Hybrid Landmark Routing in Ad Hoc Networks with Heterogeneous Group Mobility

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Abstract — Scalability is an important consideration in the design of any large network. In ad hoc networks, scalability is particularly critical as node mobility imposes additional challenges to growth. For example, frequent updates required by mobility make the conventional proactive routing protocols unable to work in large scale mobile ad hoc networks. Traditionally, node mobility in a wireless ad hoc network is viewed as the superposition of individual, independent random moves of each node. In reality, mobile users tend to exhibit some kinds of collective group mobility patterns especially when the network size grows large. In fact, group mobility has been exploited to improve the scalability of network protocols such as routing. For example, LANMAR routing uses mobile groups as the basis of hierarchical network architecture. However, the original LANMAR routing assumes that all nodes move in groups (e.g. homogeneous group mobility), which is quite unrealistic. In general, moving teams do coexist with individual roaming nodes creating what may be called heterogeneous group mobility scenarios.

In this paper, we propose a hybrid landmark routing (Hybrid LANMAR) scheme which takes advantage of group mobility to improve network scalability, while at the same time supporting individual mobility efficiently. Mobile groups are explored following a way similar to LANMAR routing and individually moving nodes are handled in an on-demand fashion. In this way, we gracefully integrate advantages of both proactive and on-demand routing. Simulation results show that hybrid LANMAR can greatly improve network scalability in heterogeneous motion scenarios.

Index Terms—MANET, routing, mobility, scalability

I. INTRODUCTION

The ad hoc wireless networking technology has been gaining increasing visibility and importance in distributed applications that cannot rely on a fixed infrastructure but require instant deployment and easy reconfiguration. Some of these applications involve several thousands of nodes. Scalability becomes then a critical design issue, especially if the nodes are mobile. One of the most challenging research areas that have recently emerged in the design of MANETs (Mobile Ad Hoc Networks) is in fact scalability, in particular, scalability of the routing protocols. Conventional proactive routing protocols, such as DSDV[12] and Fishey[11], rely on periodic exchanges of routing information of the entire network. They do not scale well because they propagate routing information of all nodes periodically throughout the whole network. With mobility present, more frequent updates are required to keep the information up to date, thus producing a large amount of control overhead. In a large scale mobile environment, the on-demand routing protocols such as AODV[13] and DSR[6] etc., which generate routing overhead only when there is data traffic to send, and thus have been traditionally considered more suitable for ad hoc wireless networks, also tend to cause heavy overhead due to the large-scale flood search.

Recently some efforts have been made to improve the scalability of ad hoc routing protocols. One technique is to explore the mobility patterns such as the group mobility. For example, the LANMAR routing scheme[4] uses one landmark node to represent a whole group of mobile nodes. Another technique is to utilize geographical information such as in LAR[9] and GPSR[8], which try to use the geographic information (typically from GPS) to achieve scalability. All of these schemes provide promising ways to improve the network scalability. In this paper, we take the same design philosophy that inspired LANMAR routing (namely group mobility), and extend it to achieve even greater scalability and robustness to mobility.

Group mobility is actually a quite common mobility pattern in the real world, especially in military scenarios and disaster recovery environments. For example, in battlefield, missions are usually group based (e.g., tank battalions, UAV (Unmanned Air Vehicles) swarms etc). During rescue operations, teams of fire-fighters and medical assistants are moving as groups following different patterns. Even in civilian scenarios, group mobility is quite prevalent. Examples include a team of travelers moving in groups, students moving to one class to another, cars platooning along the highway. Exploiting such group mobility patterns could greatly simplify routing. In LANMAR routing, a landmark node is elected from each group. Nodes in the network, but outside a group, do not need to track routes to all nodes in that group. Only one route toward the landmark is needed. Such kind of summarized routing will not affect the routing accuracy since the nodes in a group are moving together. However, the overhead reduction is significant. For example, if the average group size is g, the routing table size might be reduced to l/g. The routing control overhead is in turn reduced as the routing packet size is significantly shortened.

