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

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Abstract

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. 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 Hazy Sighted Link-State (HSLS) Routing is applied to maintain the locations of LGAs. A hybrid forwarding scheme and a coarse topology knowledge through the HSLS 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 the hole 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 offers much lower update rate required for advertisements and more robust forwarding for long distance routing. So Geo-LANMAR is 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 network 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 *table-driven* forwarding or *geo-forwarding* techniques. *Geo-routing* uses the positions of routers and the destination of packets to make decisions on packet forwarding [2]. Most geographic routing protocols use *greedy forwarding* as their basic mode of operation, where the next forwarding hop is chosen to minimize the distance to the destination. Greedy forwarding, however, fails in the presence of *void* and *dead-end* [1, 2]. In order to provide correct routing in the presence of dead-end, *face routing* has been proposed to route around the void. The most commonly used geographic routing includes greedy forwarding coupled with face routing [3]. By keeping states only about local topology, geo-routing reduces control overhead effectively. Geo-routing protocol becomes one of the most scalable solutions for ad hoc networks in the literature.

On the other hand, the table-driven routing, such as proactive link-state or distance vector routing protocol, presents the advantage of knowing the whole network topology, thus permits the calculation of the best path toward the destination. The best path is in terms of different metrics such as the number of hop, delay, bandwidth availability, or link stability, etc. The drawback of table-driven routing schemes is that the explosion of routing table size reduces the scalability when the number of nodes increases. Another issue with these schemes is that the increase of maintenance cost for a table-driven routing protocol results in a reduction of bandwidth availability. In order to offer better scalability to the link-state routing or the distance vector routing, hierarchical schemes have been proposed in the literature such as LANMAR [8] and [5, 6].

The Landmark Routing Protocol (LANMAR) reports good scalability results 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. The LANMAR protocol utilizes the concept of landmark for scalable routing. It exploits group mobility [13], and combines group mobility and IP

Group address management. LANMAR is well suited to provide an efficient and scalable routing solution in large, mobile, ad hoc environments in which group behavior applies.

Based on the above observations, we propose here a new protocol which combines the advantages of geo-routing and landmark routing. The proposed geo-coordinate extension of LANMAR routing is called Geo-assisted Landmark Routing, in short, 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. The applied geo-routing is GPSR [2] because it offers greedy forwarding and perimeter forwarding to recover by the local-maximum. The link state routing scheme applies inside the local scope within k-hop.

In this framework, the integration between geo-coordinate and table-driven IP addressing is introduced. 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. The LGA defines the zone where to send the data packets. Geo-LANMAR uses link-state propagation over a virtual topology built on the LGAs. An optimized link-state routing called Hazy Sighted Link-State (HSLS) Routing [9] is applied to maintain the locations of LGAs. A hybrid forwarding scheme and a coarse topology knowledge through the HSLS protocol running among LGAs are applied. HSLS offers good scalability properties by differentiating link state update rate in space and over time [9]. Geo-LANMAR separates local topology changes from global updates of the network. A novel metric of Effective Traveled Distance (ETD) is applied to detect the hole or obstacle.

Geo-LANMAR permits to overcome possible location inaccuracies that affect flat geo-routing (e.g., inaccurate GPS). In Geo-LANMAR, the number of landmark nodes is typically much smaller than the total number of nodes in the network. It reduces the routing update overhead of flat link-state protocol efficiently. The geo-routing 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 in respect of the number of nodes & groups, traffic loads, and mobility rates. Simulation campaigns are assessed and the Geo-LANMAR protocol has been compared with GPSR [2], AODV [14] and LANMAR by simulations.

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 necessary for the packet forwarding is introduced in section 5. Section 6 describes the global and local routing table update of Geo-LANMAR. Finally, the performance evaluation and conclusions are respectively summarized in sections 7 and 8.

2. Related Work

Many routing protocols for wireless ad hoc networks have been proposed in recent years. 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 and they do not 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>*. Each such 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] shown below) 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. 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. A landmark is dynamically elected in each group, which enables LANMAR to cope with mobile environments.

Hierarchical Scoped Link State routing (HSLS) is a proactive link-state routing protocol that presents scalability properties [9]. Different from the standard link state (SLS) routing protocols which overhead increases rapidly, HSLS reduces the control overhead efficiently through the spatial differentiation (by limiting which nodes the link state update is transmitted to) and time differentiation (by limiting the time between successive disseminations of link status information). Under the HSLS protocol, 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. HSLS achieves potential scalability by limiting the scope of link state update dissemination in space and over time.

