Dynamic Group Discovery and Routing in Ad Hoc Networks

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Abstract—
In some applications of large scale Ad Hoc networks, for example, advanced battlefield scenarios, the assumption that different sets of nodes move as groups is extremely helpful in achieving efficient and scalable routing. In some applications, the groups are known in advance. In other applications, however, groups form very dynamically. For instance, in a battle theater, new missions are often created by rearranging and regrouping the current assets in response to new emergencies etc. The regrouping is done by the applications and is not necessarily communicated to the network layer. The network layer must thus "discover" the groups independently in order to achieve group routing scalability. In this paper we assume that groups are not known in advanced. We introduce a dynamic group discovery and formation scheme that aggregates nodes based on movement affinity and assigns unique ID numbers to the groups. Once groups are discovered, we apply the Landmark Ad Hoc Routing (LANMAR) scheme to achieve scalable routing. The simulation results demonstrate that the proposed scheme can efficiently and dynamically recognize the mobile groups leading to stable LANMAR operation.

I. INTRODUCTION

Recent research has addressed many aspects of MANET operation and management, including routing, multicasting, media access protocols, distributed service discovery, TCP performance, QoS support, etc. In these areas an overarching concern is mobility. The impact of mobility is severe on several protocols which work well in traditional fixed (wired) networks. For example, routing protocols such as OSPF and RIP require extra overhead to handle route breakage due to mobility. As a result, scalability is affected in networks with a large number of communicating pairs of nodes. To maintain routing scalability in spite of mobility, a possible approach is to exploit motion affinity (also referred as group mobility), i.e., the fact that particular sets of nodes have a commonality of interests and are likely to move as a "group". Applying node grouping to routing protocols, one can take advantage of summarized routing information by group to greatly reduce routing overhead [4], similar to IP address prefix route aggregation in the Internet [6]. Grouping information can also be used for network resource/service discovery/retrieval and for communications among groups.

Motion in a group is not a rare phenomenon in ad hoc networks. For example, during rescue operations, teams of firefighters and medical assistants are moving as groups following different patterns. However, a systematic method for discovering group motion has not yet been studied in the context of ad hoc routing. In this paper, we present a scheme to dynamically discover mobile groups and to utilize the group information for routing. An important example of "affinity motion" (and, a motivating scenario for this study) is a large ad hoc battlefield network, such as the "Tactical Internet". In this scenario, the assumption that different sets of nodes move as a group is extremely helpful in achieving efficient and scalable routing. In some cases, the groups are known in advance. In other cases, however, groups form very dynamically (splitting, merging, or new groups popping up). In the battle theater, new missions are often created by rearranging and regrouping the assets in response to new emergencies, etc. The regrouping is carried out by the application layer, which may not communicate the new group formations to the network layer. Thus, it is safe to assume that the network layer must "discover" the groups independently of the applications.

In this paper we assume that nodes move as groups, and that groups are not known in advance. We introduce a dynamic group discovery scheme that aggregates nodes based on movement affinity and assigns unique group ID numbers to group members. To this end, information about nodes in a "local scope", i.e., the range in which a group typically resides, is required. We will assume that such information is available from local routing tables. No knowledge of node location and velocity (as can be obtained from GPS) is required; only node Ids and hop distances. The simulations show that our proposed scheme discovers representative and stable groups. Consequently, the group based LANMAR routing protocol performs equally well with dynamically discovered groups and preformed groups. Better group matching can be achieved using more sophisticated pattern recognition techniques [7]. This will be a future work direction. Once groups are discovered, one can take the advantage of the 2-level Landmark Ad Hoc Routing (LANMAR) [5] routing hierarchy to achieve scalable routing. Alternatively, On-Demand routing schemes such as AODV [1] and DSR [2] can be used to establish routes on demand between groups. In either case, an existing route to the group can be shared by all other sessions

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with destinations within the same group. In summary, the identification of motion affinity results in more stable routes, leading to a reduction in routing control overhead.

The current motion group discovery is implemented within LANMAR routing protocol. It utilizes LANMAR's local routing tables and produces directly usable routing information for the protocol. The rest of the paper starts from a brief overview of LANMAR routing (Section II), and then follows the introduction of dynamic group discovery scheme (Section III). We describe our simulations and give the results in Section IV. Section V reviews related work. Section VI concludes the paper.