Exploring group mobility is definitely a good way to improve network scalability and performance. However, realistic models are difficult to come by. It is unrealistic for example to assume that all nodes in the network are organized in groups. It is still quite common that some nodes may move randomly and individually. Previous work such as LANMAR routing simply assumes homogeneous group mobility. Thus, if a fraction of the nodes move randomly, LANMAR cannot support them efficiently. Of course, an individually moving node can be treated as a group of size one. But if the fraction is non negligible, this turns out to be a traditional distance vector routing which has been proven to be not scalable in the mobile environment.

In this paper, we target the large scale military ad hoc network scenarios where group mobility is common. However, we don't assume homogeneous group mobility. Instead, we assume that groups of moving nodes, individually moving nodes as well as static
nodes all coexist in the same network. This we define as heterogeneous group mobility. Our goal is then to develop an efficient and scalable routing scheme under such environment. We propose a hybrid landmark routing (Hybrid LANMAR) scheme that can explore the advantages of a group mobility pattern, and at the same time support individually moving nodes efficiently. For tracking group moving nodes, we use of course the Landmark concept. If the group size is non-trivial (e.g. beyond a certain threshold) and traffic targeting to or initiating from the group is non-trivial, the group leader will start broadcasting its existence using the Distance Vector (DV) routing scheme. All other nodes outside of this group will learn routes to it via a DV like route dissemination (as in LANMAR). On-demand routing, on the other hand, is utilized to support individually random moving nodes and nodes of groups with small size. Both proactive routing and on-demand routing techniques are well integrated with each other. The major novelty of our work is improved scalability and flexibility. Scalability is improved by using only the group leader to represent a whole group. Flexibility is guaranteed by using on-demand routing to individually moving nodes or very small groups with very light traffic. Thus, flexibility comes from the combination of proactive routing and on-demand routing.

Moreover, MANETs are highly dynamic with nodes joining and leaving; network groups splitting and merging, dynamic address allocation according to movement behavior or according to host's logical affiliation. These dynamics lead to potential frequent changes of a node's IP address. Application programs are more likely to use well known domain names that are unique, easy to remember and/or that bear logical semantics of the groups, to gain nodes' newly assigned network address via Internet Domain Name Systems quickly. Those updated network addresses can be used to distinguish individually moving nodes and group members.

The rest of the paper is organized in the following way. We briefly review some related work in section II. Section III introduces the heterogeneous group mobility scenarios targeted to be explored. In section IV, we present the proposed hybrid LANMAR routing scheme in detail. Intensive performance evaluations are presented in section V and we conclude the paper in section VI.

II. RELATED WORK
A considerable body of literature has addressed research on ad hoc routing protocols [7][12][13]. Most of these protocols work well in small or medium size ad hoc networks. However, much larger ad hoc networks emerge in several application scenarios, such as in military or disaster recovery situations. Scalability becomes an important issue in such situations. To improve routing scalability, several techniques have been proposed such as in [4][10][11][14][16]. For example, Fisheye [11] propagates link state packets with different frequencies to nodes inside vs. outside its Fisheye scope respectively. OLSR [14] reduces the control packets by selecting only part of the neighbor nodes for packet forwarding. TBRBF [10] reduces the update overhead in a Link State routing scheme by maintaining and sharing a tree for update broadcast. LANMAR [4] uses a landmark node to represent a group of mobile nodes. ZRP [16] combines both proactive routing (in local zone) and on-demand routing (to remote nodes). R-DSDV [2] introduces congeestion control to the original DSDV [12] routing for limiting control overhead. The control overhead of on-demand routing protocols can also be reduced by repairing a broken route locally at the node, which experiences the link breakage as is done in WAR[15]. Geographical information assisted routing such as LAR [9] and GPSR [8] try to use the geographic information (typically from GPS) to achieve scalability.

