A Routing Protocol for Physically Hierarchical Ad Hoc Networks *

(Preliminary Version)

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Abstract

Several routing schemes proposed for ad hoc networks assume that all mobile hosts have the same transmission power and bandwidth constraints. However, in real world, this assumption may often not be true since there exist many types of mobile hosts with different transmission capacity and mobility rate. This paper discusses a new ad hoc network architecture, called *'Physically Hierarchical Ad hoc Networks'* where two kinds of mobile hosts form the ad hoc network hierarchy: *Super Mobile Hosts(Super-MHs) and Mini Mobile Hosts (Mini-MHs)*. The paper presents a protocol for routing in such a network. The protocol is based on the idea that most communication between Mini-MHs can be provided through a Super-MH playing the role of mobile base station for Mini-MHs.

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1 Introduction

An ad hoc network is defined as "a collection of wireless mobile hosts forming a temporary network without the aid of any centralized administration or standard support services regularly available on the wide-area network to which the hosts may normally be connected" [1].

In order to develop a routing protocol suited for such an environment, several routing approaches focusing on unicast datagram routing have been proposed in the recent years. In general, routing approaches for ad hoc networks can be divided into two categories. One type is to modify existing DBF(Distributed Bellman-Ford) routing algorithms to get optimal routes in a dynamic topology[2, 3, 4]. Another type uses an on-demand system, which is operated in two phases: *route-discovery* and *route-maintenance*[1, 5, 6, 7]. In DSR (Dynamic Source Routing) proposed in [1], a route from the source to the destination is dynamically determined by the results of a route discovery protocol without periodic router advertisement in the protocol. Dube et al.[5] compare various protocols' routing types, criteria for selecting routes, and overhead. The results of their comparison imply that on-demand type algorithms are more suitable for routing in ad hoc networks. They also propose a distributed adaptive routing protocol for finding and maintaining stable routes based on information available at link level, such as signal strength and location stability. The approach of [6] is similar to that of [5] except that the property of associativity is used as additional criteria to select more long-lived route. Recently, TORA (Temporally-Ordered Routing Algorithm)[7], which is a "link reversal" algorithm, is presented. In this protocol, the important objective is to create routes as quickly as possible so that reaction to topological changes can be minimized (even if routes are sub-optimal).

An ad hoc network where all mobile hosts are "equal", and there is no logical cluster, is said to be a flat architecture. Routing in flat architecture is not scalable[8]. Thus, the scalability of "flat" routing protocols is limited by time or communication complexity. Hierarchical clustering in ad hoc networks is motivated because networks are somewhat clustered naturally, and a hierarchy improves scalability by providing a localization mechanism[9]. Several algorithms using clustering techniques have also been proposed[2, 10, 11, 12, 13].

All existing schemes are *"logically"* hierarchical routing scheme in that, physically, all mobile hosts are still assumed to have the same small transmission range, relative to the size of the network. This is indeed true in many circumstances. However, one can envisage situations where the network may include hosts with significantly more bandwidth and/or transmission range. (We refer to such hosts as Super-MHs.) As a matter of fact, mobile hosts in an ad hoc network can be envisioned as having a *"physically"* hierarchical structure in terms of transmission capacity[14]. A fleet of ships in a naval task force is a good example of having physically hierarchical structure since it consists of slow ships with high transmission capacity and fast boats with low transmission capacity. A company in military environments is another example. A company consists of a number of walking soldiers(Pedestrian) having low-capacity as well as slow moving speed and a few tanks(Vehicular) having not only high-capacity but also relatively fast velocity. Like these examples, many ad hoc environments have two or more levels characterized by several parameters, such that transmission range, velocity, and bandwidth. Hence, new routing protocols need to be developed to support such an ad hoc environment.

Now, as an illustration, we consider a two-level physically hierarchical ad hoc network, which consists of two types of mobile hosts, called *Super-Mobile Hosts(Super-MHs)* and *Mini-Mobile Hosts(Mini-MHs)*. They are considered to be having different transmission capability, such as transmission range, bandwidth, and battery power. The Super-MHs in physically hierarchical ad hoc networks are assumed to have large transmit capacity compared to Mini-MHs. Super-MHs and Mini-MHs both are moving around without any wired backbone.

The paper is organized as follows. Section 2 describes our two-leveled hierarchical architecture and section 3 presents our routing protocols for supporting this physically hierarchical ad hoc network. The performance evaluation of our protocol based on a simulation will be presented in section 4. Finally, section 5 presents our conclusion and future works.

