

IETF MANET Working Group
INTERNET-DRAFT
Expiration: May 17, 2001

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November 17, 2000

Landmark Routing Protocol (LANMAR) for Large Scale Ad Hoc Networks

[<draft-ietf-manet-lanmar-00.txt>](#)

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Abstract

The Landmark Routing Protocol (LANMAR) utilizes the concept of "landmark" for scalable routing in large, mobile ad hoc networks. It relies on the notion of group mobility: i.e., a logical group (for example a team of coworkers at a convention) moves in a

coordinated fashion. The network address of a node is <Group ID, Host ID>. A landmark is dynamically elected in each group. The route to a landmark is propagated throughout the network using a Distance Vector mechanism. Separately, each node in the network uses a "scoped" routing algorithm (e.g., FSR) to learn about routes within a given (max number of hops) scope. 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. Once the packet is within the scope of the landmark, it will typically be routed directly to the destination. Remote groups of nodes are "summarized" by the corresponding landmarks. The solution to drifters (i.e., nodes outside of the scope of their landmark) is also handled by LANMAR. Landmark dynamic election enables LANMAR to cope with mobile environments. By using a "scoped" routing scheme, we dramatically reduce routing table size and update overhead in large nets. LANMAR is well suited to provide an efficient and scalable routing solution in large, mobile, ad hoc environments in which group behavior applies and high mobility renders traditional routing schemes inefficient.

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[1.](#) Introduction

This document describes the Landmark Routing Protocol (LANMAR) [[1](#),[2](#)] developed by the Wireless Adaptive Mobility (WAM) Laboratory [[4](#)] at University of California, Los Angeles.

The concept of landmark routing was first introduced in wired area networks [[6](#)]. The original scheme required predefined multi-level hierarchical addressing. The hierarchical address of each node reflects its position within the hierarchy and helps to find a route to it. Each node knows the routes to all the nodes within its hierarchical partition. Moreover, each node knows the routes to various "landmarks" at different hierarchical levels. Packet forwarding is consistent with the landmark hierarchy and the path is gradually refined from the top level hierarchy to lower levels as a packet approaches its destination.

LANMAR borrows the concept of landmark and extends it to the wireless ad hoc environment. LANMAR scheme does not require predefined hierarchical address, but it uses the notion of landmarks to keep track of logical subnets in which the members have a commonality of interests and are likely to move as a "group" (e.g., brigade in the battlefield, colleagues in the same organization, a group of students from same class, or a team of co-workers at a convention and a tank battalion in the battlefield).

Each such logical group has an elected landmark. For each group, underlining "scoped" routing algorithm will provide a one-level scope. The routing update packets are restricted only within the scope. Accurate routing information for nodes within scope is maintained. The routing information to remote nodes (nodes outside the node's scope) is "summarized" by the corresponding landmarks. Thus, the LANMAR scheme largely reduces the routing table size and the routing update traffic overhead. It greatly improves scalability.

In addition, in order to recover from landmark failures, a "landmark" node is elected in each subnet. Landmark election provides a flexible way for the LANMAR protocol to cope with a dynamic and mobile network. The protocol also provides a solution for drifters (Nodes that are outside the fisheye scopes of the landmarks of their logical groups). Extra storage, processing and line overhead will be incurred for landmark election and drifter bookkeeping. However, the design of the algorithms provides solutions without compromising scalability. For example, the routing overhead for handling drifters is typically small if the fraction of drifting nodes is small. More analysis is given in [Section 7](#).

The LANMAR runs on top of a proactive routing protocol. It also requires that the underlining routing protocol support the scoped subnetworking. Fisheye State Routing Protocol (FSR) [[7](#),[8](#)] is such a protocol that supports LANMAR. In FSR, the link state protocol is used within the scope. However, the fisheye scope technique can also be applied to a distance vector type protocol, such as DSDV [[3](#)], in which the hop distance can be used to bind the scope for routing message updating. The main advantage of LANMAR is that the routing table includes only the nodes within the scope and the landmark nodes. This feature greatly improves

scalability by reducing routing table size and update traffic O/H.

Thus the Landmark Routing Protocol provides an efficient and scalable routing solution for a mobile, ad hoc environment while keeping line and storage overhead (O/H) low. Moreover, the election provides a much needed recovery from landmark failures.

