Stability$	LUT
r	z_4	++	t_r
g	z_5	++	t_g

Therefore, as it is shown in Fig. 3(b) the whole network can be seen as a set of connected zones where each node can communicate with another node in the network (for further information refer to [24]).

C. DDR Comparison

Similar to ZRP and ZHLS, DDR is a hybrid approach based on the notion of zone. Unlike ZRP, in DDR, the zones are not overlapped. In ZRP, each node keeps up-to-date information like distance and route to all the nodes within its zone, while in DDR each node needs to know *only the next hop* to all the nodes within its zone. This, reduces routing information and bandwidth utilization. Different from ZHLS, DDR *does not require physical location information for routing or more precisely for zone construction*. In DDR, the zone size increases and decreases *dynamically* which is not the case in ZHLS. Moreover in ZHLS, zone naming is carried out at the design phase, therefore each node can determine exactly at any time its zone ID by mapping its physical position to a predefined zone map. On the contrary, in DDR the zone name assignment is done dynamically by some selected zone members. In ZHLS, each node maintains the zone connectivity of the whole network, while in DDR, each node keeps *only the zone connectivity of its neighboring zones*. DDR *avoids global broadcast* by sending only the necessary information embedded in beacons to the neighboring nodes. To sum up, DDR reduces maintenance cost and radio resource consumption overhead and leads to a stand-alone network. Finally, in DDR there is no concept of root (as in DST) which *prevents single points of failure*.

[5]The edge that connects two gateway nodes is called bridge.

D. Goal

DDR is designed to offer a flexible infrastructure on which several routing protocols may be defined according to specific application needs.

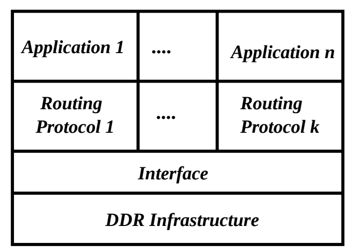


Fig. 4. DDR Infrastructure

Fig. 4 represents the *infrastructure* provided by DDR that can interact with routing protocols via an *interface*. DDR is a multimode routing infrastructure, because DDR can be degraded to the simple approach if the zone size becomes too small, and it can be expanded to the complex approach if the size of zone becomes too large.[6] DDR can be simply extended to a routing protocol as a routing infrastructure. For this purpose, DDR could be tuned via this interface in order to satisfy both application requirements and network properties. Tuning means to modify the criteria in which each phase of algorithm works regarding both application and network parameters. Application can vary from a group of sensors to a group of cars, i.e. from no mobility at all to high mobility, which in turn can potentially affects some network parameters. For instance in the algorithm, we can also benefits from minimum neighborhood degree in conjunction with maximum neighborhood degree, as a criteria for preferred neighbor election algorithm, which in turn provides other alternative routes to the destination node. These alternative routes can potentially balance the load of network. Moreover, some phase of algorithm can be skipped regarding application needs, e.g. zone naming algorithm can be skipped in the highly dynamic network (for further information refer to [24]).

[6]The average size of zone should be a function on some network parameters like average node degree, number of nodes in the network and some other parameters. Node degree is the number of nodes can be heard by a node.

V. Routing Protocol

DDR is a routing infrastructure, so in order to evaluate its performance, we consider a routing protocol called AADDR, AODV + ABR + DDR [25], which runs over it. AADDR is proactive inside a zone (inherited from DDR), and it is reactive outside a zone. AADDR contains two phases: route discovery and route maintenance. If a traffic source finds destination in its neighborhood or intra-zone table, it forwards the traffic packets using the existing route. Otherwise, it should run route discovery phase to find a route. The route discovery phase is likely to AODV [15] which gives smallest size of route request and route reply messages. But different from AODV, the route request message of AADDR propagate in the network respecting the forest structure and no propagation limitation (TTL = maximum) which assure destination can receive the message one time. The movement of intermediate nodes of a route can cause route broken. The route maintenance phase allows an alternative route to be found. Its mechanism is like to ABR [18] with which the nodes near to destination run partial route discovery to find another route to the destination. The AADDR protocol combines the advantages of AODV and ABR and using DDR as an infrastructure for routing message propagation.

