

GPS-Enhanced AODV routing

Hristo Asenov and Vasil Hnatyshin

Department of Computer Science

Rowan University

Glassboro, NJ 08028

Abstract - *Ad-Hoc On-demand Distance Vector (AODV) is a stateless reactive routing protocol for mobile ad hoc networks (MANETs). To discover a route to a destination AODV relies on flooding technique which may result in unnecessarily large number of control packets traveling through the network and consuming such already scarce network resources as bandwidth, node processing power, and node battery power. This work examines a new simple protocol for limiting the number of AODV control packets forwarded through the network during the route discovery process. Our approach, named GeoAODV, takes advantage of the Global Positioning System (GPS) and assumes that each communicating device has GPS access and knows its location. Using GPS coordinates GeoAODV limits the route discovery process to the search region that is likely to contain the path to destination. The route discovery search region is dynamically adjusted based on the “freshness” of the destination coordinates. We evaluate performance of GeoAODV through simulation using OPNET Modeler software.*

KEYWORDS: AODV, GPS, route discovery.

1 INTRODUCTION

Flooding is a simple routing technique where each node forwards arriving message to every one of its neighbors except for the node from which the message has arrived. Ad-Hoc On-demand Distance Vector (AODV) is a stateless reactive routing protocol for mobile ad hoc networks (MANET). AODV employs flooding technique to discover the route to destination. However, AODV's route discovery process is inefficient because flooding results in a large number of control packets traveling through the network and consuming such already scarce network resources as bandwidth, node processing power, and node battery power.

This paper examines a simple protocol for limiting the number of AODV control packets forwarded through the network during route discovery. Our approach, named GeoAODV, takes advantage of the Global Positioning System (GPS) and assumes that each communicating device has GPS access and knows its location. Using GPS coordinates GeoAODV limits the route discovery

process to the search region that is likely to contain the path to destination. Only nodes inside of the search region are allowed to rebroadcast RREQ messages during the route discovery process.

The work presented in this paper is based on a variation of location aided routing (LAR) called cone-shaped request zone adaptation [4]. However, unlike LAR, our proposed approach does not make any assumptions regarding the speed and direction of the moving nodes. Instead, our approach relies only on GPS coordinates to determine the search region that is likely to contain the path to destination. The main contributions of our work are providing evaluation and detailed description of the GeoAODV approach as well as introducing a new protocol for maintaining and distributing GPS coordinates in the network.

The rest of the paper is organized as follows. Chapter 2 introduces related work and provides brief overview of AODV. Detailed description of GeoAODV protocol is presented in Chapter 3 which covers such topics as updated route discovery protocol, algorithm for computing search region, mechanism for distributing and maintaining GPS coordinates, and an overview of possible optimizations. Chapter 4 provides implementation details of GeoAODV protocol. The simulation study and analysis of GeoAODV performance are discussed in Chapter 5. The paper concludes in Chapter 6.

2 RELATED WORK

2.1 OVERVIEW OF AODV

AODV is a reactive routing protocol that attempts to discover a path to the destination only when the source has data to send but does not have a route to the destination. The main phases of AODV protocol are route discovery and route maintenance. The route maintenance phase is responsible for removing routing table entries that contain information about outdated or broken paths and thus is of no interest to our study of GeoAODV, which is primarily concerned with the route discovery phase.

The originating node (i.e. source) initiates the route discovery phase by broadcasting a Route Request (RREQ) message. AODV employs an expanding ring search technique which prevents unnecessary network-wide dissemination of RREQs. In an expanding ring search technique the originating node sets the TTL field in the IP header of the RREQ message to initial value. If the route discovery process fails to find a path to the destination then the originating node increments the value of TTL field and repeats the process again. This process continues until either the originating node finds the path to destination or the whole network has been searched and the path was not found [7, 8].

If RREP arrives at the destination node or an intermediate node that has a path to destination, then the corresponding node generates a Route Reply (RREP) message. RREP travels back to the originating node by retracing the path of the RREQ message. Intermediate nodes that receive RREP message update their routing tables with the path to destination. AODV considers a route to the destination to be found and the route discovery process to end when RREP arrives at the originating node [7, 8].