2.3. Hybrid Routing Protocols

Only recently new hybrid protocols that use the location information to forward the packet and some proactive routing exchanges localized in the network are proposed. Terminodes Routing is an example of this class of protocols [7].

Terminodes routing [7] represents the first attempt to combine two kinds of routing approaches. In Terminodes routing, the link state routing is applied for the local routing within the local scope of 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 is a protocol with good scalability properties, but it does not use a routing scheme able to take advantage by group mobility. This property is supported by LANMAR protocol. In accordance with the interesting idea of Terminodes routing, our Geo-LANMAR protocol is also a hybrid routing protocol which combines proactive schemes in the local scope, long-distance geo-routing and supports group motion in large ad hoc networks. Geo-LANMAR combines the geo-routing protocol and the hierarchical routing protocol together and obtains the advantages of both protocols. The basic idea of Geo-LANMAR is presented in section 3.

3. Overview of Geo-LANMAR

The Geo-LANMAR is composed by two routing protocols: link-state routing protocol and geographic routing protocol. The link state routing protocol is managed inside the local scope of a fixed number of hops. The link state protocol permits the calculation of the shortest path and maintains good information inside the local view. For any local scope, there is a special node that transmits the information about the local scope to the entire network. This node is called Landmark. The landmark node transmits to other scopes the information about its ID group, the local location information, and the location information of other landmark nodes in the network. So, as showed in Fig. 1, the landmark node L_M transmits the information of all landmark nodes in the network, i. e., $L_1(x, y)$, $L_{N-1}(x, y)$, $L_N(x, y)$, and its position $L_M(x, y)$ to the overall network through the updating process explained in section 6. The position information is useful when sending the data packet outside of the local scope by using the greedy forwarding technique. 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 tries to send the packet toward the destination *D* through the geo-forwarding.

The beauty inherited by the LANMAR protocol is that Geo-LANMAR protocol avoids using a Location Server to get the position of the destination node *D*. Because it knows the IP address assigned to the destination *D*, it immediately understands the landmark node of the destination identified by an IP group. By knowing the group ID, it is possible to get the location information of the destination landmark L_D in the local table. So without needing of the specific location of destination *D*, we can use the information of the destination landmark. Then, when the packet is near the scope of landmark L_D, it can be directly forwarded through the table-driven forwarding.

Geo-LANMAR protocol presents the characteristics listed below:

1. 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 Route Recovery Procedure: The recovery procedure is applied when a local maximum (hole) is reached. A GPSR-like technique is deployed. The choice of the neighbor node used in the perimeter mode is based on a novel metric called Effective Traveled Distance (ETD) explained in section 4.
4. Geo-LANMAR Routing Table Update: There are intra-scope and extra-scope routing table updates. The first update modality is associated with the applied link state routing scheme. The second is associated with the area defined by the group motion (Group Area Location) and is limited in the space and in the time such as HSLS in order to offer scalability properties in terms of traffic, mobility and network size.
5. Effective Traveled Distance (*ETD*) & Hole Detection: ETD is a new metric to select the best direction toward destination. Network partitions and holes can degrade the performance of geographic routing. It is possible to avoid the hole through the long-range knowledge of the network. 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. Through the ETD and LGAs, it is possible to make the best choice of the neighbor nodes around the obstacle or hole and choose the right direction toward the destination.
6. Group Mobility Support: The clustering algorithm running in the 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.

7. 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 reducing the need to update the changes of local topology. Long distance geo-forwarding also helps its network scalability.

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 distance routing and to send the packet outside of the local scope (extra-scope routing), and the second one is used to send the packet inside the local scope (intra-scope routing). It triggers either the geo-forwarding or the table-driven forwarding by checking the IP destination address of the data packet. If the destination address belongs to the current scope, it means that the packet can be sent through 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. If the group dimension increases, intra-scope routing can affect the overall routing protocols. 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.

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, but it 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 a hierarchical knowledge of the network in Geo-LANMAR, we can use this information to choose geo-route with a higher probability to reach the destination by detouring a hole in the network. A landmark node has the knowledge of other landmarks in the network. It will be useful for us to select not only the destination landmark L_D , which may be too far away form source, but also the nearest landmark to L_D that addresses the packet toward a positive direction. This intermediate short-distance target is chosen by some optimization criteria from neighbor landmarks of the fowarding node. This approach avoids the myopic view of geo-routing derived from local topology knowledge. For example, as shown in Fig. 1, it is possible to detect the partition associated with the landmark L_2 and the scope 2 because the source landmark node L_S knows there is no route toward the destination through L_2. So it is possible to avoid sending packets in the wrong direction shown by the dotted line in Fig. 1.

