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DREAM: A Theoretical Analysis

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DREAM: A THEORETICAL ANALYSIS

by

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ABSTRACT

DREAM: A THEORETICAL ANALYSIS

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A Mobile Ad-hoc Network (MANET, for short) is a collection of mobile nodes deployed in support of a short-lived special-purpose operation. Examples include search-and-rescue missions, law-enforcement, multimedia classrooms, and among many others. Unlike cellular or satellite networks, MANET do not rely on any form of pre-existing infrastructure. The mobility of nodes combined with the lack of infrastructure makes routing in MANET notoriously difficult. It was recently suggested that routing in MANET can use to advantage geographic information that the nodes may acquire either by endowing them with a GPS chip or simply by using known localization algorithms. Distance Routing Effect Algorithm for Mobility (DREAM) is one of the first and most intuitively appealing protocols to use geographic information for route selection in MANET.

Unfortunately, as we shall prove later in this thesis, the original DREAM protocol is afflicted with a number of problems. Recently, a new implementation of DREAM was proposed that reports vastly different performance results from the original paper. For example, the original DREAM implementation claims that the recovery process, invoked when DREAM can not find a path to the destination, is used only about 10 percent of the time. The second paper argues that, in their implementation, DREAM used the recovery process more than 80 percent of the time. One of the reasons for the discrepancy in the

reported results is that these papers make different assumptions about key deployment parameters of MANET. There is not doubt what they tell are correct according to their assumption. But, we can not make a decision according to their result, when we need to select a routing protocol for an MANET.

The main goal of this thesis is not to judge whether or not DREAM is a protocol that should be used in practical applications. This, indeed, is best left to the individual applications. Our goal is to investigate and shed light on the deployment conditions under which DREAM is efficient in that it does not fall back onto the recovery mechanism which in tantamount to blind flooding.

ACKNOWLEDGMENTS

Professor Stephan Olariu was my advisor during this research. His profound knowledge of MANET provided me many helpful suggestions.

There are many other people who have contributed to the successful completion of this dissertation. I extend many, many thanks to my committee members for their patience and hours of guidance on my research and editing of this manuscript. The untiring efforts of my major advisor deserve special recognition.

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CHAPTER I

INTRODUCTION

A **M**obile **Ad**-hoc **NET**work (MANET) consists of a group of mobile nodes (mobile routers and associated hosts) connected by wireless links; the mobile nodes can self-organize into temporary network topologies. These networks are eminently applicable to situations requiring rapid deployment and lacking fixed infrastructure, including battlefield operations, multimedia classrooms, law-enforcement, search-and-rescue missions and many other special-purpose applications that require rapid deployment. However, the highly dynamic network topology and the lack of fixed infrastructure make routing in MANET quite challenging. In fact, it was realized that standard routing protocols used in wired networks (including the Internet) and in some wireless networks (including cellular and satellite networks) do not apply to the stringent conditions of MANET.

This state of affairs has motivated researchers to design routing protocols that work in the specific conditions on MANET. Given the paramount importance of routing it is not surprising that in the past decade dozens of routing protocols for MANET were proposed in the literature. More recently, it was realized that geographic information, in one form or another, may be available to the nodes of MANET. Indeed, some of the nodes may be equipped with GPS devices while some others may determine their approximate location by using any of a number of localization strategies.

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DREAM is, without doubt, one of the best-known MANET routing protocols. Not surprisingly, a number of researchers have compared its performance to that of other routing protocols for MANET. However, there does not seem to be a consensus as to whether or not DREAM works efficiently. On the whole, DREAM is appealing by its sheer simplicity but the analysis of its performance depends to a large extent on the set of initial assumptions. This is why a number of researchers have reported that DREAM is efficient, while others have obtained completely different results.

In this thesis we are going to provide a theoretical analysis of the sensitivity of DREAM to some of the key MANET attributes. One of the outcomes of this work is that it provides the end-user with a tool that should allow them to decide whether DREAM is the right routing protocol for their particular application. In fact, tools of this kind are lacking in the community where the application designer does not have at their disposal an objective set of criteria for distinguishing between various routing protocols.

The remainder of this thesis is organized as follows. In Chapter 2 we review routing protocols for MANET illustrating how they work and the advantages/disadvantages of each category of protocols. In Chapter 3 we present the details of DREAM and offer a quick survey of previous research on DREAM. In Chapter 4 we offer a mathematical analysis of DREAM. Chapter 5 presents our simulation model and extensive simulation results that confirm our theoretical analysis. Finally, Chapter 6 offers concluding remarks and maps out directions for future investigations.

CHAPTER II

ROUTING PROTOCOLS FOR MANET

The main goal of routing protocols is to "guide" the data packets to be delivered from the source mobile node to destination mobile node. Because of the lack of fixed infrastructure and of the highly dynamic topology, the design of routing protocol for MANET is a notoriously difficult task. As previously stated, since routing is a fundamental protocol in wireless networks, the past decade has seen a flurry of activity in the area of routing protocols are proposed for MANET. These routing protocols were designed with the goal of optimizing some resource of the network. For example, since most nodes in a MANET are running on batteries, a number of workers have concentrated their efforts on designing routing protocols that are as energy-efficient as possible. Other protocols were specifically designed to find the shortest possible route between the source and the destination while, perhaps, keeping the energy expenditure as low as possible. Yet another design criterion involved finding routes that guarantee a certain amount of bandwidth from the source to the destination. The latter two criteria are part of a larger effort known as Quality of Service (QoS) routing that finds natural applications to wireless multimedia.

In order to make this work as self-contained as possible, this chapter offers a gentle introduction to various types of routing protocols recently designed for MANET.

II.1. A Review of Routing Protocols for MANET

Routing Protocols for MANET can be divided into three categories: proactive, reactive and hybrid. Proactive ad-hoc routing protocols are derived from traditional distance vector and link state routing protocols in wired networks. With proactive protocols, each node maintains a route to every other node in the network at all times. Reactive protocols, on the contrary, each node needing to send a data packet will broadcast to find a path to the destination node. Hybrid routing protocols have features common to both proactive and reactive protocols. Section 2.1.1 and 2.1.2 introduce examples of routing protocols.

II.1.1. Proactive Routing Protocols

In a proactive protocol, each node maintains its own copy of routing information; when a node has a data packet to the send, it will send out the data packet without delay. The main drawback of proactive protocols is that the bandwidth used to maintain routing information is large.

DSDV (Destination Sequenced Distance Vector) [13] is based on the classical Bellman-Ford routing algorithm. Each node maintains a list of all destinations and number of hops to each destination. Each entry has a sequence number. It uses full dump or incremental packets to reduce network traffic generated by route updates. The broadcast of route update is delayed by settling time. By using Bellman-Ford routing algorithm and time out for packets waiting too long, routing loops in a mobile network of routers are prevented. With this improvement, routing information can always be readily available, regardless of whether the source node requires route or not

CSGR (Cluster Switch Gateway Routing) [14] is an ad-hoc routing protocol that groups mobile nodes into clusters and provides each cluster with a cluster head. A cluster head controls the cluster information for a group of ad hoc hosts and switch routing information among cluster heads. Nodes within a cluster only have routing information within that cluster. Data packets with destination in another cluster go through cluster heads. It uses DSDV as the underlying routing algorithm and each node maintains a cluster member table, only the cluster heads maintain routing information to other clusters.

From the two proactive protocols we introduced above, we can find out that all nodes maintains routing information to the entire MANET, or to cluster head which can route to all other clusters. So, when a data packet needs to be sent out, there is low latency in determining a route. The shortcoming of these protocols is the large amount of bandwidth used to maintain routing information.

II.1.2. Reactive Routing Protocols

In a reactive protocol, a node does not maintain routing information to other nodes when no data packets need to be sent. Before sending data packets, the source node will broadcast to find a path to the destination node; then the data packets will be transfer through this path. Reactive will consume less network bandwidth for routing, but it will have extra delay before the data packets can be sent out.

AODV (Ad hoc On Demand Distance Vector) [11]- This routing algorithm improves on the DSDV algorithm by minimizing the number of required broadcasts by creating routes on demand, without maintaining a complete list of routes as in DSDV algorithm. A path discovery (broadcast) is initiated when there is no route to a destination node.

Broadcast is used for route request. Link failure notification is sent to the upstream neighbors (this algorithm requires symmetric links). It uses bandwidth efficiently, by minimizing the network bandwidth for control messages. So it more scalable and ensures loop free routing.

SSR (Signal Stability based adaptive routing) [15] is descendent of. SSR selects routes based on signal strength between nodes and on a node's location stability. SSR route selection criteria has the effect of choosing routes that have 'stronger' connectivity. SSR can be divided into Dynamic Routing Protocol (DRP) or Static Routing Protocol (SRP). DRP is responsible for maintenance of signal stability table and routing table. SRP processes packets by passing them up the stack if it is the intended receiver and forwarding the packet if it is not

DSR (Dynamic Source Routing) [12] is based on the concept of source routing. For this protocol, mobile nodes are required to maintain route caches that contain the routes of which the mobile is aware. Entries in the route cache are continually updated as new routes are learned. There are 2 major phases of the protocol - route discovery and route maintenance Route discovery uses route request and route reply packets. Route maintenance uses route error packets and acknowledgements.

All reactive protocols introduced above need to wait for the path searching procedure before sending out data packets. They all reduce route maintaining bandwidth by searching for a route when needed and and/or by caching previous routing information. To make sure the route information is correct, they need to control the time that a route record will remain available in routing table. Additionally, the flooding of the network may lead to additional control traffic, again putting a strain on the limited bandwidth.

II.1.3. Hybrid Routing Protocols

Hybrid routing protocols have both advantage of proactive protocol and reactive protocols. The basic idea of hybrid routing protocol is to use proactive protocol for short distance nodes and to use reactive protocol for long distance node. When most of the network traffic travels short distances, hybrid routing protocols work with high efficiency.

ZRP (Zone Routing Protocol) [10] is a protocol used under hybrid category for ad hoc mobile routing protocols. It incorporates the merits of on-demand and proactive routing protocols. ZRP is similar to a cluster with the exception that every node acts both as a cluster head and a member of other clusters. The routing zone comprises mobile ad hoc nodes within a few hops of each other. But, hierarchical routing is used; the path to a destination may be suboptimal.

TZRP (Two-Zone Routing Protocol) is an elegant hybrid routing protocol, proposed recently by Wang and Olariu [9] with the goal of minimizing the sum of both proactive and reactive control overhead. In ZRP a node will maintain routing information within the zone area; but, a node in TZRP has two zones, called crisp zone and fuzzy zone. Usually the radius of crisp zone is less than that of the fuzzy zone. A node will maintain routing information with proactive routing protocol within the crisp zone area. In a fuzzy zone, which is defined to observe past routing information and provide a good approximation for the current route, much less routing packets are transferred. By adjusting the size of these two zones independently, we will have a lower routing control overhead. Extensive simulation results [9] show that TZRP is as a general MANET routing framework that can balance the trade off among various routing control overheads more effectively than ZRP in a wide range of network conditions.

II.2. Location-Based Routing

Location-based routing protocols use knowledge about the geographic position of nodes to make routing decisions in MANET. These protocols assume that each node has exact knowledge or at least a good approximation of its own location. In some protocols some provision is made for nodes to publicize their location by periodic update messages that are propagated in a certain neighborhood. For example, nodes can obtain a very good approximation of their geographic location by making use of GPS. When a node needs to send out a data packet it will deliver the packet to specific neighbors according to the location information received from other nodes; the node will compare the position of destination node and neighbor nodes, then make a route decision. Recently, a number of location-aware routing protocols were proposed in the literature. These include, among others, DREAM, GPSR, LAR and GRA.

As a subset of proactive ad-hoc routing protocols, location based routing protocols consume considerable network bandwidth to maintain routing information in every node. In location based routing, the highly dynamic character of MANET makes it very costly to maintain a consistent state of routing purpose. The more accurate routing information we need the more network bandwidth is consumed. As the total number of network nodes increases the network bandwidth used for route maintenance increases exponentially. Thus location based routing does not scale well.

Location based ad-hoc routing protocols use geographic position in ad-hoc routing to reduce the routing overhead to maintain a consistent routing table, and achieve scalability in large MANETs.

