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Journal

Wireless Communications & Mobile Computing, 6(7)

ISSN

1530-8669

Authors

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Publication Date

2006-11-01

Peer reviewed

Geo-LANMAR: A Scalable Routing Protocol for Ad Hoc Networks with Group Motion

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Summary

Network scalability is one of the critical challenges and requirements in routing protocols for wireless ad hoc networks. It is important to guarantee a good scalability to dynamic ad hoc networks when the number of nodes, the traffic load, and the mobility rate increase. This paper presents a novel routing protocol called Geo-assisted Landmark Routing (Geo-LANMAR). The proposed protocol inherits the group motion support of Landmark Routing (LANMAR) through *k*-hop clustering algorithm to dynamically elect cluster-heads (landmark nodes), and applies geo-routing concept to route packets to remote nodes.

In this framework, the integration between geo-coordinate and table-driven IP addressing is introduced. There is also integration of group management with geo-forwarding and IP group management. The novel concept of Location Group Area (LGA) that represents the area associated with the group is also introduced. Geo-LANMAR uses link-state propagation over a virtual topology built on the LGAs. An optimized link-state routing (a Fisheye like algorithm) is applied to maintain the locations of LGAs. A hybrid forwarding scheme and a coarse topology knowledge through the Fisheye routing protocol running among LGAs are applied. Geo-LANMAR separates local topology changes from global updates of the network. A novel metric of Effective Traveled Distance (ETD) is applied to detect and circumvent voids or obstacles.

Geo-LANMAR permits to overcome possible location inaccuracies that affect flat geo-routing (e.g., inaccurate GPS). With respect to LANMAR, Geo-LANMAR incurs much lower advertisement update O/H and features more robust forwarding. Consequently, Geo-LANMAR is more scalable to large ad hoc networks with group motion. A performance evaluation of Geo-LANMAR vs. other routing protocols such as AODV, LANMAR and GPSR has been carried out. Performance evaluation shows that Geo-LANMAR gives high scalability for large networks in terms of control overhead, end-to-end delay, and packet delivery ratio as compared with other routing protocols.

Keywords: Ad Hoc Networks, Scalability, Landmark Routing (LANMAR), Geo-Routing, Group Management, Mobility, Link-State.

1. Introduction

Network scalability is one of the critical challenges and requirements in routing protocols for wireless ad hoc networks. It is important to guarantee a good scalability to dynamic ad hoc networks when the number of nodes, the traffic load and the mobility rate increase. Many scalable approaches have been proposed [1, 15, 16], which are based on either *geo-forwarding* or *table-driven forwarding*. *Geo-routing* uses the physical positions of routers and the destination of packets to make decisions on packet forwarding [2]. Geo-routing only keeps the states of local topology, thus reduces control overhead effectively. Most geographic routing protocols use greedy forwarding as their basic mode of operation, where the next forwarding hop is the closest node to the destination among its neighbors. Greedy forwarding, however, fails in the presence of a void or an obstacle [1, 2]. In the presence of a void, *face routing* has been proposed to route around the void, which uses the perimeter mode packet forwarding via a planar graph traversal. Heavy control overhead is observed in perimeter mode forwarding and the need of Geo Location Service to learn the destination coordinates further degrades the performance of geo-routing. In summary, Geo-routing has two limitations to scalability: the difficulty in overcoming voids and obstacles, and the need to maintain and access a Geo Location Server. Either factor leads to extra O/H that eventually drives performance down as network size and load increase.

On the other hand, table-driven routing (such as proactive link-state or distance vector routing protocol) permits the calculation of the best path toward the destination by knowing the network topology. The best path is in terms of different metrics such as the number of hop, delay, bandwidth, or link stability, etc. The drawback of table-driven routing schemes is that the increase in routing table size reduces the scalability when the number of nodes increases. In addition, the increase in link control O/H for a table-driven routing protocol results in a reduction of bandwidth availability. In order to offer better scalability to link-state and distance vector routing, hierarchical schemes have been proposed such as LANMAR [8] and [5, 6]. The Landmark Routing Protocol (LANMAR) reports better scalability results than traditional table-driven routing by using a hierarchical routing scheme and exploiting group mobility which is common in military and disaster recovery scenarios where wireless ad hoc networks are applied most frequently.

However, LANMAR also suffers of scalability limitations. As mobility increases, the refresh rate of the advertisements must increase in order to keep track of routes. This of course increases the O/H. Mobility combined with network size increase makes LANMAR impractical for high node speeds and very large network deployments.

At this point, the careful reader will have observed that Geo Routing by its nature is extremely resilient to high speed, as it does not require the notion of routing tables (that can become obsolete). It suffers however of void/obstacle and of Geo Server limitations. LANMAR, on the other hand, has no problems with voids (since advertisements work around them); also, it propagates automatically the group information (no Geo Server required). It suffers however of routing table obsolescence at high speed. Refreshing the tables more frequently only leads to higher O/H. Thus, it is natural to consider the combination of the two schemes to achieve even higher scalability.

