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ABSTRACT

SCALABLE WIDE AREA AD-HOC NETWORKING

by
Nithin Bose

The scalability problem of routing algorithms in Mobile Ad-hoc networks (MANET) has conventionally been addressed by introducing hierarchical architectures, clusters, and neighborhood zones. In all of these approaches, some nodes are assigned different routing related roles than others. Examples include cluster heads, virtual backbones and border nodes. The selection of these nodes on a fixed or dynamic basis adds complexity to the routing algorithm, in addition to placing significant demands on mobility and power consumption of these nodes. Furthermore, the scalability achieved with hierarchical architectures or partitions is limited.

This thesis demonstrates that location awareness can greatly aid in MANET routing and proposes an enhancement to location management algorithm used by the Terminodes System. This thesis makes use of geographic packet forwarding, geocasting and virtual home area concepts. It draws from the analogy between ad hoc networks and social networks. The Scalable Wide Area ad hoc network (SWAN), nodes update their location information with a geocast group whose area is given by a well-known function. A source node queries the geocast group of the destination and obtains up to date location information. Then, packets are geographically routed to the destination. The SWAN algorithm also optimizes the control overhead and obtains location information with minimal delay. This thesis also presents the results of our comparative performance study.

SCALABLE WIDE AREA AD-HOC NETWORKING

by
Nithin Bose

Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Computer Engineering

Department of Electrical and Computer Engineering

January 2005

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This thesis is dedicated to my dad, my mom, my sister and my brother-in-law and to their unending support through all the difficult times of my life. A special dedication to my Ravi mama, thanks for all that you have done for us. We will never forget you.

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LIST OF DEFINITIONS

MANET	Mobile Ad-hoc network
VHLR	Virtual Home Location Register
LU	Location Update Message – used to update the home location register with the current location information
LQ	Location Query Message – used to query the home location register for a particular nodes location.
LR	Location Query Reply Message – response message to a location query, sent by the nodes in the queried home cell.
TR	Table Refresh Message – refresh mechanism to keep the location tables synchronized in each of the home cell nodes.
Geocasting	Multicasting a message to a particular coverage area denoted by a set of geographic coordinates
Geodesic packet forwarding	Packet forwarding based on the targets geographical location.

CHAPTER 1

INTRODUCTION

1.1 Abstract

The scalability problem of routing algorithms in Mobile Ad-hoc networks (MANET) has conventionally been addressed by introducing hierarchical architectures, clusters, and neighborhood zones. In all of these approaches, some nodes are assigned different routing related roles than others; examples include cluster heads, virtual backbones and border nodes. The selection of these nodes on a fixed or dynamic basis adds complexity to the routing algorithm, in addition to placing significant demands on mobility and power consumption of these nodes. Furthermore, the scalability achieved with hierarchical architectures or partitions is limited. This thesis demonstrates that location awareness can greatly aid in MANET routing and proposes an enhancement to location management algorithm used by the Terminodes System [1]. The thesis makes use of geographic packet forwarding, geocasting and virtual home area concepts. Scalable Wide Area Ad-Hoc Networking (SWAN) optimizes the control overhead and obtains location information with minimal delay. It also presents the results of a comparative performance study between the SWAN protocol and flooding.

1.2 Introduction

Mobile Ad-hoc Network is a networking concept that defines mechanisms using which mobiles form a temporary community without any planned installation, or human intervention. In a MANET, each node acts as a host and as a router. This means that each node participating in a MANET also forwards data packets from a neighboring node to another until a final destination is reached. The survival of a MANET relies on the cooperation between its members.

The most challenging problem in conjunction with ad hoc networks is routing. This is due to the very characteristics of ad-hoc networks such as high degree of mobility, decentralized administration and limited resources. Many algorithms have been proposed to tackle the routing problem with MANETs as discussed in the following sections.

The thesis draws from the following analogy between ad hoc networks and social networks. In social networks, to hand-deliver a package to an individual, a courier who only knows the individual's name and workplace (or department, or hometown) would first go to the workplace and ask for the individual's whereabouts. The colleagues (or neighbors) of the individual would know where he/she is at that time, so that the courier would head in that direction. The courier would get increasingly granular location information about the individual as he approaches the individual. Similarly, in the Scalable Wide Area Ad-Hoc Networking (SWAN) model, nodes update their location information with a geocast group whose area is given by a given function. This function is common knowledge to all nodes. A source node queries the geocast group of the destination and obtains up to date location information. Then, packets are geographically routed to the destination. Because of such cooperation, at the feasible cost of geocast area mapping information, users can send packets and destination ids "into thin air" and have the packets delivered.

CHAPTER 2

RELATED WORK

A routing protocol for MANETs should not only react quickly to the dynamically changing topology of the network but it should also maintain a minimal control traffic in order to preserve the available resources such as bandwidth, battery power [2]. Existing routing schemes can be broadly categorized into topological and location aware protocols. Both schemes rely on flooding mechanisms and traditionally been used in packet-switched networks. They both allow a node to determine the next hop along the "shortest path" toward a given destination. The shortest path is computed according to a specific cost, which is usually the distance in number of hops.

2.1 Topological Protocols

The topological protocols were the initial protocols developed for routing in mobile ad-hoc networks. They can be classified as proactive, reactive and hybrid protocols, based on when the route information is actually gathered by a node. Proactive schemes are simpler to implement and fast, however have higher control overhead. They are more suitable for low mobility networks and with fewer nodes. Reactive schemes are prudent on how much control traffic is put on the air, but slower than proactive schemes. They are more scalable than proactive schemes and can handle higher mobility without a high impact on performance. Hybrid schemes combine the benefits of both proactive and reactive. The following sections describe each of the protocols in detail.

2.1.1 Proactive Algorithms

Proactive algorithms employ wire-line routing strategies such as distance-vector routing (e.g., DSDV [3]) or link-state routing, for example, Optimized Link State Routing (OLSR) [4] and Topology Broadcast Based on Reverse-Path Forwarding (TBRPF) [5]. These algorithms maintain routing information about all the available paths in the network even if these paths are not currently used. The main drawback of these approaches is that the maintenance of unused paths may occupy a significant part of the available bandwidth if the topology of the network changes frequently [6]. Also high signaling traffic is required to maintain location information of all nodes by each node. Proactive algorithms however have short route discovery times.