2 A Physically Hierarchical Ad Hoc Network

2.1 Parameters for classifying Mobile-Hosts

Typically, most routing protocols based on flat architectured ad hoc networks assume that all hosts have the same transmission range, relatively small. Therefore, they may not be able to communicate with farway parts of the network without help of intermediate hosts, for their links are limited to the small range of their radio transmission. However, mobile hosts participating in real ad hoc networks may be classified by some parameters, such as transmit capacity and moving speed. Table 1 shows one way to classify mobile hosts into Mini- and Super- mobile hosts. A Super-Mobile Host (Super-MH) refers to a mobile host having large transmission power level, whereas a Mini-Mobile Host (Mini-MH) refers to one having relatively small transmission capacity. As far as velocity, Mini-MHs in this example are faster than a Super-MH.

Parameters	Mini-MH	Super-MH
Transmit Capacity	Small	Large
Moving Speed	Fast	Slow

Table 1: Classification of mobile hosts by parameters

Quite often, low-mobility environments are associated with high bandwidths and high-mobility environments with relatively lower bandwidths [16]. Therefore, in our architecture, Super-MHs are assumed to have lower mobility than Mini-MHs. As a matter of fact, it is expected that a layer of hierarchy in ad hoc network architecture can be subdivided if we consider more parameters that affect the classification of mobile hosts' types. This is an area for further research.

2.2 Network Organization

The two-level architecture considered in the rest of this report is illustrated in Figure 1.

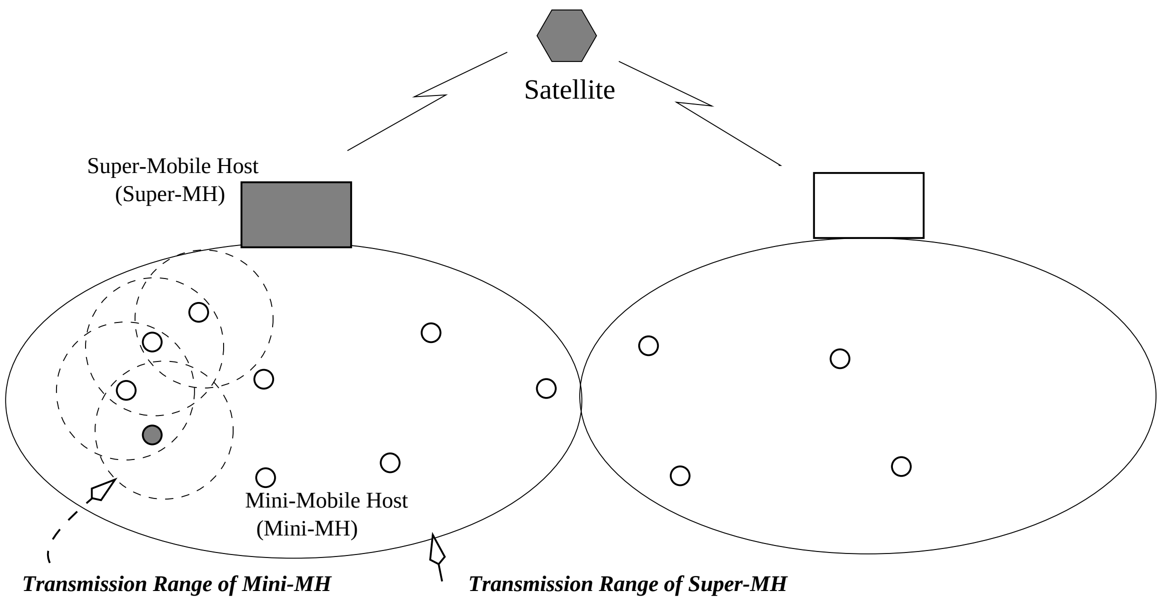

Figure 1: Physically Hierarchical Ad Hoc Networks

A given network is actually composed of many sub-networks each of which is handled via a Super-MH. (The figure shows just two such sub-networks, to simplify later discussion.) At the lower level are the Mini-MHs that have low-capacity for transmitting packets. We assume that all hosts use a common wireless channel for exchanging data and the wireless links between Mini-MHs are bidirectional, as in some previous proposals, though this may not be the case for all practical situations due to interference, fades, etc. Here, the Super-MHs are assumed to have the capability to transmit and receive information to/from a satellite. Clearly, we have assumed more hardware (satellite) and more capabilities than typically assumed. However, such capabilities are not unrealistic and may be used to reduce routing-related overhead, which tends to be high and is an inherent drawback in ad hoc networks.

In our scheme, Super-MHs may handle a lot of packets exchanged between source and destination Mini-MH pairs. But, functionally, in case that the source and destination Mini-MH exist closely enough to communicate without help of Super-MH, a routing mechanism can be done directly between each Mini-MH. This specific case is described in Section 3.