The above scheme does not mean solving any kind of local maximum (e.g., it is possible to reach a hole because of the movement of the nodes or the stale information inside the landmark tables), but it considerably reduces the frequence that local maximum occurs. So that it reduces the number of recovery procedures for the hole failures. In the case of local maximum, the similar perimeter forwarding of GPSR is applied.

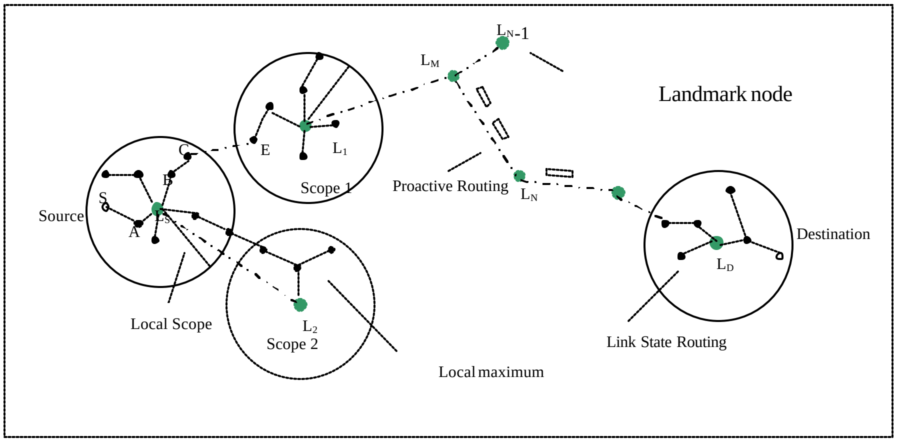

Fig.1: Partition detected in scope 2 as there is no path toward the destination for this local scope

4.3. Effective Traveled Distance & Hole Detection

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 that sends the update packet and the landmark that receives the packet. To send the update packet to other landmarks in the network, the greedy forwarding is used and the perimeter mode can be triggered in the case of recovery from local maximums, such as holes or obstacles.

Imagine that the number of nodes used for the greedy or perimeter mode are n. In this case, the ETD between two neighbor landmarks L_X and L_Y is calculated in the following way (shown in Fig. 2):

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

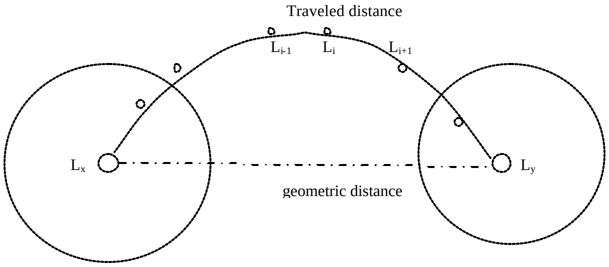

Fig. 2: Real traveled distance or ETD in the virtual topology

To calculate 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), the *ETD* can be calculated as follows:

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

Comparing the ETD $d_{X\text{-}D}$ with the geometric distance $\overline{L_X L_D}$, there can be defined a new index a shown in Eq. 3 representing the deviation of the real route distance from the geometric distance.

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

The index a can change in the range of [0, 1]. If $a \rightarrow 0$, the traveled distance is much higher than the geometric distance, it means that a hole presence, network partition or very long path can be met. If $a \rightarrow 1$, the traveled distance is close to the geometric distance, which shows the shortest path. Typically if the a value of the path *i* is lower than 0.5, it is not suitable to send the data packet on this path because the deviation from the shortest path is high. By the a value calculated in Eq. 3, we may detect the hole at LGA level. In this case, we can select a neighbor Landmark in the network that can avoid the hole. An example is shown in Fig. 3.