2.1.2 Reactive Algorithms

Reactive protocols, also called source-initiated or on-demand protocols, offer routing information with some latency since they launch the route discovery process on demand, i.e., the first time the respective destination is addressed. Reactive routing protocols maintain only the routes that are currently in use, thereby reducing the burden on the network when only a small subset of all available routes is in use at any time. Ad hoc On Demand Distance Vector (AODV) [7], the Temporally-Ordered Routing Algorithm (TORA) [8], and the Dynamic Source Routing (DSR) [9] protocols belong to the class of reactive protocols. In addition to the route discovery latency, even though route maintenance for reactive algorithms is restricted to the routes currently in use, these algorithms may generate a significant amount of network traffic when the topology of the network changes frequently.

2.1.3 Hybrid Algorithms

Hybrid protocols combine both proactive and reactive routing approaches, using the proactive scheme for the local area routing and the reactive scheme for remote area routing. A good example for hybrid protocol is the Zone Routing Protocol (ZRP) [10] developed by Haas and Pearlman. However, even a combination of both strategies still needs to maintain at least those network paths that are currently in use, limiting the amount of topological changes that can be tolerated within a given amount of time.

2.2 Location Sensitive Protocols

Native proactive, reactive and hybrid protocols have an inherent problem that they completely depend on the topology and pose a high control overhead. This shortcoming is overcome by location-aware routing protocols that utilize additional geographical location information of the nodes in the network to find the route or to forward the message. Location Aided Routing (LAR), Location Aided Knowledge Extraction Routing (LAKER), Location Area Based Ad hoc Routing (LABAR) and Terminodes are prominent examples of location aided routing protocols. Each of these protocols is discussed in detail in the following sections.

2.2.1 Location-Aided Routing (LAR)

In Location-Aided Routing (LAR) [11], a source node S uses available location information about a destination D to compute the expected zone where D could be potentially located. The expected area could be a circular region with the center being the last known location of D and radius being the distance D could have moved given its known speed. A request zone is created which encloses S and the expected region in which the route request is sent. When D receives the request, it replies to S with the route reply. Ko and Vaidya [11] have provided various shapes for the request zone, to optimize the number of route request packets being sent across the network. Iera, et al. [12] proposed adaptive request zones where the request zone is reduced as the route request travels along intermediate nodes, based on any additional information available.

The LAR protocol assumes that the mobile nodes have the location information and the speed of all other nodes in the ad hoc network. This assumption is reasonable in a small to mid-size MANET, however this would not be plausible with wide area ad hoc networks. In wide area networks, there would be a lot of control overhead to distribute location information. If only data messages and route replies are used for location information exchange, there would be a high latency and expensive location updating mechanism.

2.2.2 Location-Aided Knowledge Extraction Routing (LAKER)

Location Aided Knowledge Extraction Routing (LAKER) [13] protocol attempts to exploit the topological characteristics of networks and limit the search space in route discovery. The LAKER system utilizes a combination of caching strategy of DSR and the limited flooding area strategy of LAR protocol. It works on the assumption that even though individual nodes move frequently in the MANET, there are clustered zones in the network and the structure of these clustered places is not expected to change as rapidly as individual nodes would.

The LAKER protocol uses *guiding*_routes, which is comprised of a series of locations along the active path between a source and a destination where there seem to be many nodes clustered together. The *guiding*_routes are cached and are used as a guide to determine where to flood during the route setup process. The two major advantages of using a guiding_*route* is that it firstly guides the route discovery direction more precisely and secondly further narrows the search space and smartly passes around some void area that exists in the network.

2.2.3 Location Area Based Ad hoc Routing (LABAR)

Location Area Based Ad Hoc Routing (LABAR) [14] is a novel MANET routing algorithm, which attempts to address the problem of not all nodes in the MANET containing location aware equipment. The LABAR system segregates the nodes into location aware G nodes and location unaware S nodes. At network initiation, each of the S nodes associates themselves to one G node. The set of all S nodes that are associated with one G node is the zone of that G node. As a next step, one root G node, sends a connect message to other zones to create a virtual backbone connecting all the zones in the MANET. Routing packets between nodes in the network involves identification of the destination node's zone to route the data in the direction of the destination zone. The IP address to geographical location mapping is done by the G-nodes using the virtual backbone.

The LABAR protocol attempts to remove the requirement of all nodes to be location aware, but in the process puts additional dependency on the location aware nodes. If the mobility of G nodes were limited, LABAR performance would be close to the optimal shortest path first algorithm. However, if the G nodes have a high degree of mobility, the overhead of reconstructing the zones and the virtual backbone can pose a problem to network throughput.

2.2.4 Terminodes

L. BlaZevit, S. Giordano, et all. [15], describe an end-to-end approach to build homogenous, self-organizing, wide area ad hoc networks. Terminodes use a combination of two routing methods: Terminode Local Routing (TLR) and Terminode Remote Routing (TRR). Terminode local routing is inspired by the techniques used in ZRP. Whereas the remote routing protocol is based on geographic information routing mechanism and is this facet, which helps the MANET scale to support wide area networks. The TRR protocol is used for routing until the near vicinity of the destination, once near the destination TLR mode takes over. The TLR protocol is similar to ZRP Intra-zone Routing Protocol (IARP), where each node contains the information about all the other nodes in the zone and it uses distance vector routing to forward the packet to the intended node.

Remote routing is used to reach a node outside of the TLR zone. Terminodes uses Anchored geodesic packet forwarding technique [1]. Both parts of the Terminode packet forwarding mechanism depend on knowing the location of the destination. To determine this information, virtual home location register (VHR) is used. In this architecture, each node advertises its current position to a geographical region called the virtual home region. The VHR has a fixed center CVHR and a variable radius that adapts to the density of the area containing the VHR, in order to maintain an approximately constant number of nodes inside the VHR. Each node in the network periodically updates the VHR with its location information, so that if some other node is hoping to find this node, then it can query the VHR and obtain this information.

