Dynamic Group Support in LANMAR Routing Ad Hoc Networks

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Abstract— **In Mobile Ad Hoc Networks (MANETs) mobile nodes are often organized in groups with different tasks and, correspondingly, different functional and operational characteristics. In particular, nodes in the same group will have coordinated motion. The coordinated motion pattern considerably simplifies the mobility management and allows efficient and scalable routing. Such a mobile network can easily use Landmark Ad Hoc Routing Protocol (LANMAR) to effectively explore the motion feature. In this way, one can take advantage of an existing path to one node in a group (say, a landmark) in order to route a packet to any other destinations within that group. However, groups may form very dynamically in mobile ad hoc networks. Thus, the network layer must keep track of the dynamic formation (splitting and merging) of the groups. For example, due to the group dynamics, nodes may often change group membership. Thus, a source may need to re-discover the group ID of the destination. In this paper, we propose an efficient scheme to discover the group identifier of a given destination. Our scheme utilizes the underlying LANMAR routing structures. In our scheme, when a communication is scheduled, the source queries the landmarks for destination's group information. The newly retrieved group information is then used in normal LANMAR routing operations. Caches are used for retrieval optimization and for search overhead reduction. Different from on-demand flood-search scheme, our new approach only generates a few unicast search packets to landmarks instead of flooding the whole networks. The main advantages are that less search overhead is incurred by our scheme and as a results, there is no need to introduce into the system a separate distributed hashing based peer-to-peer look up scheme or a centralized name server. Simulation results show that LANMAR with group discovery outperforms a typical on-demand search scheme.**

Keywords— **Mobile ad hoc networks, ad hoc routing, group mobility, group identifier retrieval, address look up, proactive routing.**

I. Introduction

Mobile Ad Hoc Networks (MANETs) have found many applications in tactical communications (military and law enforcement) and civilian forums (convention centers, conferences, sensor networks and car networks). Among these applications, mobile nodes are often organized in groups with different tasks and, correspondingly, different functional and operational characteristics. In particular, nodes in the same group will have coordinated motion. For example, during rescue operations, teams of firefighters and medical assistants are moving as groups following different patterns; various units in a division can be organized into companies and then further partitioned into task forces based on their assignments in the battlefield.

One of the main challenges of MANET protocol design is continuous topology change due to node mobility. In particular, it is difficult to keep track of individual node movements and to route packets to them especially when the network grows large. The coordinated motion pattern considerably simplifies the mobility management and allows efficient and scalable routing. In this way, one can take advantage of an existing path to one node in a group (say, a landmark) in order to route a packet to any other destinations within that group.

Such a mobile network can easily use Landmark Ad Hoc Routing Protocol (LANMAR) [9], [10] for scalable ad hoc routing to effectively explore the motion feature. LANMAR works on the same assumption that nodes normally move as a group (e.g. brigade in the battlefield). However, LANMAR protocol currently does not have the ability of discovering dynamically nodes' group information nor have the ability of sending packet to remote nodes if the source does not have the group ID of its peer communicator. In this paper, we propose a request-driven retrieval scheme to discover group Ids. Our scheme utilizes the underlying LANMAR routing structures. The discovered grouping information can also be used for network resource/service discovery/retrieval and for communications among groups. Other possible solutions exists for group information lookup, e.g., a pure on demand discovery procedure, a centralized Name Server system or a distributed hashing based service lookup mechanism. However, the proposed scheme has many advantages. For example, the scheme generates only several unicast search packets to landmarks instead of flooding the entire network as in an on-demand flood-search scheme. Because the number of landmarks is much smaller than number of nodes in the network, less search overhead is incurred by our scheme than that by flood-search scheme. Also, due to the low overhead, there is no need to introduce into the network a separate distributed hashing based peer-to-peer look up scheme or a centralized name server. In addition, our scheme uses caches for retrieval optimization and for further search overhead reduction. Simulation results show that routing with our discovery scheme generates comparable results with regards to pre-known address scheme. Results also show that LANMAR with group discovery outperforms a typical on-demand search scheme.

The rest of the paper is organized as follows. We start in Section II an overview of LANMAR routing protocol. In Section III, we first discuss the problem and possible solutions and then describe our request-driven retrieval scheme in detail. Section IV gives simulation results and Section V concludes our paper.

