DICHOTOMY-BASED ROUTING PROTOCOL FOR MOBILE AD HOC NETWORKS

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ABSTRACT

Broadcasting routing control packets network-wide is the most direct and common method for finding the required destination node in ad hoc wireless networks when on-demand routing strategies are used. Even though most of the mobile nodes in the network are not related with those control packets, they have to retransmit them. Our routing protocol partitions the network into a definite number of square districts with equal sides by the aid of GPS. There are two sorts of districts namely gray districts and white districts that interlace one another. Mobile nodes in gray districts are responsible for re-transmitting the received control packets; however, mobile nodes in white districts will not re-transmit it except “listening” the transmitted packets. A mobile node in white district will respond to the transmitted packets only if it itself is the required destination node. Generally speaking, using our routing protocol will save a half amount of control packets as compared to pure flooding routing protocols. Our routing protocol does not require any location information of the required destination nodes, position database, nor hierarchically organized the networks. Furthermore, the protocol does not need to experience a “learning” stage. Our goal is to prevent the control packets from broadcasting network-wide and to save precious bandwidth.

1. INTRODUCTION

In contrast to cellular wireless networks, ad hoc wireless networks, having no fixed infrastructure, transmit any message from a source node to a destination node will pass through many intermediate nodes which requires multiple radio-to-radio hops. Ad hoc wireless networks are fast deployable and suitable for disaster recovery (earthquake, fire), battlefield, and law enforcement.

Traditional routing protocols applied to wired networks are not suitable for ad hoc mobile wireless networks. For example, distance vector (Bellman-Ford) [1, 2] and link state [3] routing schemes suffer from slow convergence to topology changed and also waste bandwidth in periodical routing table exchanges. Especially, the routing loop in distance vector routing is another serious problem. Various routing protocols were proposed to solve the problems of routing loop and provide fast convergence to topology changed in ad hoc mobile wireless networks. Generally speaking, they can be categorized into table-driven (e.g., DSDV [4], CGSR [5], and WRP [6]) and on-demand (or source-initiated, e.g., AODV [7], DSR [8], TORA [9], ABR [10,11], SSR [12], LAR [13, 14], and ZHLS [15]) routing protocols [16,17]. Table-driven routing protocols require each node to have up-to-date information, recorded in routing table, of all mobile nodes in the network. To achieve this goal, whenever each mobile node moves, the new routing table has to be broadcast to all nodes. Moreover, it has to periodically exchange routing table by broadcasting and by propagating update to all nodes in the network to keep track of the newest messages even though the network topology does not change. Each mobile node has routing information about all nodes of the whole network though most of it is undesired. As the number and the moving speed of mobile node increase, the size of routing table and the amount of routing table update increase. Such protocols waste precious wireless bandwidth on control overhead. However, on-demand routing protocols have a totally different approach; they create routes only when desired by source nodes. When a node requires a route to the destination, it initiates a route construction procedure. Route maintenance procedure is triggered whenever a route has been constructed and is in progress until any node in the route is unreachable or the route is no longer required. The control messages used in on-demand routing protocols only record the desirable data on the route such as nodes on the route and other performance metrics and so forth. Excluding any undesired data on control messages, on-demand routing protocols greatly reduce the size of control message as compared with table-driven routing protocols, and they can withstand the increasing number of mobile nodes.

1.1. Related Works

Despite having those advantages over table-driven routing protocols, on-demand routing protocols reveal the shortcoming of blindly broadcasting [22]. Whenever a route construction or a route maintenance procedure is triggered for setting up or maintaining a route, the control message is broadcast network-wide. Even though most of the mobile nodes in the network are not related with those procedures, e.g. nodes not in the route, on-demand routing protocols strongly urge that they should retransmit the control message again. Lots of wireless bandwidth is wasted in such conditions. Many papers [13-15, 18-21] were proposed to remedy the drawback. In [13-15, 18-20], the global position system (GPS) is used as an assistant during the processes of finding the desired destination node for the purpose of reducing routing overhead. Location-Aided Routing (LAR) [13, 14] is proposed to limit the search for a destination node to a smaller "request zone." The purpose of LAR is to reduce the amount of control packets by using the strategy of decreasing request area; however, the use of this strategy relies on the location information of the required destination node. The network will experience a "learning" stage during the initialization of the network to obtain this information. During the stage, control packets cannot be saved; furthermore, LAR can reduce the amount of control packets only if a destination node resides in the request zone. If the location information of the required destination node becomes stale, a further flooding search for the destination node will be broadcast network-wide again to locate the destination node. ZHLS [15] utilizes a hierarchical routing structure and with the aid of GPS, the network is partitioned into a number of zones. Table-driven routing manner is used within intra-zone; however, on-demand routing method is used among inter-zone. Owing to highly dynamic nature of the hierarchical network, the network must be defined dynamically, routing algorithms must adapt to changes in hierarchical connectivity, and finally the nodes must be able to identify "hierarchical address" of a destination node. Moreover, hierarchical routing may give a sub-optimal path between two nodes. In [18, 19], a mobile node of the network can direct messages to all the nodes currently present in a precise geographical area if the "position database" can maintain correct position information. Maintaining this identical database is a serious problem since in such a fully distributed system, position information has to be exchanged periodically to keep consistence content. Large amount of routing overhead is wasted. A position-based multi-zone routing protocol [20] is proposed to reduce control overhead; however, if the position of some node has changed by more than some distance or "Zone Refresh Timer" expired, a routing/position update is generated and propagated throughout the zone. Besides routing overhead, the protocol does incur a position update overhead. "Prior routing histories" is used in [21] for the purpose of localizing the query flood to a limited region of the network. This means that if there are not prior routing histories, the query flood cannot be limited to a region of the network and bandwidth cannot be saved.

