Hierarchical Structure for Supporting Movable Base Stations in Wireless Networks

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***Abstract*— Wireless networks with movable base stations combine the advantages of mobile ad hoc networks and wireless LAN to achieve both flexibility and scalability. We present the hierarchical mobile wireless network (HMWN) to support movable base stations. HMWN may be applied to ad hoc networks as well to build a virtual hierarchy. In such a system, mobile hosts are organized into hierarchical groups. Four basic operations for setting up and maintaining the network structure are grouping, registration, leaving, and migration. An efficient group membership management protocol is developed to support mobile hosts roaming among different groups. The segmented membership-based group routing (SMGR) protocol is proposed to take advantage of the hierarchical structure and membership information. In this protocol, only local message exchanging is required for maintaining network topology and routing information. Simulation-based experiment demonstrates the scalability of the design in terms of protocol overheads.**

***Index Terms*— wireless, mobile, movable base station, architecture, routing**

I. Introduction

Wireless communication technology is an important component in providing networking infrastructure for data delivery. Mobile ad hoc networks and wireless LAN are two typical packet-switching wireless networks [1]. A mobile ad hoc network consists of mobile hosts that communicate with each other over multi-hop wireless links in a collaborative way [1]. There is no fixed infrastructure or stationary base station to coordinate communications. These characteristics provide users with maximum flexibility, at the cost of limitations on scalability. Present research on the capacity of wireless networks provides valuable insights into the scalability problem. The impact of mobility on the capacity of ad hoc wireless networks is investigated in [2]. The authors argue that the average long-term throughput per source-destination pair can be kept constant as the number of hosts per unit area increases, given no restriction on memory size or delay. The scalability problem in practical scenarios, wherein delay cannot grow arbitrarily large and memory size is limited, is analytically studied in [3]. Six popular ad hoc routing protocols are investigated. The result shows that even the most scalable one introduces a total overhead of $\Theta(\sqrt{\lambda_{lc}\lambda_t}N^{1.5})$, if $\lambda_{lc} = O(\lambda_t)$, or $\Theta(\lambda_{lc}N^{1.5})$, if $\lambda_{lc} = \Omega(\lambda_t)$, where N is the number of hosts, λ_{lc} is the link status changes due to mobility, and λ_t is the traffic that a host generates per second. Our recent experimental study of the performance of two ad hoc routing protocols shows that increasing the number of hosts is the dominant cause for performance degradation [4].

Wireless LAN is becoming increasingly significant for people to keep connected on the move. Stationary sites (i.e., base stations) provide high-speed network connections for mobile hosts. For instance, IEEE 802.11a supports up to 54 Mbit/s communication capacity [5]. The fixed infrastructure makes it easy to manage the network, to enforce security policies, and to extend the system. It, however, limits the deployment of the network in environments where wireless access to a wired backbone is either inefficient or impossible. For tactical military networks, the fixed base stations are attractive targets, therefore, highly vulnerable.

Most limitations of wireless LAN, such as inflexibility and vulnerability, can be eliminated by letting base stations move. Base on this idea, we propose a new class of wireless networks called *wireless network with movable base stations* (WNMBS). WNMBS is comprised of mobile hosts and *movable base stations* (MBS). It can be rapidly deployed without any preexisting infrastructure. Flexibility can be achieved without losing much scalability. Supporting movable base stations in wireless networks introduces a lot of challenging research questions. One fundamental

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[1]Sensor network is a new class of wireless networks that has become an attractive research area. A sensor network is essentially an ad hoc network that consists of a large number of tiny disposable and low-power devices. These devices are immobile, or have low mobility as compared with hosts in mobile ad hoc networks.

problem that requires investigation is how to organize MBS and effectively maintain the dynamic network topology. Because all base stations and mobile hosts are moving, the location of a host is not determinable by its network address. Traditional routing protocols for wireless LAN are not suitable in this circumstance. The ad hoc routing protocols do not scale well, as indicated in [3]. They do not take advantages of movable base stations either. Thus, the design of a new routing protocol is mandatory.