2.2 GPS-ENHANCED ROUTING PROTOCOLS

The idea of using GPS coordinates to improve performance of routing protocols is not new. In [4], the authors discussed two location aided routing (LAR) schemes that improve AODV's route discovery with the help of GPS coordinates. The first LAR scheme relies on destination node's coordinates and traveling speed to identify a circle area where the destination node is likely to be located. The circle area is called expected zone. The first LAR scheme also defines a request zone which is smallest possible rectangular area that contains the originating node and the expected zone so that the sides of the rectangle are parallel to the X and Y axes. Only the nodes that are inside of the request zone may forward RREQ messages. In the second LAR scheme, an intermediate node forwards the RREQ message only if the distance between itself and the destination node is not larger than the distance between the originating node and destination. If the intermediate node forwards the RREQ message then it replaces the originating node coordinates carried by RREQ with its own [3, 4].

In [2], the authors introduced two expanding search algorithms that set initial value of TTL field in the IP header of the RREQ message based on the estimated distance between source and destination. AODV protocol with Directional Forward Routing (AODV-DFR) addresses the issues of group routing for ongoing connections. AODV-DFR relies on proactive route updates that help keep track of the moving nodes and recover from route failures [1]. Geo-LANMAR combines IP addressing with geo-coordinates for efficient packet

delivery using fisheye-like schemes [6] and link-state protocols for virtual topology built on landmarks [9].

3 GEOAODV

3.1 OVERVIEW OF GEOAODV

To take advantage of GPS coordinates we modified the original AODV protocol to support the following features:

- Keep track of the known node coordinates,
- Distribute the node coordinates in the network, and
- Use destination coordinates to limit the scope of the route discovery mechanism.

Generally, a position is defined by vector $[x, y, z, t]$, where x , y , and z represent the coordinates in three-dimensional space and t represents the time. For simplicity, we assume that the z coordinate is always 0 (i.e. all the nodes are located on the surface of the earth) and the time coordinate t is maintained separately and is not carried by AODV control messages. Thus, GeoAODV protocol keeps track of and distributes two additional values that represent the last known position of the node:

- x – GPS Latitude
- y – GPS Longitude

In GeoAODV each node maintains an additional table, called a geo-table. Each entry in the geo-table contains such information as GPS coordinates, geo-lifetime value, and IP address of the node. The geo-table entries are populated during the route discovery process via information delivered in RREQ and RREP messages. That is why we modified the format of RREQ and RREP messages to additionally carry node coordinates.

The RREQ messages additionally carry the originating node coordinates, destination coordinates, if available, and the flooding angle. The value of the flooding angle defines the route discovery search region and is computed based on the geo-lifetime value which represents "freshness" of destination coordinates. The RREP message format is modified to additionally contain the destination node coordinates.

GeoAODV utilizes the above control message changes as follows. If destination coordinates are unknown then the originating node generates a RREQ message with the originator coordinates set to its current location, the destination coordinates set to invalid values, and the flooding angle set to a maximum value, indicating that the search region is the whole network. In such a situation, GeoAODV operates the same way as AODV. Otherwise, the originating node generates a RREQ message that carries its own coordinates, the last known destination coordinates, and the flooding angle value computed based on geo-lifetime.

Upon RREQ message arrival, in addition to usual AODV verification procedures, an intermediate node uses its coordinates and the flooding angle to determine if it

belongs to the search region. If an intermediate node determines that it is located inside of the search region then it rebroadcasts the RREQ message. Otherwise the RREQ message is discarded.

As shown in Figure 1, Source, in an attempt to discover the path to Destination, generates a RREQ message with the flooding angle $A1$. If the first round of route discovery process fails to find the path to Destination then Source will generate another RREQ message with the flooding angle $A2$. It is possible that during the first round of path discovery, nodes $N1$, $N2$, and $N3$ will receive the RREQ. However, only node $N1$ will rebroadcast the RREQ because only node $N1$ belongs to the search region defined by flooding angle $A1$. During the second round of route discovery, nodes $N1$ and $N2$ belong to the search region defined by flooding angle $A2$ and thus they both will rebroadcast the RREQ message. Please note that node $N3$ will discard RREQ messages during both rounds of route discovery, because node $N3$ is outside the search regions defined by flooding angles $A1$ and $A2$.

