A Comparative Study of Proactive and Reactive Geographical Routing Protocols for MANET

Rob Hussey, Earl Huff, Zabih Shinwari, and Vasil Hnatyshin†
{hussey20, huffe72, shinwa59}@students.rowan.edu, †hnatyshin@rowan.edu
Department of Computer Science
Rowan University
Glassboro, NJ 08028

Abstract—**In the world of mobile wireless communication, it has become more and more important to establish networks that are not only capable of delivering information across vast distances but can also perform this task efficiently. Many routing protocols for mobile ad hoc networks (MANETs) rely on additional information such as geographical locations obtained via GPS to improve the overall performance of the route discovery process. This paper is an extension of our previous study of location-aided MANET routing protocols. In this paper we continue our research endeavors by comparing the performance of several AODV-based *reactive,* location-aided MANET routing protocols and Geographical Routing Protocol (GRP), an OPNET implementation of a *proactive,* geographical location-based routing protocol for MANET.**

Keywords—location-aided routing; geographical routing; LAR; GeoAODV; AODV; GRP

I. Introduction

As the world becomes more and more reliant on wireless communication, efficient delivery of information from one network device to another becomes critical. Since these devices are often mobile, it becomes even more important to develop the means for data delivery in the environments that experience frequent topological changes [3]. Mobile ad hoc networks (MANETs) are collections of autonomous mobile nodes which work together to transport information through wireless environments [11]. The dynamic nature of MANETs makes finding a route from source to destination a challenging task.

Generally, MANET routing protocols are divided into two broad categories: *reactive* – the source only tries to find a route to the destination as needed and *proactive* – the nodes continually maintain the routes in the network regardless of whether there is traffic traveling to the destination or not. The main advantage of reactive routing protocols is that they do not waste resources, which are typically very scarce in MANETs, on the routes which may not be needed. However, when a source node has data to be transmitted, a route to the destination may not be readily available. This may result in the transmission being delayed until a route to the destination is found. On the other hand, when proactive routing protocols are used, the data can be transmitted right away since each node maintains and continually updates the routes to all reachable nodes in the network. The main disadvantage of proactive routing protocols is that the nodes maintain the routes even if they are not used, which results in unnecessary waste of available resources such as bandwidth, battery power, etc.

The route discovery process in a MANET environment often relies on flooding to find a path to the destination. Typically, flooding also unnecessarily consumes available resources because it searches the whole network, including the portions of the network which are unlikely to contain a route to the destination. In recent years there have been a large number of proposals which attempt to improve the performance of the route discovery process by utilizing geographical information. In this paper we examine and compare the performance of several location-aided, *reactive* routing protocols based on Ad hoc On-demand Distance Vector (AODV) and Geographical Routing Protocol (GRP), a *proactive,* geographical location-based routing protocol for MANET. Improving MANET routing through the use of location information have been an active area of research [1-2, 4-6, 8-11]. However, in this paper we examine and study through simulation two variations of the Location-Aided Routing (LAR) protocol [9,10], two variations of Geographical AODV (GeoAODV) routing protocols [1,5], and an OPNET implementation of GRP [13]. The results presented in this paper were collected using the OPNET Modeler version 16.1 network simulation software [12].

The rest of the paper is organized as follows. We provide a brief overview of studied routing protocols in Section II. Set-up of the simulation study and analysis of results are presented in Sections III and IV. The paper discusses the plans for future work and concludes in Section V.

II. Overview of Location-Aided Routing Protocols for MANET

A. LAR

Ad hoc on-demand distance vector (AODV) is a reactive routing protocol for MANETs [3, 14 - 15]. AODV performs route discovery using flooding. When a source node, let us call it the originator, needs to send data but does not have a route to destination, it initiates the route discovery process, which works as follows. The originator node broadcasts a route request (RREQ) message to its immediate neighbors, which in turn, rebroadcast the message farther until the node that has a path to the destination or the destination itself is reached. At this point, a route reply (RREP) message is unicast back to the originator node, establishing a path between the source and destination nodes. The route discovery process completes when the originator node receives the RREP message, at which point it can start transmitting the data.

The Location-Aided Routing (LAR) protocol [6, 9 - 10] is an extension of the AODV protocol, which relies on the geographical position of the nodes and their traveling velocities to limit the search area during the route discovery process. LAR assumes that all the nodes know the Global Positioning System (GPS) locations and average traveling speed of all the other nodes in the network. LAR performs route discovery in a fashion similar to that of AODV. However, in AODV, RREQ messages are forwarded to all the nodes in the network, while LAR uses geographical information to limit the RREQ flooding to only those nodes that are likely to be part of the path to the destination. This technique significantly reduces the control message overhead of the route discovery process by forwarding the RREQ messages only in a portion of the whole network.