In this paper, we present a hierarchical structure to support movable base stations in wireless networks and address the issues of network maintenance and routing. This architecture is called hierarchical mobile wireless network (HMWN). The rest of the paper is organized as follows. Section II discusses the design considerations. The network architecture and four basic operations are described in section III. Section IV presents the detail of an efficient membership management protocol. The segmented membership-base group routing protocol is proposed in section V. In section VI, a simulation evaluation and its result are discussed. Section VII discusses related work. Section VIII concludes the paper.

II. Design Considerations

WNMBS has its unique characteristics that need to be considered in the design of the network architecture. The following issues have been taken into account in this paper.

A. Asymmetric Capacity and Asymmetric Responsibility

Most mobile hosts are portable computing facilities such as PDA, GPS, notebook computer, etc., with portable wireless communication devices. These computing facilities have limited system resources and low computing capabilities. Lightweight batteries may power these facilities along with their communication devices. The weak power and the limited battery life will impose restrictions on the transmission range, communication activity, and computational power of the communication devices. Such mobile hosts can hardly afford the overheads of providing network services. On the other hand, movable base stations (e.g., workstations mounted on vehicles) are powered by heavy-duty batteries, equipped with high-speed communication devices. They are capable of providing reliable network services. A proper design should fully utilize the capacity of movable base stations and minimize computation and communication overheads for less powerful mobile hosts. For instance, computation-complex and resource-consuming operations, such as routing maintenance and authentication, are executed at MBS.

B. Coordinated Movement

The random way-point mobility model [6] is commonly used to generate the movement of mobile hosts in the study of ad hoc networks. According to this model, individuals move independently. The speed and direction of the motion in the new time interval have no relation to those of the motion in the previous time interval. In the real world applications, the members belonging to a group tend to coordinate their movements. The reference point group mobility (RPGM) model [7] describes this kind of movement. RPGM partitions the network into several groups. Each group has a logical center. The center's motion defines the motion of the entire group. Each member in a group has independent random motion with respect to the logical center in addition to the group's motion.

C. Localized Traffic

The reality of network traffic is that a small percentage of hosts in a domain are communicating outside of the domain at any given time. Many (if not most) hosts never communicate outside of their domain [8]. For example, it is much more likely that communication will take place between two soldiers in the same battalion, rather than between two soldiers in two different brigades. To take advantage of this kind of traffic pattern, the design of networks should give priority to intra-domain communications.

D. Heterogeneous Wireless Networks

In large scale applications, incompatible wireless networks, such as bluetooth networks, waveLAN networks, or satellite networks, may coexist. A desirable feature of the network architecture is the capability of accommodating heterogeneous wireless networks and providing simultaneous and seamless support for different MAC protocols. MBS that are equipped with multiple wireless network interfaces are needed to forward packets between two groups that use incompatible protocols (like routers in wired networks).

III. The Network Architecture

Based on the considerations discussed in the previous section, *hierarchical mobile wireless network* (HMWN) is designed to support WNMBS. It can be applied to ad hoc networks as well to build a virtual hierarchy. To broaden its application, HMWN is presented in the following sections in a generic way, in which movable base stations are treated as a special type of mobile hosts.

A. Definitions

The following is a set of definitions that will be used in the rest of the paper.

Definition 1: A *group* is a set of mobile hosts. Each group has one representative (i.e., *agent*). A group is denoted as *group(M)*, where M is the agent. A host can be an agent for at most one group. The home group (HG) is where the mobile host registers its membership. A foreign group (FG) is a group other than the HG. The current group (CG) is the one that the host currently attached. The corresponding group agents are called home group agent

(HGA), foreign group agent (FGA), and current group agent (CGA), respectively. Usually, movable base stations are chosen to be agents.

For every mobile host, its HG is assigned by "Grouping" operation.This relationship keeps unchanged during the life-time of the network. A mobile host's CG is changed when the "Migration" operation completes.