DREAM (Distance Routing Effect Algorithm for Mobility) [2] is a location-based routing protocol which makes use of the location information, handles the location effect and node velocities. In order to reduce the network bandwidth used to maintain route information, DREAM protocol uses two ideas. First, farther nodes need less location information as well as the routing accuracy is not compromised. Second, nodes with lower speed need to send out less location update packets.

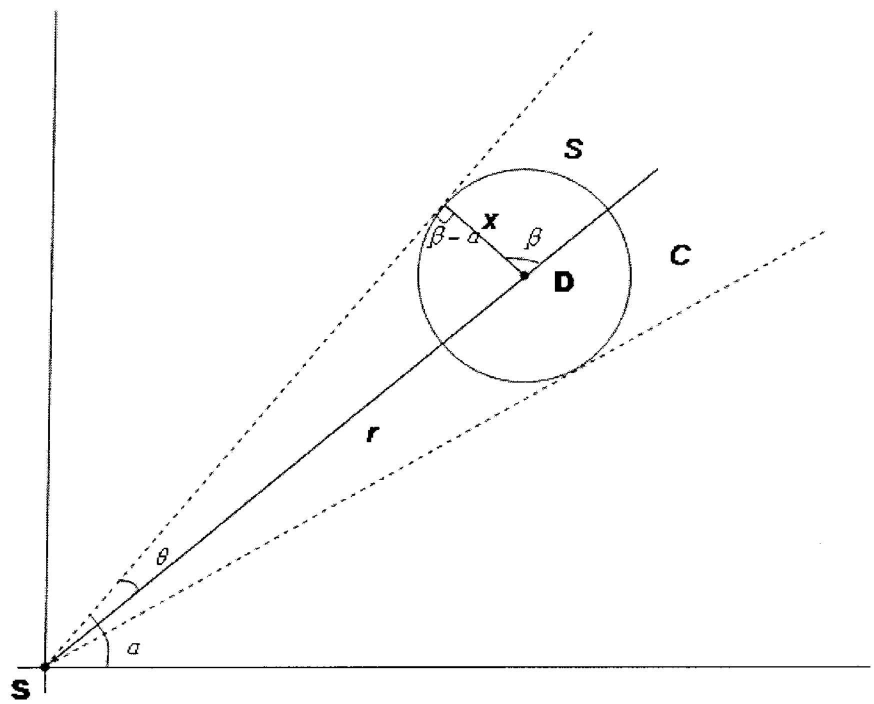


Fig.1. Basic Idea of DREAM.

Figure 1 explains the idea of DREAM. At time t_1 node S needs to send a data packet to node D; the most recent location information about D was received at time t_0; at time t_0, D's moving speed was v, and the distance to S was r. S will find one-hop neighbors according to the known information about D. Specifically, S knows that within time $(t_1 - t_0)$ D could not move out the circle with radius $x = .(t_1 - t_0) \bullet v$, so the next node for the data packet can be limited within area with angle 2θ; since $\beta - \alpha = \pi/2$, $\theta =$

$arcsin(x/r)$. If a node receives this data packet, it calculates its own θ and sends out the data packet with these rules. Finally the data packet reaches D. It is quite possible that some nodes in the middle have no neighbor node within angle θ and there is no complete path for the data packets from S to D. In such a case DREAM fails and will resort to flooding in order to route the packet to D. Indeed, flooding will be used when S does not receive an ACK packet from D before the first data packet timeout.

GRA (Geographical Routing Algorithm) [18] is a proactive algorithm, which tries to limit the size of routing tables by the use of position information. The basic idea is quite simple. Each node only knows a restricted number of other nodes. When a node wants to send a packet, it chooses among the nodes he knows, the one which is closest to the destination and sends the packet. If on the way a node knows another node even closer to the destination, then it redirects the packet to that node; the packet will be redirected one node after another until it reaches the destined node. It was shown that the mean size of routing table for a node is O(L log n), where L is the mean number of hops between two randomly chosen nodes and n is the number of nodes in the network. However this algorithm does not seem to be in a very advanced state and is mainly a theoretical study as far as we know.

GPSR (Greedy Perimeter Stateless Routing) [17] is a hybrid efficient routing protocol for mobile, wireless networks. Unlike established routing algorithms before it, which use graph-theoretic notions of shortest paths and transitive reachability to find routes, GPSR exploits the correspondence between geographic *position* and connectivity in a wireless network, by using the position of nodes to make packet forwarding decisions. GPSR uses *greedy forwarding* to forward packets to nodes that are always progressively closer to the destination. In regions of the network where such a greedy path does not exist (*i.e.,* the only path requires that one move temporarily farther away from the destination), GPSR recovers by forwarding in perimeter mode such that a packet traverses successively closer faces of a planar subgraph of the full radio network connectivity graph, until reaching a node closer to the destination, where greedy forwarding resumes.

LAR (Location-Aided Routing) [16], LAR utilizes location information to limit the area for discovering a new route to a smaller requested zone. The operation is similar to DSR: LAR performs the route discovery through limited flooding. The idea of LAR is quite similar to DREAM in trying to limit the flooding area, so that the network bandwidth for routing control will be reduces. LAR defines two kinds of zone, Expected zone and request zone. If a data source node has no location information about the destination node, then it can not compute the expected zone and will flood the path request in request zone.

II.3. Performance Research on Ad-hoc Routing Protocols

The efficiency of MANET routing protocols depends on network deployment conditions; each routing protocols will have its own goal, for example, short transmission time, reduced control overhead, low data packet lost rate and so on. Some deployment conditions are listed below.

- Deployment density of nodes

  Deployment density affects the existence a path from source node to destination node; it will be easier to find a path from source to destination node if the deployment density is high. On the other hand, the chance of collision will be higher as the deployment density increases. So, deployment density can be neither too high nor too low.

- Mobility characteristics

As we all know, in MANET, mobility characteristics are important factors for routing protocols. If the average moving speed of all nodes is high we need more network bandwidth for control overhead in proactive and hybrid routing protocols. The more network bandwidth is used for control overhead the less will be left for data transmission; so the routing protocol with less control overhead is preferable. In another condition, when the diversity of moving speed is high, it is possible to reduce the control overhead for the slow moving nodes; DREAM is a routing protocol with this goal.

- Traffic parameters

Traffic parameters include some assumptions on the network traffic. For example, ZRP and TZRP assume the traffic for nearby nodes is much more than the traffic for faraway nodes, so these protocol uses proactive within a zone area which has more traffic than outside the zone. DREAM and many other protocols assume that the probability of having network traffic between any two nodes in the network is the same. Some other protocols may have other assumptions on the network traffic parameters.

No routing protocol can work equally well in all deployment conditions. For example, some routing protocols assume that all nodes move at a low speed, some protocols assume that the nodes can keep a certain (average) number of neighbors by automatically adjusting the radio power, while others make assumptions about the traffic parameters of the network.

Although the specific assumptions may limit the applicability of a routing protocol, they are necessary due to the complexity of MANETs. Every node in MANET may move randomly, this make the routing much more complex than conventional static networks. Without simplifying any assumptions, the routing information is totally unpredictable and it is impossible to choose an optimal protocol.

Given these conditions, our main goal is to analyze a routing protocol as completely as possible, looking at it from different angles, making it easier for practitioners to make intelligent choices between various competing protocols

In this thesis, we shall focus on the DREAM protocol. Specifically, we propose to explore DREAM in the light of various network conditions, including node density, nodes moving speed and size of a network. We propose to elucidate the conditions under which DREAM is a good choice, as well as those under which DREAM is not suitable. Our results are as objective as possible since we express performance in terms of mathematical formulae connecting the assumed network parameters.

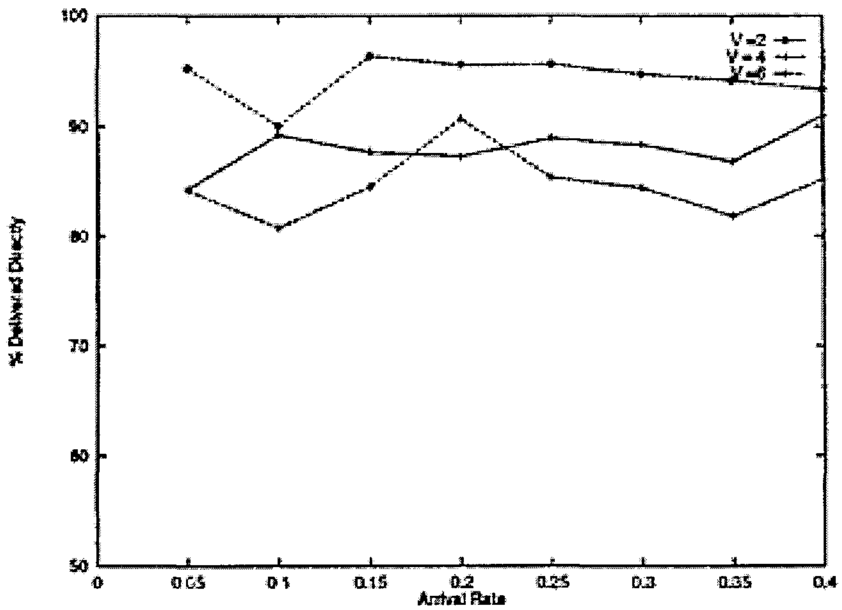
CHAPTER III

PREVIOUS RESEARCH ON DREAM

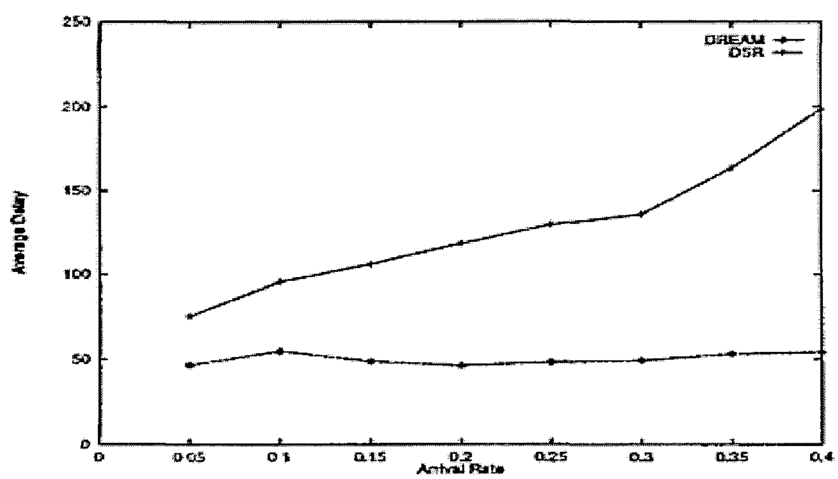
To the best of our knowledge, the only existing performance evaluation of DREAM was obtained by simulation. These simulation results DREAM presented in [2] showed that the success rate (defined in Chapter 4) of DREAM was very high and that DREAM featured an overall performance superior to that of DSP. Their simulation results are shown in Fig.2. Later on, some serious problems of DREAM were exposed and the protocol was modified. But the simulation that compared DREAM and LAR in 2002 [4] showed that the success rate of DREAM was very low (about 20% success without recovery procedure), even with the improved DREAM protocol. Their simulation scenarios were different, which caused different results. In this chapter, we will expose some problems of the original DREAM protocol and propose solutions to overcome these problems. In subsection 5.1 we suggest some enhancements to DREAM.

III.1. Location Packet Looping in DREAM

The original DREAM protocol [2] stipulated quite explicitly that the TTL of a location update packet is the geographic distance traversed by the packet from the source. A loop may occur when a group of nodes located in a circle like shape and a location packet may never die.



Percentage of messages delivered without resorting to the recovery procedure, when the nodes have three different speeds.



Average delay vs. arrival rate for DREAM and DSR when each node has speed $V = 2$.

Fig.2. Previous DREAM simulation result.

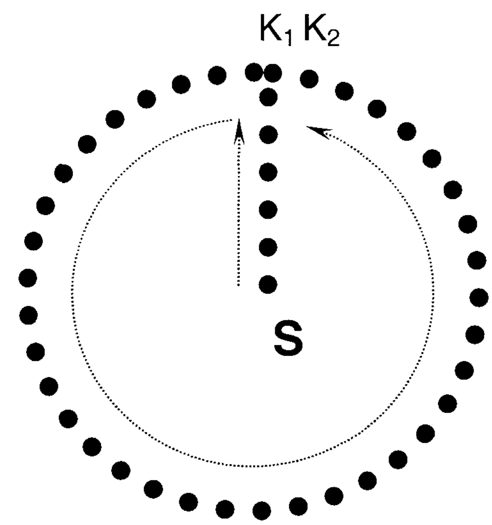


Fig.3. Location Packet Looping.