3 Routing Protocol

Our protocol is comprised of three phases:

- Route Discovery Phase

- Route Request Cancellation Phase
- Route Re-discovery Phase

Route Discovery Phase

For ad hoc mobile communication to be possible, a host discovery mechanism must exist. Initially, when a source Mini-MH needs to establish a route, a route discovery phase is invoked. In our protocol, this phase will be divided into two parts:

- The "Front Part" : Source Mini-MH $\longrightarrow$ Super-MH
- The "Rear Part" : Super-MH $\longrightarrow$ Destination Mini-MH

In the "front part", the source broadcasts an *Initial Route Discovery (IRD)* packet for searching the nearest Super-MH from itself, instead of the destination. Of course, during this part, a destination Mini-MH can be found if it exists closer than the nearest Super-MH from the source.(This will be discussed in Scenario A below). The front part of a route discovery phase will be completed when the source gets an *Initial Route Reply (IRR)* from the Super-MH (In case of scenario A, it will be done by a *Final Route Reply (FRR)* packet from the destination.)

After finding the route from the source to the nearest Super-MH, the responsibility of looking for routes to a destination belongs to the Super-MH. That is, the Super-MH initiates the "rear part" of route discovery phase by sending out a *Final Route Discovery (FRD)* packet to all Mini-MHs within its transmission range. If the destination exists within the Super-MH's coverage area, it must be hear this *FRD* packet and then have the Super-MH know its location by replying a *FRR* packet to the Super-MH. (This will be presented later in Scenario B). If a destination does not exist within the transmission area of the Super-MH, then it cannot receive a *FRD* packet at all, so the Super-MH never receives a *FRR* packet from the destination. In this case, after some time-out interval, a *Remote Route Discovery (RRD)* packet will be broadcasted via a satellite into all other Super-MHs, which may be able to find the location of the destination. (This will be explained in Scenario C).

There are (at least) three scenarios that will be commonplace in physically hierarchical ad hoc network as follows:

Scenario A: When a destination Mini-MH exists close to a source Mini-MH so that they can communicate with each other without a Super-MH's help:

The destination either being on the route from the source to the nearest Super-MH or existing closer than the nearest Super-MH from the source may get an *Initial Route Discovery (IRD)* packet before a Super-MH does. Figures 2 and 3 illustrate these two cases.