Definition 2: The groups in a HMWN system form a group hierarchy. The level of a group G, which is denoted as *lv(G)*, represents how close it is to the root of the hierarchy. The lower the level is, the closer the group is to the root. The level of the root group is 0.

Any mobile host can be a member of two different groups, in one of which it is the agent, in the other one it is a non-agent member. Suppose the agent of group G_1 is a non-agent member of group G_2, then lv(G_1) = lv(G_2) + 1. If a mobile host MH is a member of group G, the level of MH is

$$lv(MH) = \begin{cases} lv(G), & \text{MH is the agent of group G;} \\ lv(G)+1, & \text{otherwise.} \end{cases} \quad (1)$$

Definition 3: A group G_1 is a subgroup of group G_2 if and only if

1) the agent of G_1 is a non-agent member of G_2
2) or the agent of G_1 is a non-agent member of one of G_2's subgroups.

G_2 is called a supergroup of G_1. Operators *sub*(G_1, G_2) and *sup*(G_2,G_1) are used to denote that G_1 is a subgroup of G_2 and G_2 is a supergroup of G_1, respectively. In HMWN, *sub* and *sup* are partial orders.

Definition 4: A domain derived from a group G consists of and only consists of G and all its subgroups, denoted as *domain(G)*. The group agent of G is also the domain agent of domain(G). Derived domains have the following property.

$$domain(G_1) \subseteq domain(G_2) \Longleftrightarrow sub(G_1, G_2) \quad (2)$$

Definition 5: A closure domain of two groups G_1 and G_2, denoted as *closure*(G_1,G_2), is the smallest derived domain that contains G_1 and G_2. Formally, closure(G_1,G_2) = domain(G) if and only if

1) $G_1 \subseteq$ domain(G) and $G_2 \subseteq$ domain(G)
2) For any derived domain(G'), $G_1 \subseteq$ domain(G') and $G_2 \subseteq$ domain(G') $\Longrightarrow$ domain(G) $\subseteq$ domain(G')

B. An Example

Figure 1 is an example of the HMWN system. Every small square represents a mobile host and the dark ones are group agents. A solid line between two mobile hosts represents the wireless link. The dashed line circles represent groups and the solid line circles represent derived domains. The root group only contains three members {A, B, C}, where A is the agent. There are two level 1 groups, {B, D, E} and {C, F, G}. B and C are group agents, respectively. D, E, F, and G are agents for level 2 groups. Figure 2 shows an alternate representation of the group hierarchy, where every group is represented by its agent at a lower level. In this network, the domain(A) contains 7 groups and all hosts in the system. The domain(B) consists of 3 groups and mobile hosts {B, D, E, s, t, x, y, z}.