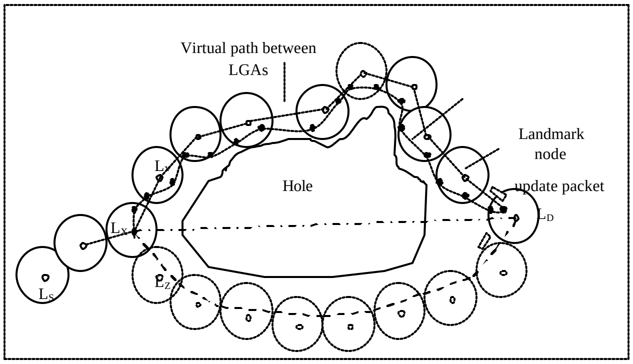

Fig. 3: Virtual Path between LGAs

In Fig. 3, the node L_X receives the update packet from the destination landmark L_D and it can detect a void or a sub-optimal path existed because the geometric distance $\overline{L_X L_D}$ << ETD $d_{X\text{-}D}$, i.e., a ? 0. So the current selected forwarding landmark L_Y may provide a sub-optimal path. We need a better path in this case. Then the landmark L_X will select its neighbor landmark with the highest a value (i. e. shortest traveled distance *ETD*) toward L_D . In Fig. 3, the landmark L_Z is selected. This path toward the landmark L_Z is an optimal path.

5. Geo-LANMAR Routing Table

The previous LANMAR protocol needs to maintain two routing tables: the local routing table and the landmark routing table. The first one is used inside the local scope to execute the table-driven forwarding through the link-state routing protocol (e.g. fisheye, OLSR etc.). This table maintains information about the IP addresses of the other nodes inside the scope and the shortest path toward any couple of nodes. This table is periodically exchanged between the nodes belonging to the local scope according to the adopted intra-scope link-state protocol.

The previous LANMAR version needs to keep the information of all landmark nodes in each node, while 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 can keep the position of the destination landmark L_D and the position of the nearest destination neighbour landmark through a localized query toward the local landmark. This permits the 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 avoids the propagation of long packet inside the local scope when the topology of landmark nodes changes. The drawback of this approach is using a query to get the destination landmark position, but it does not affect the performance because the query is localized to the local scope and it is applied only once at the beginning of the transmission.

This approach is different from that using a location server because in this case we need only a single control packet toward the local landmark and another control packet from the local landmark toward the desired source. When a location server is used, the query to get the position of the destination may involve more nodes. Geo-LANMAR doesn't need a location server because of proactively exchanged information between landmarks.

6. Geo-LANMAR Routing Table Update

In Geo-LANMAR, two kinds of routing table updates are considered: local (intra-scope) update and global (extra-scope) update. The first one is useful in maintaining the consistence of the topology for the link-state routing, and the second one is used to maintain the consistence of the landmark table and to refresh the information of next neighbour landmark toward the destination landmark. The mechanism to send an update packet outside of the local area is based on group mobility. If the gruoup does not move, no topology change is accounted for although there are some internal movements of the nodes in the group.

Two kinds of update schemes are considered in Geo-LANMAR:

1. Local event-driven update propagation: A threshold mechanism is used to determine when to send an update packet to the neighbour LGAs.
2. Global update propagation: It is used as a global update of the virtual topology of LGAs. Each LGA sends update packets to all LGAs in the network. A differentiation of the update rate is used in terms of space and time.

6.1. Local Event-Driven Update

For our scheme, we selected the landmark node as the representative of its LGA because it has been observed through the simulations that it presents the property of staying around the middle of the area. So the landmark node can track the movement of the group and it is possible to obtain the speed, the direction of the LGA, etc. Through this information, some mechanism to decide when to update the packet is proposed and presented in the following.

As an assumption, to simplify the explanation of the scheme, we can consider two nodes that move in the network and we assume the nodes are in the middle of their respective square LGAs as shown in Fig. 4. We assume no error position in the system and the LGA of L_x is fixed. In this case, the tolerance of node X_1 succesfully 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. Here, to be simple for this example, we can 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 and the connection to the destination exists, the packet will be delivered. Immagine that the group associated with L_y moves, in this case, the node L_y needs to update its position to its neighbors when moving over the distance d because, if the update is sent later, the LGA of L_y can not be reached, as shown in Fig. 4.