Based on the above observations, we propose a new protocol that combines the advantages of georouting and landmark routing and avoids their disadvantages. The proposed geo-coordinate extension of LANMAR routing is called Geo-LANMAR. The proposed protocol inherits the group motion support of Landmark Routing (LANMAR). As in LANMAR, a Landmark node is elected within each group; the election procedure is dynamic and is described in detail in [8, 20]. Roughly speaking, the Landmark is the "center of mass" of the group. The Landmark can dynamically change as nodes in the group move around and nodes join and leave. As in LANMAR, the link state routing scheme is applied locally with a scope up to k hops. As a departure from LANMAR, Geo-LANMAR uses geo-routing instead of DSDV to route packets to remote nodes. As we shall describe later, if a "void" is detected during geo-forwarding, the packet is rerouted using LANMAR proactive routing.

In this framework, a novel concept of Location Group Area (LGA) that represents the area associated to the group, i.e., the group "footprint", is also introduced. Conceptually, one can envision the network as partitioned into LGA zones, each zone corresponding to a group. At the "center" of each LGA zone is the dynamically elected Landmark for that group. Zones may partially overlap with each other, as groups may overlap as they move. Note that not all the groups move; some groups may in fact be static during the entire operation. Some nodes, in turn, may leave one group and join another during a mission. This is perfectly

consistent with LANMAR operation [8]. The LGAs and associated Landmarks form a "virtual overlay topology" that is maintained using a Link State approach. To keep overhead low, an optimized link-state routing scheme inspired to Fisheye State Routing (FSR) [18] is applied. The FSR-based strategy offers good scalability properties by differentiating link state update rate in space and over time [9]. More precisely, the Link State update rate slows down and the update propagates far away from the source and as time passes. Geo-LANMAR separates local topology changes from global updates of the network. A novel metric of Effective Traveled Distance (ETD) is applied to detect topology voids or obstacles.

In Geo-LANMAR, the number of landmark nodes is typically much smaller than the total number of nodes in the network. This greatly reduces the routing update overhead of flat link-state protocols. The georouting scheme in Geo-LANMAR offers much lower update rate required for advertisements and more robust forwarding for long distance routing. The proposed protocol presents good scalability properties with respect of the number of nodes and groups, traffic loads, and mobility rates. The Geo-LANMAR protocol has been compared with GPSR [2], AODV [14] and LANMAR via extensive simulation experiments.

The rest of the paper is organized as follows. Section 2 briefly reviews the related research in the area of scalable routing protocol. The overview of Geo-LANMAR protocol is presented in section 3. The detailed Geo-LANMAR routing scheme is addressed in section 4. The routing table structure used for packet forwarding is introduced in section 5. Section 6 describes the global and local routing table update of Geo-LANMAR. Performance evaluation and conclusions follow in sections 7 and 8 respectively.

2. Related Work

In the literature, geo-routing protocols and hierarchical routing protocols are two of most scalable solutions for ad hoc networks. Geo-routing protocols take advantage of the physical location of nodes in the network and then apply *position based forwarding*. Hierarchical routing protocols normally require that the underlying routing protocol support scoped sub-networking. They will have two level of routing schemes to handle packet forwarding: underlying routing scheme in local scope and out-of scope routing scheme.

2.1. Geo-routing Protocols

Geo-routing protocols, i.e., position-based routing protocols, require that information about the physical positions of participating nodes be available [1]. Commonly, each node determines its own position through the use of GPS or some other positioning services. A location service is used by the sender of a packet to determine the position of the destination and to include the position in the packet's destination address. The routing decision at each node is then based on the destination's position contained in the packet and the positions of the neighbors of the forwarding node. Position-based routing does not require the establishment or maintenance of routes. The nodes neither have to store routing tables nor need to transmit messages within the overall network to keep routing tables up-to-date. The above features provide the scalability of geo-routing protocols.

Most geographic routing protocols use greedy forwarding as the basic packet-forwarding strategy, where the next forwarding hop is chosen to minimize the distance to the destination. The greedy forwarding strategies may fail if there is no one-hop neighbor that is closer to the destination than the forwarding node itself. Recovery strategies are then applied to cope with this kind of failure [2]. Typically, the recovery procedure degrades the performance when this procedure is frequently applied. The drawback of this approach is the failure to find the shortest path around the obstacle and the inability to consider the global topology knowledge in order to make better routing decisions.

2.2. Hierarchical Routing Protocol - LANMAR

LANMAR is a typical hierarchical routing protocol for scalable, group motion wireless ad hoc networks. LANMAR borrows the concept of landmark which was first introduced in wired area networks [17]. It uses the notion of landmarks to keep track of logical subnets in which members have a commonality of interests and are likely to move as a group (e.g., brigade in the battlefield, a group of students from same class and a team of co-workers at a convention). The addressing scheme in LANMAR efficiently reflects such logical groups. It assumes that an IP like address is used consisting of a group ID (or subnet ID) and a host ID, i.e. *Group ID*, *Host ID>*. The address changes if a node moves from a group to another, in the same way the IP address changes when a node in the Internet moves from one subnet to another. Each logical group has an elected landmark. Each node in the network uses a scoped routing algorithm (such as

FSR [18], OLSR [10] or HSLS [9]) to learn about routes within a given scope of max number of hops. To route a packet to a destination outside its scope, a node will direct the packet to the landmark corresponding to the group ID of such destination. The route to a landmark is propagated throughout the network using a Distance Vector mechanism. Once the packet approaches the landmark, it will typically be routed directly to the destination by the local scope routing.