All these schemes attack the scalability problem in various aspects. Among them, the LANMAR routing scheme and ZRP routing scheme share various similarity with our scheme. We use the same mechanics as the LANMAR routing to explore the group mobility pattern. However, original LANMAR routing can not support individually random moving nodes efficiently, which is supported via on-demand fashion in our routing scheme. Hybrid LANMAR also shares similarity with the ZRP routing protocol. Both of them use proactive routing within the local scope or zone and on-demand routing to remote nodes. However, given the small size of the local zone, ZRP is mostly same as the conventional on-demand routing in the large-scale ad hoc network environment; thus, ZRP shares the same scalability limitations. In hybrid LANMAR, we only use on-demand routing to track individually moving nodes or very small groups. Group mobility is explored to reduce the overhead and improve the scalability.

III. TARGETED SCENARIO
Mobile ad hoc networks have found many applications in tactical communications and civilian forums. In the reality, one may notice that mobile nodes are often organized in groups (e.g., tank battalion, infantry company, UAV swarm, etc.) with different tasks and, correspondingly, different functional and operational characteristics, e.g., organized groups of small unmanned ground, sea and airborne vehicles to launch complex missions that comprise several such groups. More possible applications include: coordinated aerial sweep of vast urban/suburban areas to track suspects, search and rescue operations in areas unfriendly to humans (e.g., chemical spills, terrorist attacks, etc), exploration of remote planets, reconnoissance of enemy field in the Battle Theater, etc. The successful, distributed management of the mission will require efficient, reliable, low latency communications within members of each group, across groups and to a manned command post. In the civilian environment, group mobility is also dominant. A group of travelers heading for the same place may form an ad hoc network via their handheld. The collaboration among members of the same team makes it possible to partition the network into several groups, each with its own mobility behavior.

However, the mobility behaviors exhibited in reality is always complicated. Different mobility patterns are usually coexisting in one network. One common scenario is that some wireless nodes form several teams and move in groups. While some other nodes may move independently and randomly. In this paper, we target such scenarios where group moving nodes and individually moving nodes co-exist. The term "heterogeneous group mobility" refers to the mix of group moving nodes and individually random moving nodes. Given the commonness of such mobility scenarios, it would make sense to explore the advantages of the group mobility behaviors while supporting the individually moving nodes efficiently at the same time.

IV. HYBRID LANDMARK ROUTING SCHEME
In this section, we present our hybrid LANMAR routing in detail to exploit advantages of group mobility in the heterogeneous group mobility realistic scenarios where both group moving nodes and individually moving nodes co-exist. The basic idea of the hybrid LANMAR is to combine both the proactive routing and on-demand routing schemes together. Moving teams are tracked via proactive Distance Vectors routing. Individually moving nodes are handled via the on-demand routing scheme. By this way, we take the advantages of group mobility to improve the network scalability. The hybrid LANMAR includes three sub-schemes; the local scope limited proactive routing, proactive routing for tracking groups and
on-demand routing for tracking individual mobile nodes. In this section, we describe them in detail.

A. Proactive Local Scope Limited Routing

Proactive routing schemes provide good route quality and instant route availability. However, it triggers big routing overhead when being applied to mobile networks with medium and large size. But if we limit the propagation scope of routing packets of proactive routing schemes, it will provide good routing accuracy to nearby nodes without causing too much overhead. Thus, in hybrid LANMAR, we propose to use proactive routing schemes only within a limited scope.

In our implementation, the Fisheye routing is selected as the local scoped routing protocol. Fisheye routing is basically a Link State (LS) routing. It has different propagation frequencies of LSs to nodes different hops away. Since the local routing is run with a few hops (scope limited), only one frequency is used in Fisheye routing. That is each nodes broadcast its topology information at most \( K \) hops away. Here, \( K \) is the scope limit of the local routing. Now, with the proactive routing within the local scopes, each node will have accurate routing information to all nodes at most \( K \) hops away from it.

B. Tracking Mobile Groups

The local scope limited routing protocol only provides routes to nearby nodes. A node still has no routing information to remote nodes outside of its local scope. In this subsection we describe how we track remote nodes moving in groups. The basic idea is same as LANMAR routing. Each mobile group will elect a landmark node (e.g. the group leader). A node tracks one mobile group by maintaining only one route to its landmark node.