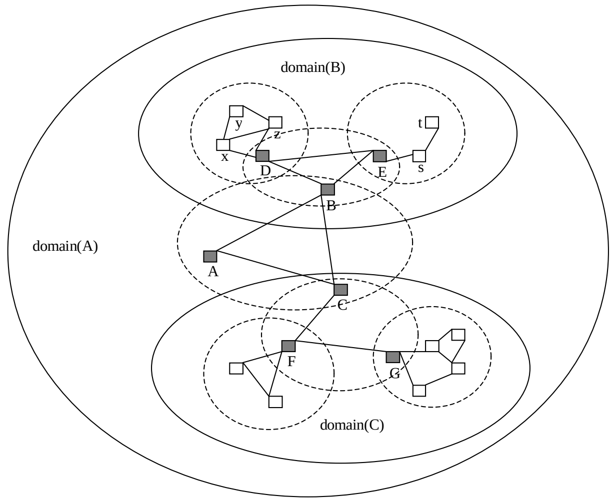

Fig. 1. Hierarchical Mobile Wireless Network

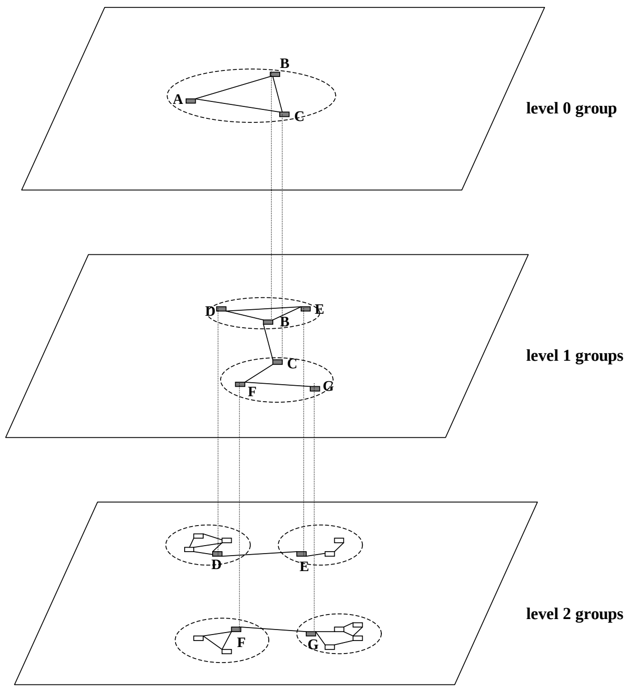

Fig. 2. Hierarchy of Groups

In HMWN, mobile hosts that belong to the same group use a multi-hop ad hoc routing protocol to communicate. Communication with a host outside the group is accomplished by the *segmented membership-based group routing* protocol presented in section V.

C. Basic Operations

The following four basic operations are defined for setting up and maintaining a HMWN system.

1) Grouping is the operation used to set up the static membership in a HMWN system. It is only performed at the bootstrapping phase. "Grouping" is accomplished in two steps. The first is to organize mobile hosts into groups (i.e., assign HG for each mobile host). The second is to determine group agents (HGA). The criteria for "Grouping" include

- Mobility: If a set of mobile hosts are going to coordinate their movements, they may form a group.
- Organization: If all mobile hosts belong to a organization that has a well established hierarchy, the hosts can be grouped based on this hierarchy.
- Wireless MAC Protocol: If multiple wireless MAC protocols are used in the network, the mobile hosts that support incompatible protocols may be grouped together.
- Capacity: Capacity is used to determine group agents. The higher the capacity is, the greater the chance is that the mobile host will be chosen as an agent. Several factors are taken into consideration when the capacity of a mobile host is evaluated, e.g., the computation capability, system resource, power level, communication bandwidth and range, the number of wireless network interfaces.

This operation can be done in a distributed or centralized way.

- Mobile hosts may autonomously organize themselves into groups, then supergroups. In the autonomous procedure, each agent will exchange the organization, the MAC protocol, and capacity information with its neighbors to determine the static membership relationship. This process is accomplished in a distributed way. It is hard to obtain the optimal result.
- A trusted authority may take charge of the operation. Every mobile host reports its information to the authority. The authority employs some global optimization algorithm to establish the hierarchy and distributes the result to all participated hosts.

The first scheme is also suitable for self-organizing ad hoc networks, in which mobile hosts have no prior knowledge about the network. In practice, a mobile host usually is assigned a home agent before joining the network, or knows some information that is helpful for grouping. Automatically grouping in a distributed fashion itself is a non-trivial problem. We do not address it in this paper.

2) Registration is the operation that a mobile host must complete before it can connect to the network. "Grouping" only determines the static membership. "Registration", along with "Leaving" and "Migration", maintains the dynamic topology of the network (e.g., CG for a mobile host). Registration takes place between a mobile host MH and its HGA. One-hop registration is recommended to reduce the possibility of denial-of-service and man-in-the-middle attacks.

This operation begins with MH broadcasting the"Registration" request. If the HGA is within the neighborhood, the operation continues with an identity verification process. Upon successfully registered, MH will obtain the group information such as group ID, group shared secrets, etc. from the HGA, and set the HGA to be its CGA. In case that MH itself is an agent of another group, all hosts in the derived domain(MH) implicitly become members of the network. MH keeps moving and sending out the request periodically if it cannot reach the HGA directly. Other hosts may provide aid to locate the HGA so that MH can adjust its movement.