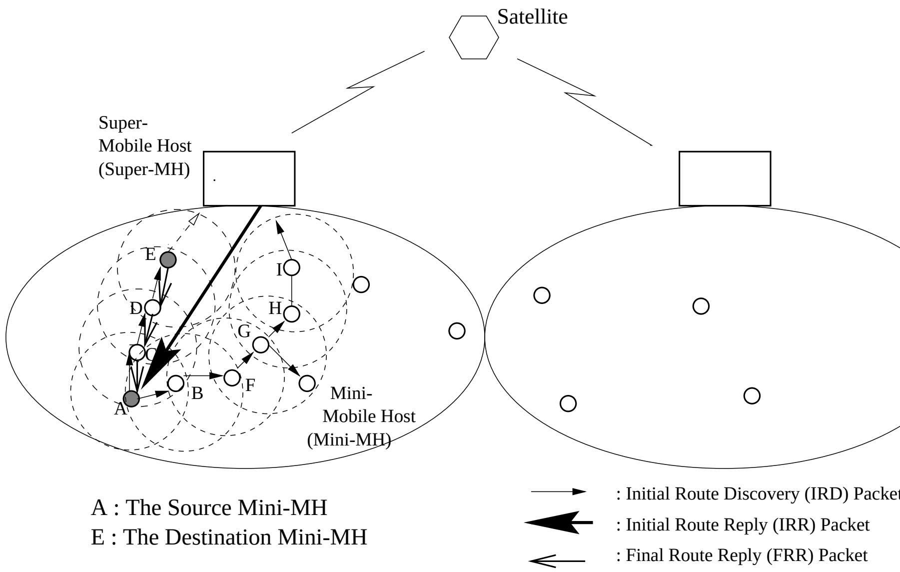

Figure 2: An Example Ad Hoc Network for Scenario A-1

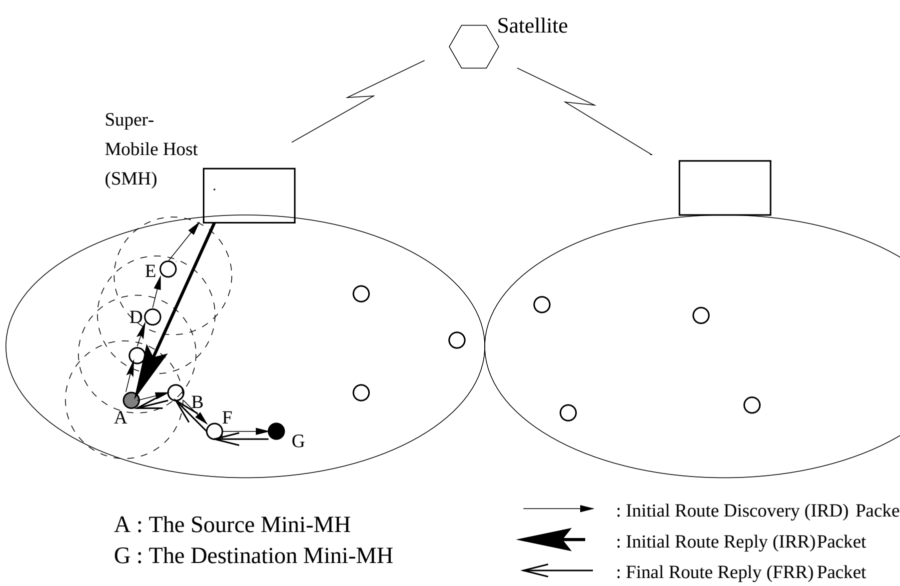

Figure 3: An Example Ad Hoc Network for Scenario A-2

Clearly, if two Mini-MHs that want to communicate are located closely enough to exchange data without a Super-MH, then it should be more efficient to do without help of any Super-MHs. However, even though the destination has already been found, if an *IRD* packet contains only Super-MHs' ID, it will be forwarded until it may reach the nearest Super-MH. For this reason, an *IRD* packet needs to contain the destination Mini-MH's ID as well as Super-MHs' ID. It can be thought as a kind of *Multidestination routing algorithm*, in which each packet contains a list of destinations[18]. The *IRD* packet has the format shown in Figure 4.

SRC ID	Super-MH ID	DEST ID	Unique_No	....

Figure 4: Initial Route Discovery (IRD) Packet Format

Upon receiving an *IRD* packet for the Super-MH, any intermediate Mini-MHs checks to see if the address field for the destination Mini-MH matches with its own address. If there is a match, it does not forward the packet to its neighbors further but returns a *Final Route Reply (FRR)* packet to the source in order to establish the route directly. The source Mini-MH can then proceed with data transmission over this route without the "rear part" of route discovery phase. Otherwise, the *IRD* packet will just be forwarded to its neighbors and the "front part" for finding routes to the nearest Super-MH will be continued.

In case of scenario A-1, the nearest Super-MH may not receive an *IRD* packet through the route on which the destination is but may receive *IRD* packets via another path. Similarly, if the destination exists not on the route from the source to the Super-MH but closer than the Super-MH from the source like scenario A-2, the nearest Super-MH may get *IRD* packets for itself via several routes. In both cases, the nearest Super-MH will reply back an *Initial Route Reply (IRR)* packet with a time-out interval to the source, which may have already received an *FRR* packet from the destination Mini-MH and transmitted the data packet. Therefore, if the source Mini-MH receives an *FRR* packet from the destination before getting an *IRR* packet from the Super-MH, then the *IRR* packet will just be dropped by the source. Now, after a time-out interval, if the Super-MH does not receive any reply from the source, then it also will ignore *IRD* packets arrived from the source.

Scenario B: When both source and destination are within the transmission range of the same Super-MH, and Super-MH is closer to source than destination:

Since an *IRD* message is broadcasted toward any Super-MHs or the destination, several Super-MHs may be able to receive the *IRD* packet caused by an identical source. But most likely the nearest Super-MH from the source will get one first. Now, the nearest Super-MH may receive multiple copies of an IRD packet via many different neighboring Mini-MHs. Figure 5 illustates the example for scenario B.