II. LANMAR ROUTING OVERVIEW

LANMAR (Landmark Ad Hoc Routing) protocol is a proactive routing [5]. It uses the notion of *landmarks* to keep track of logical subnets. Such a logical subnet consists of nodes that have a common interest and move together as a "group". A representative of the subnet, i.e., a "landmark" node, is dynamically elected in each subnet. LANMAR uses an IP like address consisting of a group ID (or subnet ID) and a host ID, i.e. $< GroupID, HostID >$. 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 (referred as LMDV) 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.

To send or relay a given packet, a node first queries a route (i.e., next hop ID) to the destination in its local routing table. With any available path, the packet will be directly forwarded to the next hop. Otherwise, the subnet ID of the destination is read from the packet header and this packet will be instead routed towards the publicized landmark in the same logical subnet with the destination.

III. GROUP DISCOVERY SCHEME

The group discovery scheme is based on observations of relative movement among nodes, as per the data available from locally exchanged routing messages (recall that it is implemented within the routing protocol). The messages propagate only to a certain hop distances (N), which actually defines the size of possible formed groups. The configurable parameter N, also referred to as the ”scope”, leads to flexibility in handling different scales of motion patterns. Having the current vicinity information, a motion group is established when an agreement is reached among local nodes about who should be the leader of the group. The motion group leader election coincides with the routing protocol's landmark election. So, the two procedures are combined in message exchange, i.e., the ”long haul” distance vector routing (LMDV) periodically advertises election information for mobile groups' ”leaders” and routes to those leaders. An elected group leader will serve as the landmark of the group and its unique host ID is accepted as the group ID. At a steady state, the leaders (i.e., landmarks) of various groups propagate their presence to all other nodes in the network.

A. Motion Affinity

Based on knowledge about vicinity which has been observed accumulately in local routing table, we define a node's motion affinity group as the members of its ”traveling companions (TCs)”. TCs are identified at each node (say, S) based on a time window W (TC window) (e.g., W = 3 minutes). A ”traveling companion” is a node that has been reachable from S in N hops or less (where N is the scope size) for W minutes or more. For nodes in the same motion group, they know each other for a period longer than W thus will declare ”traveling companions” among themselves. If node S is stationary, its ”traveling companions” are all the nodes within scope that are also stationary. The selection of a proper threshold for W is determined by relative group mobility. Let us say, typical relative speed is higher than 5 m/sec, radio transmission range is 100 m. Then, the diameter of a 2-hop ”scope” region is 400m. It will take at most 400/5 = 80 seconds for a node to fall out of scope and out of the affinity group. This calculation suggests that it may take a long time to determine whether a node is a part of one's group or not. Group creation will be faster if nodes' speeds are higher. Fortunately, if groups are identified at network initialization (referred later as ”the First Phase”), only the initialization process will take a fairly long time. After that, groups only need to be updated for members joining or leaving (referred as ”the Second Phase”).

B. Group Leader Election

Knowing all the potential group members in one's scope - these are the nodes that have stayed in its scope longer than the threshold W, a node participates in group formation procedure through the election of a group leader. The election ”weight” of a node is defined as the size of its affinity group, i.e., the number of TCs at S, denoted as TC(S, W). Each node announces in LMDV messages to its ”affine” members of its recommended leader's ID and weight. A node may recommend itself. The LMDV messages are periodically broadcast, propagating the latest election results. Each node decides by itself on the winner of the election according to a universal decision rule: the node with the largest weight will be the leader for the motion group. Thus, the node L with the largest TC(L,W) in the same affinity group will be elected as the leader. The others defer. In case of a tie, the node having the lowest ID wins. As a result, within a scope, only one node will prevail in one affinity group, and will become the leader. The ID of the leader node is thus recognized as the (unique) logical group ID of the group. When there is a large set of mutually affine nodes spanning several scopes, this large set will be partitioned in several groups, each with its leader, as each node sees only a limited area.

Different group motion patterns identify different traveling companions, thereby leading to the election of different groups. The election of the various affinity group leaders is performed independently and in parallel. As a result, the nodes that move as a group, say are part of the same mission, are clustered together around one or more leaders. At the same time, if there are static nodes in the network, these are clustered around their static leaders (similar to a conventional clustering algorithm).

As a leader's relative position within a group changes, so may the TCs of the leader change, which prompts the election of a new leader. This creates frequent changes in group IDs, an undesirable property. To alleviate this problem, one can establish the following hysteresis rule: an existing leader is replaced by a new in-scope leader only if its weight is, say, less than 1/2 of the weight of the challenger. Thus, once ousted, the old leader needs full weight superiority to be reinstated. To further achieve stability of the elected leader, our group formation consists of two phases. While the goal of the "First Phase" is to select a strongest leader for each group, when every node is encouraged to participate in election; the "Second Phase" is to keep the elected group leaders as stable as possible. Thus after entering the Phase Two (after several round of message exchanges relating to the scope size), nodes are encouraged to join (or leave) an existing group (a nearby leader which may be out of its scope) through explicit registration to the leader, rather than being a candidate for election. The probability of change in leadership is further reduced.