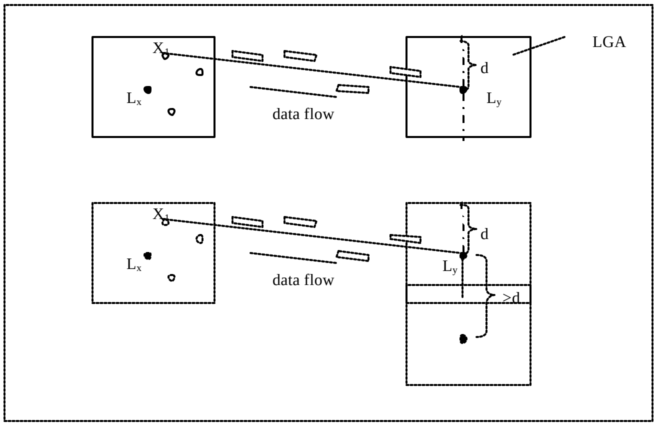

Fig. 4: Local Update based on Group Motion

So the landmark node checks its movement to see whether its traveled distance over a threshold value l. The traveled distance is calculated in this way: 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 it is stored. A sampling interval time $?t$ is considered and in the time the new position of the landamark $(x(t_1), y(t_1))$ is evaluated. So if the following condition is verified, the update packet is sent by the Group Area to the neighbour Group Areas:

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

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

A problem can occur if the landmark node changes 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, and the condition needs to be verified in the way below:

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

After getting the update packet, the new landmark is evaluated by the above condition (Eq. 5). In the instant t_1=t_0+?t, the new landmark is stored and the distance between the location in this instant and the location in new sampling instant will be evaluated. The procedure is repeated when any update arrives.

To calculate the dimension *d* of any LGA, it may use different approaches. For example, if the local scope is *k*, it is possible to fix *d* value as *k*R* where *R* is the transmission range. This is a static approach, and it does not reflect the dynamic of the network inside the local scope. In Fig. 5a, the static approach is presented. Another approach takes advantage of the topology knowledge of the link state routing. It calculates the maximum distance from the landamrk node to the nodes *k*-hop away. So *d* is expressed in the following way:

$$d = \max_{i=1}^{n}\left(\sqrt{\left(x_{L_D}-x_{N\,i}\right)^2+\left(y_{L_D}-y_{N\,i}\right)^2}\right) \qquad (6)$$

where $N_i(x,y)$ is the position of the node *k*-hop away from L_D and *n* is the number of node inside the local scope.

In Fig. 5b, the dynamic area seen by the landmark L_D for a local scope of two hops is shown. The dynamic area can be smaller than the static area when the intra-scope nodes are grouped in the middle of the area.

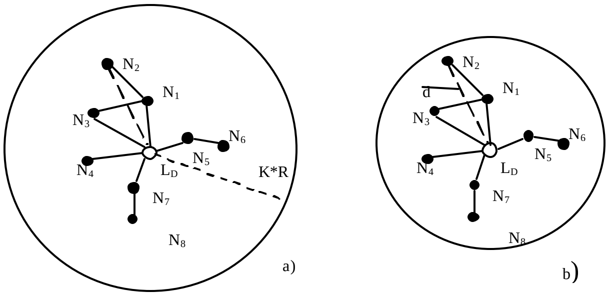

Fig. 5: a) static LGA; b) dynamic LGA

The proposed approach is event-driven and it reacts fast to the topological change. In order to capture the dynamic of the network, the timer, which regulates the updating in the timer-based update forwarding, needs to be reduced, which may produce more overhead. But in Geo-LANMAR, only if either the Eq. 4 or Eq. 5 is met, local update happens, which eliminates un-nessary updates on trivial topology changes and still keeps the topology of local scope accurate enough for packet forwarding.

6.2. Global Update Propagation

In order to offer a better scalability in terms of protocol overhead, a virtual topology among LGAs is defined. This topology is built to have a knowledge of the location of the LGAs and to use the geographic forwarding among LGAs. It is preferred to apply the link-state information propagation among LGAs because it guarantees to have a refreshed information of the location information and a geo-forwarding can be more effectively applied. To reduce the overhead of the link-state propagation to the entire network, we use a link-state routing which limits the scope of link state update dissemination in space and over time, because the position information can be coarsely refreshed for long distance and the position information can be refined when approaching to the destination [9, 11]. The link-state routing applying to the macro-level (LGA level) provides the virtual path availability quickly. The proposed approach localizes the query request inside the local scope where the link-state routing runs (e.g. OLSR, fisheye etc). It also avoids the Location Server management and maintanance [5]. Since any node in Geo-LANMAR can know the zone location LGA_D where the destination can be found, it is no longer necessary to get the position location of the destination through a query in a server disseminated in the wireless ad-hoc network.