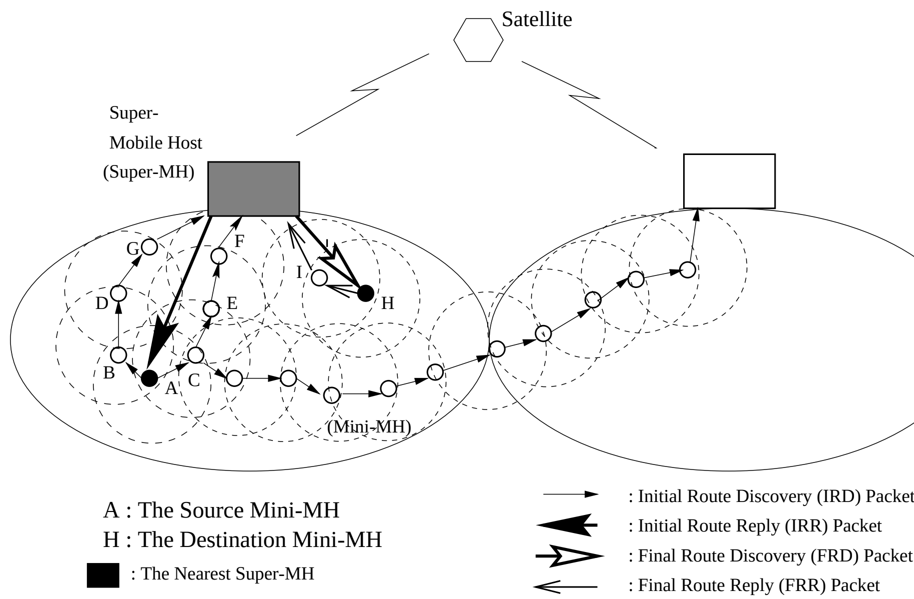

Figure 5: An Example Ad Hoc Network for Scenario B

When receiving *IRD* packets, the Super-MH replies directly to the source by broadcasting a *Initial Route Reply (IRR)* packet, in which the reverse path from the source to the Super-MH is included, in order to inform that the "front part" of route discovery phase just finished successfully. If the Super-MH gets an acknowledgement from the source within a time-out interval, it also have to initiate the "rear part" of route discovery phase. The Super-MH tries to find the destination Mini-MH within its transmission area, if it exists, by sending out a *Final Route Discovery (FRD)* packet.

The Super-MH will set an appropriate time-out after sending *IRR* and *FRD* packets. A further process depends upon the reaction of the source and destination Mini-MHs about those packets. So, it is essential to examine reactions individually.

First of all, there may be some rare cases when the Super-MH never receives both the source's acknowledgement and destination's acknowledgement until both "TimeOut" expire. These can happen in case the source moves unexpectedly and the destination does not exist within the Super-MH's transmission range. Also, we can expect the same situation in case of scenario A: the source has communicated with the destination without the help of the Super-MH when the source gets an *IRR* packet. In this case, an *IRD* packet from the source is simply dropped by the Super-MH, so the Super-MH will time out.

Secondly, there may be cases when the Super-MH receives the source's reply but not the destination's reply. The reply from the source refers to real data packets that the source wants to transmit into the destination. On receiving an em IRR packet from the Super-MH, the source transmits data packets through a path listed in an *IRR* packet. Therefore, if the source is still within the Super-MH's transmission range, then data packets should arrive before the time-out period. On the other hand, no reply from the destination can be considered as a strong indication about two cases which either the destination may be outside the Super-MH's transmission range or the destination became partitioned from the network. Even though the destination can receive a *FRD* message from the Super-MH over single hop, it may not be able to reply until such time that the network is reconnected.

In such circumstances, the Super-MH will eventually cache data packets arrived from the source and send a *Remote Route Discovery (RRD)* message to other neighbor Super-MH via a satellite communication. In result, since the destination Mini-MH exists beyond the Super-MH's transmission range, a cooperation with other Super-MHs is required. We will discuss how to work in this case in scenario C.

Finally, when both replies from the source and destination reach the Super-MH, the complete route from the source to the destination is established. As far as the destination hearing a *FRD* message, it responds to the Super-MH with a *Final Route Reply (FRR)* packet by the similar process with the "front part" of the route discovery phase, which is triggered by the source. When a *FRR* packet is arrived at the Super-MH, the Super-MH is able to make sure the fact that the destination should be within its transmission range. Since all mobile hosts within a Super-MH's transmission range can be reached over a "single hop", the Super-MH can then transmit data packets to the destination Mini-MH directly for the source Mini-MH. In data packets, the route listed in a *FRR* packet is included in order to be used by the destination.

A summary of packet transmissions between a source and destination Mini-MH via a Super-MH is presented in Figure 6.