There are two main variations of the LAR protocol which we call *LAR zone* and *LAR distance*. LAR zone uses the destination's last known coordinates and traveling speed to determine an *expected zone*, an area which is likely to contain the destination node. The expected zone is defined as a circle with radius **R**, centered in the last-known GPS location of the destination node recorded at time $\mathbf{t_0}$. The value of **R** is computed as shown in equation (1):

$$\mathbf{R = v \times (t_1 - t_0)} \quad (1)$$

In equation (1) **v** is the average traveling speed of the destination node and $\mathbf{t_1}$ is the current time. Based on the expected zone area, LAR computes the *request zone*, a rectangular area which is likely to contain the path to the destination. A request zone is the smallest rectangle that encompasses the expected zone such that the sides of the request zone are parallel to the X and Y axes. Only nodes located inside of the request zone participate in RREQ flooding, while all the other nodes simply discard arriving RREQ messages. Figure 1 illustrates two possible scenarios of the expected and request zone locations: (a) the source node S is <u>*outside*</u> of the expected zone for destination node D and (b) the source node S is <u>*inside*</u> of the expected zone for destination node D.

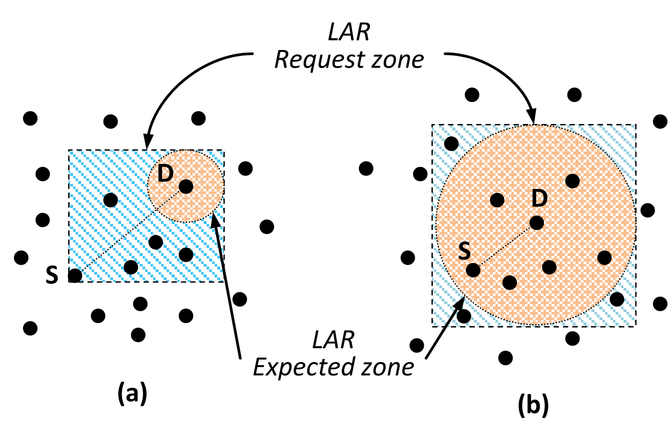

Figure 1: LAR zone: Expected and Request Zones

In the LAR distance approach a node participates in the flooding, i.e., rebroadcasts the RREQ message, only if it is located not father away from the destination than the node that forwarded an RREQ. Generally, LAR distance relies on inequality (2) to determine if node $\mathbf{N_1}$ that receives an RREQ from node $\mathbf{N_0}$ will rebroadcast the message:

$$\boldsymbol{\alpha} \times |\mathbf{N_0\ D}| + \boldsymbol{\beta} \geq |\mathbf{N_1\ D}| \quad (2)$$

In inequality (2) we denote distance between nodes A and B as $|\mathbf{A\ B}|$, while α and β are configuration parameters. We provide an example of LAR distance operation in Figure 2. Source node **S** initiates route discovery by broadcasting an RREQ. At some point node $\mathbf{N_0}$ receives this RREQ and rebroadcasts it farther. When node $\mathbf{N_1}$ receives an RREQ from node $\mathbf{N_0}$ it rebroadcasts the message because $|\mathbf{N_1\ D}| \leq |\mathbf{N_0\ D}|$. However, nodes $\mathbf{N_2}$ and $\mathbf{N_3}$ will discard an RREQ forwarded by $\mathbf{N_0}$ because $|\mathbf{N_2\ D}| > |\mathbf{N_0\ D}|$ and $|\mathbf{N_3\ D}| > |\mathbf{N_0\ D}|$, respectively.