2.3 Supporting Technologies

2.3.1 Geocast

Geocast is a specialized location-dependent multicasting technique, where messages are multicast to some specific user groups within a specific zone. While conventional multicast protocols define a multicast group as a set of nodes with a multicast address and geocasting, the protocols define a geocast group as the set of all nodes within a specified geographical region at a particular time instant. Hosts within the specified region at a given time form the geocast group at that time. The membership changes depending upon the movement of the mobile nodes with respect to the geocast region, when the nodes leave or enter the geocast region.

Flooding is the concept used for geocasting in its native form. Assume a source node S has to send a packet to the nodes D, E and F within the geocast region. Node S sends the packet to all its neighbors. A neighbor node say, A or B, compares the specified region's coordinates with its own coordinates. (Assuming all hosts are able to determine their own location using GPS mechanisms.) If the location of A or B is within the geocast region, it accepts the packet and broadcasts it to its neighbors. If the location of A or B is not within the geocast region and if they have not received the packet before then it simply broadcasts the packet to its neighbors without accepting it. If any node receives the same packet twice then it discards the packet. Same packets are detected using sequence numbers.

The currently existing geocast routing protocols may be broadly categorized under two headings namely: Data-transmission oriented protocols and Routing-creation oriented protocols. The difference between these two types lies in the procedure they adopt to transmit the information from the source to one or more nodes in the geocast region.

2.3.2 Geodesic Packet Forwarding

The mathematical meaning of geodesic is "The shortest line between two points on a mathematically defined surface (as a straight line on a plane or an arc of a great circle on a sphere)". Extending this meaning of geodesic and applying it to the ad hoc networking domain, geodesic packet forwarding may be described as a concept where in a packet is forwarded from the source to the destination via a shortest path of neighbor nodes which are in the direction of the destination. That is, every time a node has to forward a packet, it forwards it to only those neighbors who are in the direction of the destination and who are closer to the destination than itself. This happens when there is no direct path of connection between the source and the destination.

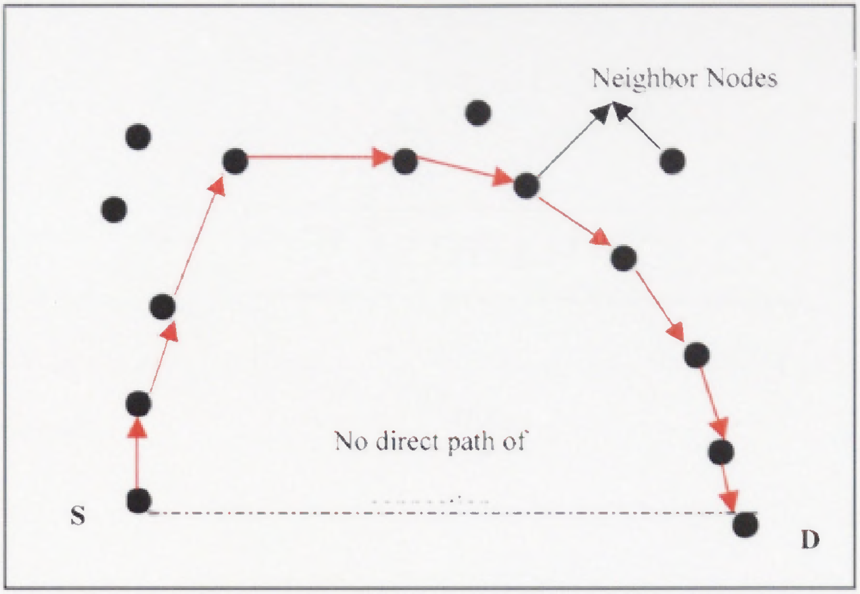

Figure 2.1 An illustration of Geodesic Packet Forwarding.

In the above example, Node S (source) wants to send a packet to Node D (destination) and there is no straight path of connection between S and D. In this scenario, first S discovers the location-dependent address (normally a triplet of geographic co-ordinates – latitude, longitude and altitude) of D using any kind of mobility management technique. Then S sends a packet to some neighbor say, A within a certain transmission range. The neighbor A is that neighbor which is the closest to the destination node D amongst all the neighbors of node S. Finally, node A also performs the same steps. It checks if it has a direct path to D, if not A forwards the packet to its neighbor who is in line of D and closest to D.

One of the variants of Geodesic Packet Forwarding is Anchored Geodesic Packet Forwarding (AGPF) as discussed in the Terminodes project [1]. AGPF uses anchors, an anchor is a point defined by certain geographic co-ordinates. The source node computes the anchors using source discovery methods. In AGPF, a source node adds a route vector described by a list of anchors, to the packet it is forwarding. This route vector will be used for loose source routing. When a neighbor receives a packet with a route, vector it checks whether it is close to the first anchor in the list. If so it removes, the first anchor and sends it towards the next anchor or the final destination itself using native geodesic packet forwarding.

CHAPTER 3

SWAN ALGORITHM

This thesis proposes an extension to the Terminode setup [1], especially on the location management aspect to offer a more efficient approach for location query and update mechanisms and to provide scalability in a self-organizing wide area ad-hoc network. The following sections provide details on how the SWAN setup works.

3.1 Ad-hoc "Virtual Cellular" Layout

The MANET coverage area is divided into a set of tiled virtual cells. Each cell is defined by a set of GPS co-ordinates. The cells are adjacent to each other and do not overlap and are identified by a unique cell number. For simplicity, the cells can be designed as rectangular shaped tiles, defined by a quadrant of GPS co-ordinates. Alternatively, the cell could also be a circle identified by co-ordinates of the center and radius.

3.2 Virtual Home Cell

Each of the MANET nodes belongs to one and only one cell, called the home cell at any point in time. The home cell for any mobile node is determined by a mapping function that is publicly known to the entire ad hoc network. The mapping function should be chosen such that the distribution of the nodes to the cells is uniform over a random sample of nodes. A simple hash function based on the mobile ID can be used to map a given node to the cell. The home cell for a node remains the same unless its ID changes.