The following sections are organized as follows. Section 2 addresses the network and our routing strategy. Section 3 proposes the coverage analysis regarding the network. Routing protocol is presented in Section 4. Section 5 and 6 offer simulation environment and the performance analysis of our routing protocol and other related routing protocols. Section 7 concludes the paper.

2. THE NETWORK AND ROUTING STRATEGY

The network is partitioned into a definite number of square districts with equal sides by the aid of GPS. There are two sorts of districts namely gray districts and white districts that interlace one another. The partitioned network with interlacing gray-white districts is shown in Figure 1. The partitioned network topology can be represented in a graph data structure *G=(V, E)*, where *V* is the set of nodes and *E* the set of edges. An edge (*x, y*) means that node *y* is node *x*'s one-hop neighbor within radio coverage, and vice versa. Furthermore, A physical edge is an edge in which both nodes of the edge must be in gray districts. However, a logical edge is an edge in which at least one node of the edge is not in a gray district. A physical edge is used for retransmission; nevertheless, a logical edge is only for reception. To conform to network terminology, we will use link instead of edge in the following sections. Figure 2 explains the fact in which solid lines represent physical links and dotted lines represent logical links.

The partition of the network is based mainly on radio transmission range and the number of mobile nodes; the speed of mobile nodes could also be another option. According to the relation between the sides of districts and the radio transmission range of mobile nodes, the network is partitioned into different combinations of gray districts and white districts. The longer the side of the districts is, the fewer the number of the districts of the network is. The number of gray districts and the number of white districts are the same if the total number of districts is even; otherwise, the number of gray districts is one greater than that of white districts.

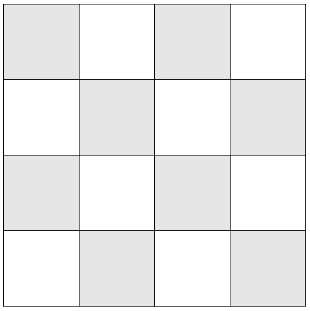


Figure 1. Network Partition

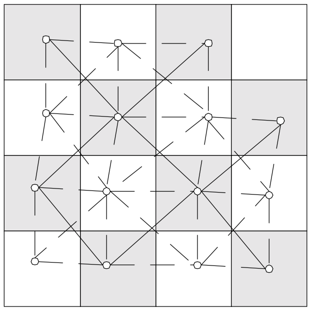


Figure 2. The partitioned network

2.1. Gray Districts Retransmission Strategy

The problems encountered with those related works center around those prerequisites, that is, the location information of the required destination nodes, position database, and hierarchical network architecture. If one of them is incorrect or lost, the control packets will be broadcast network-wide and thus the bandwidth cannot be saved. Nevertheless, we propose a novel routing protocol that does not demand any prerequisite except the use of GPS. Sometimes, the location information of the required destination node is difficult to obtain and once acquiring it, it will become stale when time passes. However, each mobile node is aware of its own location information by the aid of GPS and this information cannot be stale.