The updating mechanism inherits the HSLS approach where the link-state protocol is made more scalable through the rate differentiation in space and over time. Before explaining the link-state propagation, it may be useful to give some details about the virtual topology network among LGAs. It is said that there exists a virtual link between two LGAs if, considering respectively their average dimensions or ranges d_1 and d_2 (refers to Eq. 6), the following condition is verified:

$$D_{L_1L_2} = \sqrt{\left(x_{L_2} - x_{L_1}\right)^2 + \left(y_{L_2} - y_{L_1}\right)^2} < 2\min\left(d_2, d_1\right) \qquad (7)$$

where $D_{L_1L_2}$ is the distance between two landmark nodes L_1 (x_{L_1} , y_{L_1}) and L_2 (x_{L_2} , y_{L_2}), d_1 and d_2 are the dimension or range of the corresponding LGAs.

As shown in Fig. 6, the virtual topology between LGAs is considered. Each landmark node, representantive of a group, transmits a link-state control packet with its location. If the Eq. 7 is not satisfied, the entry in the routing table is set to infinity. By HSLS algorithm, as shown in Fig. 7, the propagation rate is reduced for an increasing number of hops and the topological changes in the landmark's network are aggregated and transmitted in some particular instant of time. Only the update of the first landmark is event-based, then the update until to k hop ($k>1$)is transmitted after a time interval.

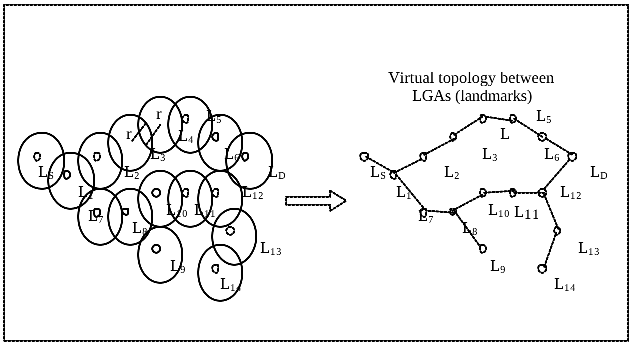

Fig. 6: Virtual topology between landmarks

The HSLS algorithm is applied to propagate the link-state control packet among the landmark nodes. HSLS belongs to the family of the Fuzzy Sighted Link State (FSLS) and it is an optimized version of this class. In the FSLS algorithm, 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_1 (scape within one hop) if there has been a link status change in the last t_e seconds. A link-status change occurs if the Eq. 7 is not satisfied and a virtul link breaks.

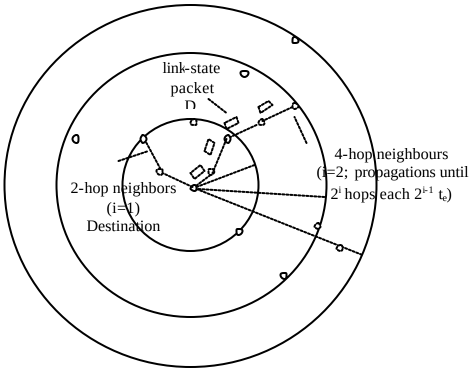

Fig. 7: Link-state updates differentiated in space and over time

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 above approach 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.

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: 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: 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 performances have 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 GEOLANMAR with respect to the traffic load and mobility rate. The last scenario tests the mobility in presence of holes, where the ETD metric and the hole detection mechanism have been evaluated.

In summary, the considered scenarios are summarized as follows:

1. Increasing Number of Group & Traffic Load without Hole:
    - Increasing number of group: The number of group increases from 4 to 36. Total 300 CBR connections are kept when the number of group increases.
    - 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 Holes: In order to test the effectiveness of the novel mechanism (Effective Traveled Distance and Hole 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. 8.

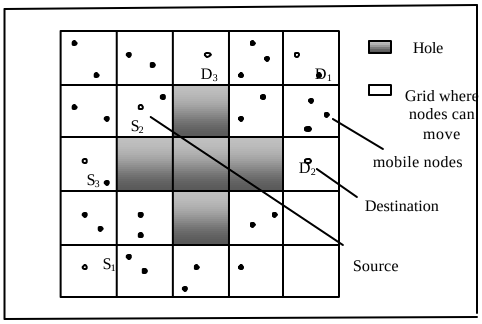

Fig. 8: Link-state updates differentiated in the time and in the space

Table 1: Simulation Parameters

Simulator	QualNet
Simulation Area	1500 m X 1500 m
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 OLSR and FSR intra-scope protocols in comparison with AODV and LANMAR with OLSR are assessed.