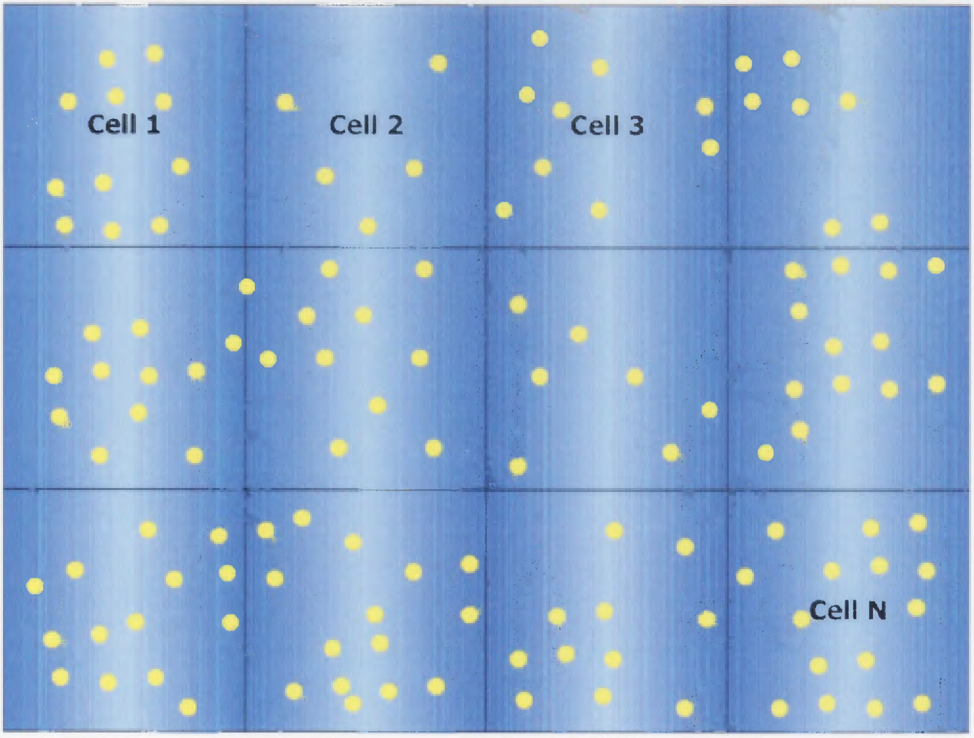

Figure 3.1 The SWAN "virtual cellular" layout.

3.3 Virtual Home Location Register

Each of the SWAN cells acts as the virtual home location register (VHLR) for a subsection of the nodes in the MANET. All the nodes in the network are assigned a home register where the location information about them is stored. The VHLR is built and maintained across all the mobile nodes present in that cell at any given instant in time. No backbone or infrastructure nodes need to be present. Every node entering a cell from a different cell empties its previous VHLR and downloads the new VHLR from its new neighbors.

If any node X needs to locate another node Y in the MANET, X would send a query message to the home cell HC-Y of node Y, one or many nodes in HC-Y would reply to X with the location information about Y. Once the location of the destination is known, the source can initiate a conversation using any location sensitive packet forwarding mechanism such as geodesic forwarding [16].

3.4 Location Update

All mobile nodes in the MANET register themselves with their respective home registers (VHLR) by sending a location update (LU) message. These messages carry information regarding the nodes current location. The update information transmitted is stored in the location tables of the nodes, which is used to service any further location queries.

The distance based location update scheme as discussed by Woo Jin [19] can be used to determine when to send the location update messages. In this scheme, the location update message is sent by a node only if it wanders more than a predefined distance R from the location it last performed an update. The location update message is sent to the home cell area by geodesic forwarding technique until it reaches the home cell boundary. The fields in the LU message and hence, in the VHLR tables is listed in Table 3.1.

A potential improvement to the location update mechanism to conserve control bandwidth in the network is to alter the frequency of LU messages can be modified to update selective home cells depending on mobility and topology. With more LU messages being sent to the home cell which would be queried more likelier than the other home cells.

Table 3.1 Fields in the Location Update Message

Sl	Field	Description
1	Node ID	Unique node id for source node
2	Home Cell	Home Cell Identification number
3	Sequence Number	Monotonically increasing sequence number
4	Current Cell	Current Cell Identification number

The Figure 3.2 shows the packet flow for a location update messages from its current cell to its home page and the propagation of the update message inside the home cell.

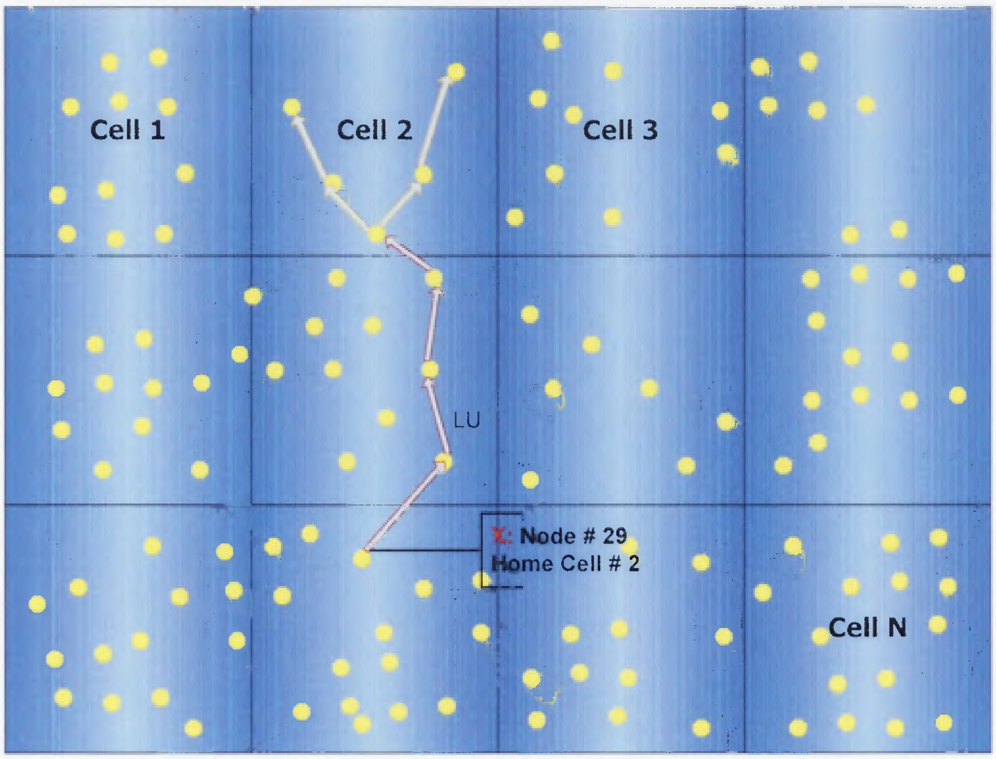

Figure 3.2 Example of a location update packet flow.