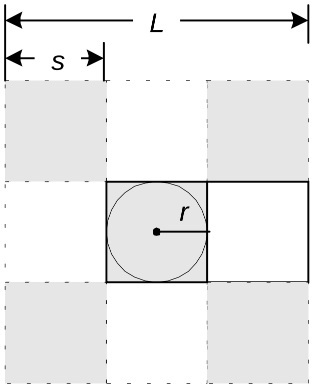
With the aid of GPS, each mobile node in the network knows its geographical location and thus the kind of district it resides in. A mobile node in the gray district is responsible for re-transmitting the received control packets; however, a mobile node in the white district acts as a listener and does not need to re-transmit the received control packets. The difference between the strategy and the traditional on-demand routing strategy is that the latter demands that all of mobile nodes have to re-transmitting the received control packet; however, the former does not. Even though a mobile node in white district is forbidden to re-transmit, it still knows the desiring destination node by listening the transmitting control packets. If it is not the destination node, it keep silence; nevertheless, if it itself is the destination node, no matter what kind of district where it resides in it will respond as soon as possible. Our protocol prevents mobile nodes from blindly broadcasting and the precious wireless bandwidth is saved almost a half.

3. COVERAGE AREA ANALYSIS

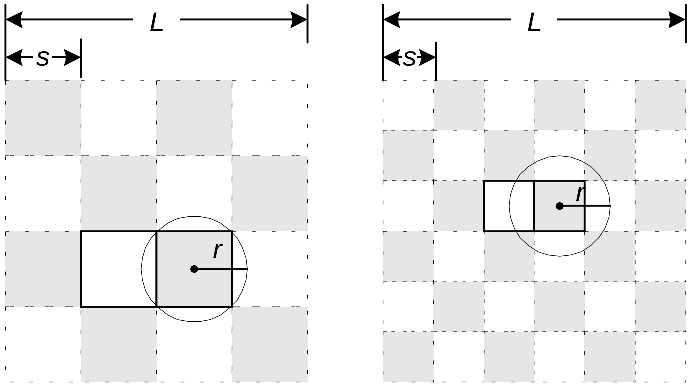
In our network topology, mobile nodes roaming in an *L x L* square meter area that is partitioned into different number of square districts, having sides of *s* meters, according to various instances. The radio transmission range of mobile nodes is *r* meter. Among the three parameters, *L* and *r* are fixed as constants while *s* is a variable varying with the relationship between r and itself. In the following analysis, we assume that $L=6r$ and consider the following five obvious relation between *r* and *s*. The relations between strategy 1, 2, 3, 4, and 5 are $r=s/2$, $r=(\sqrt{2}/2)s$, $r=s$, $r=(3/2)s$, and $r=2s$ respectively. The network topologies of these strategies are drawn in Figure 3. Our mathematical analysis focuses on the radio coverage area of a mobile node, in gray districts, on white districts. Center case, middle case, and border case are considered for the above five strategies, depicted in Figure 4 by using strategy 4. We only consider the instance that there is only one mobile node in gray district. A mobile node in the center of a gray district is defined to be the center case. A border case is defined to be the case that a mobile node is located at the boundary of a gray district and a white district. However, a middle case means that a mobile node locates in half the length between the center and the boundary of a gray district. Our purpose is to calculate the area covered by a mobile node, in a gray district, over a white district. The greater the area is, the stronger the probability of finding the required destination node is. We would like to present a more complicated example, namely the middle case of strategy 4, shown in Figure 5. The total white area of this example can be calculated as following:

$$A = a_1 + a_2 + b + c_1 + c_2 + d + e + f = 1.635r^2$$

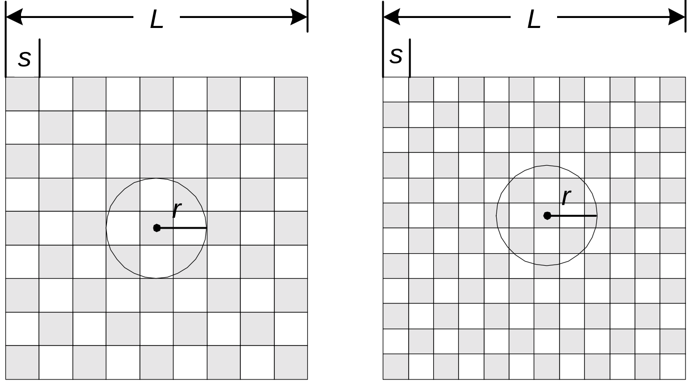
The calculations of the other cases are omitted; we only provide their results. All the cases of the strategies are tabulated in Table 1. The "area" field is the radio coverage area of a mobile node, in a gray district, over white districts; however, the "ratio" field tells us the ratio of the value of the "area" field to the radio coverage area(πr^2)of a mobile node. A more interesting fact is that no matter what case is the ratio of border case is nearly a half of the radio coverage area. Furthermore, there is a surprising truth, that is, strategy 3 has the largest area as compared to other strategies. Both of its two cases are the largest of all these strategies.