In the original LANMAR routing, the landmark node is dynamically elected to achieve reliability in case of node failures. The election algorithm basically can be any type of clustering algorithm. Here we adopt the landmark node election algorithm of original LANMAR routing. Its basic idea is to elect the nodes with the most number of neighbors within its local scope as the landmark of that group. After one node is elected as the landmark node, it will start broadcasting Distance Vectors (DV) to inform the entire network of its existence. All nodes in the network maintain a landmark distance vector routing table with maintaining routing information to landmark nodes it has heard so far.

### Membership Cache

<table>
<thead>
<tr>
<th>Host ID</th>
<th>IP Address</th>
<th>&quot;GID, Host ID&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.100</td>
<td>0.0.10.100</td>
<td></td>
</tr>
<tr>
<td>10.101</td>
<td>0.0.10.101</td>
<td></td>
</tr>
<tr>
<td>10.103</td>
<td>10.111.10.103</td>
<td></td>
</tr>
<tr>
<td>10.111</td>
<td>10.111.10.111</td>
<td></td>
</tr>
<tr>
<td>10.112</td>
<td>10.111.10.112</td>
<td></td>
</tr>
</tbody>
</table>

### Local Routing Table

<table>
<thead>
<tr>
<th>dest</th>
<th>nextHop</th>
<th>dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>j</td>
<td>n</td>
</tr>
</tbody>
</table>

### Landmark Routing Table

<table>
<thead>
<tr>
<th>GID</th>
<th>nextHop</th>
<th>dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>j</td>
<td>n</td>
</tr>
</tbody>
</table>

### On-Demand Routing Table

<table>
<thead>
<tr>
<th>dest</th>
<th>nextHop</th>
<th>dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>j</td>
<td>n</td>
</tr>
</tbody>
</table>

Figure 1. Illustration of group membership cache and routing tables of the hybrid LANMAR routing protocol

C. Tracking Individually Moving Nodes

The previous subsection has explained how remote group moving nodes are tracked using the proactive distance vector routing scheme. However, there are still two problems left unsolved. First, as we have mentioned, there are some nodes which are not in any group. They move randomly and individually. We must support such nodes efficiently. Secondly, when one node needs to send a packet to a remote node outside of its local scope, it must have a certain way to find out in which group the destination node is. It is unrealistic to assume that a node has pre-configured knowledge regarding the group membership of any other node except itself.

For the first problem, supporting individually moving nodes, one simply way is to treat each such node as a group containing only itself. This is equivalent to running a conventional distance vector routing on top of such nodes. Given the scalability problem of proactive routing schemes, this method will trigger a lot of overhead when the number of individually moving nodes is not small. To support the individually moving node without introducing significant overhead, we propose to apply the on-demand routing technique to track such nodes.

In the original LANMAR routing, since the group affiliation is static and pre-known, the node IP address is pre-configured as <Group IP, Host ID>. Such a method may not be practical in our scheme since our targeted scenarios are dynamic with nodes joining and leaving; network groups splitting and merging, dynamic address allocation according to movement behavior. These dynamics lead to potential frequent changes of a node’s IP address. Therefore, to simplify discovering the group membership, in our design, we propose to reserve the first half of the IP address, say 16 bits in IPv4, to store the group ID, and the second half of the IP address for Host ID, similar to the original LANMAR. Both Group ID (GID) field and Host ID field have same size in bits that allows us simply to use landmark Host IDs (that are unique and fixed) as Group IDs. The GID field should be kept as 0 if the node does not belong to any group, and when the node is participating in a group the GID field should be filled with the group landmark Host ID. In this paper, we reserve GID fields for exclusive access by LANMAR, and use Host IDs as domain names. Application programs can use the well known domain names, to gain nodes’ newly assigned network address via distributed Internet Domain Name Systems (DNS) quickly [17]. Those updated network IP addresses can be used to distinguish individually moving nodes and group members, thus the second problem mentioned above can be solved easily.