For each group, the underlying scoped routing algorithm will provide accurate routing information for nodes within scope. The routing update packets are restricted only within the scope. The routing information to remote nodes (nodes outside the node's scope) is summarized by the corresponding landmarks. This kind of summarized routing will not affect the routing accuracy much since the group nodes are moving together. However, the overhead reduction and thus scalability improvement is significant. For example, if the average group size is g, the routing table size might be reduced to 1/g. As a result, the routing overhead is reduced as the routing packet size is significantly shortened. Thus, by summarizing in the corresponding landmarks the routing information of remote groups of nodes and by using the truncated local routing table, LANMAR largely reduces routing table size and routing update overhead in large networks. It greatly improves the network scalability in terms of protocol overhead.

Fisheye State routing is a proactive link-state routing protocol that presents scalability properties [18]. Different from the standard link state routing protocols in which the overhead increases rapidly, the control overhead is reduced through spatial differentiation (by limiting the set of neighbors to which the link state update is transmitted) and time differentiation (by limiting the time between successive disseminations of link status information). Under the protocol, for example, a node sends a Link State Update (LSU) every $2^k * T$ to a scope of 2^k , where k is hop distance and T is the minimum LSU transmission period.

2.3. Hybrid Routing Protocols

Hybrid routing protocols use the location information to forward the packet and proactive routing information for local routing. Terminodes Routing is a good example of this class of protocols.

In Terminodes routing [7], the link state routing is applied for the local routing within the local scope up to two hops, while geo-forwarding is used for long distance routing. The advantage of this protocol is that the greedy location-based packet forwarding, which is the main benefit offered by position-based routing protocols in terms of network scalability, is applied for long distance routing. Moreover, it is also possible to get refreshed information about the topology of the network through the link state routing. So the use of local link state routing can offer the advantage to have a better knowledge of the local network topology. This protocol presents more accurate information in the local view and less accurate information for long distances.

Terminodes can be scalable to large ad hoc networks without exploiting group mobility pattern. In contrast, the scalability of LANMAR is achieved by exploiting group mobility. Geo-LANMAR [21, 22] combines the geo-routing scalability and local proactive routing efficiency of Terminodes; and the hierarchical group motion scalability of LANMAR, obtaining the advantages of both protocols. In this paper, we offer a more extensive discussion of related work containing the motivation for combining Geo + LANMAR, and provide a detailed description of the virtual topology maintenance as well. We also further investigate the performance of Geo-LANMAR with more meaningful simulation results. The essential Geo-LANMAR design principles are described in section 3.

3. Overview of Geo-LANMAR

Central to Geo-LANMAR is the concept of Landmark, a dynamically elected node that is basically in charge of the group of nodes moving together (say rescue patrol, tank battalion, etc). A landmark node is dynamically elected in each subnet using various criteria. A typical criterion used when GPS is available is the "center of mass" criterion. In case of tie, lowest ID breaks the tie. In this paper, members of each subnet (group) are pre-defined. In more general situations, members of the same motion group can be discovered using motion tracking. In all cases, the landmark is dynamically elected in each group, which enables Geo-LANMAR to cope with relative node motion within the group.

Geo-LANMAR, as its predecessor LANMAR, uses a Link State routing scheme for routing packets within a limited scope up to k hops, say. This local scheme is equipped with the FSR concept in order to

keep O/H low. In addition to the local routing scheme, there is also a "global" link state routing scheme that maintains the previously mentioned virtual LGA/Landmark topology. This global link state scheme can be viewed in fact as the extension of the local scheme, except that here only the Landmarks participate and only the landmark states are propagated. Naturally, to keep O/H in check, the FSR strategy is used. To this end, each landmark node transmits to rest of the network its ID group, its location, and the location information of other landmark nodes in the network. As a slight departure from conventional Link State routing, the Link State updates are aggregated at intermediate Landmarks instead of being propagated individually to the entire networks. This technique, originally proposed for GSR (Global State Routing) yields better efficiency by exploiting larger update packets [19]. So, as showed in Fig. 1, the landmark node L_M transmits to its immediate neighbor Landmarks the aggregate state information of all landmark nodes in the network, i. e., $L_I(x, y)$, $L_{N,I}(x, y)$, $L_N(x, y)$, and its position $L_M(x, y)$. The updating process is explained in more details in section 6. The position information is useful when geo-routing to remote destinations is used. In Fig. 1, if the source wants to communicate with a mobile node D, it checks its local scope to see if the destination D can be reached immediately through local link-state routing. If there is no such entry, it sends the packet toward the destination D through geo-forwarding.

A side benefit inherited from the LANMAR protocol is that Geo-LANMAR protocol does not require a Geo Location Server to get the position of the destination node D. From destination D address it extracts the group ID, and the position of the corresponding landmark L_D . The packet is geo-forwarded to L_D . When it is near the scope of landmark L_D , it can be directly forwarded using local routing tables.