(a) Strategy 1: *r = s/2*

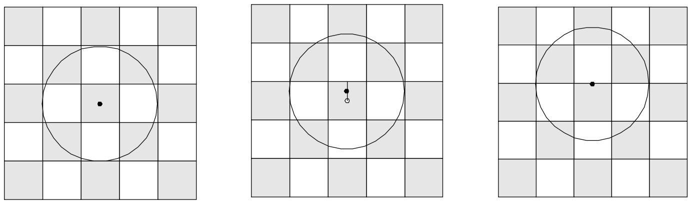


(b) Strategy 2: *r=(√2/2)s* (c) Strategy 3: *r=s*



(d) Strategy 4: *r=(3/2)s* (e) Strategy 5: *r=2s*

Figure 3. Various Kinds of Network Partition



(a) Center Case (b) Middle Case (c) Border Case

Figure 4. Case Analysis of *Strategy 4: r =(3/2) s*

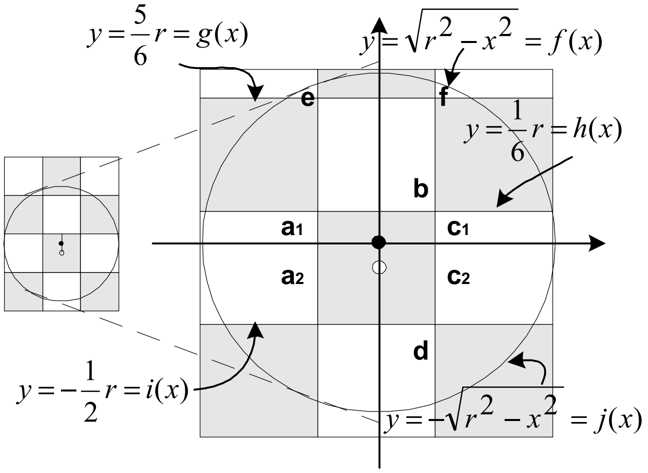


Figure 5. Sample Calculation of *Strategy 4.(b)*

TABLE 1: Coverage Area Comparisons (in r^2)

Strategies	Center Case		Middle Case		Border Case	
	Area	Ratio	Area	Ratio	Area	Ratio
Strategy 1	0.000	0.000	0.614	0.195	1.571	0.500
Strategy 2	1.140	0.363	1.263	0.402	1.571	0.500
Strategy 3	1.828	0.582	1.752	0.558	1.571	0.500
Strategy 4	1.728	0.550	1.635	0.520	1.571	0.500
Strategy 5	1.424	0.453	1.47	0.468	1.571	0.500

4. DICHOTOMY-BASED ROUTING PROTOCOL

Dichotomy-based routing protocol, short for DBR, mainly contains two phases, namely: route construction and route maintenance phases. At the commencement when a source node has packets for transmission, the route construction phase is initiated. Whenever the link of the established route changes, the route maintenance phase starts to maintain a correct and optimal route to the destination node. The main difference between DBR protocol and other on-demand-based routing protocols is that the former does not blindly re-transmit the received control packets but the latter do.

4.1. Route Construction Phase

The route construction phase consists of route request and route reply sub-phases. A request control packet is transmitted hop by hop from a source node through intermediate nodes to a destination node during route request sub-phase. However, the destination node triggers route reply sub-phase whenever it has chosen an optimal route based on information obtained from different routes. The request (REQ) and reply (REP) control packets are depicted in Figure 6.(a). The 'Packet Type' field is used to distinguish the type of control packets, '0' for request packets and '1' for control packets, while 'Sequence No.' field is used to discriminate each unique route construction phase. 'Source ID,' 'Destination ID,' 'Hop Count,' and 'Route Node List' help to distinguish source node, destination node, number of hops, and nodes discovered in this phase. One should remember that except source nodes and destination nodes, a mobile node will retransmit the received control packets only if it itself resides in gray district.

4.1.1 Route Request Sub-Phase

We give each route construction phase a unique sequence number; the control packets with the same sequence number, source ID and destination ID indicate that they belong to the same construction phase. Route request sub-phase is proceeded as follows. When having data for transmission, a source node creates a new REQ packet, generates a unique sequence number, fills in the other fields of this packet, and transmits it to its neighboring nodes. Note that the source node can always transmit its route reply packet even though it dwells in a white district. Any intermediate node receiving this packet will first check whether it resides in a gray district or not. If so, it will retransmit it again, but otherwise the node will keep silence. Furthermore, if the node resides in a gray district, it will check whether it has previously processed this packet or not. If true, the node simply discards this packet; otherwise, the node accumulates 'Hop Count,' adds its own node ID to 'Route Node List' and finally retransmits it to its neighbors. The succeeding nodes will repeat the same process until the control packet reaches the destination node. Upon receiving packets from different routes, the destination node will choose an optimal route according to time delay and hop count. A route with minimum hop count is the most desirable one.