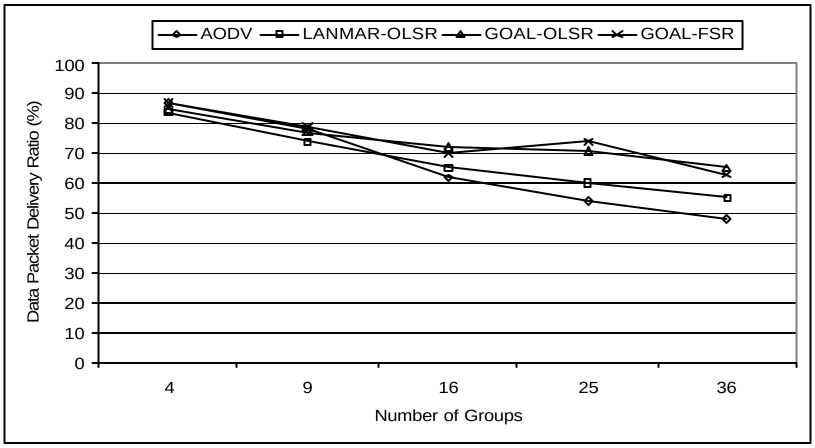

Fig. 9: Data packet delivery ratio vs. increasing number of group. The number of nodes increases according with the number of groups. Here GOAL means Geo-LANMAR.

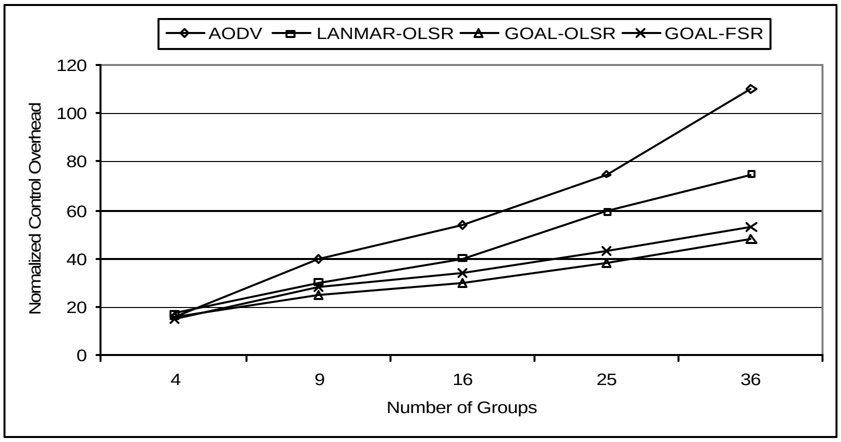

Fig. 10: Normalized Control Overhead vs. increasing number of group. The number of nodes increases according with the number of groups. Here GOAL means Geo-LANMAR.

The scenario depicted in Fig. 9 and Fig. 10 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 optimized HSLS 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. Geo-routing permits more resilience in the link breakage and the delivery ratio increases such as depicted in Fig. 9. In this scenario, because the number of nodes per group is low (any landmark can manage 25 nodes), the difference in terms of performance between Geo-LANMAR with intra-scope OLSR and Geo-LANMAR with intra-scope FSR are not so evident. This suggests that local link-state routing has an impact only when the intra-group density increases. The delivery ratio of AODV is lower than LANMAR and Geo-LANMAR because it reaches wireless channel saturation before other protocols.

The control overhead for the considered routing protocols is shown in Fig. 10. 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.