II. Overview of Landmark Ad Hoc Routing(LANMAR)

Existing ad hoc routing protocols include a new generation of On Demand schemes and efficient proactive routing protocols. The on demand routing schemes (including AODV [2], DSR [3], TORA [4] and ABR [5], etc.) compute routes only

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when needed, without incurring the O/H if there is no data traffic. Small Query/Reply packets are used to discover (possible more than one) route to a given destination. Proactive schemes (DSDV[6], TBRPF[7], OLSR[8], FSR [1]) compute routes in the background (independent of traffic demands) using routing information updated through periodical or triggered exchanges. Both On Demand and proactive protocols suffer from limited scalability when wireless network size and mobility increase (beyond certain thresholds) [12], [13] . One way to solve this problem and generate scalable and efficient solutions is proposed in Landmark Ad Hoc Routing Protocol (LANMAR) [9], [10] which uses a implicit hierarchical structure through overlaid local scope at each node .

A. LANMAR Addressing

LANMAR protocol is designed for an ad hoc network that exhibits group mobility. An address scheme that reflects group information is adopted, i.e., each group is viewed as a subnet and is identified by a unique subnet address (logical address): $< GroupID, HostID >$. Where the HostID is the unique address of each node (which could be the MAC address of the node to ensure the uniqueness), and the GroupID field carries a unique group identity.

B. LANMAR Routing

LANMAR uses the notion of *landmarks* to keep track of logical groups. Each logical group has one dynamically elected node serving as a "landmark". The LANMAR protocol is supported by two complementary, cooperating routing schemes: (a) a local, "myopic" proactive routing scheme operating within a limited scope centered at each node and exchanging route information about nodes up to only a few hops; and (b) a "long haul" distance vector routing scheme that propagates the elected landmark of each subnet and the path to it into the whole network. As a result, each node maintains two routing tables: local routing table and landmark table which maintain direct routes to near by destinations and routes to all the landmarks from all the subnets respectively.

A landmark node typically will have all route information about its group. This is because the elected landmark is the one that has the best knowledge of the group. It usually contains most of the members in its local routing table. A drifting away node (node that is outside landmark's local scope) registers proactively to its landmark. The registration path is the reverse path where comes its landmark (identified through subnet address) information.

When a node needs to relay a packet to a destination within its scope, it uses the local routing tables directly. Otherwise, the packet will be routed towards the landmark corresponding to the destination's logical subnet, which is read from the logical address carried in the packet header. When the packet arrives within the scope of the destination, it is routed using local tables (that contain the destination), possibly, without going through the landmark.

LANMAR reduces both routing table size and control overhead effectively through the truncated local routing table and "summarized" routing information for remote groups of nodes, a scalable way similar to IP address prefix route aggregation in the Internet [11]. In general, by adopting different local routing schemes [13], LANMAR provides a flexible routing framework for scalable routing while still preserving the benefits introduced by the associated local scope routing scheme. It thus greatly improves routing scalability to large, mobile ad hoc networks.

III. Group Identifier Retrieval

A. Problems and Discussions

In the current landmark scheme, a node knows a prior not only other nodes' host ids but also group Ids, i.e., their logical addresses. The predefined logical address of each node helps a remote source to direct packets to it via its landmark. In our current scenario, the logical addresses are not known a prior. When an out of scope data packet (so no direct route can be found in the local routing table) reaches network layer without group ID, the node has to obtain the destination's group Id using some mechanism before directing the packet to the corresponding landmarks.

Without a look up mechanism, a brute force solution could be let each node informs all other nodes about its subnet address, a extremely costly approach and not feassible in a resource limited mobile ad hoc network. Another possible approach is to use the existing landmarks and the membership they own, i.e., source multiply unicasts the same data packet to all the landmarks, then a proper landmark finds the destination in its subnet and forwards the packest. This is also unacceptable as the landmarks will be heavily congested.