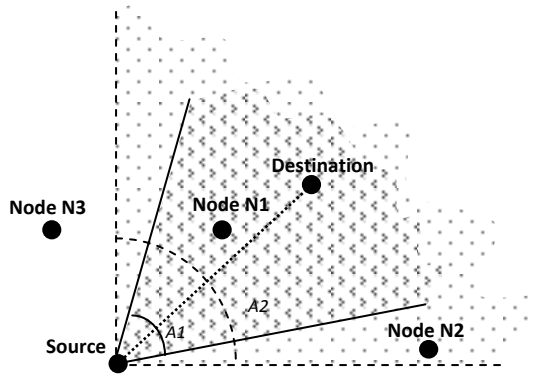


Figure 1. Example of GeoAODV operation

3.2 COMPUTING GEOAODV SEARCH REGION

To determine if an incoming RREQ message should be discarded or rebroadcast further, an intermediate node examines the angle θ formed between the source-destination and source-intermediate node vectors. If the angle θ is within half of the flooding angle then the intermediate node is in the search region and will rebroadcast RREQ. Otherwise the intermediate node is outside of the search region and will discard the RREQ message. Angle θ is computed as follows:

$$\theta = \cos^{-1} \left(\frac{|\overrightarrow{SD} \cdot \overrightarrow{SN}|}{|\overrightarrow{SD}| \times |\overrightarrow{SN}|} \right) \quad (1)$$

Where, \overrightarrow{SD} is a vector between source and destination, \overrightarrow{SN} is a vector between source and intermediate node N , while $|\overrightarrow{SD}|$ and $|\overrightarrow{SN}|$ are absolute values of vectors \overrightarrow{SD} and \overrightarrow{SN} , respectively. Figure 2

illustrates a situation where intermediate node N rebroadcasts RREQ message because angle θ formed by the source-destination and source-intermediate node vectors is within half of flooding angle α . Generally, the source-destination vector always divides the flooding angle evenly. Thus, an intermediate node belongs to the search region if it is located on either side of the source-destination vector and its angle θ is not larger than half of the flooding angle.

In practice, for efficiency reasons, GeoAODV's RREQ messages only carry one half of the flooding angle value because it is the value used by intermediate nodes to determine if they belong to the search region.

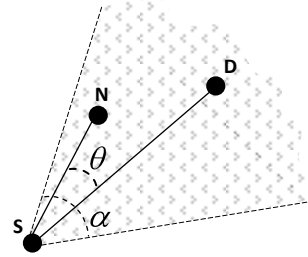


Figure 2. Example of GeoAODV Search Region

3.3 MAINTAINING GEO-TABLE

The geo-table is maintained in a similar fashion to that of the AODV routing table. Each geo-table entry contains the following information about destination of interest: IP address, geo-lifetime value, destination sequence number and GPS coordinates. IP address uniquely identifies the destination node. The geo-lifetime defines how long the geo-table entry remains valid and how recent or "fresh" the destination coordinates are. Generally, the geo-lifetime value is larger than the lifetime of the corresponding entry in the routing table because even if the route to a destination becomes stale the last known coordinates of the destination node may help reduce the size of the search region. The destination sequence number is obtained via RREQ and RREP messages, the same way as in AODV. Geo-table maintains a separate copy of the sequence number because the geo-table entries are kept for longer periods of time than the routing table entries. As a result, geo-table may contain entries for the nodes to which the routes are unknown. However, if routing table and geo-table contain the entry for the same node then the node's sequence number is the same in both tables.