Packet Type	Sequence No.	Source ID	Destination ID	Hop Count	Route Node List

(a) REQ and REP control packets

Packet Type	Sequence No.	Source ID	Destination ID	Hop Count	M-Route Node List

(b) MREQ and MREP control packets

Figure 6. Types of Control Packets

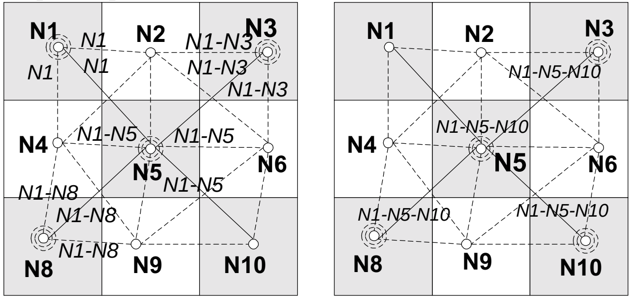
4.1.2. Route Reply Sub-Phase

Route reply sub-phase is used to confirm and deny the routes after route request sub-phase. After selecting an optimal route, the destination node sets the 'Packet Type' to be '1', put the desirable mobile nodes into 'Route Node List', records the other fields of REP control packet and finally propagates it hop by hop back to the source node to accomplish the route reply sub-phase and route construction phase. Note that our protocol does not prevent a destination node dwelled in a white district from transmitting its route request packet. Any intermediate node receiving this packet will first check whether it has already received it before. If it is true, it discards it merely. Furthermore, it will check if it itself dwells in gray district. Provided true, it will retransmit the received control packet to its neighbor; otherwise, it will not retransmit it again. The downstream nodes will repeat the same process until the control packet reaches the source node. When the control packets reach the source node, it will keep this optimal route for future data packet transmission. The route reply sub-phase and route construction phase is thus accomplished.

4.1.3 An Route Construction Example

An example telling the truth of route construction phase is shown in Figure 7 where Figure 7.(a) and 7.(b) explains route request and route reply sub-phases respectively. N1 and N10 work as the source node and the destination node respectively in this figure. Having packet for transmission, N1 generate a route request control packet, records its node ID into field 'Route Node List' and other fields of the control packet and broadcasts it to its neighbor. Among all of its neighbors, only N5 dwelled in gray district and thus, N5 updates hop count, adds its own node ID into 'Route Node List' field, and broadcasts it to its neighbors. Upon receiving the packets, N3 and N8 do the same work as N5; however, N2, N4, N6, and N9 do nothing owing to they dwell in white districts. The destination node N10 will choose an optimal route when the packet is received.

After selecting an optimal path, N10 generates a route reply control packet, records 'N1-N5-N10' into field 'Route Node List' and other fields, and broadcasts it to its neighbors. Any intermediate nodes, N3, N5, and N8, resided in gray districts will retransmit the control packet till it reaches the source node. The intermediate nodes do not require to update the content of the control packet. Whenever the control packet reaches the source node N1, it will keep the optimal route for further use.



(a) Route request sub-phase (b) Route reply sub-phase

Figure 7. Route Construction Example

4.2. Route Maintenance Phase

If any mobile node in the route discovered at route construction phase moves, the route maintenance phase is initialized. Route maintenance phase includes maintained route request (MREQ) and maintained reply (MREP) control packets that are depicted in Figure 6.(b). The 'Packet Type' field is used to distinguish the type of control packets. 'O-Route Node List' indicates the original nodes founded at route construction phase; however, 'M-Route Node List' represents nodes discovered in route maintenance phase. Without further explanation, the 'Sequence No.,' 'Source ID,' 'Destination ID,' and 'Hop Count,' have the same function as that of route construction phase. To explain the effect of mobile nodes movement, we analyze the following three conditions according to the role the mobile nodes play. (1) source nodes movement, (2) intermediate nodes movement, and (3) destination nodes movement.

4.2.1. Source Nodes Moved

If a source node moves out of the route, we have no choice but re-invoke route construction phase because of the source-initiated property. A whole new sequence number will be generated in this case to distinguish the re-invoked route construction phase from the original route construction phase. Since control packets with the same sequence number, source ID and destination ID indicate that they belong to the same construction phase. If they have the same sequence number, any intermediate node will drop it since it deems that it has already processed it previously.