VI. Performance Analysis

A. *Simulation Model*

We use a detailed simulation model based on *ns-2* [26] in our evaluation. In a recent work, the Monarch research group in CMU [27] developed support for simulation multi-hop wireless networks complete with physical, data link and MAC layer model on *ns-2*. Traffic and mobility models use similar to [28] and [5]. Traffic sources are CBR (constant bit rate). The data rate is equal to 4 packets per second and 512 bytes per packet. Three different communication patterns are used corresponding to 10, 20, and 30 CBR sources.

The mobility model uses the *random way point* model [5] in a rectangular field (1500m $\times$ 300m). 50 nodes move in it with a randomly chosen speed (uniformly between 0 and 20m/sec). Each node starts its movement from a random location to a random destination. Once the destination is reached, another random destination is targeted after a pause. The selected pause times, which affects the relative speeds of the mobile, are 0, 30, 60, 120, 300, 600, and 900 seconds. For each pause time, we randomly generate 10 different mobility scenarios. So, each data point in the performance results represents an average of 10 runs. Simulations are run for 900 seconds.

B. *Simulation Results*

We analyze AADDR's performance against DSDV - destination-sequenced distance-vector routing protocol [9] and DSR - dynamic source routing protocol [16]. The rational of this choice is to compare the hybrid approach of AADDR with proactive approach of DSDV and reactive approach of DSR.

The following three key performance metrics are evaluated:

1. *Packet delivery ratio* - The ratio of the data packets delivered to the destination to those generated by the CBR sources;
2. *Average end-to-end delay* of data packets - This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, propagation and transfer times;
3. *Routing overhead* - Total number of bytes used for routing during the simulation. Especially in the case of source routing protocol, we should count the additional bits added in the traffic packet header for routing.

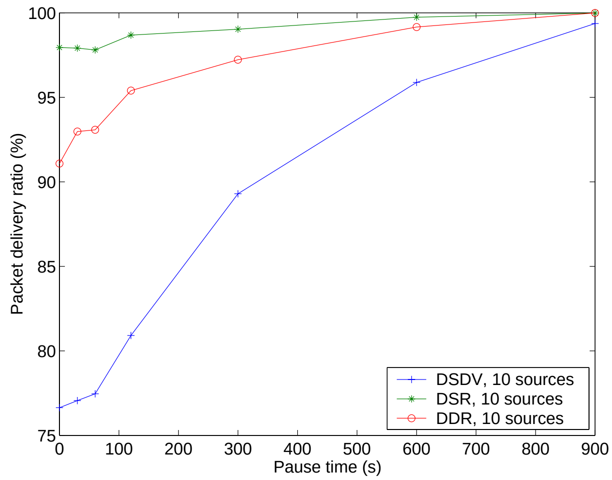
B.1 Packet Delivery Ratio

As expected, the packet delivery ratio of AADDR is between DSDV and DSR in all cases (see Fig. 5). DSDV stores all packets in the queue and waits until the route to the destination is valid. This mechanism results in losing packets when queue is full. On the contrary, in AADDR, there are route discovery and route maintenance phases which allow nodes to find an alternative route when there's no route available. So, the packet loss rate of AADDR is much less than DSDV.