If connectivity rather than security is preferred, remote registration (i.e., MH registers itself to the HGA via intermediate hosts) will be allowed.

3) Leaving operation is completed by group agents. It may be triggered by two events.

- When a mobile host MH decides to leave the network (along with all hosts in the derived domain(MH)), it sends a "leave group" message to its CGA.
- When the agent finds out that the route to a mobile host MH is broken, it starts a Leaving Timer. If a route to MH cannot be reestablished or a "Migration"message has not received within the Leaving Interval Time as described in equation 3, the agent starts the "Leaving" operation.

  Leaving Interval Time

  $$= Robustness * Ad\_Interval * (Max\_Hop + 1) \quad (3)$$

  The *Ad_Interval* is the time interval between the route advertisements sent out by a host. The *Max_Hop* is the hop number of the longest route in the agent's routing table. Robustness * Ad_Interval * (Max_Hop + 1) is the maximum time it will take to get MH's routing information if MH is still a member of the group. The *Robustness* allows tuning for the expected packet loss on wireless links. The "Leaving" operation is able to tolerate (Robustness - 1) failures. Thus Robustness must be greater than 1. If the system is expected to be lossy, the Robustness may have a larger value.

After the CGA of MH updates the membership information, it will forward the "leave group" message to its own CGA.

4) Migration operation is initiated by a mobile host that decides to leave its current group and join a foreign group. Usually, when a host MH realizes that the CGA is no longer reachable, it starts this operation by sending out a "Migration" request. Foreign agents that are in the neighborhood reply this request based the security policy that determines whether provide migration support, MAC protocol compatibility and capacity. MH chooses the FGA whose reply comes first, set it to be the CGA, and invokes

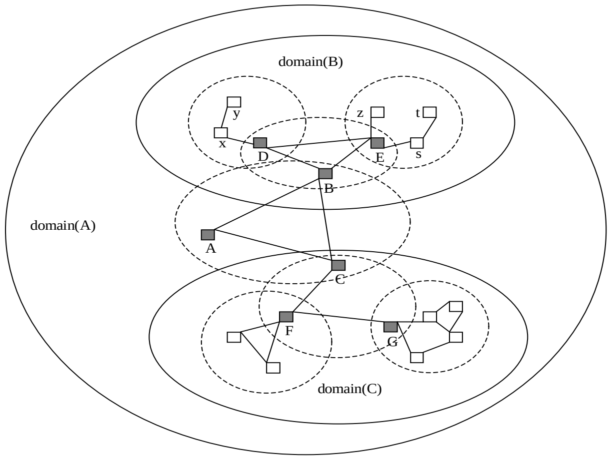

Fig. 3. Migration

the hand-off procedure. Every agent that replies the request will start a timer. When the timer expires, the agent will cancel the operation.

Figure 3 illustrates the topology of the example HMWN system shown in Figure 1 after mobile host z migrated from group(D) to group(E).

IV. Membership Management

Maintaining the network topology in an efficient way is significant in a HMWN system. Essentially, it is a membership management problem because the mobile hosts are organized as hierarchical groups. The following subsections present the membership management protocol.

A. Data Structure

The membership information is mainly used for two purposes. The first is to verify the identity of a host (i.e., the static membership). The second is to help routing protocols to choose the proper route to forward packets (i.e., the dynamic membership). Each agent G maintains two separate tables.

Static_Member_Table contains the identification information of mobile hosts whose HGA is G. This table is mainly used by security protocols such as authentication and identity verification. The table has an entry for every potential member, which is a 3-tuple {*ID*, *shared_secret*, *public_key*}. Initially, an entry only contains the ID and the shared_secret. After registration, the public key of the member will be recorded in the entry.