There are also several possible look up approaches for obtaining group membership. One approach is that the source searches for the group information with a group ID discovery packet (on demand discovery) prior to using it. This is similar to the ARP (Address Recognition Protocol) scheme in the Internet. The discovery packet (with full IP address of the destination) is broadcast into the network. The response packet carries the logical address (i.e., group ID and unique node ID). The on demand group discovery procedure resembles the path set up procedure in AODV or DSR and in fact would incur the same O/H. The difference, though, is that the group ID information, once discovered, is permanent. No new discovery is required unless the node changes group membership. An alternative solution is to use Name Servers or a distributed service lookup mechanism [14], [15]. In this approach, group leaders periodically update group membership with the Name Server(s). A hashing mechanism (hashing a node IP address into two or more NSs) can be used for redundant mapping and for protection in case the primary NS fails. If a node ID is not found in the Name Servers, an On-Demand retrieval is required.

Different from these possible approaches, we introduce a new scheme that only generates several unicast search packets to landmarks instead of flooding the whole networks in an on-demand flood-search scheme. As generally the number of landmarks is much smaller than number of nodes in the network, less search overhead is incurred by our scheme than that by flood-search scheme. The main advantages are that less search overhead is incurred by our scheme and as a results, there is no need to introduce into the system a separate distributed hashing based peer-to-peer look up scheme or a centralized name server.

B. Landmark based On-Demand Group Identifier Retrieval

The Landmark based group identifier retrieval effectively utilizes the routing information from underlying LANMAR protocol to achieve low cost look up. The scheme works in an on-demand fashion, i.e., request for group information is driven by communication traffic. In our scheme, when a communication is scheduled, the source will query the landmarks for destination's group information (if it is not known at that moment). Each logical address (this term is used interchangeably with "group information") is associated with a sequence number indicating the freshness. The newly retrieved logical addresses are then used in normal LANMAR routing operations. Caches are used for retrieval optimization and for search overhead reduction.

B.1 Group Identifier Retrieval

When a communication to a far away node is initiated, the source checks for the destination's logical address in its cache. If no valid logical address is found, the source buffers the data packet and sends a *GroupID query (GID_Q)* packet to all the landmarks through multiple unicast packets. A GID_Q packet contains the destination's host address (referred to as target node of the group ID query) and the source's logical address and its sequence number (in the following text, sequence numbers are not mentioned separately unless necessary). In response to a GID_Q, a unicast *GroupID reply (GID_R)* packet is issued. The packet contains the target's logical address and its sequence number as well as source's address. The forwarding of these unicast packets uses normal LANMAR routing.

When any host receives a GID_Q packet, it processes the query according to the following steps:

- If the target of the query matches this node's host address, the node initiates a GID_R packet back to the source immediately and discards the query packet.
- If the node is the destination of the GID_Q, it looks up for the target in its local routing table and drifter register table. If the target node is found, i.e., the target is in the same group with this landmark node, the node initiates a GID_R packet back to the sender. Otherwise, it will discard the query packet.
- In any other cases, the node will continue to route the GID_Q to its destination (a corresponding landmark).

As the logical address of the source is supplied in the GID_Q packet, the GID_R packet can easily be routed back to the source as a unicast packet through normal landmark routing. It is possible that the source will not receive a GID_R due to mobility or landmark re-election or due to the loss of query and reply packets. It will reinitiate a GID_Q after a short period.

Upon receiving the GID_R, the source extracts the logical address of the target and uses it to deliver the buffered data packets using normal LANMAR routing. The newly learned logical address is recorded in the cache. With the help from the cache, the source can often obtain a fresh logical address for the destination directly, enabling immediate delivery of data packets.

B.2 Group ID Cache and Optimization

In our group ID retrieval scheme, a cache that stores the mapping from host addresses to their current logical addresses (so the group IDs) for recently looked up destinations is maintained at each node in addition to the local routing and landmark distance tables. Each cache entry contains the group ID, its sequence number and the time the current ID is recorded. The entries of the cache are learned from direct query/reply packets. A more aggressive cache policy could be learning also from overhearing such packets. A node uses this cache table to avoid sending unnecessary GID_Q packets. In other words, if a source node has the group ID of the destination node in its cache, it will not initiate any GID_Q requests.

As a GID_Q contains the logical address and sequence number of the source node, all the nodes that receive GID_Q packets insert/update their cache entries for the source nodes if coming entry has a higher sequence number. Similarly, as a GID_R contains the logical address and sequence number of the destination, nodes that receive GID_R packets insert/update their cache for the destination nodes if the coming information is fresher. Entries in caches will be timed out if they are not updated for a long time.