GPS coordinates are also distributed in the network via RREQ and RREP messages. Upon RREQ message arrival a node (i.e. intermediate or destination) uses originator IP address to identify the entry in the geo-table. If the entry for the originating node does not exist or if the originating node sequence number is larger than that stored in the geo-table then the node updates its geo-table with the new sequence number and new originating node

coordinates. The node also restarts the geo-lifetime timer because RREQ was generated by the originating node and thus carries its most up-to-date coordinates. Similarly, the node searches the geo-table for destination node entry. If the entry does not exist or if the destination sequence number carried in the RREQ is larger than the sequence number stored in the geo-table then the node updates its geo-table with the new destination sequence number and destination coordinates. However, the node does not change geo-lifetime because the accuracy of the destination coordinates is unknown.

Similarly, upon RREP message arrival a node (i.e. intermediate or originating) examines its geo-table. If there is no entry for the destination node or if the destination sequence number carried in the RREP message is larger than the corresponding sequence number in the geo-table then the node updates its geo-table with the new destination sequence number and destination coordinates. If the RREP message originated from destination then the node restarts the geo-lifetime timer, otherwise the node resets geo-lifetime proportionally to the *Lifetime* value carried in the RREP message.

3.4 GEOAODV ROUTE DISCOVERY PROCESS

Like AODV, the GeoAODV route discovery process starts when the originating node would like to send data but has no route to a destination. The value of the flooding angle α , carried in the RREQ message, is a function of destination's geo-lifetime timer.

$$\alpha = f(\text{geo-lifetime}) \quad (2)$$

Function f in equation 2 is monotonously decreasing function which returns the flooding angle value in the range from *min_angle* to 180 degrees. Notice that *min_angle* is the smallest flooding angle value that corresponds to the maximum value of the geo-lifetime timer.

GeoAODV starts route discovery process by sending RREQ message with the flooding angle value computed according to equation 2. If the route discovery process does not succeed then the originating node doubles¹ the value of the flooding angle and sends the RREQ message again with the new flooding angle value. Eventually, the value of the flooding angle will reach 180 degrees in which case GeoAODV will behave the same way as regular AODV and will mark the route to the destination as invalid if the path is not found.

When an intermediate node receives a RREQ message it checks its routing table and sends a RREP message if it has a route to destination. If the node has no route to destination then it rebroadcasts or discards RREQ

depending on whether it is inside or outside of the search region. The intermediate node also updates its geo-table, if necessary. Please note that if the destination sequence number stored in the intermediate node is larger than the destination sequence number obtained from the arriving RREQ message then the new RREQ message is rebroadcasted with the destination sequence number and destination coordinates obtained from the node's geo-table.

Upon RREQ message arrival, the destination node sends a RREP message with a new destination sequence number and the most up-to-date coordinate values. As the RREP message travels back to the originating node, the intermediate nodes update their geo-tables with the destination sequence number and destination coordinates retrieved from the RREP. When the originating node receives the RREP message it updates its geo-table and then starts transmitting data to destination.

3.5 GEOAODV OPTIMIZATIONS

Determining the initial value of the flooding angle is important for efficient operation of GeoAODV protocol. Currently, the value of the flooding angle is computed based only on the geo-lifetime value. The idea is that the fresher the coordinates (i.e. the larger the value of the geo-lifetime timer) the more likely it is that the destination node still remains close to the location defined by these coordinates. As the result, initially, the search region could be limited to a small area defined by a narrow flooding angle. As the destination coordinates are getting "stale," the flooding angle and thus, the search region, are expanded.

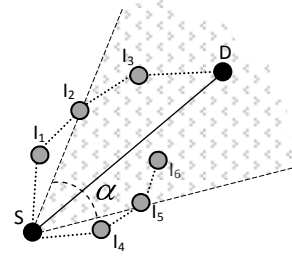


Figure 3. Flooding angle optimization

However, such logic may have a flaw. It is possible that close to the originating node, the search region is too small and does not contain any intermediate nodes that can rebroadcast a RREQ. In such a situation, the originating node would have to go through a complete round of expanding ring search [8] before it can increase the value of the flooding angle and try again. The reason for such inefficient behavior is GeoAODV's inability to determine whether the route discovery failure occurred due to TTL field value reaching 0 or due to the value of the flooding angle being too narrow and thus the search region being too small.