In Figure 3, at time t_0, node S sent out a location control packet with TTL larger than the distance from S to K_1 or to K_2, all the nodes within TTL coverage area are show in Fig.3; K_2 was not in the transmission range of K_1 when the location packet arrived to K1 at time t_1. This location packet was re-transmitted by the nodes along the circle and arrived to K_2 at time t_2; because K_1 or K_2 moved a little bit during time interval t_2 -t_1, they were within the transmission range of each other at time t_2. So, this location packet was accept by K_2 and would be transmitted for another circle.

One way to solve this problem is to add a serial number SN to each location packet, and add memory buffer for nodes ID and SN record in each node. When a location packet reaches a node, e.g. K_1, K_1 will check if it is a new packet or not, and ignore the old location packets. Since a location packet will never be retransmitted twice by any node, the looping problem is solved.

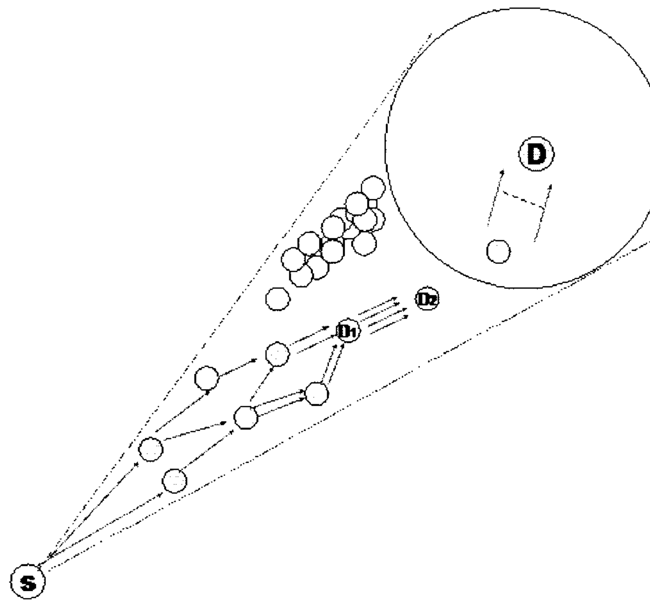


Fig.4. Duplicate data packet.

III.2. Duplicate Data Packet Control

In the original DREAM proposal, each node would re-transmit a data packet more than once when it received multiple copies of a data packet; if one node received four copies of a data packet A from different neighbors, it will send out four copies of the data packet A. This will lead to a large amount of data packet generated, especially in a high node density mobile network and the distance from source node to destination node is long. For example, in Figure 4, node D_1 will send 4 identical packets to node D_2, which originate from S and are destined for D. Since data packets tend to be quite large, the many duplicates waste large amounts of network bandwidth.

The SN (Serial Number) and memory buffer proposal, proposed in Subsection 3.1 as a solution for location packet looping problem, can also solve this problem. This solution controls the duplicated data packet problem by comparing the source node ID and SN in a data packet to the information in its history record table; when duplicate copies of one data packet, having the same source node ID and SN, are received by a node D_1 from different neighbors, D_1 compares source ID and SN with the records in its history table; if this packet is in the history table, it is not re-transmitted. Since each node will transmit a data packet can only once, no matter how many copies of this data packet were received, duplication of transmissions packets is eliminated.

III.3. Location Information Packet Update Mechanism

DREAM transmits data packets according to the location information of destination nodes, so the location information packet received from other nodes is a very important factor to the successful data transmission. If the location packet is stale, the location information of the destination is not accurate, and then the data packet fails to reach the destination node; on the other hand, if location packets are sent out too frequently, a lot of network bandwidth will be consumed for routing information update, and transmission of data packets may fail due to the lack of network bandwidth. To balance between location information accuracy and network bandwidth, we need a reasonable location information update mechanism. In Subsections 3.3.1 and 3.3.2 we explain the location information update mechanism used in [4]. In Chapter 4 we provide further analysis on the location information update mechanism and give a more sophisticated solution for DREAM.

III.3.1. Effect of Mobility on Performance

DREAM is based on the idea that the faster nodes transfer location packets more frequently, further more DREAM try to not reduce routing accuracy for either fast or slow moving nodes. Therefore the implementation of DREAM should have the same routing accuracy for all nodes with various moving speeds. In [4], the time interval Δt between two consecutive location update packets for one-hop neighbors is a function of the transmission range and moving speed. For location information to longer distance than one-hop neighbors, (1) is extended by a distance factor. This idea is used in our analysis in Chapter 4 we denote the transmission range to one-hop neighbors as T_{range}.

$$\Delta t = T_{range} / (\alpha \bullet v) \tag{1}$$

Here α represents the accuracy of the location information, and α equals $T_{range}/(v \bullet \Delta t)$. Larger α means more accurate location information in the network, but, increasing α will also increase the location control overhead when T_{range} is a constant. As shown in Figure 5, the nodes inside the ring of width $v \bullet \Delta t$ may travel out of node S's transmission range within time Δt when a data packet is sent to them. So that $1/\alpha$ could be consider as the probability a neighbor received an inaccurate location packet. We discuss location information for nodes outside T_{range} in Subsection

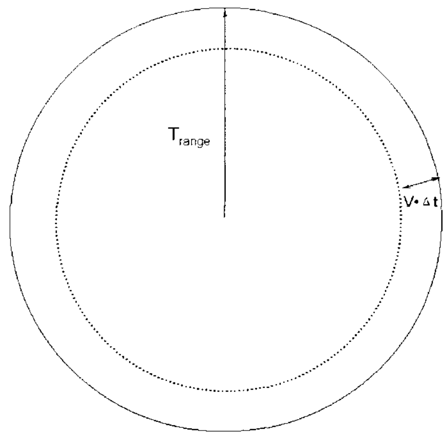


Fig.5. Definition of α.

III.3.2. Distance Effect

In [4], the location packets are divided into two types, nearby LPs (Location Packets) and faraway LPs. Nearby LPs are for one-hop neighbors, nodes within T_{range}; faraway LP are for multi-hops nodes, nodes outside T_{range}. The time interval between two nearby LPs Δt is calculated according to (1). In [4], a constant X is defined for measuring the time interval for faraway LPs. A node will send out one faraway LP after it sends out X nearby LPs since the last faraway LP, in another word, the time interval between two faraway LPs is $\Delta t \cdot X$. Known from (1) Δt is the reverse ratio of a nodes moving speed V, if V is very small Δt will be very large. If Δt is too large other problem will happen, for example, a node is dead (no power) while all other nodes still think it is alive. In order to prevent Δt becoming too large, a constant Y is defined as maximum time interval between two LPs. So, if $\Delta t \cdot X > Y$, the time interval for two faraway LPs will be set to Y; if $\Delta t > Y$, time interval between any two LPs will be set to Y.

This solution is based on DREAM's idea that distant nodes need less location information without compromising the routing accuracy. But, we still want to increase the routing accuracy, so that we make DREAM more scalable. We will introduce our enhancement on location effect in Chapter 4.

III.3.3 Minimum θ and very slow moving destination nodes

When the destination node moves at low speed, or even does not move at all, θ will be too small (0° if the node is static) then the probability of finding a neighbor within the wedge of angle 2θ is extremely small. If the average moving speed for the entire mobile network is slow, DREAM may fail to identify suitable neighbor nodes for delivery of data packets. In [4], a threshold of θ, call θ_{min} is used, when moving speed of node is too low; θ_{min} is an experimental value. In Chapter 4, we derive a mathematical way to compute an ideal θ_{min} in a MANET. We also introduce the concept of θ_{max}.

CHAPTER IV

THEORETICAL ANALYSIS OF DREAM'S SUCCESS RATE

In this chapter we present our main contribution, a theoretical analysis of the success rate of DREAM and propose some improvements on the location packet upgrade mechanism. Using our formulae, the end-user can decide if DREAM is suitable for their specific application. In Subsection 4.1 we define the success rate in a formal way. In Subsection 4.2 we analyze the location packet update mechanism and propose an improved implementation of location update method. Finally, in Subsection 4.3 we present the details of the analysis of DREAM's success rate.

IV.1. Definition of Success Rate

In order to evaluate the factors that affect the success rate of DREAM, or, equivalently, one minus the rate at which DREAM will have to use blind flooding. First, we define the successful data delivery as a data packet delivered from source to destination without any recourse to flooding. Formally, the success rate is the ratio of the number of successful data packets delivered to the total data packets. We denote the success rate for one hop transfer as P_{nei}; we use P_s, probability of success, for success rate of a data packet delivered from source to destination node (multiple hops).

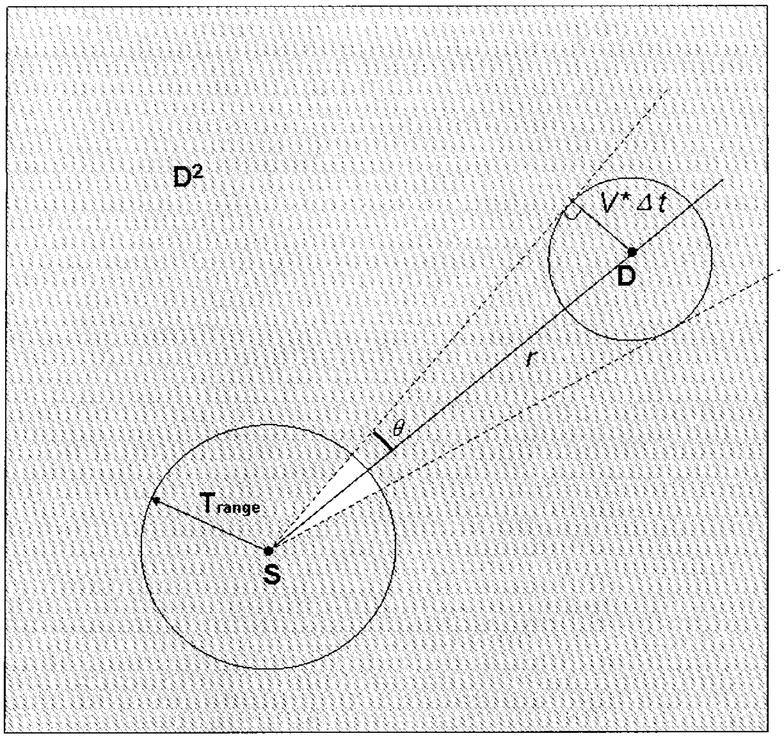


Fig.6. Definition of success rate.

Referring to Figure 6, it is easy to see that P_{nei} is the probability of existence of at least one neighbor within the wedge subtended by the angle 2θ centered at the source. Consequently, P_{nei} is equal to (1-probability of no nodes within 2θ). In Figure 6, S need to send a data packet to D; before sending out this data packet, S will calculate angle θ according to the location information of D it has. If one or more one-hop neighbor nodes are currently in the wedge subtended by the angle 2θ centered at S, the bright area showed in Fig, S can successfully find a next hop to D. On the contrary, if all nodes are located in the shaded area, no neighbor could be select as the next hop to D. To explain this idea in a mathematical way, we use equation (2) to illustrate the computation of P_{nei}; in this equation, D^2 represents the total area of this MANET.

$$
\begin{aligned}
P_{nei} &= 1-\left(\frac{D^2-\pi T_{range}{}^2 \bullet \frac{2\theta}{2\pi}}{D^2}\right)^{n-2} \\
&= 1-\left(1-\frac{T_{range}{}^2 \bullet \theta}{D^2}\right)^{n-2}
\end{aligned}
\qquad (2)
$$

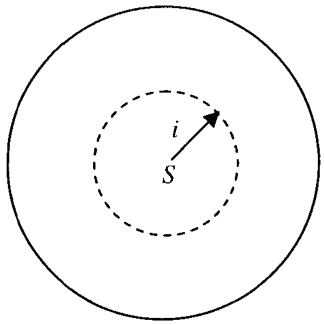
n – total number of nodes in the simulation

D^2 –Total area / Simulation area

T_{range} – transmission range

If a node x is randomly dropped into the disk centered at S and of radius the transmission range T_{range} of S, the expected distance between S and x about 2 T_{range} /3, as shown in Figure 7. In Subsection 4.2.1 we show that θ is not affected by the distance between source and destination, denoted as r. So, all nodes, along the entire path from source to destination, will have the same θ in an ideal module; hence, they will have an identical P_{nei}. Consequently, the success rate P_s of transferring a data packet from S to D is shown in (3) below.

$$
P_s = (P_{nei})^{\left\lfloor \frac{3r}{2T_{range}} \right\rfloor} \qquad r \geq T_{range} \qquad (3)
$$



Consider a neighbor node is at distance i from node S. the probability of a node in the circle with radius i and center S is $\frac{2\pi i}{\pi R^2} = \frac{2i}{R^2}$. Thus the average distance to the center S of a random direction is as follows.

$$\int_0^R i \bullet \frac{2i}{R^2} di = \frac{2}{R^2}\int_0^R i^2 di = \frac{2}{R^2}\frac{i^3}{3}\int_0^R = \frac{2R}{3}$$

Fig.7. Average Distance.