D. Packet Forwarding Procedure

In this subsection, we describe in detail the routing tables and the group membership cache maintained at each node and the procedure of data packet forwarding. After the hybrid LANMAR routing is performed, each node will now have one group membership cache and three routing tables. The group membership cache keeps the group membership information of destination nodes discovered via distributed DNS. This cache is refreshed and its entries are expired.
after a certain time. The refresh time of these entries are highly related to the stability of the groups. If the group members seldom change their group affiliation, long refresh time can be used. If, on the country, the mobile groups are very dynamic with frequent group split or mergegence, the group membership cache should be refreshed frequently. The three routing tables are 1) Local proactive routing table, 2) Landmark Distance Vector routing table, and 3) On-demand routing table. They provide complete routing information to all destination nodes. The local routing table is built via the local scoped proactive routing protocol (e.g. FishEye in our implementation). It provides the exact routing information to any nodes within the local scope of current node. The landmark distance vector routing table contains routing information to landmark nodes of all groups learned through propagated landmark distance vectors. The on-demand routing table maintains the route information to individually moving nodes discovered via their checking GID fields.

The group membership cache and three routing tables are illustrated in Figure 1. When a data packet needs to be routed, the node will first consult the local routing table as it provides the accurate and up to date routing information to nearby nodes. If a route is found by examining only Host ID, the packet is routed directly. If, unfortunately, the destination node is a remote node not in the local routing table, the node then checks the group membership cache to see if the destination node is a member of any group. If it is a member of a group, then the packet is routed towards the landmark node of that group via the landmark routing table. Once the packet reaches the remote group, it will then be forwarded via the local routing table. If the node is an individually moving node, then the on-demand routing table is used for forwarding the packet. It is also possible that the destination node is neither in the routing tables nor in the group membership cache, e.g. if a remote destination node is requested the first time. In such situations, gaining an update IP address via distributed DNS is performed. The packet is then temporarily cached until the group membership of the destination node is discovered. This routing procedure is illustrated in Figure 2.

V. PERFORMANCE EVALUATION

We use the QualNet [1] simulator, a packet level simulator to evaluate the proposed hybrid LANMAR routing scheme. The main purpose is to verify its scalability in various scenarios and its flexibility to handle both individual moving nodes and groups. In our simulations, standard IEEE 802.11 radios are adopted with channel rate as 2M bps and transmission range as 367 meters. Randomly generated UDP based Constant Bit Rate (CBR) traffic is used for evaluation.

CBR traffic pairs are randomly selected among all network nodes. The number of pairs ranges from 10 to 60 pairs; this causes a gradual change of the traffic load injected into the network. Individual nodes move following the random waypoint mobility model. The group moving nodes adopt the group mobility model presented in [4].

Metrics selected include 1) Data packet delivery ratio: the ratio between the number of data packets received and those originated by the sources; 2) Average end-to-end packet delay: the average time from when the sources generate the data packets to when they reach the destination nodes; 3) Normalized routing overhead: the total number of routing control packets divided by the total number of successfully delivered data packet; 4) Aggregated Throughput: the aggregate of the throughput of all connections, computed at each destination node.

The original LANMAR has two choices to handle the individually moving nodes. One way is to treat each such node as one group. Another way is to view all the individually moving nodes as a big group. The former method can provide accurate routing information to each individual node. However, it has to maintain a big landmark routing table, thus big overhead. The latter method does not introduce any additional overhead. However, since the individual nodes move independently, perhaps they are not physically close to each other. Thus, remote nodes may not be able to route packet to such individual nodes unless they are in the local scope of the sources (in such situations, routing is done via the local scoped routing). In our experiments, we take the second way since the first method shows very poor performance and in any way worse than the second method.