[2. Terminology](#)

[2.1. General Terms](#)

This section defines terminology used in LANMAR.

node

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A MANET router that implements Landmark Routing Protocol.

neighbor

Nodes that are within the radio transmission range.

scope

A zone that is bounded by hop distances.

host protocol

A proactive protocol underlines the Landmark Routing Protocol.

subnet

Logical groups of nodes that present similar motion behavior.

group

This is used interchangeably with subnet.

[2.2. Specification Language](#)

The keywords "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",

"SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC 2119](#) [5].

3. Protocol Applicability

3.1. Networking Context

LANMAR is best suited for large scale mobile ad hoc wireless networks. The landmark scheme on top of "scoped" routing algorithm has large advantages in reducing routing update packet size and keeping progressive accurate routes to remote nodes. It achieves high data packet to routing packet ratio. Moreover, the fact that the route error is weighted by distance obviously reduces the sensitivity to network size.

LANMAR is also suited for high mobility ad hoc wireless networks. This is because in a mobility environment, a change on a link far away from the source does not necessarily cause a change in the routing table at the source and that all the information about remote nodes is summarized by landmarks.

3.2. Protocol Characteristics and Mechanisms

* Does the protocol provide support for unidirectional links?(if so, how?)

Yes. Since LANMAR is on top of a host protocol, if the host protocol supports unidirectional links, e.g., the FSR protocol, LANMAR can use the unidirectional link states as well.

* Does the protocol require the use of tunneling? (if so, how?)
No.

* Does the protocol require using some form of source routing? (if so, how?)

No.

* Does the protocol require the use of periodic messaging? (if so, how?)

Yes. The LANMAR periodically broadcasts landmark information to its neighbors. But the updates are piggybacked in the host routing update messages.

* Does the protocol require the use of reliable or sequenced packet delivery? (if so, how?)

No. As the packets are sent periodically, they need not be sent reliably.

* Does the protocol provide support for routing through a multi-technology routing fabric? (if so, how?)

Yes. It is assumed that each node's network interface is assigned a unique IP address.

* Does the protocol provide support for multiple hosts per router? (if so, how?)

Yes. The router that has multiple hosts can use network ID of these hosts as the address to participate LANMAR.

* Does the protocol support the IP addressing architecture? (if so, how?)

Yes. Each node is assumed to have a unique IP address (or set of unique IP addresses in the case of multiple interfaces). The LANMAR references all nodes/interfaces by their IP address.

This version of the LANMAR also supports IP network addressing (network prefixes) for routers that provide access to a network of non-router hosts.

* Does the protocol require link or neighbor status sensing (if so, how?)

No.

* Does the protocol have dependence on a central entity? (if so, how?)

No.

- * Does the protocol function reactively? (if so, how?)

No.

- * Does the protocol function proactively? (if so, how?)

Yes. The LANMAR proactively maintains landmark information at each node.

- * Does the protocol provide loop-free routing? (if so, how?)

Yes. As the protocol uses routing paths learned from the host protocol for in-scope destinations, if the host protocol provides loop-free routing, so does LANMAR. For out-scope destinations, only routes to landmarks are used. Because these routes are DSDV, it is loop free. When a packet is approaching the destination, in-scope routes are used again.

- * Does the protocol provide for sleep period operation?(if so, how?)

Yes. However, this requires TDMA MAC layer support. The router can be scheduled to sleep during idle periods.

- * Does the protocol provide some form of security? (if so, how?)

Yes. When a node broadcasts routing update message, only entries of in-scope nodes and landmarks are included. This will prevent other remote nodes from being heard.

- * Does the protocol provide support for utilizing multi-channel, link-layer technologies? (if so, how?)

Yes. In fact, the multi-channel can be used to separate routing messages from user data packets.