3.5 Location Table Synchronization

Each node in the MANET maintains a Location Table (LT) containing the location information about the nodes belonging to the cell that it currently resides in. The location table collated across the nodes across each cell constitutes the VHLR for any given cell. The LU message once received by any one of the nodes in the home area is processed and the local LT is updated. However, the LU message is not forwarded in the home area any further. Instead, the registration entry is cached for a certain predefined time-period, waiting for further registration packets.

After a predetermined time-out period, all nodes in the VHLR forward their entire LT to all other nodes in the same VHLR as a Table Refresh (TR) packet. To ensure that the TR packets for various cells are not sent at the same time, the time-out period can be offset for each cell in the MANET. If any conflicts arise for LU messages for the same remote node from many VHLR nodes, then the update with the most recent timestamp is used. With a high time out, not all nodes in the home cell will have exact location information for any node belonging to the home cell. Hence, some queries may result in stale location results. Depending on the network requirements, this parameter could be optimized.

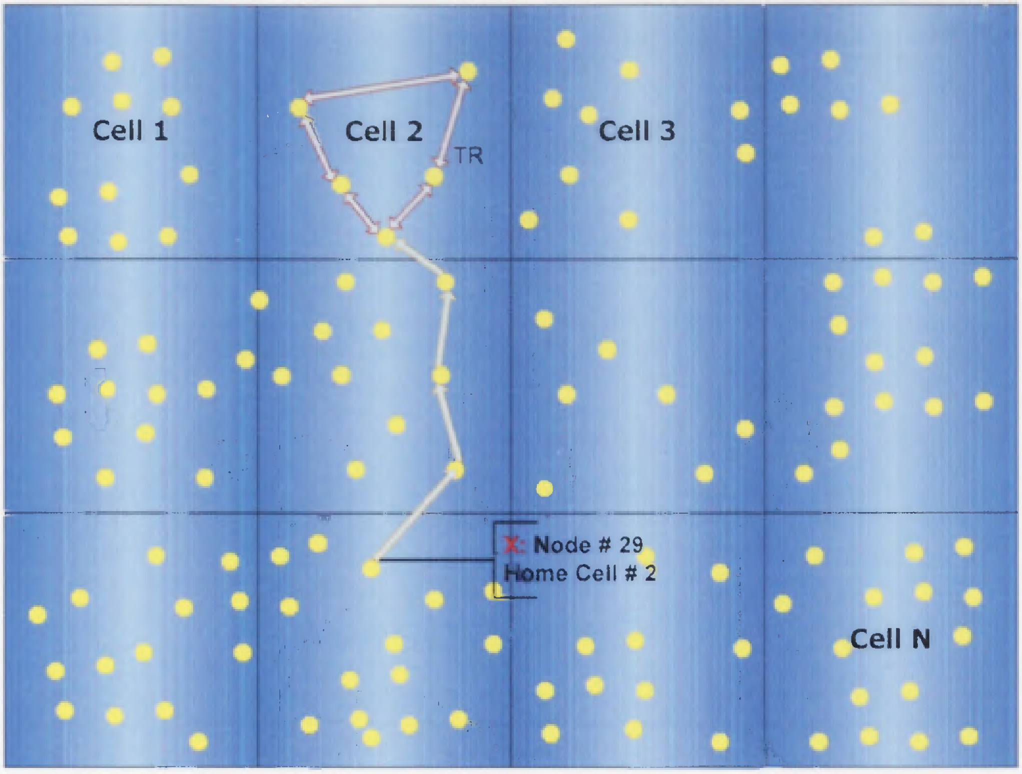

Figure 3.3 Example of a location table refresh packet flow.

3.6 Location Query

Any source node that needs to establish a connection with another mobile node first checks in the local routing table, if the location information is present locally. If the local information is present and has not expired, a packet is sent directly in the direction of the assumed location of the destination node.

If the location information is not present locally or the entry has expired, then the source node first determines the nearest VHLR of the destination node using the global node-cell mapping function. The source node then sends a location query (LQ) message out to the VHLR inquiring about the location information of the destination node. The source node waits for a preset time-out period for a reply to the LQ message. If the reply does not arrive, then the source node sends another LQ message to the VHLR. After three trials, the source node indicates to the upper layers that the connection establishment failed. Table 3.2 describes all the elements of a LQ message.

Table 3-2 Fields in Location Query Message

Sl	Field	Description
1	Source Node Id	Unique node id for source node
2	Destination Node Id	Unique node id for destination node
3	Sequence Number	Monotonically increasing sequence number
4	Source co-ordinates	Geographic coordinates for the VHLR to respond with a unicast reply message