C. Routing Using Group Membership

The so-formed groups and their leaders can help in many aspects, e.g., directing a route to a group, searching for resources in a group or communicating among groups. Before the group information can be used, the group membership of the target node must be known to the source. The search for the group membership, however, is out of the scope of this paper. Interested readers please refer to [15]. For simplicity, in this paper, a global Name Server system is assumed for membership registration and retrieval. Thus, assisted with the group membership lookup in the name server, one can take advantage of the LANMAR routing hierarchy to achieve scalable routing.

The discovered mobile groups are reflected in nodes' logical addresses, i.e., the IP like two-field addresses $<GroupID, HostID>$. Where the Group ID field carries a unique group identity which is filled in during the discovery process when a group membership is established. Note that the Group ID in a mobile ad hoc system plays the same role as the subnet address in the IP address plays in the fixed Internet. Here however, the IP subnet address has no useful meaning as there are, no permanent, geographically static subnetworks, rather, groups of nodes moving together.

LANMAR routing with dynamic group discovery inherits routing efficiency from LANMAR in packet delivery for remote destinations. It also enables a more robust and flexible routing protocol in large scale ad hoc networks exhibiting group mobility.

IV. Performance Evaluation

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 250m respectively.

Our simulations investigate first the convergence and the stability of the dynamically discovered groups and their correspondence to real motion patterns, and then the routing performance. *Reference Point Group Mobility (RPGM)* model [17] is used to generate different group motion patterns, i.e., sets of nodes move in common trajectories with a little randomness.

B. Stability of Dynamic Group Discovery

Experiments studying the characteristics of the group discovery scheme use a 100-nodes network consisting of two motion groups. The two groups, each having 50 nodes uniformly distributing in a 250m X 500m rectangular field (transmission range is 90m), move in opposite directions in a relative speed of 10 m/s. Various scopes are tested. Figure 1 shows the changes in the number of elected groups vs. simulation time. The figure also includes a reference line representing the real configured motion groups. The figure shows that after an initial warm up period (no activities) and a following oscillation time, the number of dynamically discovered groups converges for all the scope values. Larger scope requires a longer warm up period. Different scopes lead to different numbers of groups, e.g., 4 groups for scope 2 and 2 groups for scope 4. This is because when the scope is set to 2 hops, the maximum area that a leader's local scope can cover is smaller than the area of the configured motion group. Thus other nodes traveling together in the same configured mo-

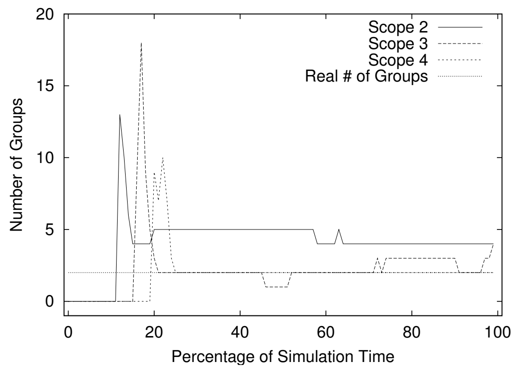

Fig. 1. Elected Groups over Time

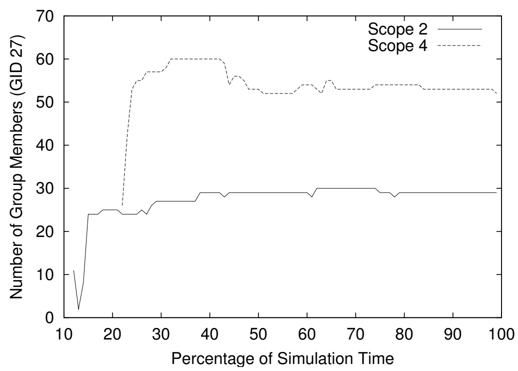

Fig. 2. Membership for Leader 27

tion group form another group, resulting in 4 groups. When the scope is large enough, e.g., scope = 4, one leader of each group can effectively cover all the members, leading to elected groups exactly equal to the real number. The initial warm up time is necessary so each node can build up enough knowledge about their travel companions.