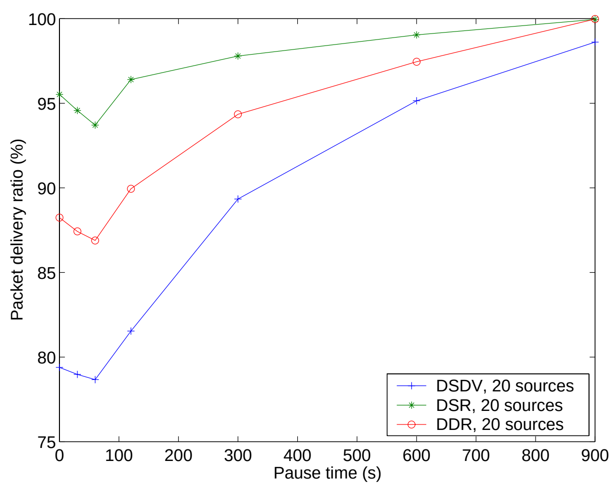
If an intermediate node in DSR can not deliver a traffic to the next hop of the discovered route, it attempts to find a new route in their route cache to salvage the packet and at the same time it sends a route error to the source so that the source can stop sending traffic via this path and run route discovery phase to find another route. In this procedure less packets are affected by the link failures, and there is a possibility of salvaging these packets. But, in the route maintenance phase of AADDR, the intermediate nodes which are closer to source than destination drop the packets immediately. Moreover, partial route discovery run by the other intermediate nodes gives smaller possibility to find a route than using normal route discovery. During the execution of partial route discovery, source node keeps sending traffic through the broken route. These AADDR's packets are affected more than DSR by the link failures, and has smaller possibility of salvaging these packets. So AADDR's packet loss rate is greater than DSR ones when nodes move a lot. When the network is stable, both of AADDR and DSR can deliver nearly 100 percent of packets.

B.2 Average End-to-End Delay

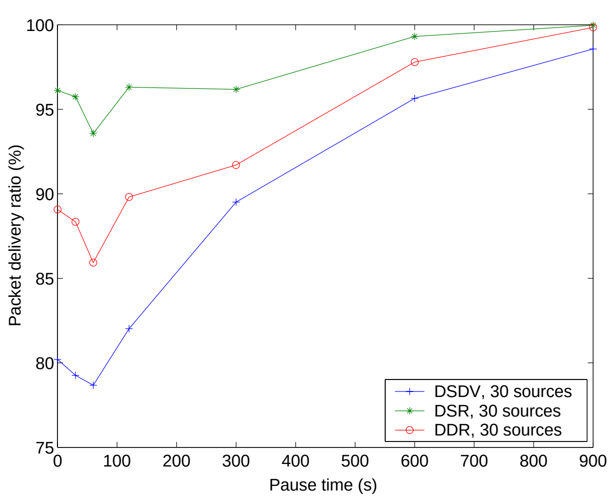
As it is illustrated in Fig. 6(a), AADDR has the best delay with 10 sources, especially when the network topology changes a lot (pause time $<$ 300s), thanks to the hybrid approach used by DDR. In low load case i.e. 10 sources, the delay is mainly stemmed from packets waiting for a route to be prepared. Proactivness of DDR provides routes to the nodes within a zone. If source and destination belong to the same zone, transmission occurs immediately without running route discovery phase. So, the delay of DDR is better than DSR, because DSR should execute route discovery phase when there is no route to the destination in the route cache. Reactivness of AADDR finds a route