A. Performance under Different Load

In the set of preliminary experiments, we investigate the scalability of the proposed hybrid LANMAR routing. 225 mobile nodes are deployed in a 3000mX3000m field. 20% of these nodes (e.g. 45 out of 225) are assigned as individually moving nodes. These 45 nodes are initially randomly deployed in the whole field. The rest 180 nodes are then divided into 9 groups (20 nodes per group). These groups are uniformly assigned to the field where each group occupies a 1000mX1000m square. Nodes within each group are also uniformly distributed within their group area. Mobility speed is fixed as 6 meters per second. We vary the traffic load (e.g. number of CBR pairs) to investigate the performance of the proposed hybrid LANMAR routing as well as original LANMAR routing and AODV routing. From Figure 3, we observe that when the network load is light, AODV routing shows better packet delivery ratio. However, when the traffic is increased, its packet delivery ratio drops rapidly. The LANMAR routing and the hybrid LANMAR routing schemes outperform AODV as network load increases. Moreover, the hybrid LANMAR routing constantly shows better data packet delivery ratio than the original LANMAR. This because that there are 20% mobile nodes that are individually moving, which the original LANMAR cannot support well. The aggregated throughput of the CBR applications under the three routing protocols in Figure 4 shows similar behavior.

Figure 5 shows the average end-to-end data packet delay under the 3 different routing protocols. The packet delay of AODV increases very quickly when the network load is increased. It also consistently shows longer packet delay than LANMAR routing and the hybrid LANMAR routing. This can be explained by its on-demand nature. When there is no path available or the path the broken, data packets are queued until the route discovery procedure finds a path. The same reason explains why the hybrid LANMAR routing shows slightly longer packet delay than the original LANMAR. Under the hybrid LANMAR routing, packets targeting the individually moving nodes are routed similar to the on-demand routing AODV. Similar results are also observed in Figure 6, where the normalized routing overhead of the three routing protocols is presented. The reason that the routing overhead of AODV increases dramatically along with the increase of traffic is because link breaks will happen more frequently when the network load is increased. AODV generates a lot of additional overhead to recover the paths when link breaks happen.

B. Performance under Different Fraction of Individually Moving Nodes

In this set of experiments, we demonstrate the flexibility of the proposed hybrid LANMAR routing scheme in handling the coexistence of groups of moving nodes and individually moving nodes. The scenario is the same as the previous experiment. However, now the number of CBR pairs is fixed to 40 pairs. We instead vary the fraction of individually moving nodes from 100% to 0% to compare the hybrid LANMAR routing scheme with the original LANMAR routing. The results are given in Figure 7 and Figure 8.
In Figure 7, we observe that, when a lot of nodes are individually moving, the hybrid LANMAR shows much better delivery ratio than the original LANMAR due to the incapability of the original LANMAR to handle the individually moving nodes. When the fraction of group moving nodes is increased, the performance of hybrid LANMAR is more and more close to the performance of the original LANMAR. When all nodes are moving in groups (e.g. fraction of individually moving nodes is 0%), the two protocols show identical data packet delivery ratio. The reason that the delivery ratio of the original LANMAR is above zero even there is no group mobility is because of the local scope routing of LANMAR. Even perhaps no any landmark is elected as all nodes are moving independently and individually, the local scope routing can still route some packets if their destination nodes happen to be in the local scope of the source nodes.

Figure 8 shows the normalized routing overhead of the hybrid LANMAR and original LANMAR under different fractions of individually moving nodes. The hybrid LANMAR routing generates more overhead than the original LANMAR when the fraction of individually moving nodes is large. This is because hybrid LANMAR triggers more route request and reply packets to search the paths to individually moving nodes. When most nodes are moving in groups, the landmark distance vector routing takes care of most of the data packets. Then the two protocols have mostly same routing overhead.

VI. CONCLUSION

In this paper, we proposed a unified routing scheme called hybrid LANMAR, which explores the advantages of mobility patterns in the heterogeneous group mobility scenario where both group moving nodes and individually moving nodes co-exist. The major contributions are the scalability and flexibility of the proposed routing scheme. Good scalability is realized by exploring and exploiting the group mobility pattern. Flexibility comes from the fact that the hybrid LANMAR gracefully combines the proactive routing and on-demand routing together. Thus the resulting scheme takes advantage of both kinds of routing schemes to support various network environments. The simulation results prove that our scheme can work well in various scenarios (e.g. flexibility) and achieves good scalability.

REFERENCES