4.2.2. Intermediate nodes moved

If any intermediate node moves out of the route, its immediate upstream node will trigger route maintenance phase. Same sequence number will be used during this phase to indicate the relationship between route maintenance phase and route construction phase. The intermediate node first records the original route node list into "O-Route Node List' field and route nodes starting from the source node to itself into 'M-Route Node list' field, fills in other fields of the MREQ packet, and broadcasts it to its neighbors. This MREQ packet will be re-transmitted by nodes dwelled in gray districts hop by hop till it reach the required destination node. Upon receiving it, the destination node will choose an optimal route, fills in each field of the MREP control packet, and broadcast it hop by hop back to the intermediate node that broadcast the MREQ control packet. Any node in the 'O-Route Node List' field of the MREP packet will drop itself from the route; however, any node in the "M-Route Node List' field of the MREP packet will add itself into the route.

4.2.3. Destination nodes moved

Similarly, the required destination node move outside the route will trigger another route maintenance phase. The immediate upstream node of the destination node invokes route maintenance phase by recording the original route node list into "O-Route Node List' field and route nodes starting from the source node to itself into 'M-Route Node list' field, filling in other fields of the MREQ packet, and broadcasting it to its neighbors. Any nodes dwelled in gray districts will re-transmit the received MREQ packet till it reaches the destination node. Upon receiving it, the destination node will choose an optimal route, fills in each field of the MREP control packet, and broadcast it hop by hop back to the intermediate node that broadcast the MREQ control packet to accomplish the route maintenance phase.

5. SIMULATION ENVIRONMENT

The objective of our simulation is to analyze the performance of DBR regarding different sorts of network partitions and to make a noticeable performance comparison of the proposed DBR strategies, LAR [13, 14] protocol, and traditional on-demand routing protocol, named flooding in our paper. The performance metrics are control overhead and success rate that are defined in the following section. The network consists of a predefined number of mobile nodes roaming randomly in all directions in a geographical area of size 1500 x 1500 square meter at a predefined average speed. The roaming area is defined by a closed square area whose vertices are represented by GPS latitude and longitude coordinate. Furthermore, the roaming area is partitioned into different numbers of gray districts and white districts for each different simulation run to test the performances of different partitioned situations. They are 9, 16, 36, 81, and 144 districts in our different simulation run and are labeled as '9 districts,' '16 districts,' '36 districts,' '81 districts,' and '144 districts' respectively. With the aid of GPS receiver, each mobile node knows its exactly geographical location and thus the sort of district it resides in. Mobile nodes resided in gray districts are responsible for retransmission control packets, but otherwise they do not retransmit them. Data rate is 2 Mbits/s. Radio transmission range of each mobile node is fixed to be 250 meters and free space propagation channel is assumed. The data packet inter-arrival time is exponentially distributed with a mean of 50 ms. A source node and a destination node of data packet are chosen randomly among all of the mobile nodes. The simulation varies the number of mobile nodes, from 25 to 200, and the average speed, from 20 to 80 km/hr, for each simulation run to test the influence of these parameters on each protocol. Total simulation time for each simulation run is 250 seconds.

6. PERFORMANCE ANALYSIS

In this section we present simulation results and performance analyses for DBR strategies, LAR protocol, and pure flooding routing protocol. The performance metrics considered in this paper focus on success rate and control overhead. Our goal is to reduce control overhead during the route construction phase and route maintenance phase. However, it is possible that route construction phase or route maintenance cannot successfully find the source node or the destination node. This metric will help us measuring the performance of DBR strategies and LAR routing protocol significantly. If the probability of success rate is weak, these routing protocols, including DBR strategies and LAR routing protocols, are useless since they will incur a lot of control overhead than pure flooding protocol. If the probability of success rate is strong, it means that these routing protocols are feasible. Subsection B will further discuss the control overhead saved by DBR strategies and LAR routing protocol.

6.1. Success Rate

The success rate for DBR strategies and LAR routing protocol is defined to be the rate of successfully finding the required source node within definite time constraint. The time constraint is defined to be the worst case time complexity *O(2d)* of on-demand routing protocols, where d is the diameter of network. Reader can refer Table 2 of [16] for further information. We also assume that pure flooding routing protocol has one hundred percent success rate and do not take into account of it in this subsection. The parameters we test for success rate include the number and the speed of mobile nodes. When one parameter is tested, we usually fix the other parameter to provide a more objective view of the discussed parameter.