4. Geo-LANMAR Route Forwarding

The Route Forwarding phase of Geo-LANMAR consists of two kinds of packet forwarding: *geo packet forwarding* and *table-driven packet forwarding*. The first one is used for "long haul" routing and the second one is used for "local" routing inside a local scope. The forwarding process in each node triggers either geoforwarding or table-driven forwarding by checking the IP destination address of the data packet. If the destination address belongs to the current scope, the packet can be forwarded by using the local link-state routing, i.e., intra-scope routing, to the destination. If the destination data packet does not belong to the

current scope, the data packet is sent outside of the scope through the geo- forwarding, i.e., extra-scope routing.

4.1. Intra-scope Routing

Intra-scope routing represents a routing scheme inside the local scope. The choice of the local routing scheme is important because it affects the overhead of the protocol. Intra-scope routing can provide a better scalability when the local scope is limited to a few hops and the node density in the local scope is low. Intra-scope routing is a table-driven forwarding and the metric of the shortest path toward the target destination is used. It is possible to apply different link-state protocols in the local scope, such as Optimized Link-State Routing (OLSR) [10], Fisheye State Routing (FSR) [18], etc. In our implementation, FSR was used.

4.2. Extra-scope Routing

Extra-scope routing represents a routing scheme outside of the local scope. Geo-routing is applied in the extra-scope routing. The basic operation is greedy forwarding which however will fail when a local maximum is met. Different kinds of recovery procedures can be applied, such as the perimeter forwarding [2] or the Face routing [3], etc. The recovery procedure may degrade the performance due to the sub-optimal path used to conquer the local maximum.

Since there is knowledge of the virtual LGA topology in Geo-LANMAR, we can use this information to circumvent a void in the network. In particuar, if a void is detected (or suspected), the packet is sent to a safe intermediate destination. This intermediate target destination is selected among neighbor landmarks. It is in fact the Landmark on the shortest path to destination on the virtual LGA topology. Since any neighbor Landmark by construction is at most 2k hops away, it can be reached via two set of local routing tables (of origin and destination Lanmark) without using greedy forwarding. Thus, this leg of the route is free from "void" problems. After reaching the neighbor Landmark, greedy forwarding can be resumed. In Fig 1 example a packet directed from S to D gets stuck in scope 2. Using the virtual LGA topology detour it is returned to S and routed to scope 1. Greedy forwarding is used thereafter.

The above recovery scheme completely eliminates the dead-end routing problem as long as local routing tables are refreshed with sufficient frequency. The careful reader however will realize that the virtual topology route is suboptimal in that it may introduce zig-zagging through Landmarks. Thus, geo routing is preferred when the topology is void-free.

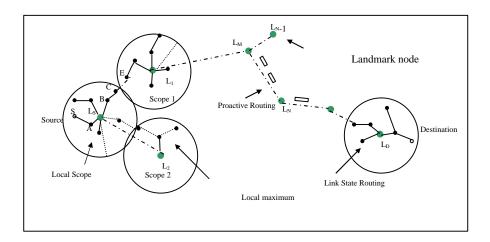


Fig.1: Void detected in scope 2 as there is no path toward the destination for this local scope

4.3. Effective Traveled Distance & Void Detection

In the previous example, the packet got stuck in a void and backtracking was required to rescue it. It is possible to predict the presence of a void and thus avoid backtracking using the notion of Effective Traveled Distance (ETD). To this end, in the update packet, the position of the landmark as reference for the LGA and a field called *Effective Traveled Distance* (ETD) are inserted. ETD accounts for the real traveled distance between the landmark sending the update packet and the landmark receiving the packet. The source and any intermediate node along the path can initiate the process of ETD.

The ETD between two neighbor landmarks L_X and L_Y is calculated in the following way (shown in Fig. 2):

$$dist(L_X, L_Y) = \sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$$
 (1)

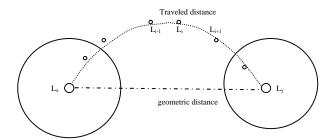


Fig. 2: Real traveled distance or ETD in the virtual topology

The total real traveled distance between the landmark L_X and the destination landmark L_D which is m hop away (shown in Fig. 3) is computed as follows:

$$ETD = d_{X-D} = \sum_{i=1}^{m} dist_i(L_i, L_{i+1})$$
 (2)

Comparing the ETD d_{X-D} with the euclidean distance $\overline{L_X L_D}$, one can define the detour index a shown in Eq. 3 representing the deviation of the real route distance from the euclidean distance.

$$a = \frac{\overline{L_X L_D}}{ETD} = \frac{\sqrt{(x_X - x_D)^2 + (y_X - y_D)^2}}{\sum_{i=1}^{m} dist_i(L_i, L_{i+1})}$$
(3)

The index a varies in the range of [0, 1]. If a is close to 0, the traveled distance is much higher than the geometric distance, which indicates the presence of a void or obstacle. If a is close to 1, the traveled distance is close to the geometric distance. By the a value calculated in Eq. 3, we thus can "predict" a void at the LGA level. In this case, we select a neighbor Landmark to circumvent the void. An example is shown in Fig. 3.