(a) 10 Sources

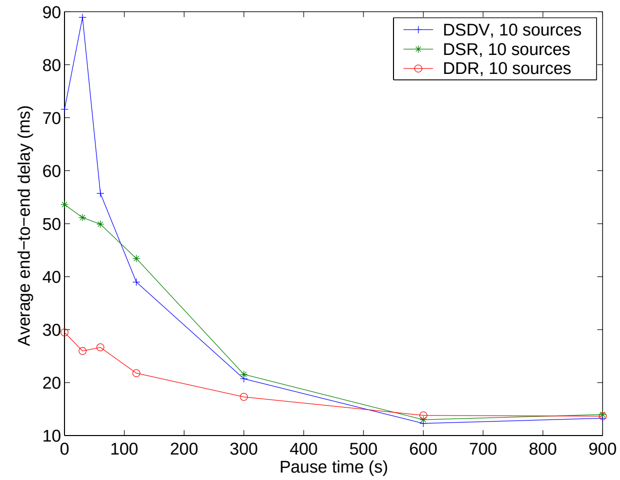


(b) 20 Sources

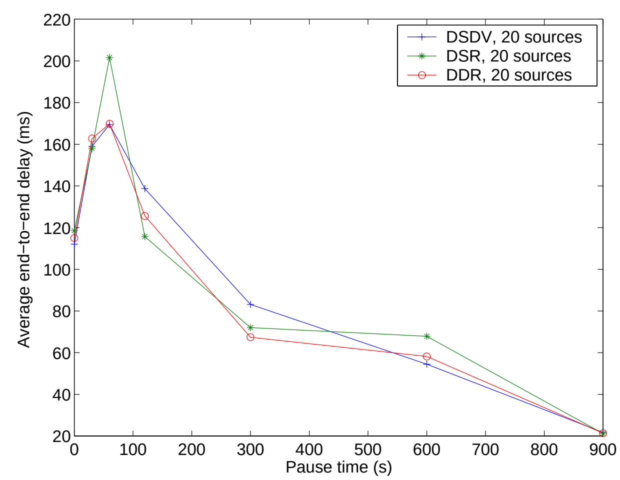


(c) 30 Sources

Fig. 5. Packet Delivery Ratio



(a) 10 Sources



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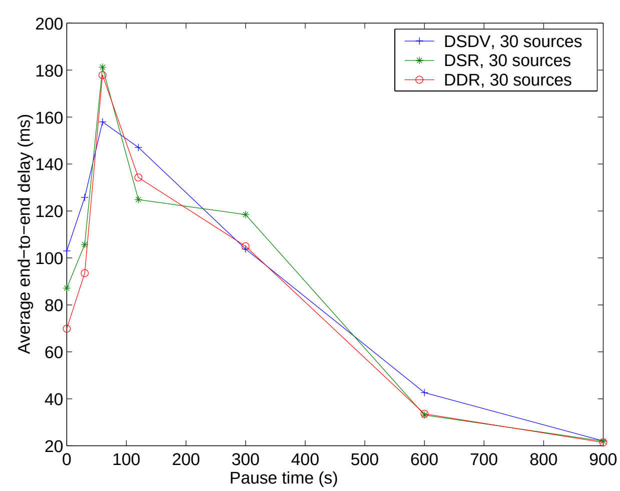
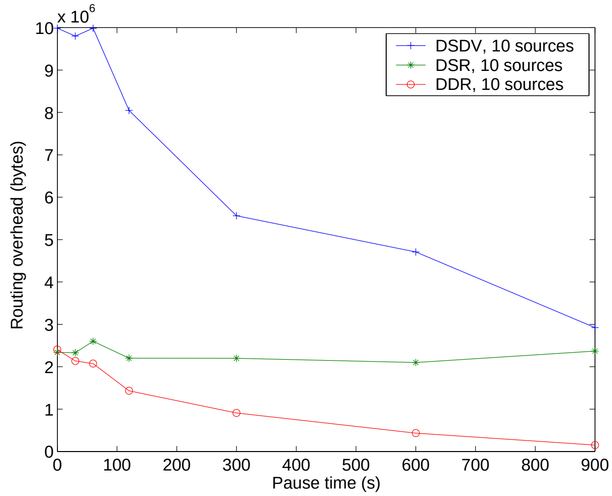
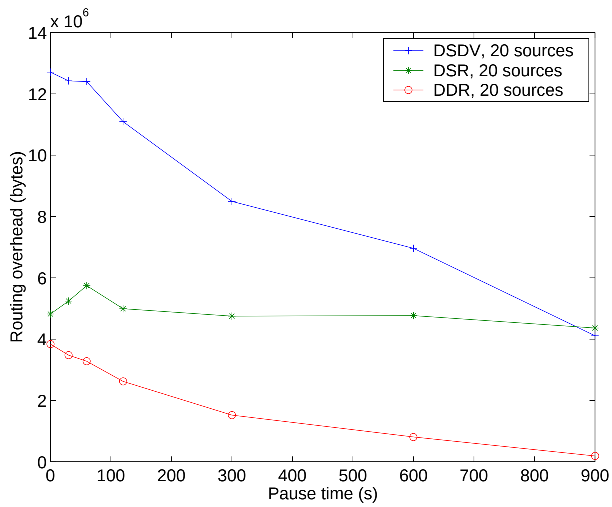