Current_Member_Table contains the information of all the mobile hosts that currently belong to the domain whose agent is G. The entry of the table is a 3-tuple {*ID*,*intermediate_host*, *home_agent*}. The intermediate_host is the non-agent member in this group whose Current_Member_Table also contains the mobile host (i.e., the mobile host is in the domain derived from the intermediate_host). The home_agent is the HGA of the mobile host. This table is used by the routing protocol to locate mobile hosts.

Depend on the size of the tables and the available memory, these two tables can be maintained using a hash table, a ordered list, or a trie to accelerate the searching process. "Registration","Leaving", and "Migration" will operate on these two tables.

B. Registration

Upon successful registration, a host will get the group information from the agent. The host sets the agent to be its CGA. In case that security protocols are deployed, a mutual challenge-and-response process will be initiated to verify the identity of the host and the agent. If verification succeeds, the agent will record the host's public key in the corresponding entry of Static_Member_Table, the host will get the group key, the agent's public key, and other information required by the security protocols such as a certificate.

The host will send a list of all members in its Current_Member_Table to the agent so that all members in its derived domain will be implicitly registered. This list will be forwarded via the path from the agent to the root of the hierarchy. Every agent on the path will add the members to its own Current_Member_Table.

C. Leaving

When a host leaves a group, all members in its derived domain also leave the group implicitly. The host sends a list of all members in its Current_Member_Table to the agent. This list will be forwarded via the path from the agent to the root of the hierarchy. Every agent on the path will remove the members from its own Current_Member_Table.

D. Migration

When a mobile host MH is leaving the current group G_1 and joining another group G_2, both the CGA and the FGA will update their Current_Member_Table. If MH is an agent, all mobile hosts in domain(MH) also implicitly leave domain(G_1) and join the domain(G_2). After joining the foreign group, MH will send messages to the CGA and the FGA to help them update the membership.

1) Update at FGA side: MH sends the following message to the foreign agent.

[ADD, ID, previous_agent, member_list]

where ID is the identification of MH, previous_agent is MH's CGA before joining the group, member_list is MH's Current_Member_Table.

For each host in the member_list, the FGA adds it to the Current_Member_Table if it does not exist already, and sets the intermediate_host to the MH that sent the message. If previous_agent is not a member in the Current_Member_Table, the FGA sends the same message to its own CGA. Every agent that receives the message will update the membership as well.

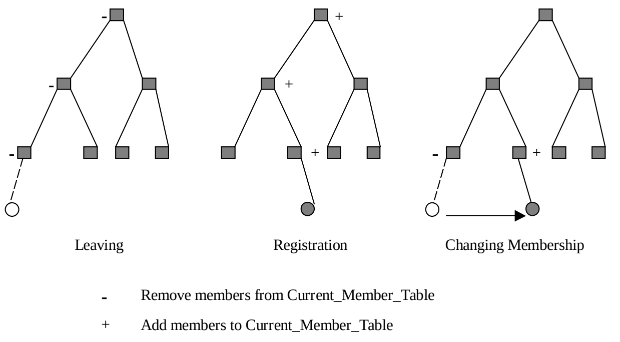

Fig. 4. Membership Modification

2) Update at CGA side: MH sends the following message to the current agent.

[REMOVE, ID, foreign_agent, member_list]

where ID is the identification of MH, foreign_agent is the agent of the foreign group, member_list is MH's Current_Member_Table.
If the foreign_agent is also a member in the Current_Member_Table, which means the MH moves from one sub-group to another, then the CGA does nothing. Otherwise, it removes every host in the member_list from the Current_Member_Table and forwards the message to its own CGA. Every agent that receives the message will update the membership as well.