¹ Alternatively, the value of the flooding value could be incremented in the similar fashion to that presented in [2].

Figure 3 illustrates a situation where the search region defined by flooding angle α does not include nodes I_1 and I_4 that can rebroadcast RREQ. As a result, the first round of GeoAODV route discovery process will fail because the flooding angle is too narrow. To address this issue originating node S should set the initial flooding angle value so that the corresponding search region includes at least one neighboring node (i.e. a node that can directly communicate with S). Such value of the flooding angle can be computed if GPS coordinates of the neighboring nodes are known. Similarly, the intermediate nodes could widen the flooding angle if the search region defined by the arriving RREQ message does not contain any neighboring node. Dynamic nature of MANET topology allows possibility of dead-end routes such as route $S - I_4 - I_5 - I_6$ shown in Figure 3. That is why such an optimization reduces but does not eliminate the possibility of the route discovery failure due to flooding angle being too narrow.

Finally, similarly to idea presented in [2] the originating node can estimate the distance to destination node and set the initial value of the TTL field in the RREQ message based on that estimated value. Currently, we are in the process of developing simulation models for and examining feasibility of proposed optimizations.

4 IMPLEMENTATION SPECIFICS

We used OPNET Modeler version 14.5 [5] to study performance of GeoAODV protocol. We modified the `aodv_rte` process model to simulate operation of GeoAODV protocol. Most of the described features of GeoAODV have been implemented with the exception of the geo-table timers, computation of the initial flooding angle, and optimizations described in section 3.5. In the current version of GeoAODV implementation, the originating node computes the flooding angle using the following methodology: if destination address is unknown then GeoAODV sets the value of the flooding angle to 180 degree and performs a network-wide RREQ flooding which functions as AODV, otherwise the initial value of the flooding angle is set to 45 degrees. If the first round of route discovery fails then the originating node doubles the flooding angle value and repeats the route discovery process.

Currently we are working on completing full implementation of GeoAODV including optimizations. We are also planning to implement both versions of LAR [3, 4] and to compare their performance with that of GeoAODV.

5 SIMULATION STUDY AND RESULTS

5.1 SIMULATION SET-UP

This simulation study represents the initial step in our evaluation of GeoAODV protocol. The primary goal of this study is to verify that GeoAODV reduces the number of control messages traveling through the network.

We created a network topology that consists of 50 MANET nodes randomly placed within the 1000 meters by 1000 meters area. We examined several scenarios with different number of communicating nodes. In each scenario, communicating nodes and their destinations were selected randomly. We examined scenarios with 5, 10, 20, and 30 communicating nodes. Each communicating node was configured to transmit over a 11 Mbps channel with transmit power of 0.005 Watts and received power threshold of -95dBm.

In examined simulation scenarios, each communicating node starts transmitting data to a randomly selected destination at time 100 seconds and continues transmission until the end of simulation. The packet inter-arrival time is computed using exponential distribution with mean outcome of 1 second, while the packet size is computed using exponential distribution with mean outcome of 1024 bits. Each simulation scenario ran for 300 seconds.

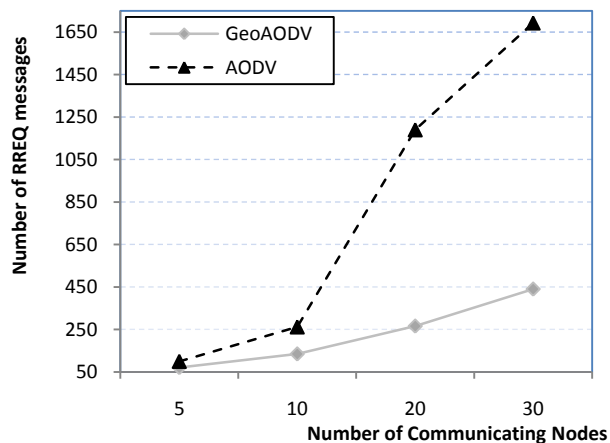


Figure 4. Number of RREQs sent in stationary nodes scenario

5.2 STATIONARY NODES SCENARIO

First we considered a set of scenarios where each node was stationary throughout the whole simulation. To compare performance of AODV and GeoAODV we examined the total number of the RREQ and RREP messages sent in the network. Figures 4 and 5 provide the summary of results, which indicate that GeoAODV consistently generates fewer control messages than AODV. In particular, as Figure 4 shows, GeoAODV significantly reduced the number of RREQ messages sent throughout the network. Such behavior was expected