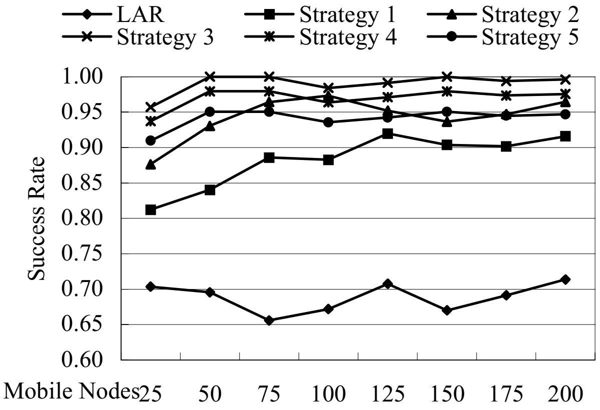


Figure 8: Success rate for different number of moile nodes (speed=50km/hr)

The influence of the number of mobile nodes on success rate is depicted in Figure 8, where the average moving speed of each mobile node is fixed to be 50 km/hr. We would like to discuss LAR routing protocol first. During the network initiation stage, each mobile node of the network does not have any location information of other mobile nodes. Thus, during this "learning" stage, the success rate for LAR is zero; furthermore, even though LAR has location information of other mobile nodes, the ratio of request zone to the total area of the network is about 0.6 to 1. Only 60 percent of control packets are saved under the situation of having the location information of the required destination node. This is the reason that why LAR routing protocol has poor performance than DBR strategies.

As for DBR strategies, each mobile node does not need to experience a "learning stage" as LAR routing protocol since it does not need to acquire the location information of the required destination node. DBR strategies can save bandwidth during the commencement stage of the network. Generally speaking, the number of mobile nodes influences DBR strategies largely; this can be judged from the curves of these strategies. When there is only a few numbers of mobile nodes, say 25, the success rate is weaker than the other number of mobile nodes. As the number of mobile nodes increases, the success rate is raised. '36 districts,' '81 districts,' and '144 districts' strategies seem to have better performances than '9 districts' and '16 districts' strategies and '36 districts' strategy has the best performance of these strategies. When there is enough number of mobile nodes, say 75, all of these strategies achieve saturation, but '9 districts' and '16 districts' and '36 districts' strategies achieve saturation when the number of mobile nodes is 50. Although the number of mobile nodes extends to be 200, '9 districts' strategy still cannot achieve a good performance as the other strategies. The reason is that there is a transmission gap surrounding with it. The partition of the network into nine districts is too rough.

The influence of the average moving speed on success rate is drawn in Figure 9, where the number of mobile node is fixed to be 125. From the curve of LAR routing protocol, we realize that the success rate decrease largely as the average moving speed go beyond 50 km/hr. The truth is that as the speed increase, the probability of location information becoming stale increases. If the required destination node is not resides in the request zone, the success rate of LAR will be decreased.

DBR strategies do not need to keep the location information of the required destination node. Thus, the probability of stale location information is zero. What we want is the own location information of each mobile node. Because each mobile node can know its own location all the time, there is no problem regarding stale location information. From these curves of DBR strategies, the influence of average moving speed on success rate is little since the gray-white districts of the partitioned network are fixed. Among DBR strategies, '36 districts' also has the best performance.

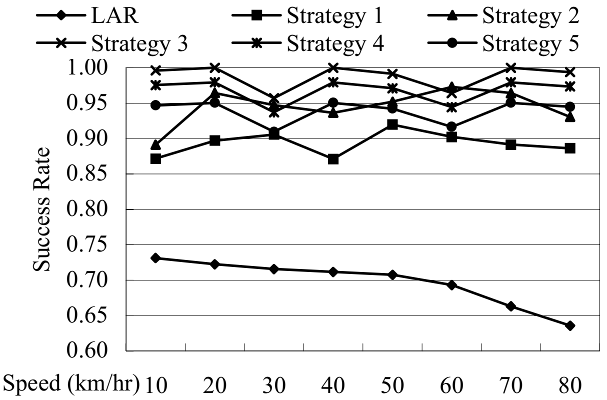


Figure 9: Success rate for different speed (number of mobile nodes is fixed to be 125)

6.2. Control Overhead

The control overhead of DBR strategies and LAR routing protocol includes control overhead triggered at normal procedure and the control overhead incurred when the normal procedure fails. We mean the normal procedure to be the procedure that a source node can successfully find its destination node when DBR strategies or LAR protocol is used. The parameters we test for control overhead also include the number and the speed of mobile nodes. Similar to the evaluation of success rate, if one parameter is tested, we will fix the other parameter to provide a more objective view of the discussed parameter.