Figure 4 shows the difference between "Registration", "Leaving" and "Migration" with respect to the modification of Current_Member_Table. The small circles represent the mobile host. For "Registration" and "Leaving", the effect will be propagated to the root of the hierarchy. Thus lv(A)+1 unicast are required, where A is the agent. For "Migration", the effect is only propagated to the agent of the domain *closure(previous_agent, foreign_agent)*. The number of required unicast is

$$lv(previous\_agent) + lv(foreign\_agent)$$
$$-2 * lv(closure(previous\_agent, foreign\_agent)) \quad (4)$$

V. Segmented Membership-based Group Routing

Segmented membership-based group routing (SMGR) protocol is proposed for the HMWN system to take advantage of the hierarchical group structure and available membership information.

A. Data Structure

SMGR protocol requires two tables. One is the routing table, in which each entry is a 4-tuple <*destination, next_hop, distance, sequence_number*>. The sequence_number represents the freshness of the route. Each host maintains a sequence_number for itself. This number is monotonically increasing. Only routes to the group-mates are maintained in the routing table. These routes are updated using DSDV [9] protocol.

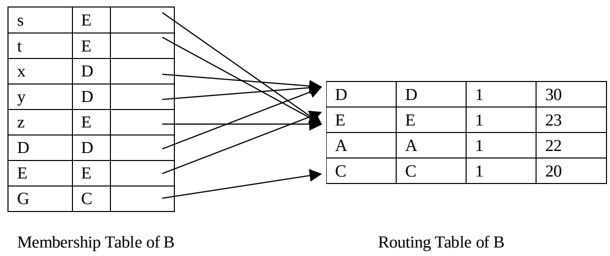

Fig. 5. Membership Table and Routing Table

The other is the membership table, in which every entry is a 3-tuple <*final_destination*, *intermediate_host*, *routing_entry*>. *routing_entry* is a pointer to the entry in the routing table that specifies the route to the *intermediate_host*. Every entry in Current_Member_Table has a corresponding entry in this table.

Take host B in Figure 3 as an example, figure 5 shows the routing table, the membership table, and the pointers maintained by B.

The size of the routing table is bounded by the size of the group, which is nearly a constant.

SMGR protocol will add a header, which is a 4-tuple <*source*, *final_destination*, *intermediate_host*, *next_hop*>, to each packet. The header is used to route the packet.

B. Routing

When a host receives a data packet, either from another host or from a application running on itself, it takes different actions to forward the packet, based on whether it is the intermediate_host or not. Here we assume that the routing table is up-to-date.
If the host is not intermediate_host, it simply forwards the packet based on the available routing information. Otherwise, it is responsible for locating the next intermediate_host (or the final destination) from its membership table. The packet is forwarded to the next intermediate_host if it is located, otherwise, the packet is forwarded to the CGA. Since the root group agent can locate any mobile host, the packet will eventually reach the destination. In the routing process, "membership expires" or "redirect" message may be sent out to update the membership information.

A host will removes the corresponding entry from the membership table when it receives a"membership expires" message.

When a host receives a "redirect" message, it adds an entry in the membership table, set intermediate_host to be the redirected host.

The detailed description of the SMGR protocol is available in [10].

VI. Simulation-based Evaluation

Currently, we have implemented a simplified version of SMGR in the network simulator ns-2 [11]. In this version,

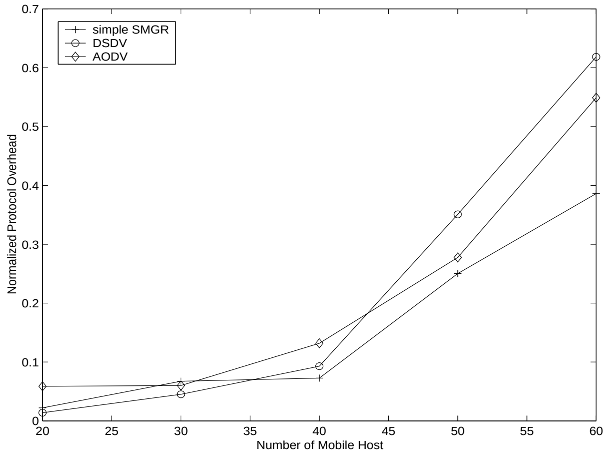

Fig. 6. Normalized Protocol overheads vs Number of Mobile Hosts

the membership modification is completed through broadcast instead of unicast. It is predictable that more protocol overheads will be introduced by the simplification. We have also implemented the computation delay component to simulate different computation capacities. The purpose of the experiment is to evaluate the scalability of HMWN in terms of protocol overheads. Because there is no other routing protocol designed for WNMBS, we apply HMWN to ad hoc networks for comparison purpose. Since SMGR utilizes distance vector, we compare it with two distance vector based ad hoc routing protocols, DSDV and AODV [12].