IV.2. Location Packet Update Mechanism

The success rate of DREAM is highly dependent on the accuracy of other nodes' location information, which is obtained from the location update packets. So, the location packet update mechanism is very import to the success rate of DREAM. If we need more accurate location formation, more bandwidth will be used by location packets, and less bandwidth will be available for data packets. In order to balance between location information accuracy and network bandwidth consumption, we need to carefully design the location packet update mechanism.

IV.2.1. Distance Effect

As described before DREAM is based on the idea that the farther nodes are apart the fewer location packets are needed, furthermore routing accuracy for remote nodes are not reduced. So, in an ideal module, the distance r between source node S and destination node D will not affect the routing accuracy. In another words, if D's speed is fixed, no matter how far away it is from S, S should have the same θ_{max}, and should attempt to route packets destined to D to neighbors within a wedge of angle $2\theta_{max}$. In order to satisfy this condition, we need to have a location packet update mechanism that transfers short distance location packets more often than the long distance location packets. Figure 8 explains a ideal mechanism to satisfy this condition.

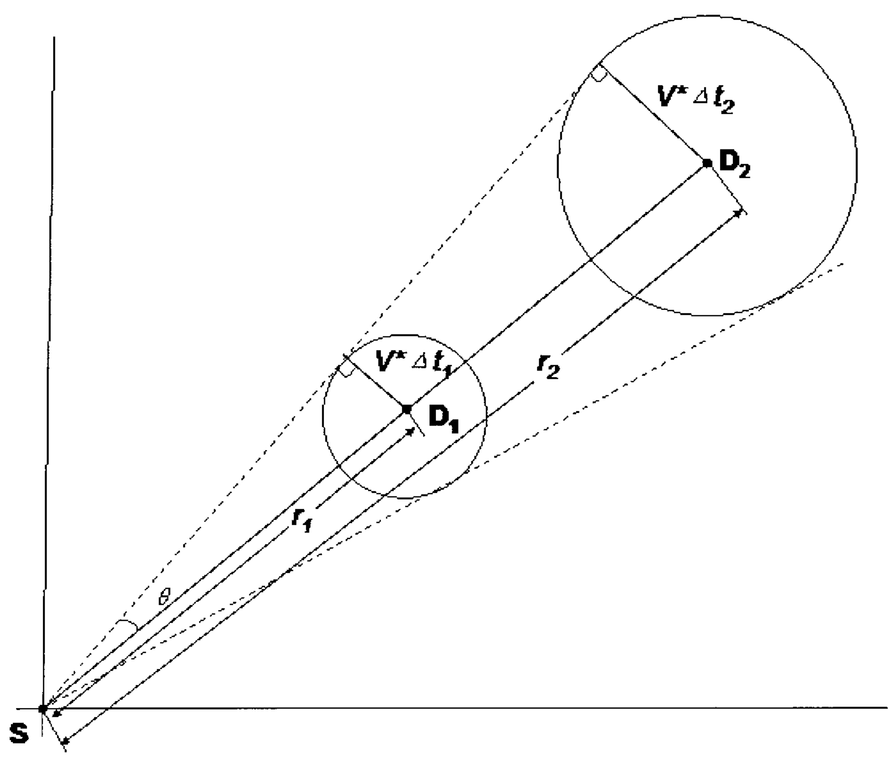


Fig.8. Distance effect.

The time interval Δt between two consecutive location packets sent by D and received by node S changes according to the distance r, between S and D. If two node D_1 and D_2 have the same moving speed, the time interval between two location packets received by S, Δt_1 and Δt_2, should satisfy the relation below:

$$\frac{\Delta t_1}{\Delta t_2} = \frac{r_1}{r_2} \tag{4}$$

In order to keep routing accuracy and reduce location control overhead for father nodes, we need to know how many location packets are required to keep the routing accurate. In an ideal module, the relation between time interval of two location packets and distance from source to and destination nodes are described by (4). When calculating the ideal time interval of two location packets divide at a random distance, we use the time interval between two one-hop location packets as a reference. Time interval of two one-hop location packets is denoted as Δt. Then a node at the distance of r will need a time interval that equals

$$\frac{r}{T_{range}} \bullet \Delta t .$$

When a node sends out a location packet, the distance to a potential receiver is unknown. So, a node can not use the formula above to compute location packet time interval for a specific node. One solution to broadcast location packets, with different time interval, is to group nodes into many levels according to there distance to location packet source. The simplest module is to group nodes with distance between two sequential integer number times T_{range} together; each level includes nodes with distance between $(n-1)\bullet T_{range}$ and $n \bullet T_{range}$. Throughout this thesis we assume that all nodes have the same transmission range T_{range}.

We use the location packets to one-hop neighbors, r< T_{range}, as the base time interval, denoted as Δt. So, time interval for location packets to distance r is $\left\lceil \frac{r}{T_{range}} \right\rceil \bullet \Delta t$. If a node too far away the time interval between two location packets will be extremely large; as a make up for far away nodes, proposed in subsection 3.3.2, a constant Y is used; if $\left\lceil \frac{r}{T_{range}} \right\rceil \bullet \Delta t > Y$, Y is used as time interval between two location packets.

Accord to Figure 1 in Subsection 2.2, $\sin\theta = \frac{(t_1 - t_0) \bullet v}{r}$; when $(t_1-t_0)= \Delta t$, θ has the maximum value, denoted as θ_{max}. Combining with (4) and using T_{range} as base, we can write

$$\theta_{max} = \arcsin[(v \bullet \Delta t)/ T_{range}] \qquad (5)$$

We can use equation (5) to compute the maximum success rate, more implemental detail is revealed in Subsection 4.2.2.

IV.2.2. Implementation of Location Packet Update

In fact, the location updates idea in Subsection 4.2.1, which groups the nodes by an integer number multiples T_{range}, is hard to implement as such. For example, node S sends out location packets periodically; time interval for nodes with r in range $(7 \bullet T_{range}, 8 \bullet T_{range})$ is $8 \bullet \Delta t$, we call them group 8; at the same time, for nodes within $(8 \bullet T_{range}, 9 \bullet T_{range})$, called group 9, the time interval is $9 \bullet \Delta t$. Suppose, at time t_0 all nodes receive a location packet from S, nodes in group 8 will need location update packets at time $t_0+8\bullet\Delta t$, while nodes in group 9 need update packets at time $t_0+9\bullet\Delta t$. It is quite obvious that location update packets for group 9 need to be retransmitted by nodes in group 8; so, nodes in group 8 will get location information at time $t_0+9\bullet\Delta t$; the rule is broken.

One feasible solution is the idea in the Fish Eye [3] protocol, and we used this idea for DREAM's location packet update. We separate the location update packets into many levels to their transmission distance; packets in level n can be transmitted to distance from 0 to $2^{n-1}\bullet T_{range}$. The closest nodes are one-hop neighbors, we denote as level 0; next is level 1, the transmission distance is from 0 to $2^1\bullet T_{range}$; …; level n cover distance 0 to $2^{n-1}\bullet T_{range}$. As in previous sections, we use time interval for one-hop neighbor Δt as a time base. At time $\Delta t \cdot 2^{n-1}$ the location packet source node will send out a location packet of level n. When a node boots up, it transmit out a longest distance location packet, we mark it as time t_0; at time $t_0+\Delta t$, it transmits a location packet with coverage $2^0\bullet T_{range}$; at time $t_0+2\bullet\Delta t$, it transmits out transmitted out a location packet covers $2^1\bullet T_{range}$; at time $t_0+3\bullet\Delta t$, $2^0\bullet T_{range}$; at time $t_0+4\bullet\Delta t$, $2^2\bullet T_{range}$; …; and so on. Fig 10 is an example of the location packets with maximum distance $2^4\bullet T_{range}$. In Fig.9 nodes transmit out the location information may move within the solid edge area, and the θ_{max} is shown as the dot-line. Fig.9 shows that the only effect of this location packet mechanism is to make the θ_{max} larger. We mark the new θ_{max} as θ'_{max}, and its value is

$$\theta'_{max} = \arcsin\left(\frac{2v \bullet \Delta t}{T_{range}}\right) \tag{6}$$

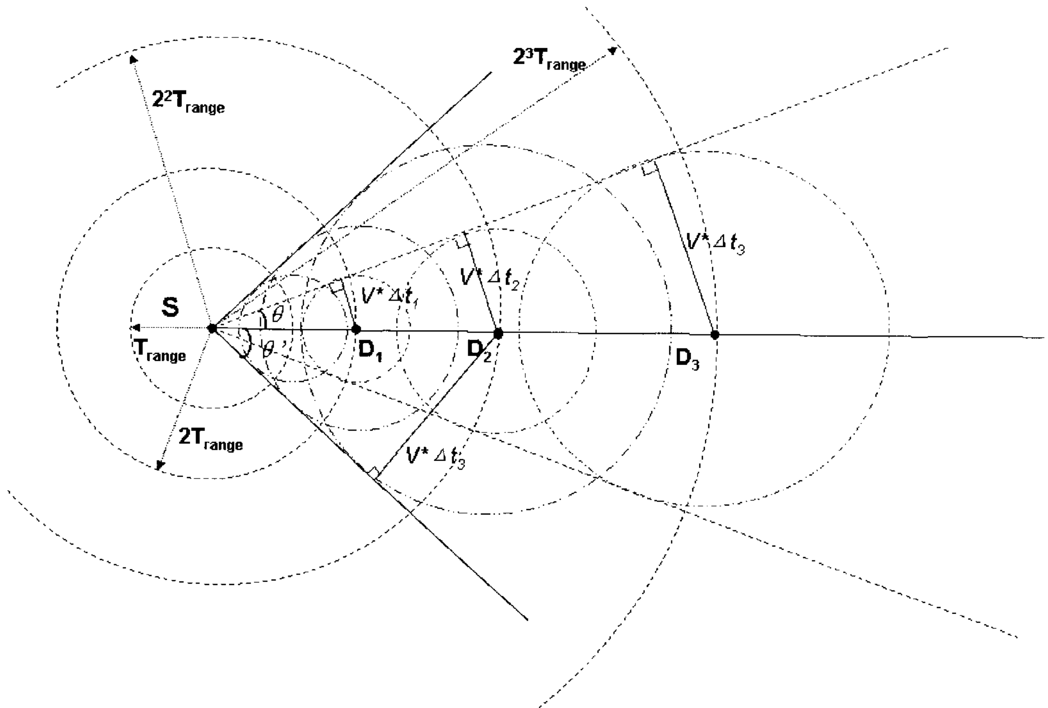


Fig.9. Difference between θ'_{max} and θ_{max}.

Figure 9 shows the difference between θ'_{max} and θ_{max}. θ_{max} is equal to $\arcsin(v\bullet\Delta t_2/R_{SD2})$, R_{SD2} is the distance from nodes S to D_2. When we use a location update mechanism such as fisheye protocol, each node in layer will use the largest θ_{max} of this layer as θ_{max} for all nodes, so that θ'_{max} is equal to $\arcsin(v\bullet\Delta t_3/R_{SD2})$. Because $R_{SD3}=2\bullet R_{SD2}$, and $v\bullet\Delta t_3= 2v\bullet\Delta t_2$, θ'_{max} could be present as $\arcsin(2v\bullet\Delta t_2/R_{SD2})$.