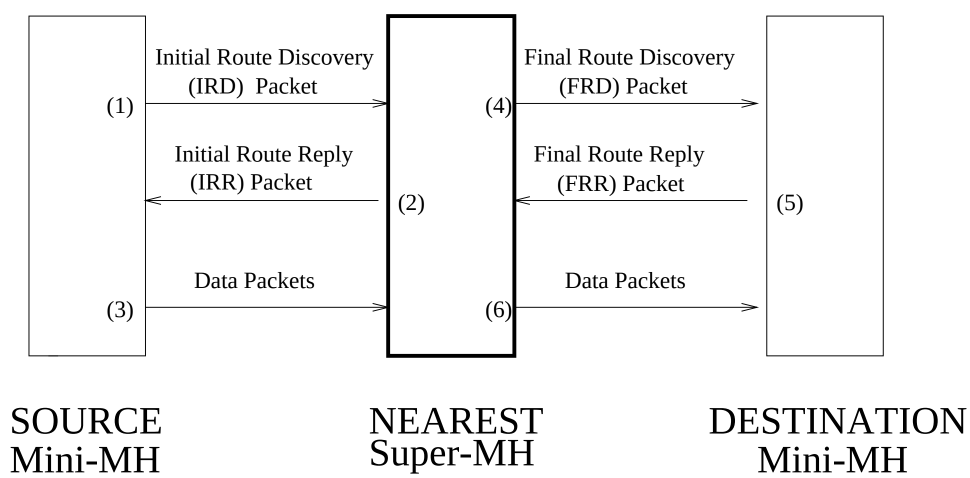

Figure 6: Summary of Packet Transmissions in Scenario B

Scenario C: When a receiver is outside the transmission range of the sender's Super-MH:

If the destination Mini-MH exists beyond the transmission range of the sender's Super-MH, it will not get any messages from that Super-MH. Consequently, the communication between the sender and the destination cannot be performed through only one Super-MH. In this case, during the "rear part", the Super-MH has to ask other Super-MHs to find the destination so that the Super-MH can relay the message to the destination with the help of other Super-MHs. The communication between Super-MHs can be provided by satellite communication. Figure 7 shows an example for scenario C.

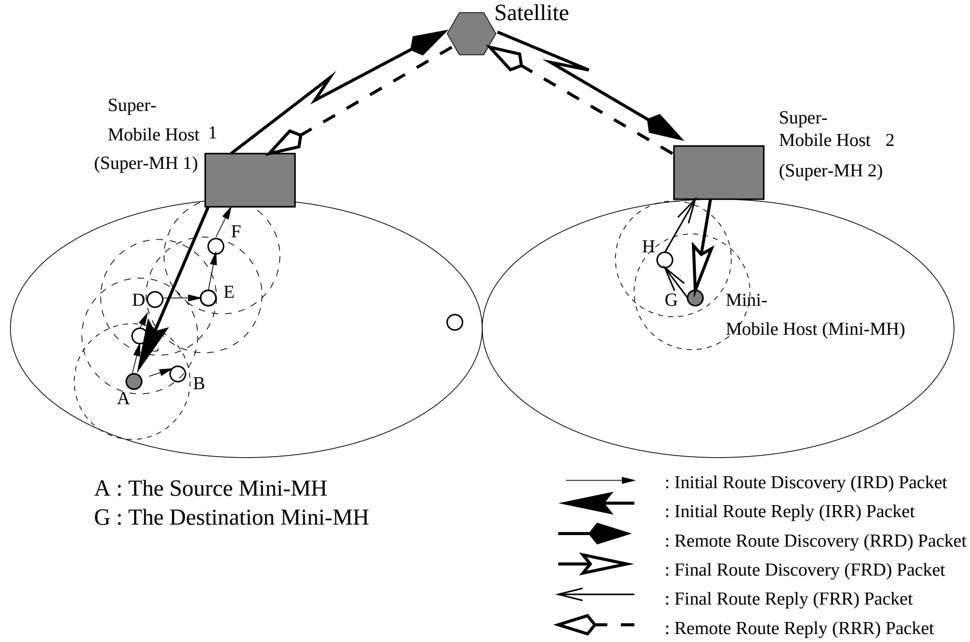

Figure 7: An Example Ad Hoc Network for Scenario C

Route Selection Scheme at a Super-Mobile Host

In many existing ad hoc routing protocols, the best route among a set of possible routes from the source to the destination is utilized. For instance, DSR[1] and Lightweight Mobile Routing (LMR)[17] is described as simply selecting the route contained in the first arriving route request packet. DSDV[3] provides only a single path for routing between each given source/destination pair. The Associativity-Based Routing (ABR) approach[6] also uses the optimal single route, which is selected by the destination based on the stability of the route and the shortest path. Like the ABR approach, in Signal Stability based Adaptive Routing (SSA) protocol[5], the first arriving route among routes through the most stable area of the network is chosen. Consequently, they all provide only single route based on the concept that "First route is the Best one".

There are some problems in the scheme of providing a single route between each given source and destination pair. One serious problem is that this scheme may cause frequent execution of route re-construction phase, in which valid route is re-established quickly when a failure occures on the single route. Frequent reaction to route failure can result in low data throughput and excessive communication overhead due to a significant amount of routing control packets. Inefficient use of the limited available bandwidth is not good in ad hoc networks.

