Landmark Routing for Large Ad Hoc Wireless Networks

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Abstract—**In this paper, we present an enhanced version of the routing protocol Landmark Ad Hoc Routing (LANMAR). LANMAR combines the features of Fisheye State Routing (FSR) and Landmark routing. The enhanced version features landmark election to cope with the dynamic and mobile environment. Other advantages of LANMAR include the use of landmarks for each logical group (e.g., a team of co-workers at a convention or a tank battalion in the battlefield) in order to reduce routing update overhead in large networks, and the exchanging of neighborhood link state only with neighbors. When network size grows, remote groups of nodes are "summarized" by the corresponding landmarks. As a result, each node will maintain accurate routing information about immediate neighborhood; at the same time it will keep track of the routing directions to the landmark nodes and thus, to remote groups. Simulation experiments show that the enhanced version suffers some performance degradation at steady state because of election overhead. However, it still provides an efficient and scalable routing solution in a mobile, ad hoc environment. Moreover, the election provides a much needed recovery from landmark failures.**

I. Introduction and Background

As the wireless and embedded computing technologies continue to advance, increasing numbers of small size and high performance computing and communication devices will be capable of tetherless communications and ad hoc wireless networking. An ad hoc wireless network is a self-organizing and self-configuring network with the capability of rapid deployment in response to application needs. An important characteristic which sets ad hoc networks apart from cellular networks is the fact that they do not rely on a fixed infrastructure. Ad hoc networks are very attractive for tactical communication in military and law enforcement. They are also expected to play an important role in civilian forums such as convention centers, conferences, and electronic classrooms. Node mobility/dynamics, potentially very large number of nodes, and limited communication resources (e.g., bandwidth and power) make routing in ad hoc networks extremely challenging. The routing protocols for ad hoc wireless networks have to adapt quickly to the frequent and unpredictable changes of topology and must be parsimonious of communications and processing resources.

Existing wireless routing schemes can be classified into two categories according to their design philosophy: (a) proactive (i.e., distance vector or link state based); and (b) reactive (i.e., on demand). Proactive schemes compute routes in the background, independent of traffic demands. Historically, the first type of routing scheme used in early packet radio networks such as the PRNET was the distance vector type [5]. The distance vector approach is simple but suffers from slow convergence and tendency of creating loops. These problems were later resolved by the Link State (LS) approach, which is widely used in wired nets (e.g., Internet [12] or ATM [1]). In Link State, global network topology information is maintained in all routers by the periodic flooding of link state updates by each node. Any link change triggers an immediate update. As a result, convergence to a new topology is faster and preventing loops is easier due to global topology knowledge. Unfortunately, excessive control overhead may be generated by LS dissemination especially when high mobility triggers frequent updates.

Typically, when wireless network size and mobility increase (beyond certain thresholds), current "flat" proactive routing schemes (i.e., distance vector and link state) become infeasible because of line and processing O/H. One way to solve this problem and generate scalable and efficient solutions is hierarchical routing. A hierarchical version of link state called HSR (Hierarchical State Routing) has proven to be quite effective in large wireless networks [10]. HSR, however, requires complex bookkeeping of hierarchical addresses. A much simpler version of Link State with hierarchical "flavor" is Fisheye State Routing (FSR) [10]. FSR uses the "fisheye" technique (first proposed by Kleinrock and Stevens [11] for visual displays) to reduce routing update overhead. In FSR, each node progressively slows down the update rate for destination with increasing hop distance. Thus, entries corresponding to nodes within a smaller scope are propagated to neighbors with a higher frequency. As a result, a considerable fraction of topology table entries (corresponding to remote destinations) are suppressed in a typical update, thus reducing line overhead. This approach produces accurate distance and path quality information about the immediate neighborhood of a node, with progressively less detail as the distance increases. As a packet approaches its destination, the route becomes more precise. As network size grows and mobility increases, however routes tend to become stale quickly and delays to nodes afar tend to grow large.

Another recent approach to scalability and routing overhead problems is the reactive, on demand routing. Several schemes have been proposed including AODV [15], DSR [7], TORA [13] and ABR [17] etc. In these "reactive" protocols a node discovers a route "on demand", namely, it computes a route only when needed. Small Query/Reply packets are used to discover (possible more than one) route to a given destination. However, since a route has to be entirely discovered prior to the actual data packet transmission, the initial search latency may degrade the performance of interactive applications (e.g.,

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distributed database queries). Moreover, it is impossible to know in advance the quality of the path (e.g., bandwidth, delay etc) prior to call setup. Such a priori knowledge (which can be easily obtained from proactive schemes) is very desirable in multimedia applications, since it enables more effective call acceptance control.