If $v\Delta t = T_{range}/2$, $\arcsin[(2v\bullet\Delta t)/T_{range}]$ is invalid. This means if $\sin\theta_{max}$ is larger than 0.5 the data packet will flood into the entire network. On the other hand, when moving effects and location information accuracy are taken into consideration, shown in 2.3.2, $\sin(\theta_{max})$ is equal to $1/\alpha$. Because $1/\alpha$ is a small number, for example 0.1, $\sin(\theta_{max})$ is usually smaller than 0.5, this location packet transmit mechanism can be adopted. We will use $\theta'_{max} = \arcsin(2/\alpha)$ as the maximum value for θ in this paper.

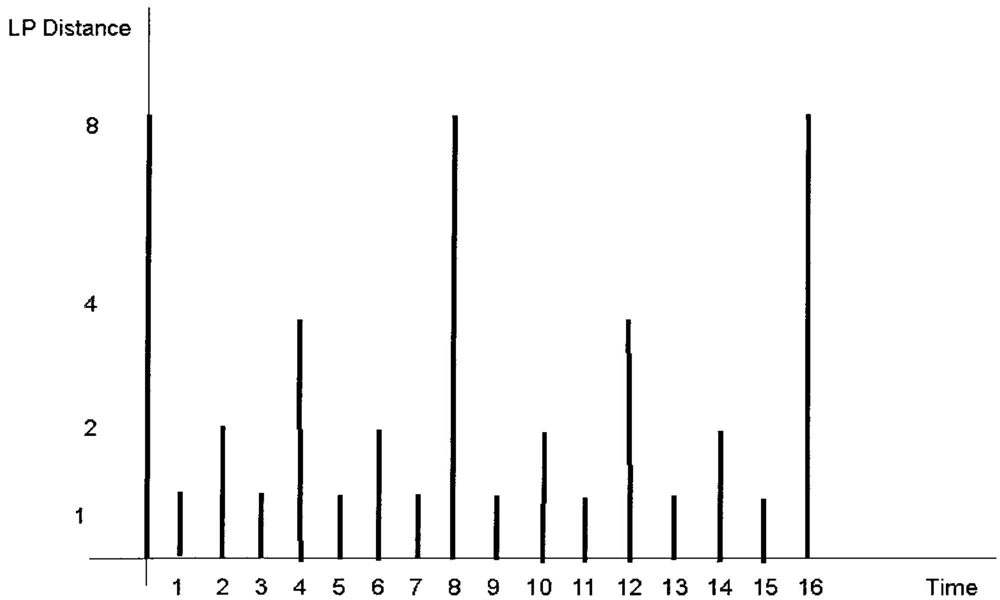


Fig.10. 4 Level Location Update Packets.

Fig.10 explains the location packet update mechanism we recommend. In this Fig, the longest location packet can be transferred to the nodes located within 8 T_{range}. A node in the MANET, we name it S, at time slot 0, will send out a longest location packet which transfer to nodes within 8 T_{range}; at time slot 1, it send out a location packet only to nodes within T_{range}; at time slot 2, (2^1), it sends out a location packet only to nodes within 2 T_{range}; at time slot 3, it send out a location packet only to nodes within T_{range}; at time slot 4, (2^2), it send out a location packet to nodes within 4 T_{range};.....; at time slot 8, (2^3), it send out a location packet to nodes within 8 T_{range}. When we need to expand DREAM to larger network, we can make the longest location packet distance to a larger number.

IV.2.3. Relationship Between θ_{max} and Location Packet Update

A node will send out a data packet to neighbors in the area of $2\theta_{max}$, when the data packet is ready just before a new location update coming in. According to (1) and subsection 4.2.2, θ'_{max} for one hop neighbor is equal to $\arcsin(2/\alpha)$, where α is equal to (T_{range} / $v \bullet \Delta t$). Based on our analysis in subsection 4.2.1 distance between source and destination does not affect the value of θ; so that, ideally is always equal to $\arcsin(2\ v \bullet \Delta t$ / T_{range}). If we increase Δt, θ_{max} will be larger, and then the existence of a one-hop neighbor within area $2\theta_{max}$ will have higher probability. But, when Δt is too large ($2\ v \bullet \Delta t$ / T_{range}) will be larger than 1, meaning the data packet will flood the entire network. In order to eliminate this problem, Δt should not be too large.

IV.3. Analysis of the Success Rate

In this section we will analyze the success rate of DREAM. In our analysis, the angle θ is the key element; because if θ is small, the probability of existing a one-hop neighbor will become low, and then the overall success rate of data packet transfer will be low; one the other hand if θ is too large, the data packet will flood the network, which consumes many unnecessary network resources. In previous chapters we defined the upper bound of θ as θ_{max}, in subsection 4.3.1 will define the lower bound of θ as θ_{min}. Here will analyze the relation among θ_{min}, θ_{max} and success rate in subsections 4.3.1 to 4.3.3; in subsection 4.3.4 and 4.3.5, we will extend our analysis to how DREAM works with different network node density and moving speed.

IV.3.1. θ_{min} and lowest success rate

If θ is too small, no neighbors will be in area of 2θ, and then DREAM fails. To prevent P_{nei} (defined in section 4.1) from being too small, we define a minimum θ note as θ_{min}; when the actuarial θ for a data packet is smaller than θ_{min}, the node will use θ_{min} instead of θ. If the node density is higher, it would be easier to find a one-hop neighbor within 2θ; hence, θ_{min} should be affected by the node density.

Because θ_{min} is proposed to prevent P_{nei} from being too small, we define a constant k, and the expect number of neighbor nodes within 2θ area equals to constant k. The relationship among θ_{min}, k, T_{range} and node density ρ is described as equation (7.1).

$$k = \theta_{\min} \bullet \mathrm{T}_{\mathrm{range}}{}^{2} \bullet \frac{\mathrm{n}}{\mathrm{D}^{2}} \quad \Rightarrow \quad \theta_{\min} = \frac{k \bullet D^{2}}{T_{range}{}^{2} \bullet n} = \frac{k}{T_{range}{}^{2} \bullet \rho} \tag{7.1}$$

$$\rho = \frac{\mathrm{n}}{\mathrm{D}^{2}} \tag{7.2}$$

n – Total number of nodes in the simulation

D^2 –Total area covered by the MANET

If ρ is too small, θ_{min} will be too large, when 2θ is large than π the data pack will flood in the whole network; another problem caused by a extremely small ρ is that even θ_{min} reaches its maximum 2π, the average number of neighbors will be less than the predefine constant value k. In another words DREAM is not a good choice for low node density MANETs.

In the worst case, most data packets are sent out using θ_{min}; in this case, the success rate equal to its lowest value. According to (2) and (7.1), we can compute lower bound of P_{nei} when θ_{min} is used, shown in (8).

$$\begin{aligned} P_{nei} &= 1-(1-\frac{T_{range}{}^{2} \bullet \theta_{min}}{D^2})^{n-2} \\ &= 1-(1-\frac{T_{range}{}^{2} \bullet \frac{k}{T_{range}{}^{2} \bullet \rho}}{D^2})^{n-2} \\ &= 1-(1-\frac{k}{D^2 \bullet \frac{n}{D^2}})^{n-2} \\ &= 1-(1-\frac{k}{n})^{n-2} \end{aligned} \tag{8}$$

Described as (8), when θ_{min} is used in DREAM, in the worst case, P_{nei} is a function of total number of nodes in the simulation and the average number of nodes in 2θ area. For example, if k=2, P_{nei} =0.8xxxx; if k=3, P_{nei} =0.9xxxx. So, we may balance the benefit and drawback to select k=2 or 3.

IV.3.2. θ_{max} and highest success rate

Shown in Subsection 4.2.3, the θ'_{max} is equal to arcsin($2/\alpha$), when the data packet is ready just before a new location update coming in. Explained in subsection 3.3.1, $2/\alpha$ should be a small value to keep the accuracy of location information, for example 0.2. In the case of $2/\alpha$ =0.2, θ'_{max} is 11.5°. If all data packets are sent out using θ'_{max}, the success rate reaches its upper bound; in this case, the value of P_{nei} is shown as equation (9).

$$P_{nei} = 1-(1-\frac{T_{range}^{\ 2} \bullet \theta'_{max}}{D^2})^{n-2}$$
$$= 1-[1-\frac{T_{range}^{\ 2} \bullet \arcsin(\frac{2}{\alpha})}{D^2}]^{n-2} \qquad (9)$$

IV.3.3. Relationship between θ_{min} and θ_{max}

In an ideal module, the value of θ should in the range of (θ_{min}, θ'_{max}). But, in some condition this rule may be broken; if the node density ρ is very low, θ_{min} may be larger than θ'_{max}. In previous analyst, we know the value of θ_{min} and θ'_{max} are affect by K, ρ , α and T_{range}; in this section, we explain in detail the relation of θ_{min} and θ'_{max}.

IV.3.3.1. $\theta_{min} > \theta'_{max}$

When $\theta_{min} > \theta'_{max}$, all data packet will be transmitted out using θ_{min}; from (8), the success rate P_{nei} will become a fix value: $1-(1-\frac{k}{n})^{n-2}$. This may happen when the node density ρ is too low, in order to keep the success rate in an acceptable value, we need to increase the θ_{min}, so that it may be larger than θ'_{max}. If is larger than π/2, then DREAM broadcast data packets in all directions. Another possible reason for this happen is the location packet update is too frequent; a small Δt leads to a small θ'_{max}. This situation also leads to a low success rate of data transfer. So, when we want to deploy DREAM on a MANET, we should avoid this condition; if we can not avoid this in the MANET, DREAM is not an ideal selection.

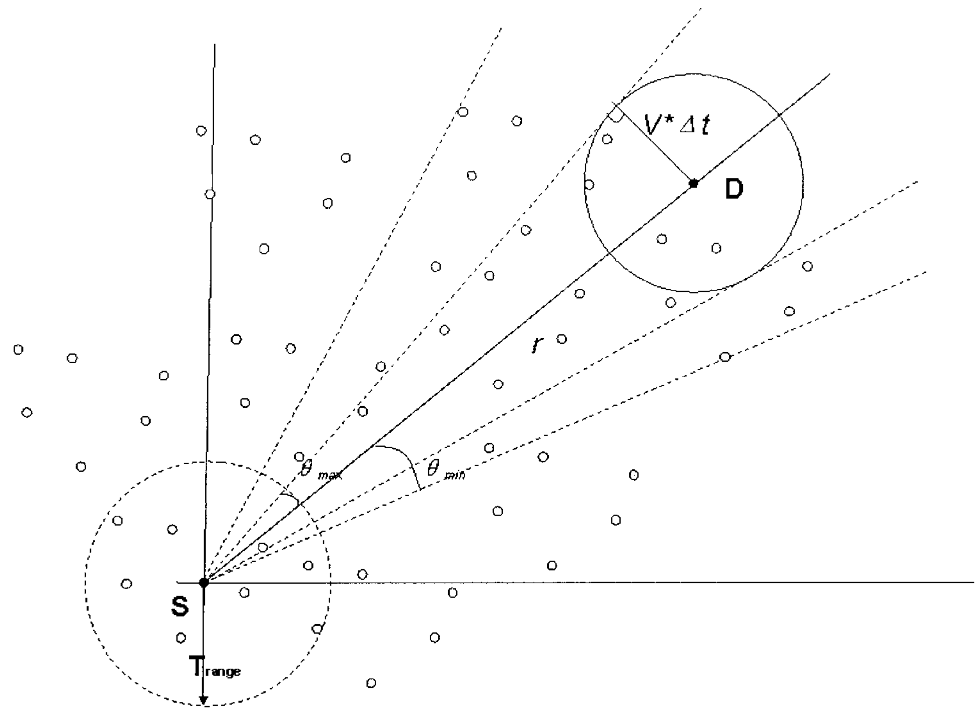


Fig.11. the $\theta_{min} > \theta'_{max}$.

In Figure11, the node density is very low, so the $\theta_{min} > \theta'_{max}$; all data packets from node S to node D will use θ_{min}, a fixed value, to find neighbors.