[4. Protocol Overview](#)

[4.1. Protocol Descriptions](#)

As mentioned in [Section 1](#), the landmark concept we adopt here uses the notion of logical subnets in which the members have a commonality of interests and are likely to move as a "group". Each logical subnet has one node serving as a "landmark" of that subnet. The protocol requires that the landmark of each subnet have the knowledge of all the members in its group. The LANMAR protocol also uses a scope at each node. The size of the scope is a parameter measured in hop distance. It is chosen in such a way that if a node is at the center of a subnet, the scope will cover the majority of the subnet members. If the shape of a subnet is likely to be a cycle, the center node's scope will cover all the members of the subnet. If this center node is elected as a landmark, it fulfills the requirement of the protocol. If a landmark does not locate at the center, there will be some members drifting off its scope. The landmark will keep records for these drifters.

The LANMAR relies on an underlining proactive protocol with the ability of providing "scoped" routing. The LANMAR itself is a distance vector type protocol. Each node maintains a distance vector for landmarks of all the subnets and a distance vector for drifters in its subnet. The distance vectors for landmarks and drifters are exchanged through piggybacking in the periodical routing update packets (link state or distance vector) of the underling routing protocol. The size of the landmark distance vector equals to the number of logical subnets and thus landmark nodes. Both sizes of the two distance vectors are small.

The routing update scheme uses the "scoped" routing algorithm. The main idea is summarized below. Each node broadcasts routing information periodically to its immediate neighbors. In each update packet, the node sends routing table entries within its scope and also piggybacks the landmark and drifter distance vectors. Sequence numbers are used in LANMAR update packets. Each node advances its sequence number before sending an update packet. Through the exchange process, the table entries with larger sequence numbers replace the ones with smaller sequence numbers.

Let's take, for example, the FSR as our host protocol. For nodes within the scope, the updating is in a certain frequency. But for nodes beyond the scope, the update frequency is reduced to zero; Only the update frequency of the landmark nodes remains

unaltered. As a result, each node maintains accurate routing information for in-scope nodes and keep routing directions to the landmark nodes for out-scope nodes, or say, for remote groups. A packet directed to a remote destination initially aims at the landmark of that remote group; as it gets closer to the landmark, it may eventually switch to the accurate route to the destination provided by in-scope nodes of the destination.

4.2. Landmark Election

Dynamic election/re-election of landmark node is essential for LANMAR to work in a wireless mobile environment. Basically, each node tracks other nodes of its group in its scope and computes "weight", e.g. the number of the nodes it has found. At the beginning of the LANMAR, no landmark exists. Protocol LANMAR only uses the host protocol functionality. As host routing computation progresses, one of the nodes will learn (from the host protocol's routing table) that more than a certain number of group members (say, T) are in its scope. It then proclaims itself as a landmark for this group and adds itself to the landmark distance vector. The node broadcasts the landmark information to the neighbors jointly with the host update packets.

When more than one node declares itself as a landmark in the same group, as the landmark information floods out, each node will perform a winner competition procedure. Only one landmark for each group will survive and it will be elected. To avoid flapping between landmarks (very possible in a mobile situation), we use hysteresis in the replacement of an existing landmark. I.e., the old landmark is replaced by the new one only if its weight is, say less than $1/2$ of the weight of the current election winner. Once ousted, the old leader needs the full weight superiority to be reinstated.

This procedure is carried out periodically in the background (low overhead, anyway). At steady state, a landmark propagates its presence to all other nodes like a sink in DSDV. It is extremely simple and it converges (by definition). In a mobile environment, an elected landmark may eventually lose its role. The role shifting is a frequent event. In a transient period, there exist several landmarks in a single group. The transient period may be actually the norm at high mobility. This transient behavior can be drastically reduced by using hysteresis.

When a landmark dies, its neighbors will detect the silence after a given timeout. The neighbors of the same group will then take the responsibilities as landmarks and broadcast new landmark information. A new round of landmark election then floods over

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the entire network.

[4.3. Drifters](#)

Typically, all members in a logical subnet are within the scope of the landmark, thus the landmark has a route to all members. It may happen, however, that some of the members "drift off" the scope, for example, a tank in a battalion may become stranded or lost. To keep track of such "drifters", i.e., to make the route to them known to the landmark, the following modification to the routing table exchange is necessary. Each node, say i , on the shortest path between a landmark L and a drifter l associated with that landmark keeps a distance vector entry to l . Note that if l is within the scope of i , this entry is already included in the routing table of node i . When i transmits its distance vector to neighbor, say j , then j will retain the entry to member l only if $d(j,l)$ is smaller than the scope or $d(j,L)$ is smaller than $d(i,L)$. The latter condition occurs if j is on the shortest path from i (and therefore from l) to L . This way, a path is maintained from the landmark to each of its members, including drifters.