In general, on demand routing performs extremely well (low line and storage O/H) in large networks with light traffic (directed to a few destinations) and with low mobility. As mobility increases, however the precomputed route may break down, requiring repeated route discoveries on the way to destination. Route caching becomes ineffective in high mobility. Since flooding is used for query dissemination and route maintenance, routing control O/H tends to grow very high [4]. In the case of 100 nodes and 40 sources with uniform traffic pattern, the results in [4] show that both DSR and AODV generate more routing overhead than actual throughput. Similar findings are also reported in [10].

In [19] we first introduced the LANMAR scheme, a table driven routing scheme which combines FSR and Landmark routing [18]. In this paper, we introduce an enhanced version of LANMAR which supports landmark election and provides a flexible way for the protocol to cope with a dynamic and mobile network without compromising scalability.

The rest of the paper is organized as follows. In section II, we review LANMAR and describe election. Section III presents the performance results and section IV concludes the paper.

II. Landmark Ad Hoc Routing with Election

A. Network Model and Data Structures

Each node has a unique identifier, transmission range R, and landmark flag. Nodes move around and change speed and direction independently. An undirected link (i, j) connects two nodes i and j when the distance is less than or equal to the transmission R. For each node i, one list and three tables are maintained. They are: a neighbor list A_i, a topology table TT_i, a next hop table $NEXT_i$ and a distance table D_i. Each destination j within fisheye scope has an entry in table TT_i which contains two parts: $TT_i.LS(j)$ and $TT_i.SEQ(j)$. $TT_i.LS(j)$ denotes the link state information reported by node j. $TT_i.SEQ(j)$ denotes the time stamp indicating the time node j has generated this link state information. Similarly, for every destination j which is within its fisheye scope or which is a landmark node, $NEXT_i(j)$ denotes the next hop to forward packets destined to j on the shortest path, while $D_i(j)$ denotes the distance of the shortest path from i to j. Additionally, one or more link weight functions may be defined and used to compute the shortest path based on a specific metric, possibly with constraints. For instance, a bandwidth function can be used to support QoS routing. In this paper, we limit ourselves to min hop paths, thus the link weight is 1.

B. Overview of Landmark Ad hoc Routing Protocol (LANMAR)

The key novelty in LANMAR is the notion of keeping track of logical subnets in which the members have a commonality of interests and are likely to move as a "group" (e.g., brigade in the battlefield, colleagues in the same organization, or a group of students from same class). Moreover, a "landmark" node is elected in each subnet. The scheme is an extension of FSR. It improves scalability by reducing routing table size and update traffic O/H. More precisely, It resolves the routing table scalability problem by using an approach similar to the landmark hierarchical routing proposed in [18] for wired networks. In the original landmark scheme, the hierarchical address of each node reflects its position within the hierarchy and helps finding a route to it. Each node has full knowledge of all the nodes within the immediate vicinity. At the same time each node keeps track of the next hop on the shortest path to various landmarks at different hierarchical levels. Routing is consistent with the landmark hierarchy and the path is gradually refined from top level hierarchy to low levels as a packet approaches destination.

We apply the above landmark concept to FSR to reduce routing update overhead for nodes that are far away. Each logical subnet has one node serving as "landmark". Beyond the fisheye scope the update frequency of the landmark nodes remains unaltered, while the update frequency of regular nodes is reduced to zero. As a result, each node will maintain accurate routing information about immediate neighborhood and as well as to landmark nodes. When a node needs to relay a packet, if the destination is within its neighbor scope as indicated in the routing table, the packet will be forwarded directly. Otherwise, the packet will be routed towards the landmark corresponding to the destination logical subnet. The packet does not need to go all way to the landmark. Rather, once the packet gets within the scope of the destination, it is routed to it directly.

The routing update exchange of LANMAR routing is similar to FSR. Each node periodically exchanges topology information with its immediate neighbors. In each update, the node sends entries within its fisheye scope. It will also piggy-back a distance vector of all landmark nodes. Through this exchange process, the table entries with larger sequence numbers replace the ones with smaller sequence numbers. As a result, each node has detailed topology information about its neighborhood and has a distance and routing vector to all landmark nodes.

Typically, all members in a logical subnet are within the scope of the landmark, thus the landmark has a route to all members. It may happen, however, that some of the members "wonder" outside of the scope because of lack of coordination in the group mobility pattern. To keep track of such "outsiders", i.e. to make a route to them known to the landmark, the following modification to the routing table exchange was made. Each node, say i, on the shortest path between a landmark L and an "outsider" member l of such landmark keeps a distance vector entry to l. Note that if l is within scope of i, this entry is already included in the vector. When i transmits its distance vector to neighbor j, say, then j will retain the entry for member l only if $d(j,l) <$ scope or $d(j,L) < d(i,L)$. The latter condition occurs if j is on the shortest path from i (and therefore from l) to L. For more detail see [19].