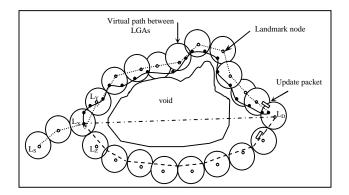


Fig. 3: Virtual Path between LGAs

In Fig. 3, the node L_X receives the update packet of the destination landmark L_D from both landmarks L_Y and L_Z and it can detect a void or a sub-optimal path existed because the geometric distance $\overline{L_Y L_D} <<$ ETD d_{Y-D} . In this example, the detour measure a of the path through the landmark L_Y is lower than that of the path through the landmark L_Z . In other words, the traveled distance through the landmark L_Y is longer than through the landmark L_Z . Thus the landmark L_Z is selected as the forwarding landmark and this path toward the landmark L_Z is an optimal path (the shortest traveled distance ETD) for landmark L_Z . This example demonstrates another important advantage of Geo LANMAR over GPSR, namely, the ability to choose the best among several detours. In the above example GPSR would have selected either path with 50/50 chance.

5. Geo-LANMAR Routing Tables

The Geo-LANMAR protocol needs to maintain two routing tables: the local routing table and the Landmark (or LGA) routing table. The latter points to the landmarks and LGAs. The former is used inside the local scope to execute the table-driven forwarding through the link-state routing protocol (e.g. Fisheye, OLSR etc.). It maintains information about the IP addresses of the other nodes inside the scope and the shortest path toward any couple of nodes, and is periodically exchanged between the nodes belonging to the local scope according to the adopted intra-scope link-state protocol.

The previous LANMAR version needed to keep global landmark information at each node. In Geo-LANMAR we only need to keep the information about the local landmark and the neighbour landmarks according to the geo-forwarding paradigm. When a node needs to transmit a packet outside the local scope, it only needs the position of the destination landmark L_D and the next hop to the nearest destination neighbour landmark. This leads to a drastic reduction of the dimension of the table size of any node inside the local scope that is not a landmark. Only the lanmark node needs to maintain the information about all other lanmarks. It reduces table update overhead inside the local scope when the Landmark topology changes.

6. Geo-LANMAR Routing Table Update

Two routing table updates must be considered: local (intra-scope) updates and global (extra-scope) updates. The local event-driven update maintains accurate topology information for the link-state routing. It uses a threshold mechanism to determine when to send an update packet to the neighbour LGAs. The global update is used to maintain the consistency of the landmark table and to refresh the information of next neighbour landmarks toward the destination landmark. It keeps the update of the virtual LGA topology. Each Landmark propagates update packets in the network. The Fisheye principle is used to reduce the update process overhead in space and time. The decision to send a link state update packet outside of the local area is based on group mobility. If the group does not move, no topology change must be advertised to nodes out of scope, even though there may be some internal movements within the group.

6.1. Local Event-Driven Update

In this section we discuss the issue of local update triggering. To simplify the explanation of the scheme, we can consider two landmark nodes L_x and L_y that move in the network and assume that these two nodes are in the middle of their respective square LGAs as shown in Fig. 4. We assume no position error in the system and the LGA of L_x is fixed. In this case, the tolerance of node X_1 successfully exploiting the greedy forwarding to reach a destination inside the LGA of landmark L_y is 2d, where d is the dimension of the LGA. To simplify the case, we may assign d as a half of the edge of the square LGA. If a data packet reaches any node inside the LGA of L_y , the packet will be delivered to the destination. Imagine that the

group associated with L_y moves, in such case, the node L_y needs to update its position to its neighbors when moving over the distance d. If the update is sent later, the LGA of L_y can not be reached, as shown in Fig. 4.

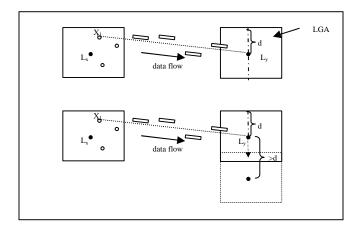


Fig. 4: Local Update based on Group Motion

Thus the landmark node checks its own movement to see whether its traveled distance is over a threshold value l. The traveled distance is calculated as follows: after the election of the landmark at the instant t_0 , its position $(x(t_0), y(t_0))$ is calculated through the GPS system and stored. After a sampling interval time t_0 , the new position of the landamark t_0 , t_0 is evaluated. If the following condition is verified, the update packet will be sent by the Group Area to the neighbour Group Areas.

$$\sqrt{(x(t_1) - x(t_0))^2 + (y(t_1) - y(t_0))^2} > l - \boldsymbol{e}$$
(4)

where $t_1 = t_0 + ?t$; l can be fixed to a target value or it can be dynamically changed by considering group motion; \boldsymbol{e} refers to the location inaccuracy caused by inaccurate GPS.

A problem may happen if the landmark node is changed after the landmark election procedure during the sampling time. In this case, a packet with the location of the old landmark at time t_0 is sent to the new landmark when the following condition is verified.

$$\sqrt{\left(x_{NEW LAND}(t_1) - x_{OLD LAND}(t_0)\right)^2 + \left(y_{NEW LAND}(t_1) - y_{OLD LAND}(t_0)\right)^2} > l - e$$
 (5)

In the instant $t_1 = t_0 + ?$ t, the new landmark is stored and the distance between the locations between the sample interval will be evaluated. The procedure is repeated when any update arrives.