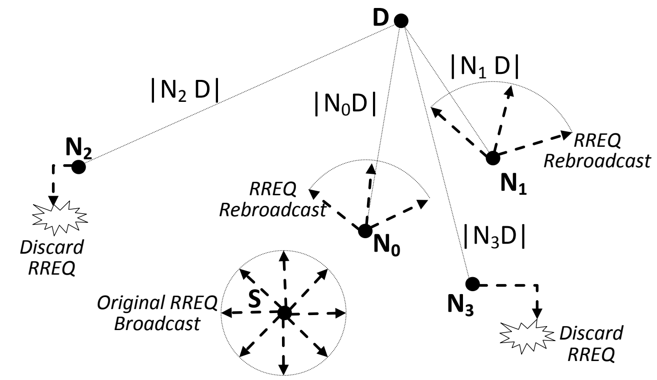

Figure 2. Example of LAR distance scheme

The major difference between these approaches is that LAR zone assumes universal availability of GPS coordinates and traveling velocities needed for computation of a search area where the path to the destination may reside. LAR distance only relies on the availability of GPS coordinates for computing the distances between the nodes. LAR zone has no restrictions as to how the path to destination is constructed; the route can move farther away from the destination before actually reaching it. LAR distance on the other hand, constructs the path by attempting to come closer and closer to the destination during each RREQ rebroadcast. Such an approach may result in a failure to find a route to the destination even though it exists. LAR distance attempts to mitigate this issue by parameterizing the inequality (2) through configuration parameters α and β. However, in practice, determining the optimal values for α and β is a challenging task. Furthermore, LAR zone also suffers from a similar problem: it may fail to find the path to the destination if a portion of the path resides outside the request zone area. Both LAR schemes have no mechanism for expanding the search after a failed attempt to find a route; the route discovery process is stopped if a limited RREQ flood did not find a route to destination. Geographical AODV (GeoAODV) attempts to address this issue by increasing the search area after each failed attempt until GeoAODV morphs into regular AODV.

B. Geographical AODV

GeoAODV is based on the same idea as the LAR zone protocol: only nodes within the search area, i.e., the request zone, participate in route discovery. However, unlike LAR zone, GeoAODV does not assume that GPS locations and traveling velocities of the nodes are readily available to all the other nodes in the network. Instead, GeoAODV assumes that the nodes only know their own location information. In GeoAODV, the location information is dynamically distributed during the route discovery process; i.e., the RREQ and RREP messages are modified to also carry the location information which is recorded by all intermediate nodes that receive these messages.

GeoAODV defines the request zone in the shape of a cone as shown in Figure 3. The originator node **S** serves as an apex of the cone-shaped request zone. The "width" of the area is controlled through the configuration parameter **α** called the flooding angle, which is evenly divided by the straight line between originator **S** and destination **D**. After each failed attempt to find a route to destination, i.e., a single round of route discovery, the value of the flooding angle increases, expanding the search area and the process is repeated again, i.e., the next round of route discovery is started. This continues until either a path to the destination is found or the route discovery fails to find the path with the flooding angle value of 360 degrees, in which case the whole network has been searched). Thus, since GeoAODV eventually may search the whole network, it guarantees that a route to the destination will be found if one exists.

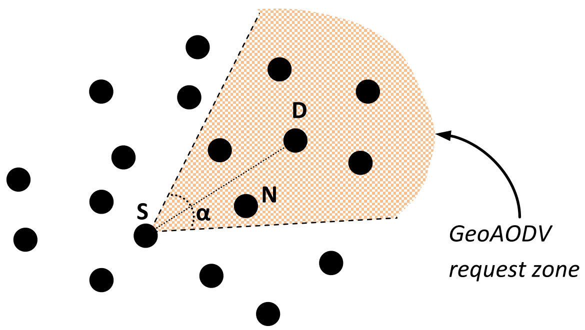

Figure 3: GeoAODV request zone

There are two variations of the GeoAODV protocol: *GeoAODV static* and *GeoAODV rotate*. In GeoAODV static, the originator node always serves as an apex of the request zone cone. This means than the request zone remains the same through each round of route discovery. GeoAODV rotate dynamically adjusts the search area during the route discovery process. Specifically, in GeoAODV rotate each intermediate node re-computes the request zone area based on the location of the previous hop, instead of the originator node, which effectively realigns the search area towards the destination node. Figure 4 illustrates the idea of GeoAODV rotate: node $\mathbf{N_1}$ belongs to the request zone computed based on location of node **S** while node $\mathbf{N_2}$ belongs to the new, re-adjusted request zone computed based on the location of node $\mathbf{N_1}$. Both $\mathbf{N_1}$ and $\mathbf{N_2}$ participate in route discovery even though they belong to different request zones. On the other hand, $\mathbf{N_3}$, which receives an RREQ from $\mathbf{N_1}$, will not participate in the route discovery because it does not belong to the request zone computed based on the location of its previous hop, which is node $\mathbf{N_1}$. However, when GeoAODV static is used, $\mathbf{N_3}$ is part of the request zone computed based on the location of originator node **S** and thus will be a part of the route discovery process.