Cache entries are also used in responding to GID_Q queries. A possible way could be letting intermediate nodes directly initiate GID_R packets without further consulting destinations or their corresponding landmarks. This method will cause the source and the intermediate nodes unable to refresh the destination's new group information. Alternatively, we adopt a policy that does not allow any replies from caches. GID_Rs are issued only from the targets and destinations. The tradeoffs between the two schemes are that the former scheme provides fast reply but may fail to provide fresh group information, while the latter provides fresh information in the cost of longer delay.

IV. SIMULATIONS

In this section, we evaluate the proposed approach under increasing mobility and increasing traffic load. We compare the performance of LANMAR with group ID retrieval (denoted as OGID) and the original LANMAR (using known predefined logical address). We also compare the performance of OGID with that of a pure on-demand routing scheme (AODV), where the destinations are found through flood-search. The simulations are conducted in identical network scenarios across all the participating protocols.

The evaluation metrics used are (i) *Control Packet overhead* – the number of routing control **packets** transmitted by a node, averaging over all the nodes. Each hop-wise transmission of a routing packet is counted as one transmission. (ii) *Packet delivery fraction* – the ratio between the number of data packets received and those originated by the sources. (iii) *Average end-to-end packet delay* – the time from when the source generates the data packet to when the destination receives it. This includes: route acquisition latency, processing delays at various layers of each node, queueing at the interface queue, retransmission delays at the MAC, propagation and transfer times.

A. Simulation model

Our simulation runs on the GloMoSim simulation platform [16], a discrete-event, detailed simulator for wireless network systems. The massage exchange uses a MAC layer that realizes the default characteristics of the distributed coordination function (DCF) of IEEE 802.11, where RTS/CTS/DATA/ACK mechanism is used to provide virtual carrier sensing for *unicast* data packets, and CSMA/CA is used for *Broadcast* packets. The radio model uses characteristics similar to a commercial radio interface (e.g., Lucent's WaveLAN). The channel capacity and transmission range are 2 Mbits/sec and 200m respectively. The network has 100 nodes initially uniformly distributed in a 1000m X 1000m simulation area. They are partitioned into four motion groups. The mobility model is *Reference Point Group Mobility* model [17]. Each node in a group has two components in its mobility vector, the individual component and the group component. The individual component is based on the *random waypoint* model [3]. The pause time is fixed to 10-second, while mobility speed for each node varies between 0 to 10 m/sec. The group component of mobility is also based on the random waypoint model.

Constant Bit Rate (CBR) (512 bytes/packet/sec) applications are used to generate network data traffic. Each CBR session lasts for 2 minutes. During the simulation, when one session closes, another source-destination pair will be randomly selected. Thus the input traffic load is constantly maintained all the time. Simulations run for 10 minutes. LANMAR updates local table every 1.5 second and landmark table every 0.7 second. The group Id cache entry expires 2 minutes after the time it is last heard.

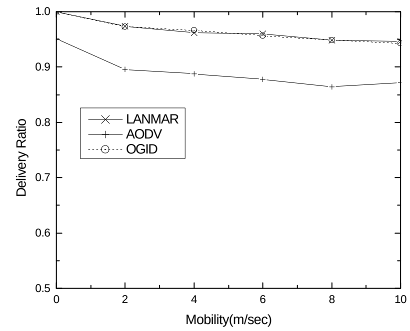

Fig. 1. Delivery Fraction vs. Mobility

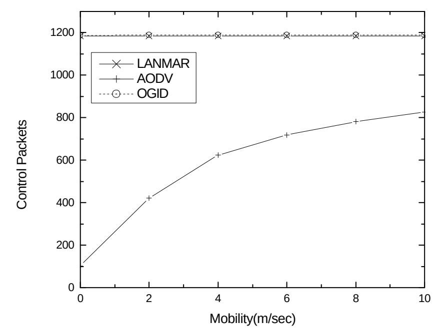

Fig. 2. Control Packets vs. Mobility

B. Results

B.1 Increasing Mobility

Experiments with increasing mobility use 10 pairs of scattered CBR traffic. Figure 1 gives delivery ratio as a function of increasing mobility. The figure shows that OGID has almost the same performance as original LANMAR. Both are better than AODV. The reason for lower delivery radio of AODV is that the scattered traffic model incurs a lot of flooding packets that collide with data packets.