In the situation of low node density, we could enlarge the θ_{min} to increase success rate. But, location and moving speed information are no longer needed for θ computation; we should not deploy DREAM to this MANET, while DREAM makes use of this information to reduce network load for routing update. In another situation, if location information is updated too often, we could lower the update rate to improve the performance.

IV.3.3.2. $\theta_{min} < \theta'_{max}$

When $\theta_{min} < \theta'_{max}$, the data packets will be transmitted using an actual θ if $\theta > \theta_{min}$;

otherwise, is θ_{min} adopted. So the success rate P_{nei} is between $(1-[1-\frac{k}{n}]^{n-2})$ and $(1-[1-\frac{T_{range}{}^{2} \bullet \arcsin(\frac{2}{\alpha})}{D^{2}}]^{n-2})$. In this situation, DREAM is working to reduce the routing control overload, so that we should apply DREAM, when the ad-hoc can satisfy $\theta_{min} < \theta'_{max}$.

IV.3.4. Node Density in DREAM

Ideally, DREAM works in the condition $\theta_{\min} < \theta'_{\max}$; as analyzed in the previous subsection, this rule may be broken when node density is too low. Here, we will take a detail look at the relation between DREAM and node density in the MANET. According to (6) and (7.1) the inequation $\theta_{\min} < \theta'_{\max}$ can be expressed as $\frac{k}{T_{range}{}^{2} \bullet \rho} < \arcsin(\frac{2}{\alpha})$.

So, condition $\theta_{\min} < \theta'_{\max}$ can also be expressed as

$$\rho > \frac{k}{T_{range}^{2} \bullet \arcsin(\frac{2}{\alpha})} \qquad (10)$$

Formula (10) shows node density requirement for DREAM. If (10) is not satisfied, $\theta_{\min} > \theta'_{\max}$, DREAM is not an ideal routing protocol for this MANET, as explained in Subsection 4.3.3.1.

To take a more intuitively look at the node density, we can express the node density as average number of one-hop neighbor for any node in a MANET; this approach is quite popular in analyzing routing protocol for MANETs. Combine (7.1) with (10) we may have (11).

$$Average\ number\ of\ one-hop\ neighbors = \rho \bullet \pi \bullet T_{range}^{\ 2} > \frac{k \bullet \pi}{\arcsin(\frac{2}{\alpha})} \qquad (11)$$

As we discussed in previous section k is a constant number. To prevent transfer success rate becoming too low k is usually set to 1 or 2; ($2/\alpha$) is used to measure the accuracy of location information, usually set to a small decimal number, say 0.2. If we put k=1 and ($2/\alpha$) =0.2 into (11), the average number of one-hop neighbors is larger than 16 ; when k=2 and ($2/\alpha$)=0.2, larger than 31; when k=3 and ($2/\alpha$)=0.2, larger than 46.

Compared to other routing protocols, the average number of one-hop neighbors for an ideal MANET using DREAM is quite high. In another word, DREAM should work well in very high node density situations. If DREAM is applied to a low node density scenario, the success rate will drop to a very low value. We will show the relation between success rate and node density in our simulation in Chapter 5.

Figure 12 explains the relationship between node density and θ_{min} in MANET. The network with higher node density (the left part of Figure 7) will have smaller θ_{min}; on the contrary, with lower node density (the right part of Figure 7), θ_{min} is larger.

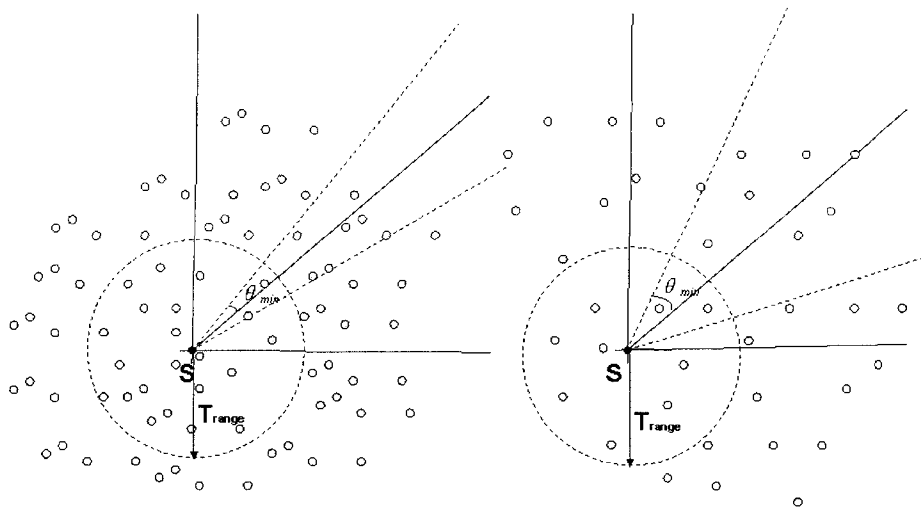


Fig.12. θ_{min} and node density.

IV.3.5. Nodes Moving Speed and DREAM

According to sections 3.3 and 4.2, the value of v•Δt is a constant in DREAM. From (1) we may have $v \bullet \Delta t = \frac{T_{range}}{\alpha}$ for one-hop neighbors. In and ideal DREAM module the value of v•Δt is not affected by distance from source to destination. In subsection 4.2.1 when we use an update mechanism like the Fish-Eye protocol the value is 2v•Δt is used for θ_{max}. So, in our module of DREAM, a node's the location packet update frequency will change according to its moving speed, and the moving speed not affect the accuracy of routing information decided by location information. Although the accuracy of routing information is not changed, when the location packet update frequency increased, the network overload for location packets is increased, and then less network overload is available for data packets. In recent years the network bandwidth for wireless network has increased dramatically from 2.4MB/s to 108MB/s; hence, in our simulation, we assume the network bandwidth is enough and the network is collision free.

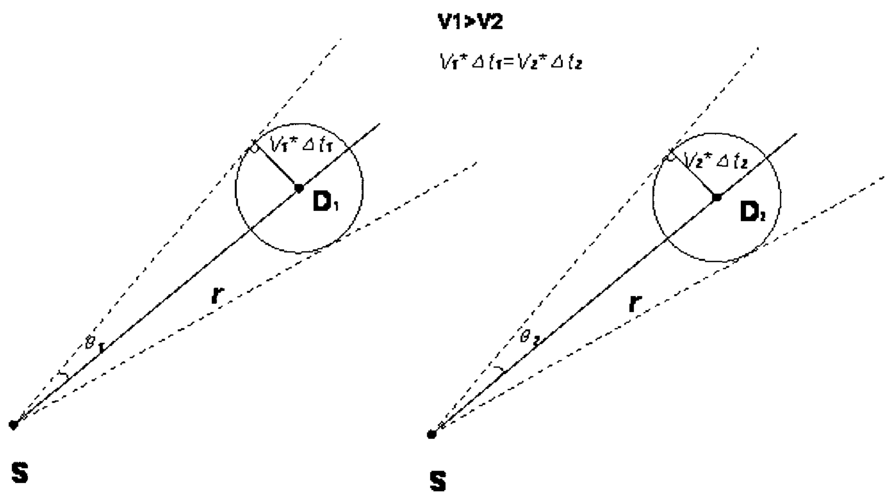


Fig.13. Nodes moving speed and DREAM.

In Figure 13, a node S is sending two data packets to two nodes, D_1 and D_2. The moving speed of D_1 is higher than D_2. DREAM can adjust Δt, so that $v_1\Delta t_1$ is equal to $v_2\Delta t_2$, and then θ_1 is equal to θ_2. With the automatic adjustment for Δt , DREAM may have a constant θ_{max}.

From the formulas above, we know that a node routed with DREAM will select a one-hop neighbor between θ_{min} and θ_{max}. The success rate is only affect by total number of nodes, simulation area and α value. Moving speed will not affect θ_{min} or $\theta_{max.}$ Some other factors may cause moving speed to be related to data transfer success rate indirectly. For example, increasing moving speed leads to more network overload consumed by location update packets, what follows next is lack of network bandwidth for data packets. As we discussed above, we don't consider the network bandwidth as a problem for location update packets.

Although we neglect network bandwidth when analyzing DREAM, saving network overload consumed by routing control packets is always a challenge in MANET research. In fact, dream is an ideal solution for a MANET with both high speed and low speed nodes; DREAM can use less routing packet for low speed nodes while more routing packets are used by fast moving nodes. In most of other routing protocols for MANET, a node can not adjust the number of routing packets it sends out according to its own moving speed.

CHAPTER V

SIMULATION AND MANET SCENARIO ANALYSIS

Chapter 4 introduced previous research and theoretical analysis on DREAM; this chapter predicts some MANET simulation result with the theories we proposed above, and compares the simulation results and predicted results. Section 5.1 presents the analysis of the MANET in original DREAM proposal [2], and the comparison to the simulation result in that paper. In section 5.2, we analyze the MANET in Tracy Camp, Jeff Boleng and Brad Williams's research [4], compare the theoretical result and their simulation result; we analyze the reason why the success rate in this MANET network is low. Finally, we will explain our simulation with DREAM and explain the simulation result in section 5.3. In the simulation analysis, we will focus on the success rate of DREAM and the network elements which may affect the simulation result, such as node density and moving speed.

V.1. High density and large θ in small MANET

In the original DREAM proposal [2], the simulation scenario is described as fig.14; it is a small MANET with high node density. Here we will analyst the P_{nei} and Ps for this simulation.

Total number of nodes:	N=30
Ad-hoc network cover Area:	D2=100 * 100
Transmission Range:	T_{range} =40
Nodes' moving speed:	v = 2 fixed
LP Update Interval:	Δt = 125 for one hop neighbors
	one long distance location packet every 10 one-hop location packets
No θ_{min} is defined	

Fig.14. Simulation 1.

In this example, $\alpha = T_{range} /(v\Delta t) = 40 / (125*2) = 0.16$. So that $1/\alpha > 1$, which means θ_{max} is $\pi/2$, $2\theta_{max}$ is π. The number of one hop neighbors is $\frac{N \bullet \pi \bullet T_{reange}^2}{D^2} \approx 150$. According to the given condition, we can compute the max P_{nei} is close to 1. For one hop neighbors, when Δt is larger than (T_{range} /V), θ is equal to π; because (T_{range} /V) =20, more than 84% of the data packets will use $2\theta_{max} = \pi$, about 16% data packets will use a θ less than $\pi/2$. For four hops neighbors, (4 T_{range} /10V)=8, 99% of the data packet uses use $2\theta_{max} = \pi$, so that actual P_{nei} will be more than 96%; due to the network is not large, Ps will be about 90%.

The simulation result in the original DREAM proposal [2] tells us that more than 90 percents of data packets are send without using recovery protocol, which mean the success rate is 90 percents. It is quite obvious that the simulation result is the same as the theoretical result we have.

The success rate in this kind MANET is very high; but we need to satisfied two conditions: (1) a very high node density and (2) data transmission uses the large θ_{max} most of the time limits. This two conditions make this kind of MANET very limited.

V.2. Using DREAM in low node density and $\theta_{max} < \theta_{min}$ MANET

The simulation MANET in Tracy Camp, Jeff Boleng and Brad Williams's research [4] is described as fig.15. In this scenario, θ_{max} will be smaller than θ_{min}. We will also analyst the P_{nei} and Ps for this simulation

Total number of nodes:	N=50	
Ad-hoc network cover Area:	D2=600 * 300	
Transmission Range:	T_{range} =100	
Nodes' moving speed:	v = 5	average
α for short LP :	10	
Short LP Update Interval:	$\Delta t = T_{range} / (\alpha \cdot v) = 100 / (10 \cdot 5) = 2$	
Long LP Update Interval:	one update per 10 Short LPs	
θ_{min} :	15°	

Fig.15. Simulation 2.