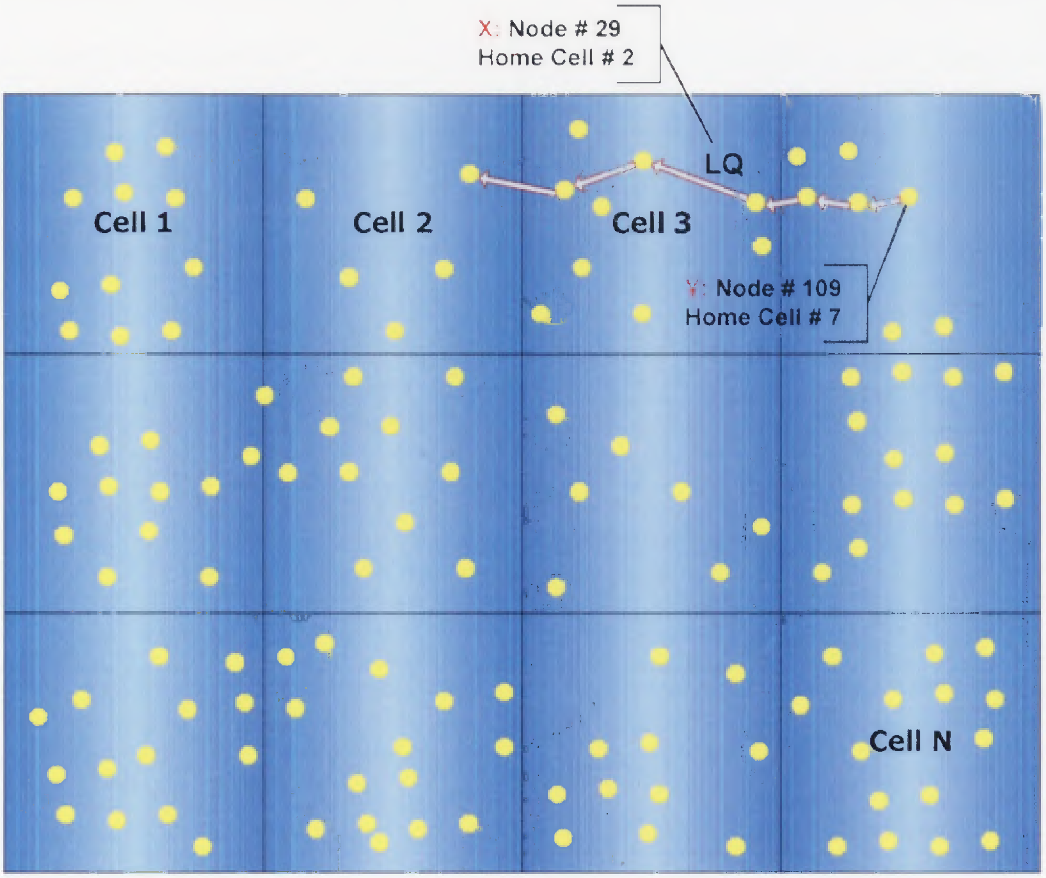

Figure 3.4 Example of a location query packet flow.

3.7 Location Query Response

Once a VHLR node receives a LQ message, the VHLR nodes respond to the source X with a location query response (LR) message. Since multiple VHLR nodes, can receive the query message sent from S and reply to S, the source node waits for a small-predefined amount of time after it gets the first location response to check if any more nodes reply. If there are multiple replies, the location query reply with the latest timestamp is used.

To optimize the traffic caused by a location query and location response messages, instead of the location query message being propagated to all the nodes in the HLR, it is forwarded to the limited set of neighbors only. If any node receives a duplicate query, they are not forwarded. The number of hops (LQ Hop Count) the query needs to be forwarded can be decided based on the time elapsed since the last location table refresh occurred. The more time has passed more the number of hops that need to be covered. There exists a probability of the source node not being able to locate the correct location of the destination. To reduce this probability, the LQ hop count can be increased if the network mandates such a requirement. If SWAN LQ fails, the node could revert to any other mechanisms of route discovery.

Table 3.3 Fields in Location Reply Message

Sl	Field	Description
1	Source Node Id	Unique node id for source node
2	Destination Node Id	Unique node id for destination node
3	Sequence Number	Sequence number used for LQ message
4	Destination co-ordinates	Geographic coordinates of the destination
5	Destination Cell Id	Home cell number/GPS co-ordinates

CHAPTER 4

THE SIMULATION MODEL

For simulation purposes, the SWAN algorithm is compared with the naïve MANET packet flooding algorithm. The comparison is based on the amount of control traffic generated to locate any node by any other node in the network. During the simulation the SWAN algorithm was not completely implemented and the simulation results were obtained from a simplified version of the algorithm. Hence, some of the results shown below will contain both the SWAN-ideal and SWAN-simulated entries. The SWAN-ideal results were mathematically obtained from the simulated network.

4.1 Assumptions

The SWAN algorithm assumes that all the nodes know each other's identification information such as the mobile node Id. The algorithm also assumes that the nodes in the MANET are cognizant of the network information such as the mapping function and number of cells that comprise the VHLR. This information can be passed on to a new node joining the network along with the hello packets.

4.2 Traffic Categorization

Traffic can be categorized into data and control messages. The control traffic consists of Location Update, Table Refresh, Location Query and Location Response Messages. Control traffic also includes hello packets exchanged between nodes. These hello packets help nodes keep track of their neighbors.

4.3 Control Overhead

Control overhead in SWAN can be estimated using the number of packet transmissions taken for a route discovery. The number of route request used in SWAN is compared with a similar transmission count for the flooding algorithm where the route request eventually reaches all the nodes in the network. Any transmission from the source to the destination after the route discovery in SWAN can be considered as a data packet itself and is not used in this comparison. As shown in the Figure 4.1, the number of packets transmitted in SWAN is substantially lower than in the flood mode. This difference is magnified with the increase in the number of nodes in the network.

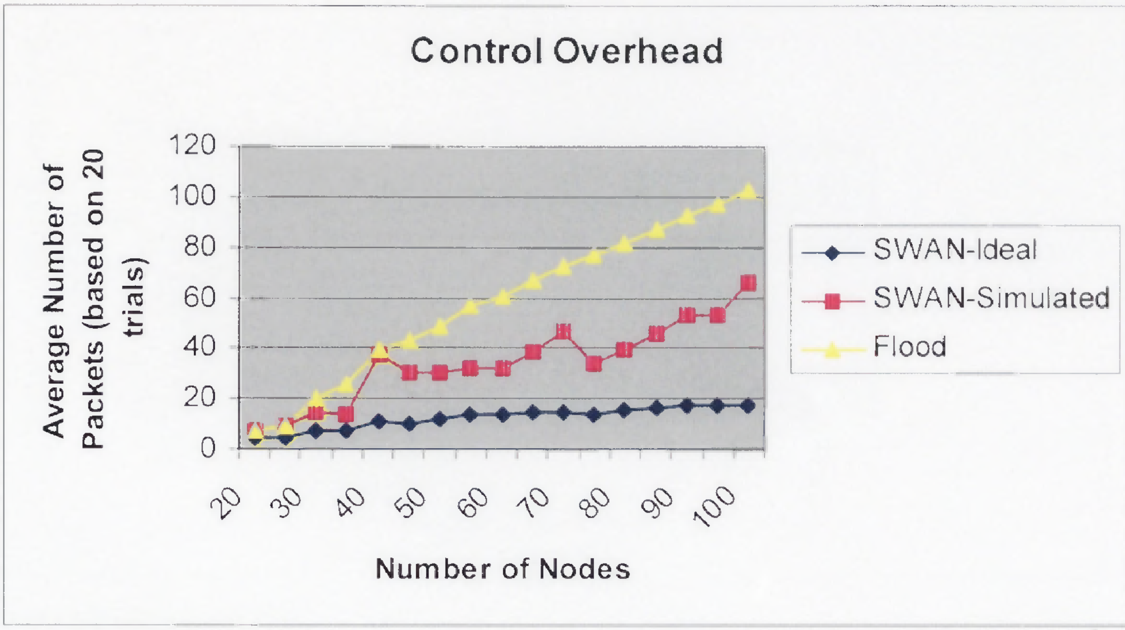

Figure 4.1 Hop count in flooding and SWAN protocols.