As it is possible that while keeping the number of group the same during the simulation, the network may consist of different groups (group Ids), we show in Figure 2 a dominant leader's hit number (or say, membership) as a function of time. The hit number records the number of nodes that choose it as their group leader at each particular time instance. As long as the hit number is not zero, the node retains its leader role. The figure presents cases of both scope 2 and 4 for leader 27 because it acts as a leader in both settings. The figure suggests that after an initial time, the membership is quite stable. Membership is higher in scope 4 than scope 2 due to the larger group size.

These results suggest that the dynamic group discovery scheme converges to stable group membership over time with a good match to the real motion pattern.

C. Routing Performance with Dynamic Group Discovery

Experiments here investigate routing performance in: (i)*Packet delivery fraction* – the ratio between the number of data packets received and those originated by the sources. (ii) *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. And (iii) *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.

The simulations runs in a network occupying a square field of 4000m X 4000m, with 900 uniformly distributed static nodes and 100 mobile nodes. The mobile nodes are in 4 small groups, each having 25 nodes spreading in a 600m X 600m area. The motion of the mobile groups is modeled using RPGM. Group motion speed is given in the figures. We simulated a communication model with traffic going only among mobile nodes. Constant Bit Rate (CBR) data sessions with randomly chosen (from mobile nodes) source-destination are used. Client offered traffic load over the entire network is reported in the graphs. For those CBR sessions, the average path length is 12 hops, while some typical path lengths will reach 20 hops or more. Each simulation runs for 10 minutes with a warm up period of 2 minutes (to suit all the scope and mobility cases). The communications start after the warm up period. Results presented are an average of three runs.

We compare here the LANMAR routing in the dynamic group-forming scenario (DG-LANMAR) with it in a scenario where mobile groups are pre-configured (PD-LANMAR). For DG-LANMAR, each node has no group identity at the beginning and then obtains one through group discovery and leader election. In simulations, the scope is set to 2 hops. With this setting, an elected leader in a mobile group is expected to cover most group members in its local scope. The static nodes maintain connectivity among mobile groups. With the group formation scheme, they will form network partitions (each partition is recognized as a group and represented by a group leader). Meanwhile, in PD-LANMAR, each node in a mobile group is pre-assigned a persistent group ID corresponding to its motion group, the remaining nodes perform the same group discovery and have the same network partitions as in DG-LANMAR. The routing protocol then directly elects landmarks in each mobile group. Both protocols update local routing tables in 2.1 seconds and landmark tables in 0.9 seconds. As a reference, the performance of AODV is also studied and presented in the results.

Figure 3 gives packet delivery fraction as a function of client offered load in different mobility. With increasing load, all the schemes reduce the success rate of packet delivery. However, DG-LANMAR and PD-LANMAR render higher delivery ratio and degrade much slower than AODV. PD-LANMAR and DG-

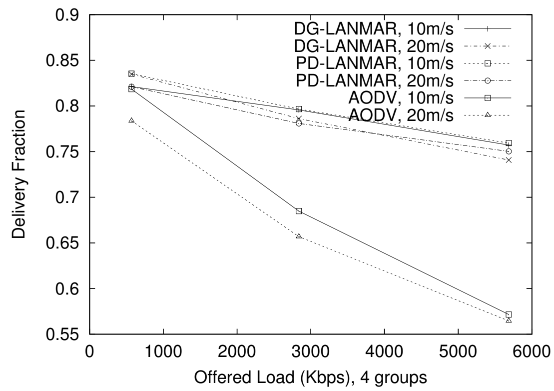

Fig. 3. Delivery Fraction

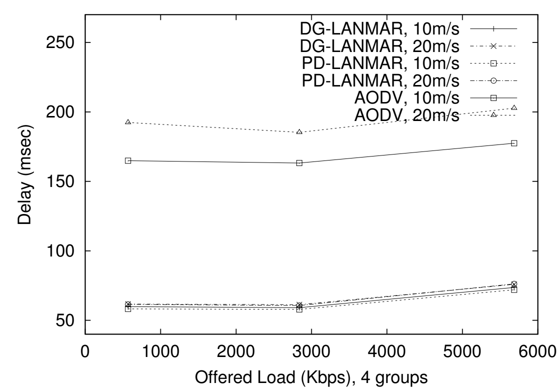

Fig. 4. End-to-end Delay

LANMAR generate close delivery fractions and mobility has a little impact on them due to their proactive nature.

Figure 4 reports changes in packet end-to-end delay when offered load increases. Generally, AODV generates much longer delay than DG-LANMAR and PD-LANMAR because of the large initial route-search waiting time in this 1000-node network. Mobility also increases the delay in AODV. In the meantime, DG-LANAMR and PD-LANMAR do not incur initial path setup time and are almost not affected by mobility. The figure also shows that offered load affects the end-to-end packet delay, i.e., when load increases to the largest value in the figure (5700kpbs in 100 pairs), the delays of all the protocols are increased. This phenomenon suggests the building-up of congestion in the network.