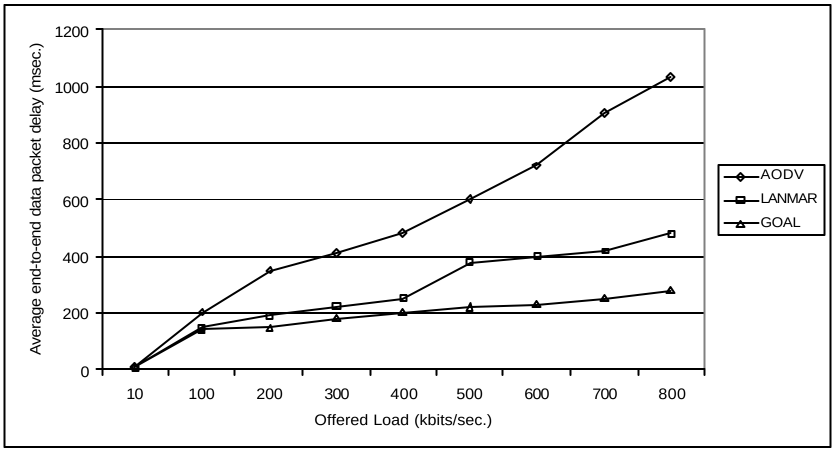

Fig. 11: Average end-to-end delay vs. increasing traffic load. The offered load is increased by increasing the number of connections. Here GOAL means Geo-LANMAR.

The average end-to-end delay when traffic load is increasing is shown in Fig. 11. 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 Holes

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 hole 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 holes or obstacles. So the data packet delivery ratio of GPSR is lower than Geo-LANMAR as shown in Fig. 13.

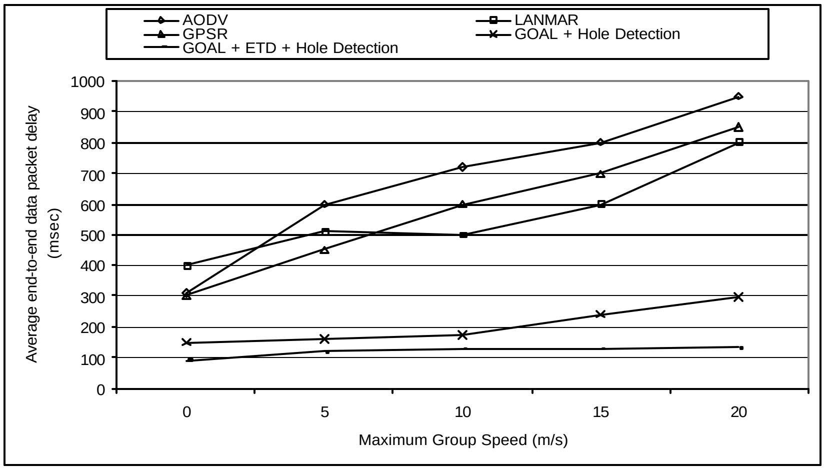

Fig. 12: Average end-to-end delay vs. increasing group speed. Here GOAL means Geo-LANMAR.

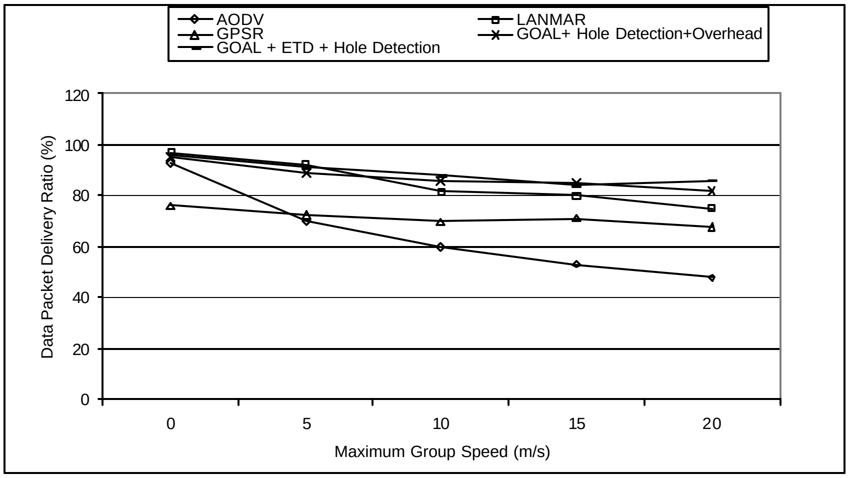

Fig. 13: Data packet delivery ratio vs. increasing group speed. Here GOAL means Geo-LANMAR.

8. Conclusions

A novel routing protocol for scalable wireless ad hoc networks with group motion has been developed. The proposed protocol called Geo-LANMAR introduces the integration between 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 Hazy Sighted Link-State (HSLS) Routing is applied to maintain the locations of LGAs. A hybrid forwarding scheme and a coarse topology knowledge through the HSLS 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 the hole 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 offers much lower update rate required for advertisements and more robust forwarding for long distance routing. So Geo-LANMAR is 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 network in terms of control overhead, end-to-end delay, and packet delivery ratio as compared with other routing protocols.

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