4.4 Delay Characteristics

The delay characteristics were obtained from the same simulation runs used to obtain the hop count analysis. Delay in SWAN node discovery is defined as the time taken between the point the location query message was dispatched from the source to the time it takes for the location reply message to reach the source from the VHLR. The delay in obtaining a response in SWAN when compared to a flooding algorithm is slightly higher. And increases in a linear fashion when compared to flooding, as shown in the Figure 4.2. The delay involved in SWAN can be reduced by the optimizations discussed in the scalability section.

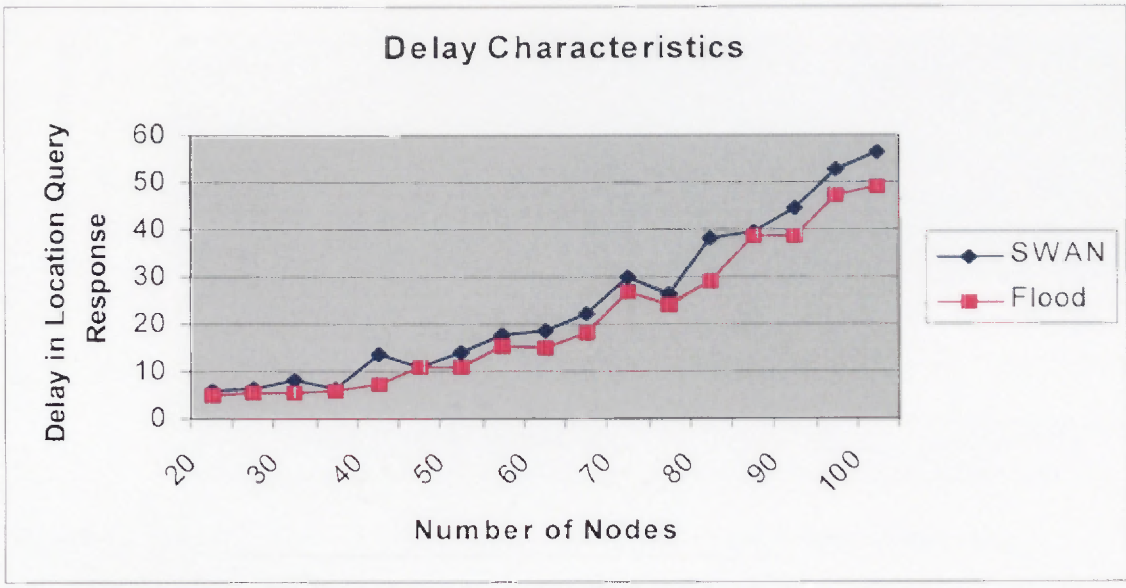

Figure 4.2 Delay characteristics in Flooding and SWAN schemes.

4.5 Location Query Failures

Location query fails in SWAN simulation in the event of a fragmented network or if no nodes are present in the home cell of the destination node. The probability of LQ failure in a uniformly distributed MANET is (1-1/M)N. Where N is the number of nodes and M is the number of cells in the SWAN network. As expected the probability of location query failure decreases with the increase in the number of nodes in the MANET, as demonstrated in the Figure 4.3.

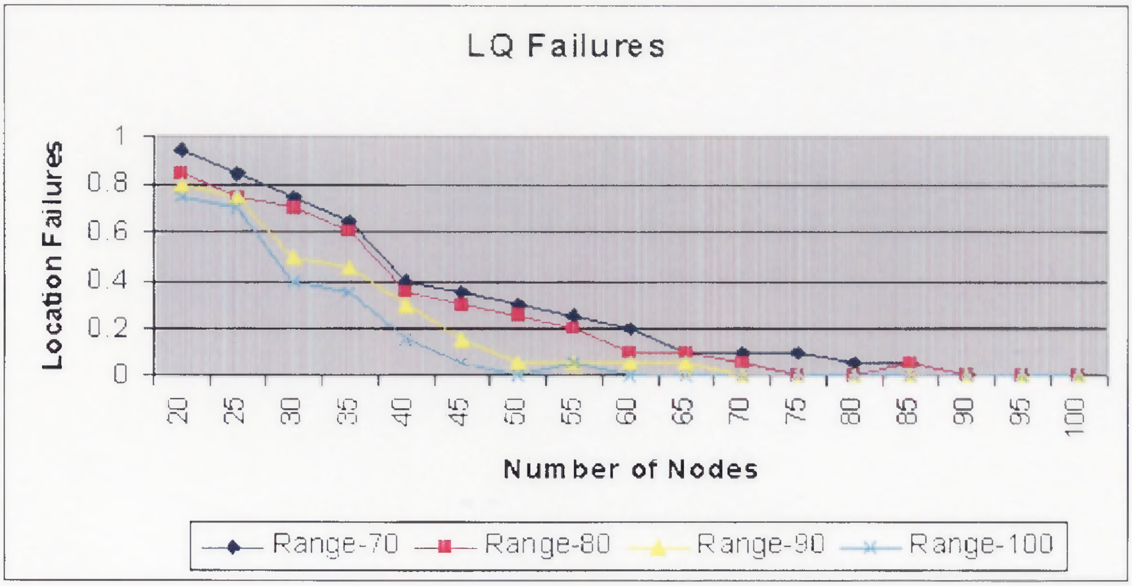

Figure 4.3 Location failure characteristics of SWAN with varying communication ranges.