The occurrences of drifters are dynamic in a mobile network. In order to timely remove the staled drifter information, the time when a node detects itself a drifter is propagated with the distance vector.

[5. Protocol Specifications](#)

This section discusses the operation of LANMAR routing protocol. The sending and receiving of landmark updates are in the proactive nature. The routing packets are processed separately from ordinary data packets.

[5.1. Data Structures](#)

Each node has a unique "logical" identifier defined by a subnet field and a host field. The host field is unique in the subnet and might in fact coincide with the physical address. The "logical" identifier can also be an IP address when the subnet address can logically group the nodes. Moreover, each node keeps a landmark status as part of identifier. As LANMAR runs on top of a host

routing protocol, it shares the underlining data structures. Particularly, LANMAR requires the underlining data structures to associate a landmark status with each node's identifier. In addition, LANMAR keeps a drifter list and a landmark distance vector.

[5.1.1. Landmark Status](#)

Each node has not only a "logical" identifier, which basically is its address, but also a landmark status. The status includes a flag which indicates whether the node is a landmark or not and a weight (the number of group members the node detects within its scope). Anywhere in the tables of the host protocol, when a node's address is kept, a landmark status is recorded. The status is piggybacked in the periodical routing update packets of the host protocols together with the node address. There are two fields for a status:

- Landmark flag
- Number of group members in its scope

[5.1.2. Landmark Distance Vector](#)

Landmark distance vector (LMDV) gives the next hop information to all landmarks in the network. Every subnet has an entry in LMDV. Initially, the entries in the underlining routing table, which point to landmarks, are copied to LMDV. The LMDV entries are updated when landmark update message is received or underlining topology table is changed. LMDV functions as a part of the routing table. It has the following fields:

- Landmark status
- Next hop address
- Distance

[5.1.3. Drifter List](#)

The drifter list of LANMAR provides the next hop information to forward the packets to the drifters known to the current node. The entries are updated explicitly using landmark update message. It works as a part of routing table. The drifter list (DFDV) has following fields:

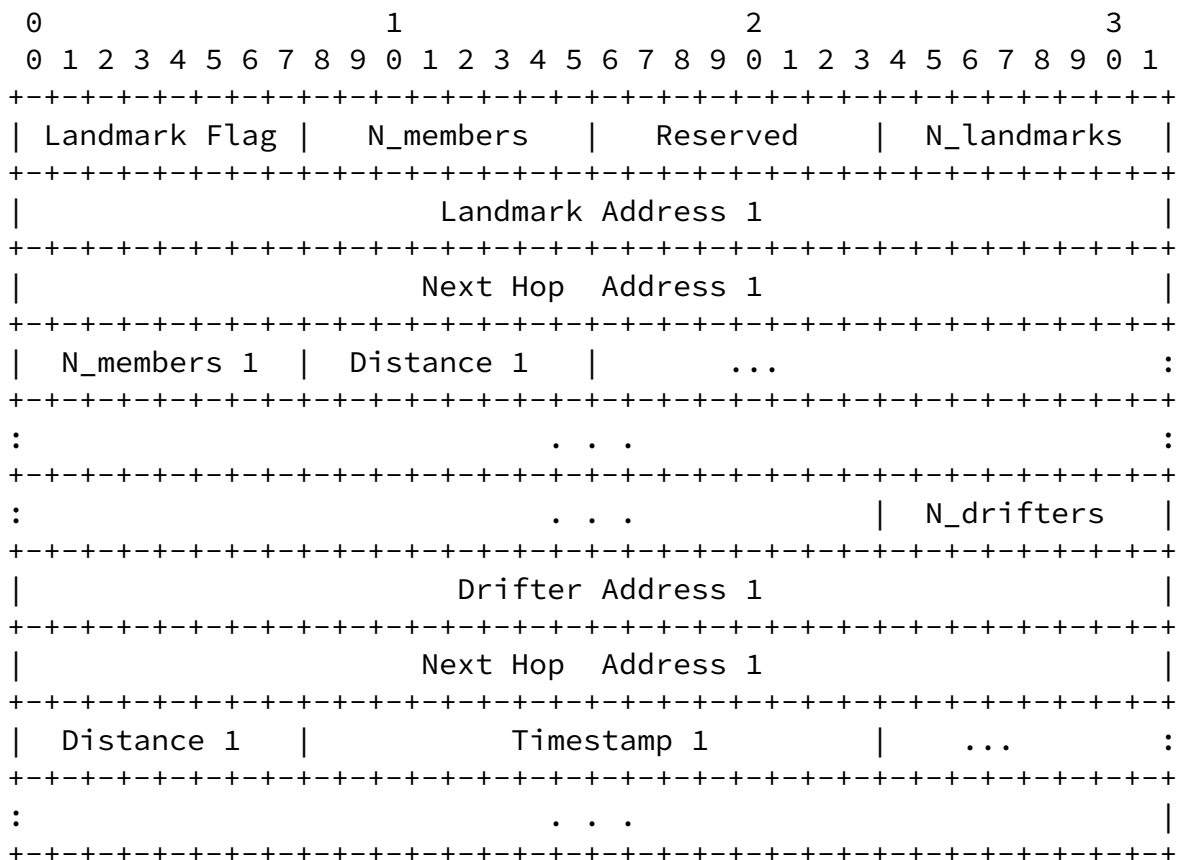
- Destination drifter address

- Next hop address
- Last declaration time

5.2. LANMAR Update Message Format

The messages necessary for LANMAR protocol are piggybacked in the host periodic update packets. The format given below is not exactly how the bits appear in the host update packets. Where to put these fields in the host update packets is an implementation issue. The necessary fields include current node's landmark status (assuming that the node's address can be obtained from IP header), its landmark distance vector LMDV and the drifter list DFDV. The next two subsections will describe how these

information is processed.



5.2.1. Description of the fields

Landmark Flag and N_members

These two fields are the landmark status. N_members is the number of group members in the node's scope.

Reserved

The bits are set to '0' and are ignored on reception.

N_landmarks

The number of entries of the landmark distance vector.

Landmark Address 1, Next Hop Address 1, N_members 1 and Distance 1

The first entry in the landmark distance vector.

Landmark Address 1 and N_members 1 are the destination landmark status.

Next Hop Address 1 and Distance 1 is the next hop and distance

to the landmark.

These fields are repeated N_landmarks times for each entry in landmark distance vector.

N_drifters

The number of entries of the drifter list.

Drifter Address 1, Next Hop Address 1, Distance 1, Timestamp 1

The first entry in the drifter list.

Next Hop Address 1 and Distance 1 are the next hop and distance to the Drifter Address 1.

Timestamp 1 is the time when the node becomes a drifter.

These fields are repeated N_drifters times for each entry in the drifter list.

The length of the message (including the host update fields) is limited to the maximum IP packet size. In that case, multiple

packets may be required to broadcast all the topology entries for host protocol. The landmark distance vector and drifter list will be piggybacked in each packet with the same sequence number.

5.3. Processing Landmark Updates

Landmark update information is a part of the LANMAR periodic routing update message, which is carried in host updating packets. The update information includes sender's landmark status and LMDV. Landmark update message is used for landmark election and helps nodes build their LMDV.

5.3.1. Originating a Landmark in a Subnet

Every time a node detects a topology change, it recalculates the number of group members in its scope. The new number of group members is recorded in its landmark status and replaces the old values in all the tables containing the landmark status. If this number is greater than a threshold T , the node qualifies as a landmark only when there is no landmark for the group according to its LMDV, or it wins the election when competing with the existing landmark. The landmark distance vector is updated accordingly. If the host protocol has new shortest paths to landmarks, the new paths are copied from the host routing table to the LMDV. The landmark status and the LMDV will be broadcast to neighbors with the next host update packet.

5.3.2. Receiving Landmark Updates

When a node receives a landmark update message, it compares its LMDV entries with the incoming LMDV entries for each subnet. New landmark entries will be copied. Competing landmarks will be solved through a winner competition algorithm. The winner will be elected as the landmark for the subnet. The node's landmark status and LMDV will be updated according to the outcomes of the competition. The distance information can be obtained either from the incoming LMDV entry or from host routing table. The updated LMDV and the node's landmark status will be propagated jointly with the host routing update packets.