Figure 10 shows the control overhead (in packet) for different number of mobile nodes when average moving speed of each mobile node is fixed to be 50 km/hr. Because of the fact that the communication complexity of on-demand routing protocol is *O(2N)* [16], where *N* is the number of mobile nodes in the network, as the number of mobile nodes increases, the total amount of control packets of the whole network increases linearly with the number of mobile nodes. Since control packets is retransmitted network-wide, pure flooding protocol has the largest amount of control packets overhead than the other protocols. Because LAR routing protocol has to experience the "learning" stage during the initialization stage of the network, what LAR can do is to blindly flood the control packets network-wide and thus increases the amount of control packets. That is the reason why LAR has larger amount of control overhead than DBR strategies. That is why the figure says.

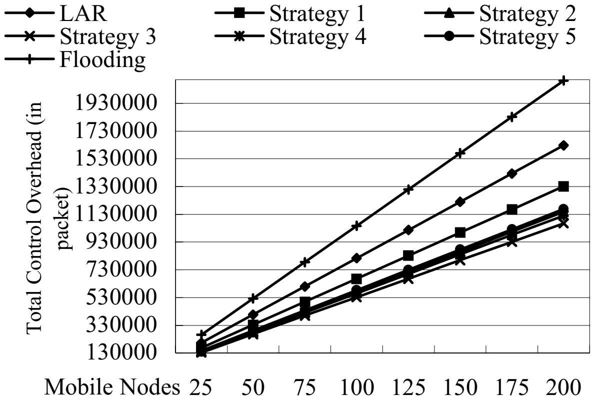


Figure 10: Control overhead for different number of moile nodes (speed 50 km/hr)

As for DBR strategies, since they do not need such kind of "learning" stage as LAR, they will not transmit the control packets network-wide except normal procedure fails and thus save a lot of control packets. Moreover, the probability of failed normal procedure is so weak that the probability of control packets transmitted network-wide is so weak. Thus, control packets are saved. From the curves of DBR strategies, '36 districts' seems to have the best performance than the other four DBR strategies.

Figure 11 presents the control overhead (in packet) for different average speed of mobile nodes when the number of mobile nodes is fixed to be 125. Generally speaking, the amount of control overhead increases with the average moving speed of mobile nodes; the curves of pure flooding and LAR protocols present the truth. The slope of LAR is steeper than that of pure flooding protocol because as average speed of mobile nodes increases, the probability of the location information of a required destination node becoming stale increases. Thus, the probability of successfully finding the required destination node decreases and the probability of control packets transmitted network-wide increases. That is the reason why as the average moving speed of mobile nodes increases, the amount of control overhead of LAR protocol increases rapidly. However, DBR strategies present a more random nature than the other protocols since the required destination node can randomly reside in white districts or gray districts, which is independent of the average moving speed of mobile nodes. Nevertheless, to a broaden view, the total amount of control overhead also increases with the average moving speed because as the moving speed increases, the probability of a broken route also increases. Judging from these figures, we know that DBR strategies save almost a half amount of control packets of pure flooding protocols.

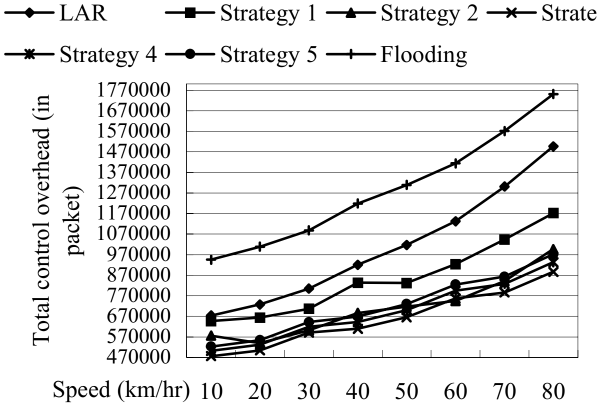


Figure 11: Control overhead for different speed(# of mobile nodes= 125)

7. CONCLUSIONS

DBR protocol partitions the network into two sorts of districts namely gray districts and white districts with the aid of GPS. A Mobile node will retransmits the received control packets only if it resides in gray districts. Generally speaking, DBR protocol will save almost a half amount of control packets as compared to pure flooding routing protocols and success rate will be increased if the network is partitioned suitably. DBR protocol does not require any location information of the required destination nodes, position database, nor hierarchically organized the networks. Furthermore, the protocol does not need to experience a "learning" stage as LAR routing protocol. Immensely reducing the amount of control packets is our main contribution.

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