In Simulation 2, θ_{min} is a fixed number, so that the expected number of neighbors in $2\theta_{min}$ (we call it k in section ....) is

$$\begin{aligned} k &= \theta_{\min} \bullet \mathrm{T}_{\mathrm{range}}{}^{2} \bullet \rho \\ &= \frac{15 \times \pi \times 100^{2} \times 50}{180 \times (600 \times 300)} \\ &= 0.72722 \end{aligned}$$

When the distance between source and destination node is larger than 4 T_{range}, θ_{max} = arcsin(10vΔt /400)=arcsin(0.25) < θ_{min}. So that data packets will be transmitted using θ_{min}.

$$\begin{aligned} \mathrm{P}_{\mathrm{nei}} &= 1 - \left(1 - \frac{T_{range}{}^{2} \bullet \theta'_{\max}}{D^{2}}\right)^{\mathrm{n\text{-}2}} \\ &= 1 - \left[1 - \frac{T_{range}{}^{2} \bullet \arcsin(\frac{2}{\alpha})}{D^{2}}\right]^{\mathrm{n\text{-}2}} \end{aligned}$$

For distance more than $4T_{range}$, data packets will always use θ_{min}.. So that P_{nei} depends on node density and θ_{min}; we could use k to represent them.

$$\mathrm{P}_{\mathrm{nei}} = 1 - \left(1 - \frac{k}{n}\right)^{n-2} = 1 - \left(1 - \frac{0.72722}{100}\right)^{98} = 0.51094 .$$

If distance between S and D is within range ($3T_{range}$,$4T_{range}$), we have $\theta_{\max} = \arcsin(\frac{10 v \Delta t}{300}) = \arcsin(\frac{100}{300}) = 19.47^{\circ}$, close to θ_{min}. So that max P_{nei} is a little bit larger than minimum P_{nei}, 0.51094.

For distance of two 2 T_{range}, max P_{nei} is about 0.76. Of course, data transfer to one-hop neighbor will be success for almost all the time if collision rate is not too large.

If a data packet is transferred to a 4-hop away node, the success rate P_s is between $0.51094^2 \times 0.76 = 0.198$ and $0.51094^3 = 0.133$; for 3-hop neighbors, the max success rate P_s is between 0.39 and 0.26; for more than 5 hops the success rate will be less than 0.1.

According to our analysis above, there is no doubt that the simulation result in their research shows DREAM will use recovery protocol for more than 80% of all data packets. From chapter 4, $\theta_{max} < \theta_{min}$ may either caused by low node density or by a location update frequency that is too large. The simulation in section 5.3 will avoid $\theta_{max} < \theta_{min}$.

V.3. Simulation with changes in ρ, θ_{min} and moving speed

In order to prove the relation among v, ρ, Δt, θ_{max}, θ_{min}, and success rate P_s, we will do some simulations with changes in ρ, θ_{min} and v. We only have 3 levels of Long distance LP in our simulation; and we use fixed θ_{min}. In the first simulation, we change the node density ρ in the MANET, when the value of ρ is too small, $\theta_{max} < \theta_{min}$ and the success rate P_{nei} low; as ρ increased, P_{nei} will also increase. Because we define θ_{min} as a constant in our simulation, k can be treat as a variable, increasing ρ will lead to a larger k; when k is large enough, $\theta_{max} > \theta_{min}$. MANET elements in our simulation are listed in Fig 16. In the first simulation, we use the average nodes moving speed 5, and we can see how the node density affects the success rate. When the node density is increased, the success rate will be also increased. In our simulation, we define the network as a collision free network, so that increase of node density will not increase data transmission failures caused by network collision.

Total number of nodes:	N=50,100,150,200
Ad-hoc network cover Area:	D2=600 * 300
Transmission Range:	T_{range} =100
Nodes' moving speed:	v = 5,10,15 average
α for short LP :	10
Short LP Update Interval:	$\Delta t = T_{range} / (\alpha \bullet v) = 100 / (10 \bullet 5) = 2$
3 T_{range} LP Update Interval:	one update per 8 Short LPs
7 T_{range} LP Update Interval:	one update per 16 Short LPs
θ_{min} :	15°, 30°

Fig.16. Simulation 3.

According Formula 9 in section 4.3.1, when the node density increases the k will increase, so that P_s will increase. Simulation result in Figure 17 shows the relation between ρ and P_s; success rate P_s will increase as ρ increases until P_s is close to 100%. We can also know from this graph, when ρ is small, P_s will be very small; for example, when the total number of nodes is 50, or ρ =50/(300*600), or 9 one-hop neighbors on per node on average, the success P_s is equal to 20%. In another word, when the node density is too low, DREAM is not a good protocol for this MANET. If we hope to satisfy a condition that 70 percent of total data transferred are using DREAM without recovery process, a node needs to have 35 neighbors on average.

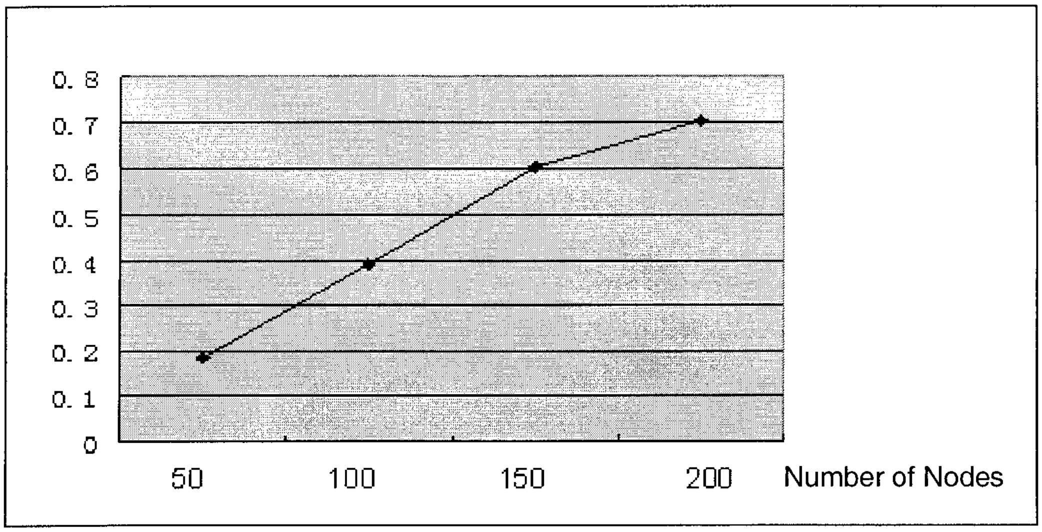


Fig.17. Simulation Result with Different Node Density I.

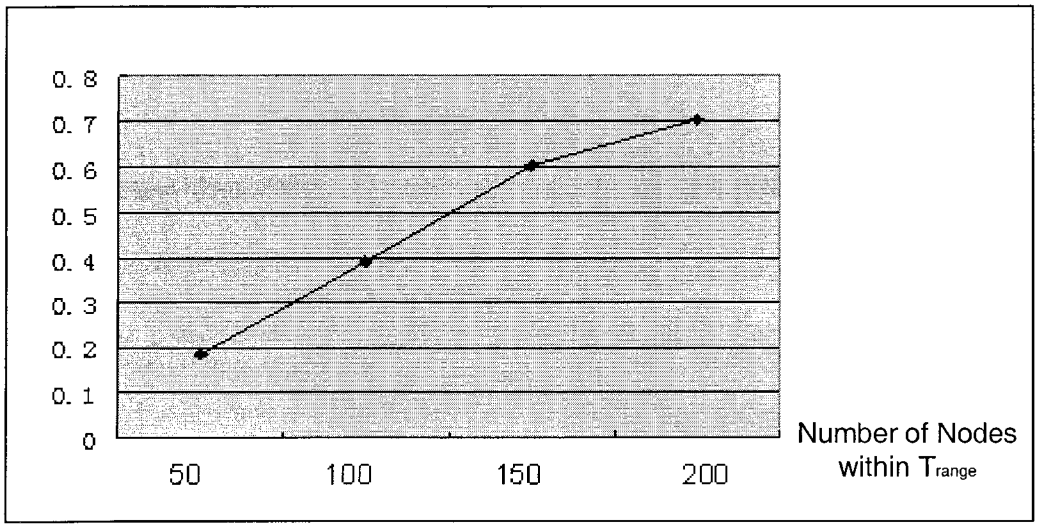


Fig.18. Simulation Result with Different Node Density II.

Figure 19 and Figure 20 show the relation between average node speed and P_s. (In high bandwidth and low collision MANET). We may notice that the average nodes moving speed dose not affect the success rate P_s greatly. If the node density is low, no matter the average node speed is high or low, the success rate will always be very small value; when the node density is high, increasing node speed will not lead to a drop in success rate. This simulation result proves that in our model of DREAM, speed does not affect the success rate of DREAM. So DREAM is suitable for both high and low mobility networks or for a mix of high and low mobility networks.

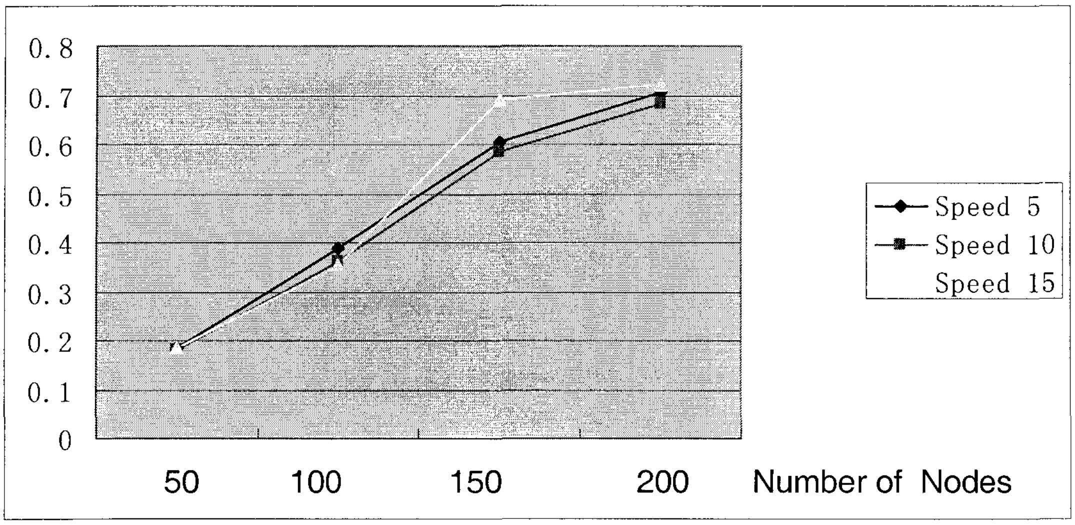


Fig.19. Simulation Result with Different Node Speed I.

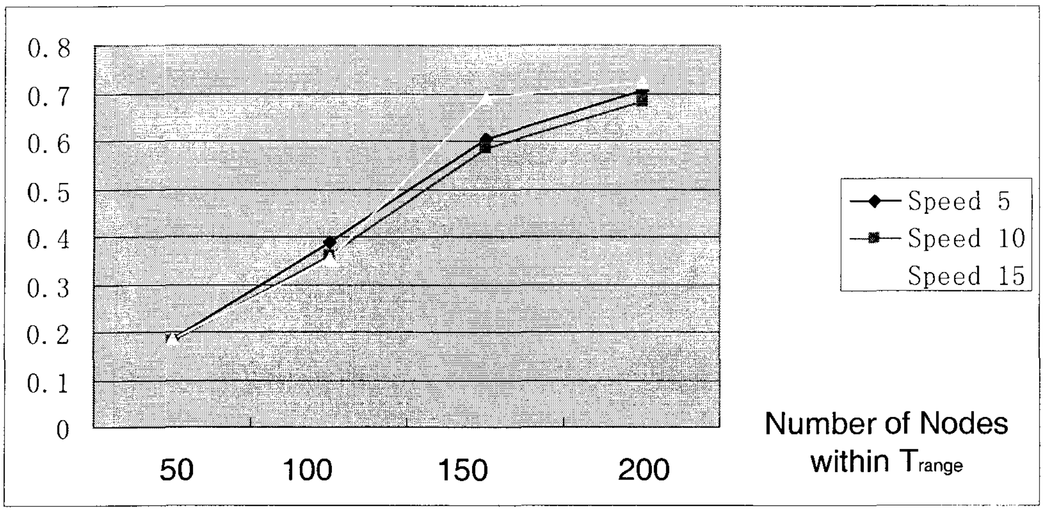


Fig.20. Simulation Result with Different Node Speed II.