6.2. Global Update Propagation

Before explaining the link-state propagation, it may be useful to give some details about the virtual topology network among Landmarks. A virtual link between two Landmarks exists, if they are separated by 2k hops, where k is the radius of the intra-scope routing scheme. The virtual topology is the set of all Landmarks and all virtual links connecting them. Fig. 5 shows an example of virtual topology.

We assume that all the nodes in the system belong to some motion group. Also we assume that any node in a motion group is at most k hops away from its Landmark. Thus, the group diameter is at most 2k hops. If the group is larger than 2k, it is split into coordinated subgroups. From these assumptions it easily follows that if there is a path between any two nodes in the original topology, there is a path also in the virtual Lanmark topology.

During global update propagation, each landmark node broadcasts a link-state control packet. This update is destined to its virtual topology Landmark neighbors. The update travels on the broadcast tree of depth = k embedded in the local routing tables. The intermediate nodes that receive the update will forward it to their Landmarks. Duplicates are suppressed on the way to landmarks. Multiple topology changes are aggregated and transmitted all at the same time. Only the updates to the neighbor landmarks are event-triggered. The updates to Landmarks further away are transmitted after a time interval.

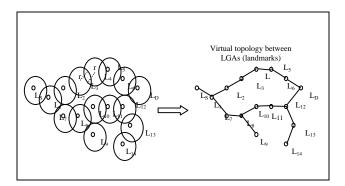


Fig. 5: Virtual topology between landmarks

A Fisheye like algorithm is applied to propagate the link-state information among the landmark nodes [11]. The Time to live (TTL) is used in order to limit the spatial propagation of the link-state update (LSU) packet and the transmission is differentiated in time. At the beginning, the TTL value is set to a specific value that is a function of the current time. After one global LSU transmission (when TTL value is set to infinity), a node wakes up every t_e seconds (observation time) and sends a LSU with TTL set to s_I (scope within one hop) if there has been a link status change in the last t_e seconds. A link-status change occurs if a virtul link breaks.

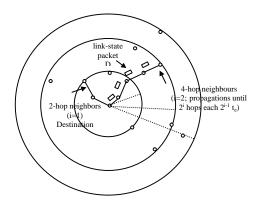


Fig. 6: Link-state updates differentiated in space and over time

As shown in Fig. 6, the node wakes up every $2t_e$ seconds and transmits a LSU with TTL set to s_2 (scope within two hop) if there has been a link-status change in the last $2t_e$. In general, an LSU is transmitted with TTL set to s_i (scope within i hops) if there has been a link status change in the last $2^{i-1}t_e$ seconds. In addition, to guarantee a LSU transmission also in low mobility scenarios, a soft state protection is introduced in the algorithm and a LSU is sent also without a virtual link breakage every t_b second where $t_b >> t_e$.

The proposed global update propagation guarantees that landmark nodes that are s_i hops away from a reference landmark node will learn about a link status change at most after $2^{i-1}t_e$ seconds.

6.3 Geo-LANMAR: summary of the features

In summary, the Geo-LANMAR protocol presents the following innovative characteristics:

- Geo-LANMAR Route Forwarding: It is composed of a local table-driven forwarding and a long distance geo-forwarding.
- 2. Geo-LANMAR Routing Table: It has two main routing tables. The first table inside the local scope maps the topology of *k*-hop neighbors, and the second one gives a coarse knowledge of the overall network.
- 3. Geo-LANMAR Routing Table Update: There are intra-scope and extra-scope routing table updates. The intra-scope is associated with the local link state routing scheme. The extra-scope is associated with the area defined by the specific group (Group Area Location); is limited in space and in time by FSR in order to offer extra scalability.
- 4. Effective Traveled Distance (*ETD*) & Void Detection: ETD is a new metric to select the best direction toward destination. Network partitions and voids can degrade the performance of geo-graphic routing. It is possible to avoid a void through overall topology knowledge. The proactive information exchange between LGAs builds a virtual topology with geo-coordinates, so it is possible to know whether there exists a path between two LGAs. Using ETD metric and LGA virtual topology, we will show that it is possible to find the best detour around any obstacle or void.
- 5. Group Mobility Support: The clustering algorithm running in each local scope permits the election of a landmark node as the representative node of the group. This cluster leader gives information about the group area location to the entire network in order to permit the use of the geo-routing.
- 6. High Network Scalability: The link-state routing limited within the scope reduces the routing overhead. Optimized link-state routing with spatial and time diversity in the virtual topology of LGAs offers a higher scalability by reducing the propagation rate of local topology changes. Long distance geo-forwarding provides long range route scalability.

7. Performance Evaluation

The protocol has been implemented in a QUALNET simulator that represents an extension of the Glomosim simulator [12]. The considered channel capacity is 2 Mb/sec. CBR sources are used to generate network data traffic. The source-destination connections are randomly spread over the entire network. During a simulation, a fixed number of connections are maintained all the time. When one session closes, another pair of communications will be randomly selected. Thus, the input traffic load is constantly maintained.

The adopted mobility model is the RPGM [13]. Each node in a group has two components in its mobility: group movement and intra-group movement. In our simulation, the group speed varies in the range of [0-25 m/s] while the intra-group speed varies in the range of [0-5 m/s].