Clearly, providing multiple routes is one property that a well-suited routing algorithm in an ad hoc environment should possess[7]. However, if the overhead associated with providing multipath routing is significant, then it makes any routing protocol impractical for this environment as well. From this point of view, the above selection criteria providing only single route seems to make sense in flat architecture or logically hierarchical structure based ad hoc networks. Since all mobile hosts including the source and destination are considered as having both power and memory constraints. For example, the Wireless Routing Protocol (WRP)[4] provides only single path routing due to potential overhead for maintaining the shortest path spanning tree reported by each neighbor, although each host keeps sufficient information to perform multipath routing.

In our routing protocol, it is possible to provide multiple routes by using a Super-MH having significantly higher transmission power level than Mini-MHs. That is, our routing algorithm can be thought as kinds of *multipath routing protocol* for any source/destination pair which requires a route. The following describes how to be selected several routes. As mentioed earlier, multiple copies of an IRD packet may be reached the nearest Super-MH through various routes consisting of different intermediate Mini-MHs. After the nearest Super-MH from the source gets the first arrived IRD packet, it sets the acceptable time interval(Tg). The route in this first arrived IRD is considered as "the best route" between a source/Super-MH pair. When the Super-MH replies the source by returning IRR packet directly, just the best route is included in IRR to use it as an initial single route. Although the Super-MH chooses the best route as an initial path for the source, it also selects multiple copies of IRD packet arrived within acceptable time interval Tg. Such routes, except for the best one, chosen by the Super-MH are considered as "Good routes". "Good routes" implies that there exist some routes through the more stable connectivity in the network, even though they are not the best one. Those good routes are cached by the Super-MH in order to be used when the best route no longer works. That is, if intermediate Mini-MHs on the best route move out unexpectedly, one of good routes can be used as an alternative path without performing route reconstruction process.

Route Request Cancellation Phase

In ad hoc networks, network bandwidth, battery power, and available CPU processing time on each hosts are likely to be limited resources [1]. Consequently, useless packets in networks unnecessarily increase the overhead for processing it. For example, even after a path from the source to the Super-MH has been discovered by one *Initial Route Discovery (IRD)* packet, there may still be many *IRD* packets (stale by now), that may be propagated in the network. There is, ordinarily, no mechanism for cancelling such requests. A Super-MH can be used for this purpose. After a route is discovered, a Super-MH may be informed that route discovery has been completed. The Super-MH (possibly, with the help of other Super-MHs) can broadcast a *Route Request Cancellation (RRC)* message to all the mobile hosts, to discard any copies of the route request still propagating in the network.

Route Re-discovery Phase

A path established by the route discovery phase may become unavailable due to highly dynamic migration of the Mini-MHs. In case that a route between a source/destination pair is determined by on-demand dynamically, the process of adapting to route changes is necessary. Our routing algorithm also needs to react quickly to topological changes in the network. Our protocol has some distinguishing features from most existing on-demand routing protocols in that the Super-MH can be used for the purpose of minimizing the frequency of invoking route re-discovery phase.

A good routing protocol for ad hoc networks should have a low communication overhead, by minimizing route setup and maintenance messages[5]. This is because the expence of excessive radio bandwidth consumption is clearly undesirable in ad hoc networks. The DSR[1] is limited in that, if the rate of topological change becomes higher, the amount of control packets broadcasted in the route maintenance phase also become larger. In DSR, any intermediate hosts send a *route error packet* to the original sender of the packet encountering the error, when they find any transmission problem on their hop to a destination. Since the sender has to be notified each time a route is truncated, the route maintenance phase does not support fast route reconstruction[6]. To reduce the frequency of invoking route maintenance phase, Toh[6] and Dube et al.[5] have proposed routing protocols, in which routing decisions to select the longer-lived route are performed at the destination. In ABR by Toh[6], given a set of possible routes from the source to the destination, the route indicating the highest connection stability is chosen by the destination. This method utilizies the property of 'Associativity', which is based on the idea that an intermediate mobile host's high association with its neighbor exhibits a high degree of node's stability. In SSA[5], the signal quality of the channel is used as a route selection criteria by the destination as well as stability of individual hosts. In both protocols, when route maintenance phase is triggered due to change of the established route topology, intermediate nodes discovering the failed next-hop send an error message to the source, as in DSR. Then the source repeats a route discovery phase to find a new route and sends a *route erase message* to remove the old route. Consequently, this mechanism still causes the same problem pointed out above in DSR protocol.