C. Landmark Election

At the beginning of the execution, no landmark exists. Protocol LANMAR only uses the FSR functionality. As the FSR computation progresses, one of the nodes will learn (from the FSR table) that more than a certain number of group members (say, N) are in the FSR scope. It then proclaims itself as a landmark for this group. The landmark information will be broadcast to the neighbors jointly with the topology update packets. The landmark information is a status pair containing the ID of the landmark and the number of group members it can reach within the FSR scope. When more than one node declares itself as a landmark in the same group, the node with the largest number of group members wins the election. In case of tie, lowest ID breaks the tie. The competing nodes defer.

After first few topology updates, nodes near the center of a group will have enough group members in their table to qualify as landmarks. These nodes will take the role of landmark, and build their LMDV. The landmark status pair and the LMDV will be broadcast to neighbors with the next FSR exchange packet. When its non-landmark neighbors receive this update message, they will update their LMDV using the incoming LMDV. If a neighbor is a landmark itself, a winner competition is performed. The landmark status pair and LMDV at this node is set up corresponding to the competition result. The updated LMDV and the node's landmark status pair will be propagated again jointly with the routing update packets. When the last landmark change information reaches every node, only one node will remain as landmark for each group. The election converges quite rapidly. At steady state, a landmark propagates its presence to all other nodes like a sink in DSDV [14].

In a mobile environment, an elected landmark may eventually lose its role. The role shifting is a frequent event. In a transient period, there exist several landmarks in a single group. The transient period may be actually the norm at high mobility. This transient behavior can be drastically reduced by using hysteresis. Work is in progress.

A great advantage of landmark election in LANMAR is recovery from landmark failures. In a dynamic network, nodes may die and come up. When a landmark dies, its neighbors will detect the silence after a given timeout. The neighbors of the same group will then take charge as landmarks and broadcast this new landmark information. A new round of landmark election then starts over the entire network.

III. Performance Evaluation

A. Simulation Model

The simulator for evaluating routing protocols was implemented within the GloMoSim library [16]. The GloMoSim library is a scalable simulation environment for wireless network systems using the parallel discrete-event simulation language PARSEC [2]. The distributed coordination function (DCF) of IEEE 802.11 [9] is used as the MAC layer in our experiments. It uses Request-To-Send (RTS) and Clear-To-Send (CTS) control packets to provide virtual carrier sensing for *unicast* data packets to overcome the well-known hidden terminal problem. Each data transmission is followed by an ACK. *Broadcast* data packets are sent using CSMA/CA only. The radio model uses characteristics similar to a commercial radio interface (e.g., Lucent's WaveLAN). Radio propagation range for each node is 150 meters and channel capacity is 2 Mbits/sec. Each simulation executed for 20 minutes of simulation time.

B. Traffic Pattern and Mobility Models

The source-destination pairs are spread randomly over the network. The number of source-destination pairs is varied in the experiments to change the offered load in the network. The interarrival time of the data packets on each source/destination connection is 2.5 seconds to model an interactive environment. The size of data payload is 512 bytes. The load in the network is increased by increasing the number of connections (each with fixed traffic rate), instead of keeping the number of connections constant and increasing their rate as previously done in [4]. Also all previous simulation studies [4], [3], [6] focused on performance evaluation for small number of traffic pairs (up to 40 pairs) with high data rate (3 - 4 pkts/sec).

The mobility model uses the *Reference Point Group Mobility* model [8] in a square field. 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 [7], [3]. A node randomly picks a destination within the group scope and moves towards that destination at a fixed speed. Once the node reaches the destination, it selects another destination randomly and moves towards it after a 10-second pause time. This behavior is repeated for the duration of the simulation. Mobility speeds used in this study are 2,4,6,8 and 10 m/sec. The pause time is not considered in computing node speed. The group component of mobility is also based on the random waypoint model. We use a relative short pause time of 10 seconds to make the topology change more frequently to challenge the routing algorithms.

C. Performance Metrics

We have used the following metrics as in [4] to compare protocol performance: (i) *Packet delivery fraction* – the ratio between the number of received data packets 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, queuing at the interface queue, retransmission delays at the MAC, propagation and transfer times. (iii) *Normalized routing load* – the number of routing control packets transmitted per data packet delivered at the destination. Each hop-wise transmission of a routing packet is counted as one transmission.

D. Simulation Results

First, we compare the performance of the basic LANMAR protocol (without election) with three other schemes implemented in the GlomoSim library, i.e., AODV, DSR and FSR. The network size is 100 nodes. The number of logical groups is 4 for LANMAR. The Fisheye scope for both FSR and LANMAR is 2 hops and the update frequency within scope is also the same.