The commonly used metrics to evaluate routing protocols for wireless ad hoc networks have been considered:

- Packet Delivery Ratio: it is the number of data packets delivered to the destination node over the number of data packets transmitted by the source node.
- Average end-to-end data packet delay: it includes the delay associated with MAC retransmissions,
 queuing delays, and path detour delay when local maximum recovery procedure is applied for the
 geo-routing protocol, and buffering delays associated with the AODV protocol.
- Normalized Routing Overhead: it is the total number of transmitted control packets for each data packet delivered; for packets sent over multiple hops, each packet transmission (on each hop) counts as one transmission.

Geo-LANMAR performance has been tested under many scenarios in which traffic load, mobility rate and network size have been considered. In order to test the scalability of the protocol in respect to the network size with group motion, a scenario in which the number of groups is increased is considered. Another considered scenario refers to a network with heavy traffic load. In this case, the number of connection pairs and the speed of groups are increased inside the network in order to see the scalability of

Geo-LANMAR with respect to the traffic load and mobility rate. The last scenario tests the mobility in presence of holes or voids, where the ETD metric and the void detection mechanism have been evaluated.

In summary, the considered scenarios are summarized as follows:

- 1. Increasing Number of Group & Traffic Load without Void:
 - o Increasing number of groups: The number of groups increases from 4 to 36. The number of members per group is 25. Thus the total number of nodes ranges from 100 to 900.
 - Total number of CBR connections is 300, a constant while the number of groups increases.
 - o Increasing traffic load: A grid of 1500 meter X 1500 meter with 9 logical groups is considered. The number of connections is varied between 5 and 500. Each connection sends 2 packets per second and lasts 30 seconds. Five CBR connections provide 10 kbps traffic load, while 500 pairs of CBR connections provide 800 kbps traffic load.
- 2. Mobility with Voids: In order to test the effectiveness of the novel mechanism (Effective Traveled Distance and Void Detection) proposed in Geo-LANMAR, a particular scenario has been built. In particular, a grid with some obstacle has been considered as shown in Fig. 7.

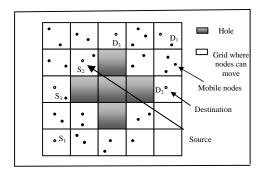


Fig. 7: Link-state updates differentiated in the time and in the space

Table 1: Simulation Parameters

Simulator	QualNet
Simulation Area	1500 m X 1500 m
Number of Groups	4-36
Number of Members in each Group	25
Traffic Source	CBR
Number of Connections	30-400
Sending Rate	2 packet/second
Size of Data Packet	64 bytes
Transmission Range	250 m
Simulation Time	500 second
Mobility Model	RPGM
Pause Time	10 second
Group Mobility Speed Range	[0-25 m/s]
Intra-group Mobility Speed	[0-5 m/s]
MAC Protocol	IEEE 802.11b
Link Bandwidth	2 Mbps
Confidence Interval	95%

7.1. Increasing Number of Group & Traffic Load without Hole

Performance evaluations of Geo-LANMAR protocol in comparison with AODV and LANMAR are assessed. We did not report the results for GPSR because they are practically identical to those for Geo LANMAR in this case. In fact, given the relatively high density, voids rarely happen and Geo LANMAR uses almost exclusively Geo Routing.

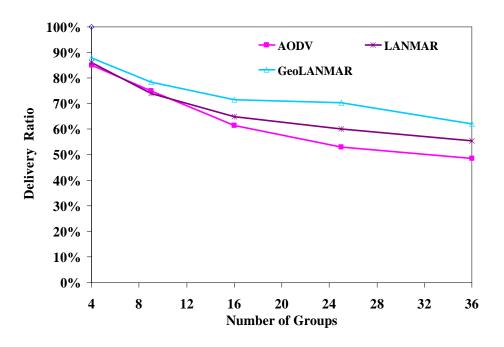


Fig. 8: Data packet delivery ratio vs. increasing number of group. The number of nodes increases according with the number of groups.

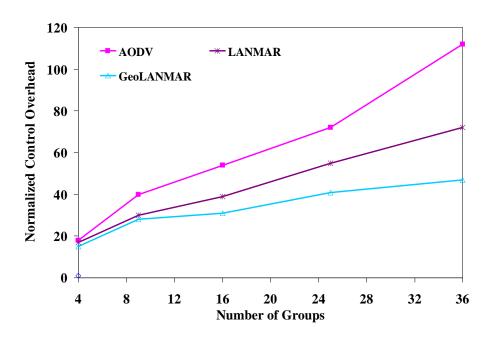


Fig. 9: Normalized Control Overhead vs. increasing number of group. The number of nodes increases according with the number of groups.

The scenario depicted in Fig. 8 and Fig. 9 is related to fixed density intra-group and an increasing number of groups. When the group increases in the network, the number of landmarks inside the network also increases, which results in an increase in control traffic for the virtual topology of LGAs. However, the FSR inspired scheme permits the reduction of the propagation of LSU packets in space and over time. Another benefit of Geo-LANMAR is the reduction of the frequency rate associated with the link changes that are associated with virtual topology, because the virtual link breaks more slowly than a real link. Georouting permits more resilience in the link breakage and the delivery ratio increases such as depicted in Fig. 8. The delivery ratio of AODV is lower than LANMAR and Geo-LANMAR because it reaches wireless channel saturation before other protocols.