because the nodes in the network are stationary and thus the originating nodes need to discover destination coordinates only once. Furthermore, since the network is somewhat densely populated, all subsequent route discoveries benefit from the known destination coordinates and thus will significantly reduce the search region and thus the number of the intermediate nodes that rebroadcast RREQs.

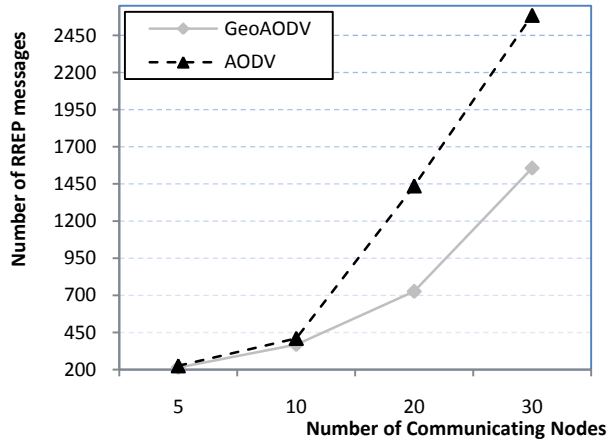


Figure 5. Number of RREPs sent in stationary nodes scenario

GeoAODV also reduced the number of RREP messages sent through the network. However, the overall observed performance improvement was slightly worse for the RREP messages than for the RREQ messages. When the number of communicating nodes is small then there are fewer chances for the intermediate node to discover the route to destination. As a result, in such situations, only the destination nodes generate RREP messages. Thus, the number of RREP messages generated by AODV and GeoAODV protocols for a small number of communicating nodes is similar. This phenomenon is illustrated in Figure 5.

When the number of communicating nodes increases the probability that the intermediate node knows the path to destination and thus will generate a RREP message also increases. However, the intermediate nodes that know the path to destination are primarily located inside the search region of the GeoAODV's route discovery process. That is why, the difference between the number of nodes that generate RREP by AODV and GeoAODV protocols is smaller than the difference between the number of nodes that rebroadcast RREQs.

5.3 MOBILE NODES SCENARIO

Next, we examined a set of scenarios where every node in the network is moving according to the random waypoint model. The average node speed is uniformly distributed between 1 and 10 meters/second. The nodes do not pause between moves and continued their

movement until the end of simulation. Figures 6 and 7 provide the summary of results, which indicates that GeoAODV consistently generates fewer control messages than AODV even in mobile environment.

However, the overall performance improvement in mobile scenario was smaller than performance improvement in static scenario. Such behavior is expected since the node movement may cause the originating nodes to rediscover locations of the destination nodes. When a destination node moves too far away from its last known position, GeoAODV may end up doing a full broadcast. This results in more RREQs sent by GeoAODV than AODV because GeoAODV has to go through several rounds of the route discovery process before doing a full broadcast. GeoAODV increases the flooding angle value during each round until it finds the path to destination or determines that the path does not exist. AODV, on the other hand, does full broadcast only once.