4.6 Extending SWAN

To extend SWAN to ensure that with increased coverage area the route discovery and route setup process is fast, multiple sets of VHLR can be setup in the network, tiled and covering the entire network coverage area. This approach helps gain the scalability needed for wide area ad hoc networks. With multiple sets of location registers, the network mapping function will map any given node to a virtual cell in each of the location registers. Each node when sending location updates will eventually update all of its home location registers. Any node trying to determine the location of another node, will query the nearest virtual home cell. This ensures that the latency involved in location query and response time is reduced.

However, not all the virtual home cells need to be updated at the same time. The update mechanism can be staggered, based on the probability and frequency of arrivals of location queries. This entirely depends on the topology of the network; whichever virtual homes surrounded by a denser population will be queried more whereas the home cells surrounded by rarefied populations. Therefore, the home cells, which have higher probability of being queried, can be update more often than the others can.

CHAPTER 5

CONCLUSION AND FUTURE WORK

Efficient usage of location information to reduce routing overhead is the key to building wide area ad hoc networks. This thesis presents the Scalable Wide Area Ad-hoc Networking (SWAN) protocol. SWAN uses the distributed virtual home location registers to maintain the location information of a subset of nodes. SWAN optimizes the control overhead involved in maintaining the location information and has low latency in route setup.

The simulation runs compare SWAN with only the native flooding algorithm. SWAN needs to be compared with other location aware MANET routing algorithms proposed and implemented. To improve the route maintenance process, the source and destination node after establishing a connection can embed information on their mobility to ensure that the other node knows its location accurately throughout the lifetime of the connection or transmission. Another performance gain could be obtained by caching the LR packets for certain duration in any node that receives it. So, all nodes involved in the routing of the LR packet can temporarily store the location information, however, it still needs to be studied if the performance gain obtained by caching is worth the effort in caching the messages.

Extending SWAN to support multicast messages in addition to unicast messages also needs to be explored. Applying security on top of the control messaging and access to the SWAN network also remains unexplored currently.

REFERENCES

[1] L. Blazevic, L. Buttyan, S. Capkun, S. Giordano, J. P. Hubaux, J. Y. Le Boudec, "Self-Organization in Mobile Ad-Hoc Networks: the Approach of Terminodes", IEEE Communications Magazine, pp. 166-174, Jun 2001.

[2] L. Guemari, "An OPNET model implementation for Ad-hoc On demand Distance Vector Routing Protocol", Information Technology Laboratory, National Institute of Standards & Technology, Thesis report, pp. 6-60, Aug 2001.

[3] C. E. Perkins and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance Vector Routing (DSDV) for Mobile Computers", Proceedings of ACM SIGCOMM' 94, London, UK, pp. 234-44, Sep 1994.

[4] P. Jacquet, P. Muhlethaler and A. Qayyum, "Optimized Link State Routing Protocol", Internet draft, draft-ietfmanet-olsr-00.txt, Oct 2003.

[5] B. Bellur, R. Ogier and F. Templin, "Topology Broadcast Based on Reverse-Path Forwarding (tbrpf)", RFC 3684, rfc3684.txt, Feb 2004.

[6] S. R. Das, R. Castaneda and J. Yan, "Simulation Based Performance Evaluation of Mobile, Ad Hoc Network Routing Protocols", CM/Baltzer MONET J., pp. 179-89, Jul 2000.

[7] C. E. Perkins and E. M. Royer, "Ad-hoc On-Demand Distance Vector Routing", Proceedings of 2nd IEEE Workshop on Mobile Computing Systems and Applications, New Orleans, LA, pp. 90-100, Feb 1999.

[8] V. D. Park and M. S. Corson, "A Highly Adaptive Distributed Routing Algorithm for Mobile Wireless Networks", IEEE Conference on Computer Comm., INFOCOM '97, Kobe, Japan, pp. 1405-1413, Apr 1997.

[9] D. B. Johnson and D. A. Maltz, "The Dynamic Source Routing in Ad-Hoc Wireless Networks", Mobile Computing, edited by T. Imielinski and H. Korth, Kluwer Academic Publishers, chapter 5, pp. 153-181 1996.

[10] Z. J. Haas and M. R. Pearlman, "The Zone Routing Protocol (ZRP) for Ad Hoc Networks", Internet draft, draft-ietfmanet-zone-zrp-01.txt, Aug 1998.

[11] Y-B. Ko and N. H. Vaidya, "Location-Aided Routing (LAR) in Mobile Ad Hoc Networks", Proceedings of the 4th International Conference on Mobile Computing and Networking ACM MOBICOM, pp. 66-75, Dallas, TX, Oct 1998.

[12] A. Iera, A. Molinaro, F. Rango and S. Marano, "Multi-step Increase of the Forwarding Zone for LAR Protocol in Ad Hoc Networks", Vehicular Technology Conference, Jeju, Korea, pp. 186-190 vol.1, Mar 2003.

[13] J. Li and P. Mohapatra, "LAKER: Location Aided Knowledge Extraction Routing for Mobile Ad Hoc Networks", Proc. IEEE WCNC, New Orleans, LA, pp. 1180-1185, Mar 2003.

[14] G. V. Záruba, V. K. Chaluvadi and A. M. Suleman, "LABAR: Location Area Based Ad Hoc Routing for GPS-Scarce Wide-Area Ad Hoc Networks", IEEE International Conference on Pervasive Computing and Communications PerCorm'03, Fort Worth, TX, pp. 1-5, Mar 2003.

[15] L. BlaZevit, L. Buttyan, S. Tapkun, S. Giordano, J.-P. Hubaux and J.-Y Le Boudec, "Self-Organization in Mobile Ad Hoc Networks: The Approach of Terminodes", IEEE Communications Magazine, pp. 166-175, Jun 2001.

[16] O. B. Ko and N.H. Vaidya, "Geocasting in mobile ad hoc networks: Location-based multicast algorithms", Proc. WMCSA, New Orleans, LA, pp. 1-10, Feb 1999.

[17] W. J. Choi, S. Tekinay, "An adaptive location registration scheme with dynamic mobility classification", ICC 2002 - IEEE International Conference on Communications, vol. 25, no. 1, pp. 440-444, Apr 2002.