Figure 5 shows the average number of control packets emitted into the network vs. the increasing traffic load. As DG-LANMAR and PD-LANMAR are proactive protocols, they generate constant number of control packets regardless of the traffic load and mobility. For AODV, more data sessions incur more flood-search packets for path discovery. The fast increasing number of such packets of AODV eventually exceeds the number of control packets generated by DG-LANMAR and PD-LANMAR. The graph also shows the impact from mobility on AODV. High mobility causes more link breakage, leading to more search packets for new paths.

In general, the figures suggest that DG-LANMAR performs as well as the original LANMAR, owning to the ability in capturing the group mobility and in maintaining the leaders to direct routes to remote destinations.

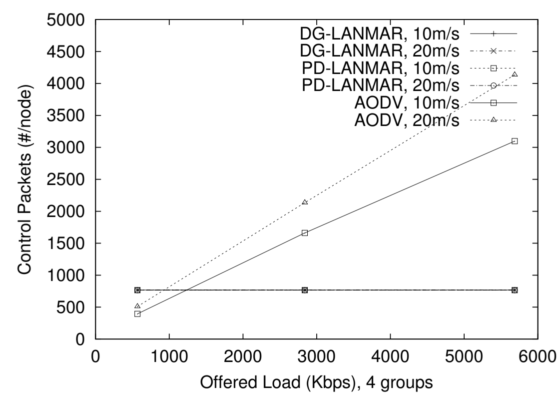

Fig. 5. Control Overhead

V. Related Work

Previous research on routing in mobile ad hoc networks includes a new generation of On Demand ad hoc routing schemes, efficient proactive routing protocols and schemes having both flavors. Among them, some have utilized group motion property. However, none of them has exploited the discovery of group mobility and the benefit of using it for routing. Some related work has been done in organizing nodes for routing and using mobility estimation for route choices. Here we present a brief review of such schemes and compare them with our work.

Instead of using movement affinity as a basis for organizing nodes, previous research has used ID ranking or connectivity to form clusters ([8], [9], [10], [11], [12], [13]). The clusters provide hierarchical routing through connections among cluster heads (CHs) and gateways (GWs). Typical algorithms for electing cluster heads use Lowest ID (LID) [8], Highest Degree (HD)[8] or First Declaration (FD) [14] as criteria. In our dynamic group discovery, election algorithm is also used for the selection of group leaders. However, our decision rules are different from the traditional cluster head elections, i.e., our election uses the highest membership, a desirable criteria to find a best node that represents the motion group which does not reflect a node's connectivity degree. Unfortunately, in terms of cluster head stability, our rule is equivalent to Highest Degree, a rule that has been proven less stable than others [8]. To combat instability, hysteresis is used in our design to preserve the elected leaders. Moreover, the group discovery does not generate critical nodes (e.g., CHs and GWs) for network connectivity but identifies possible partitions of the networks. As a result, our group leader election algorithm may produce isolated groups (even in a connected network, if such motion pattern exists), or totally overlapped groups, while a clustering scheme by its nature attempts to bridge clusters via gateways.

Related work in [3] has outlined a scheme to identify associativity (a measure affected by mobility pattern) among nodes and to use the associativity to facilitate the selection of long-lived routes. A higher associativity is given to a neighbor that remains longer in the vicinity than other neighbors, implying a longer period of stability for a possible connection. Similar to this neighbor stability, our group discovery scheme considers the "associativity" of all the nodes within a local scope. However, the discovery of motion affinity can be independently implemented from routing protocols and the group information can be available for other applications beside routing. Further, when cooperating with routing, the grouping information is used not only for routing decisions at individual nodes but also for route summarization to entire groups.

VI. CONCLUSIONS

In this paper, we have proposed a scheme to dynamically discover mobile groups. The scheme identifies the motion affinity among nodes and aggregates them under unique group IDs. While the information of discovered group can be used by many MANET applications, we have discussed here the use of the dynamic group formation for LANMAR routing. As a result, the need to predefine the groups in LANMAR is relaxed, leading to a more robust, flexible scalable routing protocol for large ad hoc networks that exhibit group mobility. The simulation results show that the dynamic discovery scheme successfully produces stable motion group IDs that are consistent with the real configurations. Results also show that routing performs equally well both with the dynamically formed groups and the pre-defined groups.

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