5.3.3. Winner Competition

When more than one node declares itself as a landmark in the same group, a simple solution is to let the node with the largest number of group members win the election and in case of tie, lowest ID breaks the tie. The other competing nodes defer. However, this method is likely to cause the oscillation of landmark roles between nodes.

To use hysteresis in replacing an existing landmark, let us assume the competing node's number of members is M , the existing landmark's number of members is N and a factor value S . When M is greater than $N*S$, then the competing node replaces the existing landmark. Or, when N reduces to a value smaller than a threshold T , then it gives up the landmark role. A tie occurs when M falls within an interval $[N*1/S, N*S]$, then the node with larger member number wins the election. If a tie occurs again with equal member number, i.e., M equals to N , it is broken using lowest ID. A tie can always be broken using lowest ID as the address is used as ID and it is unique.

[5.4.](#) Processing Drifter Updates

Drifter update information is a part of the LANMAR periodical routing update message, which is carried in host updating packets. The update information is the drifter list (DFDV) of the sender. The computation of the DFDV at each node includes checking the node itself to see whether it is a drifter and recording paths to other drifters.

[5.4.1.](#) Originating a Drifter Entry

By checking the distance to the landmark of its group, each node easily knows whether it has become a drifter. If the distance is larger than the scope, the node will put itself into its drifter

list and record the time instance. This drifter information will be sent back to the landmark hop by hop along the shortest path to it which can be learned from the LMDV. For each drifter, only the node on its shortest path to the landmark needs to receive its information, so before the entry is broadcast, the next hop to landmark is attached with its entry. The DFDV will be propagated with the next host routing update packet.

[5.4.2.](#) Receiving Drifter Updates

Upon receiving an update packet, the DFDV part is retrieved and processed. If an entry of incoming DFDV indicates that the current node is its next hop to the landmark, i.e., the current node is on the drifter's shortest path to the landmark, the current node will insert or update its drifter list. The node sending the update packet is recorded as the next hop to the drifter. The reverse path to the drifter is thus built up. The procedure ends when the landmark receives the drifter entry. The updated DFDV will be propagated with the next host routing update packet.

[6.](#) Data Packet Forwarding

Data packets are relayed hop by hop. The host protocol routing table, drifter list and landmark distance vector are looked up sequentially for the destination entry. If the destination is within a node's scope, the entry can be found directly in the routing table and the packet is forwarded to the next hop node. Otherwise, the drifter list DFDV is searched for the destination. If the entry is found, the packet is forwarded using the next hop address from DFDV. If not, the logical subnet field of the destination is retrieved and the LMDV entry of the landmark corresponding to the destination's logical subnet is searched. The data packet is then routed towards the landmark using the next hop address from LMDV. The packet, however, is not necessary to pass through the landmark. Rather, once the packet gets within the scope of the destination on its way towards the landmark, it is routed to the destination directly.

[7.](#) Discussion about Storage and Processing Overhead for Drifters

The routing storage and processing overhead introduced by the distance vector extension to handle drifters is typically small if the fraction of drifting nodes is small. Consider a network with N nodes and L landmarks, and assume that a fraction F of the members of each logical subnet have drifted. In the worst case, the path length from landmark to drifter is the square root of N

(assuming a grid topology). Thus, \sqrt{N} is the bound on the number of extra routing entries required at the nodes along the path to the drifter. The total number of extra routing entries is $\sqrt{N} * L * (F * N / L)$ where N/L is the average logical group size. Thus, the extra storage per node is $F * \sqrt{N}$. Now, let us assume that the number of nodes in the scope = # of landmarks = logical group size = \sqrt{N} . Then, the basic routing table overhead per node (excluding drifters) is $3 * \sqrt{N}$. Thus, the extra overhead caused by drifters is $F/3$. If 20% of the nodes in a group are outside of the landmark scope, i.e., have drifted, the extra routing O/H required to keep track of them is only 7%.

Acknowledgments

This work was supported in part by NSF under contract ANI-9814675 and in part by DARPA under contract DAAB07-97-C-D321.

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