A. Simulation

In this preliminary experimental study, we take the normalized protocol overheads (protocol overheads divided by throughput) [13] as the metric to evaluate the scalability of routing protocols. The experiments simulate a 1000m x 1000m area. Random way-point mobility model is used to generate movement for mobile hosts, the maximum speed is 5m/s, the pause time is 3 seconds. The number of end-to-end connections is equal to the number of hosts. The source-destination (S-D) pair of each connection is randomly chosen. Constant bit rate (CBR) traffic is generated for all connections. The number of hosts ranges over {20, 30, 40, 50, 60}. For each value, five scenarios are created. Individual simulation runs 1000 seconds. The normalized protocol overheads is extracted from the traffic trace file.

B. Normalized Protocol Overheads

The result of the experiment is shown in figure 6. The curves present the mean value of the normalized protocol overheads for each protocol. When the number of hosts is less than 40, three protocols have similar performance, with AODV being outperformed a little bit. When the number of hosts reaches 60, the overheads of DSDV is about 50% higher than that of the simple SMGR, while the overheads of AODV is about 38% higher. The result shows that the simple SMGR is more scalable in terms of protocol overheads.

Considering the random way-point mobility model and the random traffic pattern that are used for the experiments favor ad hoc networks, and the simple SMGR introduces extra protocol overheads because of unnecessary broadcast, we may expect a HMWN system supported by SMGR protocol to be more scalable with the presence of movable base stations.

VII. Related Work

Many research efforts are trying to introduce structures on ad hoc networks to provide scalable solutions for routing, location management, and resource allocation, etc. Professor Haas at Cornell University proposed the Zone Routing Protocol (ZRP) [14], where every mobile host maintains a routing zone. Researchers at University of Maryland at College Park introduced a clustering scheme for hierarchical control in wireless sensor networks [15]. An applicable hierarchy for multi-hop wireless networks for quality-of-service support is proposed in literature [16]. Most schemes assume that ad hoc networks are self-organized to discover and maintain the structure. It requires extra message exchanges that may consume a large portion of the limited bandwidth.

We propose a new type of wireless networks called WNMBS and a hierarchical network structure HMWN to support WNMBS. In HMWN, asymmetric capacity determines asymmetric responsibility. Group agents (usually movable base stations) take major responsibilities for managing membership and routing packets. HMWN integrates the routing protocol with membership management to reduce protocol overheads. It is capable of accommodating incompatible wireless MAC protocols and managing heterogenous wireless networks in a unified way.

VIII. Conclusion

In this paper, we present a hierarchical structure to support movable base stations in wireless networks. In a HMWN system, mobile hosts form hierarchical groups. Four basic operations that are used to set up and maintain the hierarchy have been discussed. The detail of an efficient membership management protocol is presented. The segmented membership-base group routing protocol for HMWN is proposed. An experimental study is carried out to compare the scalability of SMGR with AODV and DSDV ad hoc routing protocols in terms of normalized protocol overheads. The SMGR outperforms these two protocols for about 50% when the number of hosts reaches 60.

This work is only the first step in the research on wireless networks with movable base stations. We are developing multiple MAC protocols and supporting modules in ns-2 to carry out experimental studies on HMWN and SMGR protocol with respect to other performance metrics. Automatically grouping in a distributed way and introducing security mechanisms are the next steps. We hope this work will help to build a foundation for the research of flexible, scalable, and secure wireless networks.

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