The normalized control overhead for the considered routing protocols is shown in Fig. 9. As confirmed in the results, LANMAR and Geo-LANMAR outperform AODV protocol. In particular, Geo-LANMAR outperforms LANMAR because the virtual topology management is more efficient.

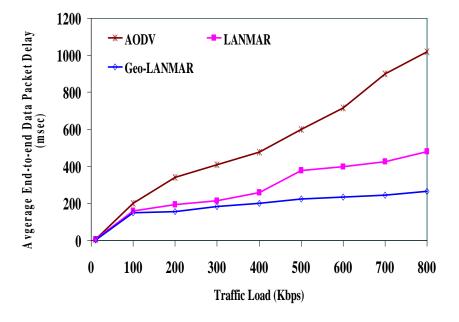


Fig. 10: Average end-to-end delay vs. increasing traffic load. The offered load is increased by increasing the number of connections.

The average end-to-end delay when traffic load is increasing is shown in Fig. 10. The data packet delay increases for high traffic load due to queuing delay. LANMAR and Geo-LANMAR behave similarly and they outperform AODV because the accuracy of the route to the landmark proves to be very cost effective, in spite of a possible minor detour toward the destination. Geo-LANMAR performs better than other protocols because the geo-routing scheme with the reference point represented by the LGAs permits reaching the destination at a low cost.

7.2. Mobility in Presence of Voids

In this scenario, we have considered 20 groups with 25 nodes for each group. The group speed is chosen from the following values [0, 5, 10, 15, 20 m/s] consecutively. The motion inside each group is characterized by a speed randomly selected in the range of [0-5m/s]. The considered grid is 2500m X 2500m and the transmission range for each node is 250 meters.

Geo-LANMAR protocols are expected to perform well also in more realistic scenarios in which the node movement is not totally free in space, but where there are obstacles or network partitions that can occur. In this case, Geo-LANMAR protocol can make use of the novel proposed metric that accounts for real traveled distance, and of the void detection mechanism. The capability of seeing over the local scope through the link-state propagation of LGA locations permits the detection of a path which is not connected to the destination, thus avoids long detours. On the other hand, GPSR makes only local decisions and often applies the recovery procedure of perimeter forwarding, which produces long detours for the data packet and a consequent increase of end-to-end data packet delay, as shown in Fig. 12. Similarly, the greedy forwarding of GPSR is merely based on geometric distance in local neighbors, which easily makes myopic decision and selects wrong next hop which is geometrically nearest to the destination but is trapped in voids or obstacles. So the data packet delivery ratio of GPSR is lower than Geo-LANMAR as shown in Fig. 11.

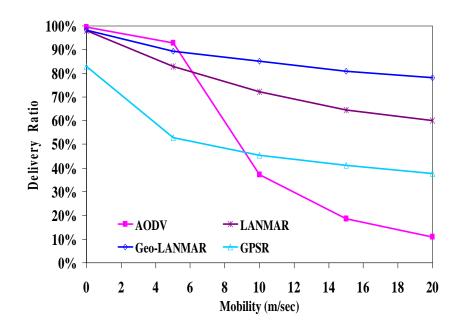


Fig. 11: Data packet delivery ratio vs. Mobility.

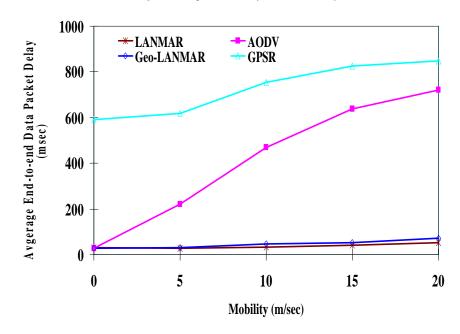


Fig. 12: Average end-to-end delay vs. Mobility.

8. Conclusions

A novel routing protocol for scalable wireless ad hoc networks exploiting group motion has been developed. The proposed protocol called Geo-LANMAR introduces the integration of geo-coordinate and table-driven IP addressing. It also integrates group management with geo-forwarding and IP group management. A novel concept of Location Group Area (LGA) that represents the area associated to the group is also introduced. Geo-LANMAR uses link-state propagation over a virtual topology built on the LGAs. An optimized link-state routing called Fisheye Routing (FSR) is applied to reduce the overhead associated with LGA virtual topology maintenance. A hybrid forwarding scheme and a coarse topology knowledge through the FSR protocol running among LGAs are applied. Geo-LANMAR separates local topology changes from global updates of the network. A novel metric called Effective Traveled Distance (ETD) is applied to detect the void or obstacle. Geo-LANMAR permits to overcome possible location inaccuracies that affect flat geo-routing (e.g., inaccurate GPS). It reduces the routing update overhead of flat link-state protocol efficiently. The geo-routing scheme in Geo-LANMAR reduces the update rate of advertisements and features a more robust forwarding for long distance routing. To sum up, Geo-LANMAR is very scalable in large ad hoc networks with group motion. A performance evaluation of Geo-LANMAR vs. other routing protocols such as AODV, LANMAR and GPSR has been carried out. The results confirm that Geo-LANMAR gives high scalability for large networks in terms of control overhead, end-to-end delay, and packet delivery ratio as compared with other routing protocols.

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