The first experiment (Fig. 1) reports the packet delivery fraction under heavy traffic load with different mobility. LANMAR outperforms all the other protocols. Comparing the performance of FSR and LANMAR routing, one notices that it is more important to keep accurate routes to "landmark" nodes rather than "blurred" routes to all nodes.

Fig. 2 shows the average packet delay as a function of offered load. As the offered load increases, delay increases because of queue buildup. The delay of AODV increases faster than the other protocols because of the higher routing O/H and thus higher load.

Fig. 3 reports the normalized routing load. Low routing load is a desirable property for scalability. Recall that the normalized routing load is the ratio of control packets over data packets delivered. For LANMAR and FSR, the number of control packets is a constant. It is independent of mobility and number of source/destination pairs. In AODV and DSR the number of control packets increases with number of pairs as well as with mobility. As number of pairs and load increase, the normalized load of on demand schemes is much higher than that of LANMAR and FSR.

Next, we evaluate the variation in control overhead introduced by dynamic election (see Fig. 4). We note that at low mobility the ratio of control overhead is 1, as expected. As the mobility increases, the landmark role shifts from one landmark to another, causing extra control messages and possible packet loss during landmark transitions.

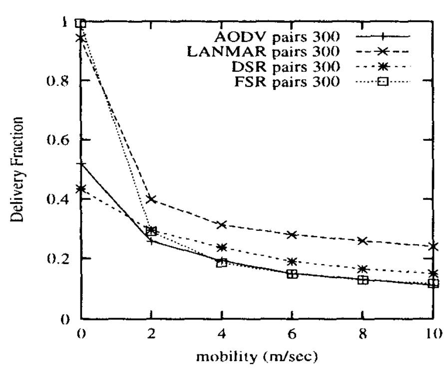

Fig. 1. Delivery Fraction

Focusing now on the comparison of LANMAR vs FSR, we note that LANMAR is superior under all measures. Moreover, LANMAR requires a much lower routing table storage. In fact, in our 100 node example, the storage O/H per node is 2600 bytes for FSR and 690 bytes for LANMAR. More generally, consider an ad hoc network with N nodes and $\sqrt{N}$ logical subnets, with nodes within the "scope" = $\sqrt{N}$. The storage overhead of FSR is $O(N)$; for LANMAR, it is $O(\sqrt{N})$. Note also that lower storage O/H is coupled with lower route processing O/H and thus lower power consumption, an important consideration in power limited nodes.

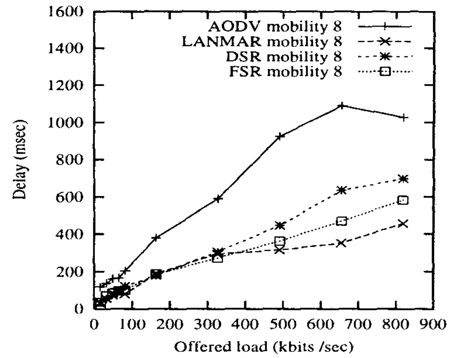

Fig. 2. Delay

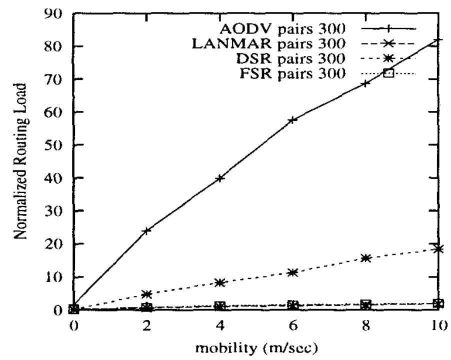

Fig. 3. Normalized routing load

IV. Conclusions

In this paper, we propose a new routing scheme, Landmark Ad hoc Routing (LANMAR), which provides an efficient, scalable solution for wireless, mobile ad hoc networks. We have compared performance of our routing protocol with FSR, DSR and AODV. When the number of communication pairs increases, AODV and DSR will generate considerable routing overhead. LANMAR maintains the overhead constant and thus outperforms AODV and DSR for large number of communication pairs. Moreover, LANMAR provides a dramatic reduction in route table size with respect to FSR leading to both line and storage overhead reduction. We have also implemented and evaluated the distributed landmark election protocol. The

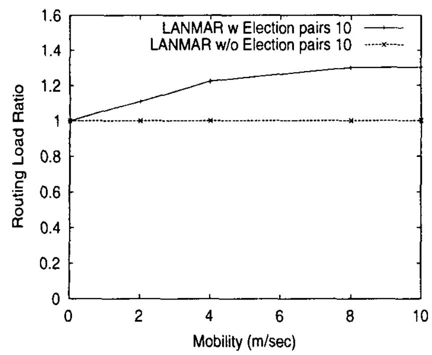

Fig. 4. Routing Loads with and without election

additional control overhead is quite modest, confirming the effectiveness of the landmark election scheme.

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