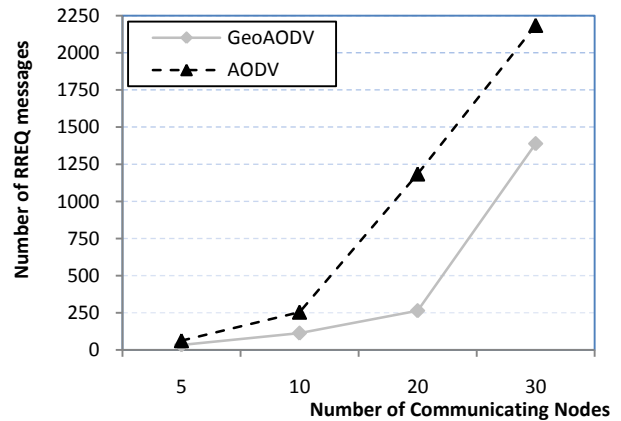


Figure 6. Number of RREQs sent in mobile nodes scenario

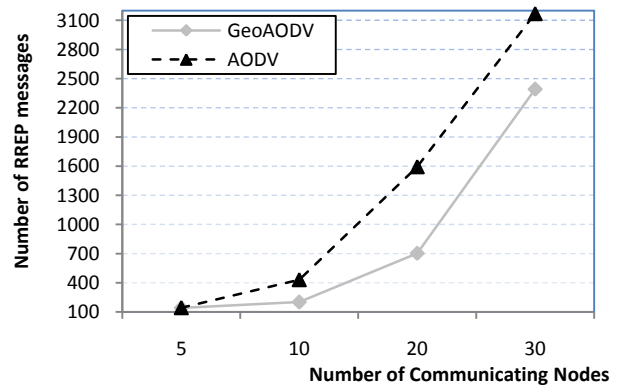


Figure 7. Number of RREPs sent in mobile nodes scenario

6 CONCLUSIONS

This paper presents a new protocol for improving performance of route discovery process in AODV routing

protocols. The proposed protocol, titled GeoAODV, takes advantage of the GPS system and assumes that each node in the network is aware of its position. The paper presents details of the new route discovery process, a mechanism for maintaining and distributing node positions in the network, and a set of optimizations for more effective selection of the flooding angle and the search region. Simulation study conducted using OPNET Modeler network simulation software has showed that GeoAODV reduces the overhead associated with the route discovery process for both stationary and mobile scenarios and thus warrants further investigation.

Currently, we continue development and implementation of a full-featured version of GeoAODV together with a set of optimization techniques presented in this paper. We also plan to implement both LAR schemes and compare their performance with that of GeoAODV.

7 REFERENCES

- [1] J. Chen, H. Zhou, Y. Z. Lee, M. Gerla, and Y. Shu, "AODV-DFR: Improving Ad Hoc Routing Scalability to Mobility and Load," 2006 IEEE International Conference on Mobile Ad Hoc and Sensor Systems (MASS), Oct. 2006, pp. 550-553.
- [2] D. Espes, Z. Mammeri. "Adaptive expanding search methods to improve AODV Protocol," IST Mobile and Wireless Communications Summit, July 2005.
- [3] Y. Ko and N. H. Vaidya, "Flooding-based geocasting protocols for mobile ad hoc networks," *Mobile Networks and Applications*, 7(6), Dec. 2002, pp. 471-480.
- [4] Y. Ko and N. H. Vaidya, "Location-aided routing (LAR) in mobile ad hoc networks," *Wireless Networks*, 6(4), July 2000, pp. 307-321.
- [5] OPNET Modeler ver. 14.5. OPNET Technologies, Inc[®], www.opnet.com last visited 3/2/09.
- [6] G. Pei, M. Gerla, and T.-W. Chen, "Fisheye State Routing: A Routing Scheme for Ad Hoc Wireless Networks" in *Proc. of the IEEE International Conference on Communication*, New Orleans, LA, June 2000.
- [7] E. M. Royer and C. E. Perkins. "An Implementation Study of the AODV Routing Protocol," *Proc. of the IEEE Wireless Communications and Networking Conference*, Chicago, IL, September 2000.
- [8] C. E. Perkins and E. M. Royer. "Ad hoc On-Demand Distance Vector Routing," *Proc. of the 2nd IEEE Workshop on Mobile Computing Systems and Applications*, New Orleans, LA, Feb. 1999, pp. 90-100.
- [9] B. Zhou, Y. Lee, M. Gerla, and F. de Rango, "Geo-LANMAR: a scalable routing protocol for ad hoc networks with group motion: Research Articles", *Wireless Communications & Mobile Computing*, 6(7), Nov. 2006, pp. 989-1002.