Figure 2 shows the number of control packet as a function of increasing mobility. OGID does not generate noticeable extra control overhead than LANMAR as the request and reply packets are relative smaller compared to the periodic routing updates. Also because OGID and LANMAR are proactive protocols and the communication traffic is sparse, both generate more routing packets than AODV. However the figure shows that AODV has the tendency of continuously increasing control packets due to the increasing broken links when mobility increases while the control packets of OGID and LANMAR are not affected by mobility.

Figure 3 shows the end-to-end delay as a function of increasing mobility. The figure shows that OGID incurs longer delay than LANMAR due to the data buffering at source waiting for destination's group identity. However, AODV generates even longer delays due to the on-demand search for the destinations. When mobility increases, increasing broken routes increase the delay of AODV, while OGID is not affected as the requests and replies are routed using underlying LANMAR routing.

B.2 Increasing Traffic Load

The network traffic load is increased by increasing the number of communication paires each with fixed data rate. The simulation runs in low mobility (= 2 m/s). Figure 4 shows delivery ratio as a function of traffic load. In the graph, OGID shows comparable performance as LANMAR. Both are better than AODV. The figure also shows a saturation phenomenon for both OGID and LANMAR after load increases beyond 1600kbps. Meantime, AODV generates lower packet delivery ratio and degrades constantly while load increases. The degradation comes from the increasing collisions due to increasing flood-search packets.

Figure 5 reports the number of control packets as a function of traffic load. The graph shows that LANMAR with group ID retrieval (OGID) generates more control packets than LANMAR due to the query and reply packets. And the amount of the extra control packets increases with increasing traffic load as expected. When compared to AODV, OGID and LANMAR generates far less control packets. AODV increases the number of control packets greatly when traffic load increases.

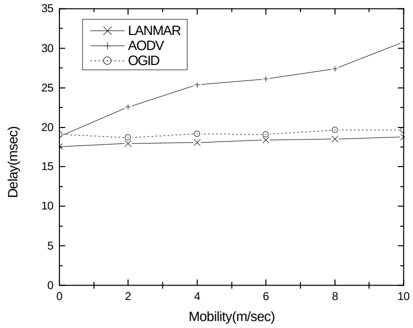

Fig. 3. Delay vs. Mobility

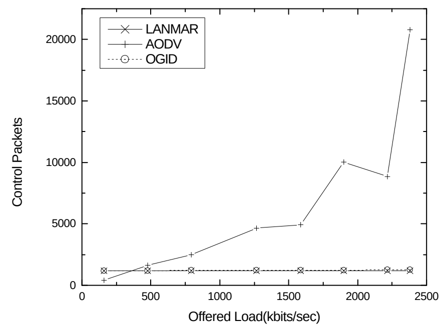

Fig. 5. Control Packets vs. Traffic Load

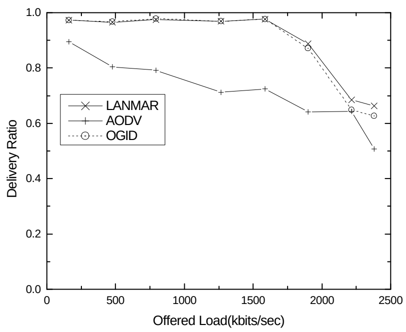

Fig. 4. Delivery Fraction vs. Traffic Load

V. Conclusions

In this paper we proposed a request driven group identifier retrieval scheme based on the underlying Landmark Ad Hoc routing protocol. With the proposed scheme, LANMAR routing is able to work in a mobile environment with dynamic forming motion groups. In our scheme a communication source queries landmarks for the destination's group information. The newly retrieved group ID is combined in destination's logical address for normal LANMAR routing operations. Caches are used for retrieval optimization and for search overhead reduction. The scheme greatly reduces the search overhead compared to an on-demand flood-search routing protocols. Simulation results show that routing with our discovery scheme generates comparable packet delivery ratio with regards to pre-known address scheme, and LANMAR with group discovery only introduces into the network a very small amount of additional query and reply overhead, far less than a typical on-demand search scheme. Results also show that LANMAR with group discovery outperforms a typical on-demand search scheme.

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