Unlike most on-demand routing protocols which try to re-build an alternative route by sending another route request control packet, our protocol first attempts to use already known "good routes" before trying to find a new route. If good routes are still working until such time that a new route is needed, the source doesn't have to waste its resources by trying to find a new route everytime it receives an error message. Of course, if good routes are all stale, the route re-discovery phase should be performed to get a new route. For doing this, when any intermediate Mini-MH detects a link failure on the route, it informs the Super-MH, not the source. That is, any Mini-MH detecting of a failure on the route sends an *Error on Route (ERR)* message into the immediate downstream neighbor so that an *ERR* packet can be forwarded by the Super-MH. We assume that node i is "upstream" from node j while node j is "downstream" from node i, if a link *(i,j)* is directed from node i to node j. On receiving an *ERR* message, the Super-MH has the source stop transmitting data packets by sending out a *Waiting Data Transmission (WDT)* message including time-out *Tw*. The source then sets time *Tw* and waits for "Hello" messages from the Super-MH until *Tw* is expired.

After broadcasting a WDT message to the source, the Super-MH checks its cache to see if good routes for that source are kept or not. If good routes are found, then the Super-MH sends out "Hello" messages to the source via the reverse of those good routes. The purpose of sending Hello message is to check whether or not those routes are still working. Lists of good routes are deleted from the Super-MH after they are sent to the source as well as when they are too old. The source may receive one of "Hello" messages before time *Tw* is expired. Then, the source chooses the route in the first arrived Hello message as the best one and starts sending data packets again via that route. However, the source may not get any Hello message within the time-out *Tw* because all good routes do not work any more. In this case, the source tries to re-establish a valid route by broadcasting an IRD message such as route initial phase. The ability of our protocol to use already found routes serves to reduce communication overhead expended at the route re-discovery phase.

4 Performance Evaluation

There are no simulation results available at this time, though such work is underway.

5 Conclusion and Future Work

This paper has presented a routing protocol between Mini-Mobile Hosts that is well-suited in physically hierarchical ad hoc networks. Several variations on the *Physically hierarchical* structure and algorithms can be envisaged and may be used to improve performance. For example, by allowing Mini-MHs to receive information from a satellite, the latency of route discovery can be improved. That is, if a Super-MH received a route request for a destination Mini-MH(D) propagated from a source Mini-MH(S), then the Super-MH transmits the request to the satellite. In turn, the satellite relays the request to host D. Host D, on receiving the request, initiates its own route discovery for host S. If the route request from S and D "meet" at an intermediate node, then the partial routes piggybacked on the requests, together, provide a complete route from S to D (and vice-versa). As the requests from S and D are propagated in parallel, the latency in route determination would be reduced. It is easy to ensure that this does not increase the number of route discovery messages. Variations on the structure of hierarchical network are a subject for future research.

We believe our proposed scheme offers a number of potential advantages over traditional ad hoc structure.

First, the distinguishing feature of our protocol as opposed to most previous works is that several good routes from a source Mini-Mobile Host to its nearest Super-Mobile Host can be selected and cached by the Super-MH. The advantage of this is that a route maintenance phase to find a new route will be performed relatively less than that of traditional ad hoc networks using flat routing. In ad hoc networks, the communication connectivity is fairly "weak", as any migration by mobile hosts participating in a route will cause the route to become invalid. Moreover, their quality is highly sensitive to environmental conditions including: the distance and terrain between mobile hosts, externally generated noise[15]. Therefore, some route determined by routing protocols for a traditional ad hoc network may not work quite often, in result it causes an overhead for frequently finding a new route and wastes of network bandwidth.

In our physically hierarchical ad hoc networks, the route from a source to a destination is usually via a Super-MH having not only low mobility but also large transmission capacity. In such a mechanism, the Super-MH may be able to keep several alternative routes and try to use them when an initial route no longer works. Therefore, our protocol may not perform a route re-discovery phase everytime some problems happen on the route. It is likely that minimizing route maintenance is important in terms of a communication overhead.

Secondly, in a traditional ad hoc network, there are no mechanisms to cancel useless route request packets except for discarding duplicate ones by some intermediate nodes. In DSR, when any host receives a route request packet and if it finds that the packet has been already seen before,it discards that copy of the request and does not propagate that copy further. However, since the route request packet is propagated to any mobile hosts within wireless transmiss ion range of itself, it is impossible for all of them to be detected and discarded only by that mechanism. Only discarding packets by such a mechanism can be done if packets are dropped by the same intermidiate host twice. Therefore, even after finishing the route discovery process, there still exist useless packets for searching route in the wireless environment. These useless packets will consume too much network bandwidth and battery power. In physically hierarchical ad hoc networks, The Super-MHs can make those useless packets delete by doing *Route Request Cancellation (RRC)* phase. This is possible because the transmit capacity of Super-MHs is much greater than Mini-MHs.

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