Figure 21 and Figure 22 show the simulation with θ_{min}=30°. We may know from these figures that the increase of θ_{min} will make the probability of successful transfer higher. Also higher node density ρ leads to higher P_s as before, and the increasing trends are almost the same.

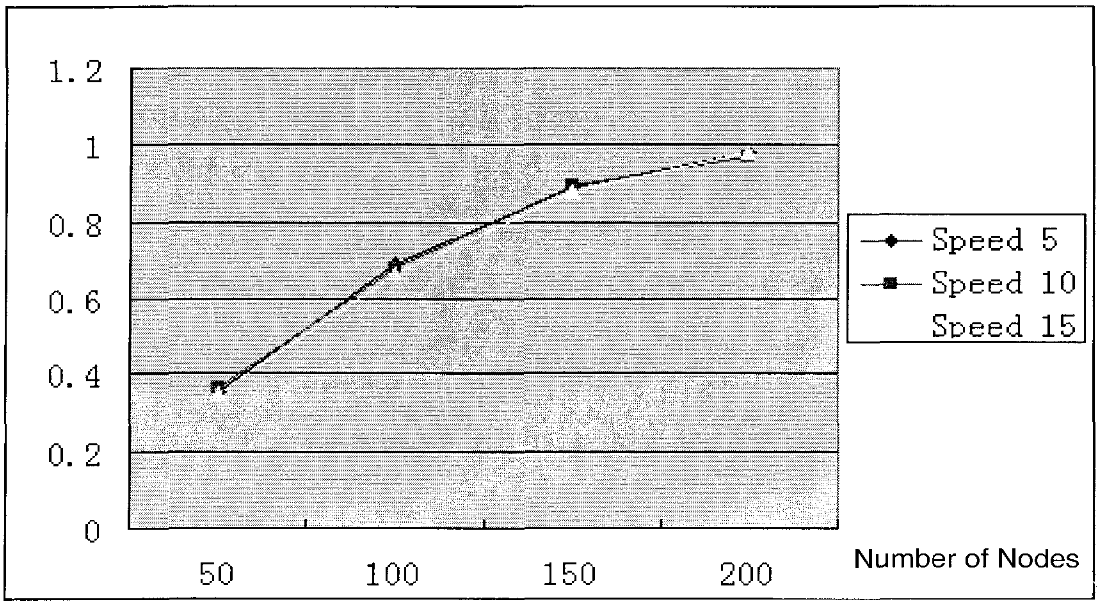


Fig.21. Simulation Result with Large θ_{min} I .

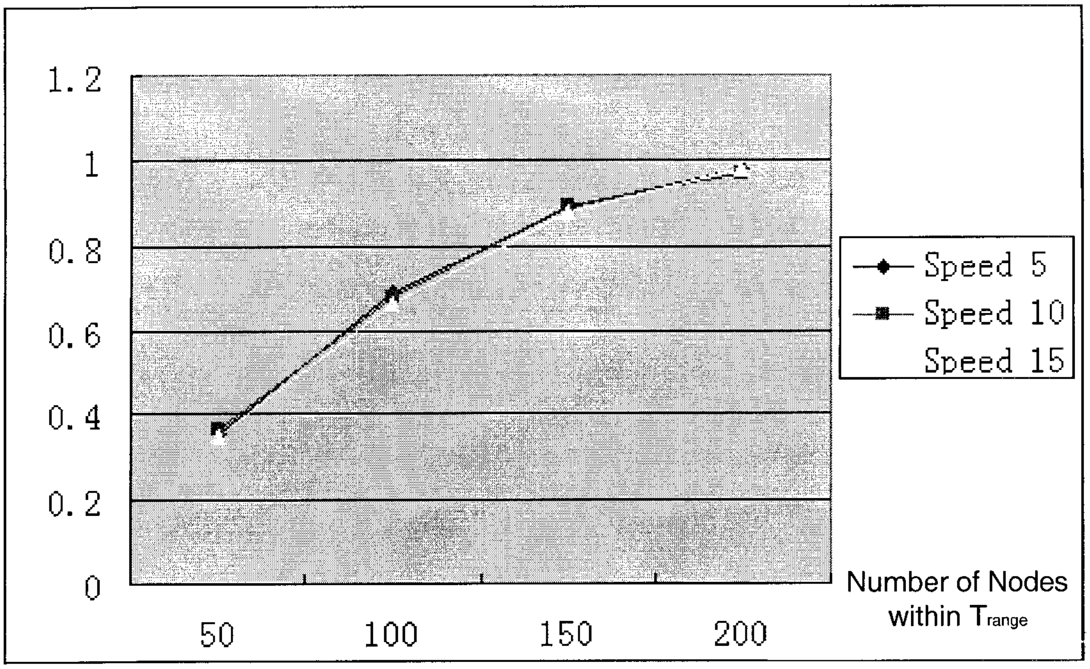


Fig.22. Simulation Result with Large θ_{min} II.

CHAPTER VI

CONCLUSION AND FUTURE WORK

DREAM is a routing protocol which makes use of location information to reduce the network overhead for routing control information; DREAM can also reduce the number of routing control packets for long distance communication. But, not all MANETs will benefit from DREAM; according to our research, DREAM should be conditionally deployed. We defined a success rate for DREAM as the ratio of successful data transfer without using recovery protocols to total number of data transfer. We then establish criteria based on the average success rate for deciding whether to use DREAM in a particular MANET.

In order to help end users predict the success rate of DREAM in particular MANETs, we give some formulas to calculate the success rate. When using our formulas, end users need to know the nodes density of the MANET, and then decide reasonable values of θ_{min} and θ_{max} with the help of our formulas. Followed the steps in this paper, end users could predicte success rate in short time. If the predicted success rate is high, we could use DREAM in that MANET; on the other side, if the predicted success rate is low, we should not use DREAM.

In the future, we plan to investigate the relationship between MANET elements and other mobile ad-hop routing protocols, and make a list of the conditions for deploying each routing protocol; with this research, people could select the most suitable routing protocol for a particular MANET.

REFERENCES

[1] E. M. Royer and C. -K. Toh, "A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks," *IEEE Personal Communications*, pp.46-55, April 1999.

[2] S. Basagni, I. Chlamtac, V. R. Syrotiuk, and B. A. Woodward, "A Distance Routing Effect Algorithm for Mobility (DREAM)," ACM/IEEE MobiCom, pages 76–84, October 1998.

[3] Y. -B. Ko and V. H. Nitin, "Location-Aided Routing (LAR), in mobile ad hoc networks," ACM/IEEE MobiCom, pages 66–75, October 1998.

[4] T. Camp, J. Boleng, and B. Williams, "Performance Comparison of Two Location Based Routing Protocols for Ad Hoc Networks," Proceedings of the IEEE INFOCOM , 2002.

[5] R. Jain, A. Puri, and R. Sengupta, "Geographical routing using partial information for wireless ad hic networks," IEEE personal Communications. Feb. 2001.

[6] T. Camp, J. Boleng, and L. Wilcox, "Location information services in mobile ad hoc networks," International Communications Conference (ICC), 2002.

[7] B. Karp and H. T. Kung, "GPSP: Greedy Perimeter Stateless Routing for Wireless Networks," Proc. ACM MOBICOM, Aug. 2000, 243-254.

[8] M. Gerla, "Fisheye State Routing Protocol (FSR) for Ad Hoc Networks," IEEE MANET Internet Draft, dreaft-ietf-manet-fsr-03.txt, June 2002.

[9] L. Wang and S. Olariu, "A Two-Zone Hybrid Routing Protocol for Mobile Ad Hoc Networks," IEEE Transactions on Parallel and Distributed System, Dec. 2004.

[10] Z. J. Haas, P. Samar, and M. R. Pearlman, " The Zone Routing Protocol (ZRP) for Ad Hoc Networks," IETF Internet Draft, draft-ietf-manet-zone-zrp-04.txt, July 2002.

[11] C. E. Perkins, E. M. Belding-Royer, and S. R. Das, "Ad Hoc On Demand Distance Vector (AODV)," IETF Internet Draft, 1999.

[12] D. B. Johnson, D. A. Maltz, Y. -C. Hu, and J. G. Jetcheva, "The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks," IETF Internet Draft. Mar, 1998.

[13] C. E. Perkins and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," ACM SIGCOMM, vol.24, no.4, October 1994.

[14] C. C. Chiang, H. K. Wu, W. Liu, and M. Gerla, "Routing in Clustered Multihop Mobile Wireless Networks with Fading Channel," IEEE Singapore International Conference on Networks, pp. 197-211, Apr. 1997.

[15] R. Dube, C. D. Rais, K. –Y. Wang, and S. K. Tripath, "Signal Stability based Adaptive Routing (SSA) for Ad-Hoc Mobile Networks," IEEE Personal Communications Magazine, pp. 36-45 February 1997.

[16] Y. -B. Ko and N. H. Vaidya, "Location-Aided Routing (LAR) in mobile ad hoc networks", Wireless Networks 6, pp. 307–321, 2000.

[17] B. Karp and H. T. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks," ACM/IEEE MOBICOM, 2000, pp. 243–254.

[18] R. Jain, A. Puri, and R. Sengupta, "Geographical Routing Using Partial Information for Wireless Ad Hoc Networks," IEEE INFOCOM, 2001.

[19] I. Stojmenovic, "Position based routing in ad hoc networks," IEEE Communications Magazine, 40(7), 2002, 128-134.

[20] P. F. Tsuchiya, "The landmark hierarchy: a new hierarchy for routing in very large networks," ACM SIGCOMM Computer Communication Review, 18(4), 1998, 35-42.

[21] L. Kleinrock and K. Stevens, "Fisheye, a lenslike computer display transformation, Technical report," UCLA, Computer Science Department, 1971.

[22] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," IEEE Workshop on Mobile Computer Systems and Applications, February, 1999, 90-99.

[23] A. B. McDonald and T. Znati, "A dual-hybrid adaptive routing strategy for wireless ad-hoc networks", IEEE Wireless Communications and Networking Conference (WCNC'2000), Chicago, IL, September 2000, 1125-1130.

[24] M. Lewis, F. Templin, B. Bellur, and R. Ogier, "Topology broadcast based on reverse-path forwarding," IETF MANET Internet Draft, November 2002 (work in progress).

[25] V. D. Park and M. S. Corson, "A highly adaptive distributed routing algorithm for mobile wireless networks," IEEE INFOCOM, Kobe, Japan, April, 1997, 1405-1415.

[26] C. E. Perkins and P. Bhagwat, "Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers," SIGCOMM Symposium on Communications Architectures and Protocols, London, UK, September 1994, 212-225.

[27] M. Lewis, F. Templin, B. Bellur, and R. Ogier, "Topology broadcast based on reverse-path forwarding" IETF MANET Internet Draft, November 2002.

[28] M. R. Pearlman and Z. J. Haas, "Determining the optimal con-guration for the zone routing protocol," IEEE Journal on Selected Areas in Communications, special issue on Ad-Hoc Networks, 17(8), 1999, 1395-1414.

[29] A. B. McDonald and T. Znati, "A dual-hybrid adaptive routing strategy for wireless ad-hoc networks," Proc. IEEE Wireless Communications and Networking Conference (WCNC'2000), Chicago, IL, September 2000, 1125-1130.

[30] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distances vector routing," Proc. 2nd IEEE Workshop on Mobile Computer Systems and Applications, February, 1999, 90-99.

[31] D. B. Johnson, D. Maltz, Y. Hu, and J. Jetcheva, "The dynamic source routing protocol for Mobile Ad Hoc Networks," IETF MANET Internet Draft, February 2002.

[32] A. Helmy, S. Garg, P. Pamu, and N. Nahata, "Contact based architecture for resource discovery (CARD) in large scale MANETs," Proc. International IEEE/ACM Parallel and Distributed Processing Symposium, Nice, France, April 2003, 219-227.

[33] A. Iwata, C. Chiang, G. Pei, M. Gerla, and T. Chen, "Scalable routing strategies for ad hoc wireless networks," IEEE Journal on Selected Areas in Communications, Special Issue on Ad-Hoc Networks, 17(8), 1999, 1369-1379.

[34] P. Jacquet, P. Muhlethaler and A. Qayyam, "Optimized link-state routing protocol," IETF MANET Internet Draft, draft-ietf-manet-olsr-11.txt, work in progress, July 2003.

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