(c) 30 Sources

Fig. 6. Average End-to-End Delay



(a) 10 Sources



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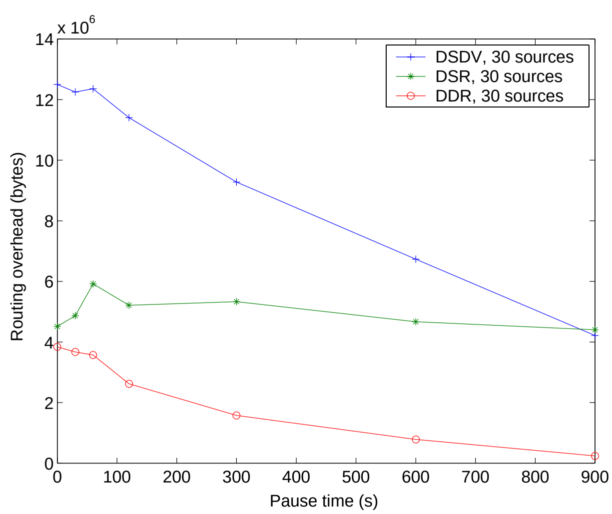

(c) 30 Sources

Fig. 7. Routing Overhead

to the desired destination outside of the source node's zone. On the contrary, in DSDV, traffic should wait in queue until routing information concerning the destination arrives. So, in AADDR, the traffic waits less time for a route than in the case of DSDV.

But with 20 sources and 30 sources (see Fig. 6(b) and 6(c)), there is no difference among the AADDR, DSDV and DSR protocols because all of them suffer from congestion problem and none of them has load balancing mechanism. Hence, one of the main factors of delay stems from congestion problem.

B.3 Routing Overhead

Thanks to the usage of beacon and forest structure, AADDR has a significantly lower routing overhead than DSDV and DSR, as it is shown in Fig. 7). Normally, beacon is smaller than routing information in DSDV and routing message (routing request and routing reply packets) in DSR. Moreover beacon is not globally broadcasted throughout the network. So, establishing routes based on beacon is more efficient in term of routing overhead. Forest structure can detect non-gateway leaf nodes. These nodes do not forward route request messages through the network which also reduce routing overhead.

C. Simulation Summary

The simulation results show that the performance of AADDR relies on DDR's properties. The forest structure of DDR and route discovery mechanism of AADDR provide loop-free routes. DDR uses *only* beacon to provide a routing infrastructure and offers forest which leads AADDR to have a significantly lower routing overhead especially in low mobility case. AADDR benefits from the proactiveness of DDR within a zone and adds reactive mechanism among zone for routing. So, in low load case, AADDR has the optimal end-to-end delay because the waiting time is less for the route to be prepared. But in the high load case, the delay of AADDR is like DSDV and DSR since all of them have no load balancing mechanism to solve congestion problem which cause high delay.

VII. Conclusion

We present a classification of routing design issues for mobile ad hoc networks according to three criteria: routing philosophy, routing architecture and routing information. We derive the notion of hybridization degree to characterize the behavior of routing protocols. This hybridization degree should be tuned in order to satisfy both application requirements and network properties. DDR is presented as a way to provide a multimode routing infrastructure for mobile ad hoc networks. The AADDR example shows that a good performance can be achieved via DDR infrastructure. In future we address the mapping between hybridization degree and application requirements.

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