Unlike LAR, which assumes that location information and traveling velocities are readily available everywhere in the network, GeoAODV makes more realistic assumptions about the availability of GPS location information, in that the nodes only know their own location information, which is distributed during the route discovery process. Furthermore, by increasing the search area after each failed attempt, GeoAODV guarantees that a route to the destination will be found if it exists.

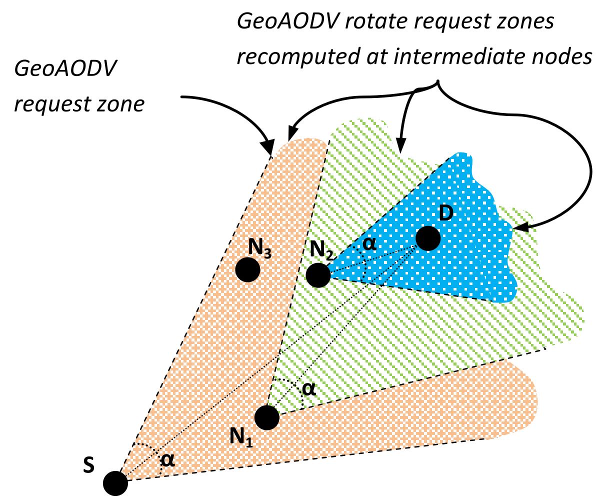

Figure 4: GeoAODV rotate request zone

C. GRP

The Geographic Routing Protocol (GRP) is a custom location-based MANET routing protocol developed by OPNET Technologies**,** Inc [12]. GRP is a proactive, distance-based, greedy algorithm which assumes that each node in the network knows its own GPS location. GRP relies on physical distances for routing: the next hop on the path to the destination is selected as the node geographically closest to destination.

GRP relies on the concept of quadrants or neighborhoods for routing. The network area is divided into square quadrants as shown in Figure 4. Given the GPS coordinates of the node, GRP can easily determine the quadrant it belongs to. Every four quadrants of the lower level form a square or quadrant of a higher level. As Figure 4 illustrates, quadrants **Aa1**, **Aa2**, **Aa3**, and **Aa4** from level 1 form the single level 2 quadrant **Aa**. The size of the lowest-level quadrant is a configurable parameter.

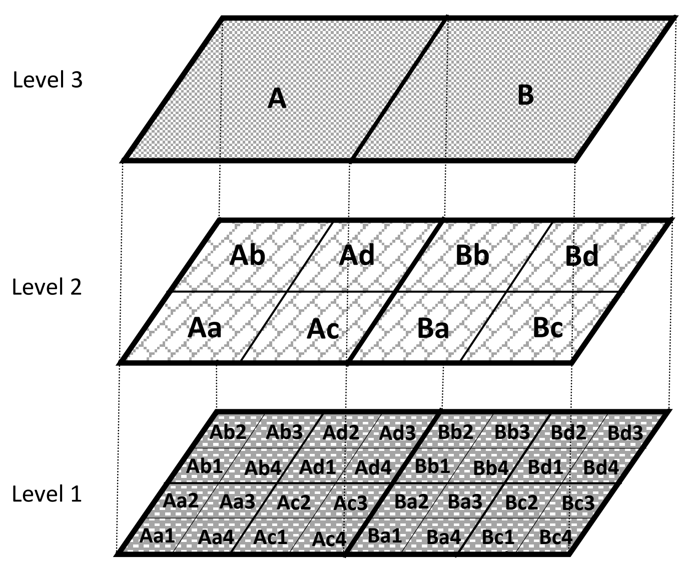

Figure 5: Quadrant division in GRP

GRP maintains forwarding tables as the geographical positions of the nodes in the network. Specifically, the forwarding table of a node stores precise GPS locations of all the other nodes in the same quadrant and the highest level neighboring quadrant label for the nodes located in different quadrants. For example, assume that nodes N_1 and N_2 are located in quadrant **Ac2**, while nodes N_3 and N_4 are located in quadrants **Ad1** and **Bb4**, respectively. In this case, node N_1 will store the following location information: N_2 – precise coordinates since N_1 and N_2 are both in the same quadrant; N_3 – quadrant **Ad** because **Ad** is the highest level quadrant adjacent to **Ac2**; N_4 – quadrant **B** because **B** is the highest level quadrant neighbor of **Ac2**.

The GRP forwarding process works as follows. If the source and destination nodes are located in the same quadrant then the source sends the data to its immediate neighbor geographically closest to the destination. The intermediate node does the same by forwarding the data to its immediate neighbor closest to the destination, and this process will continue until the data arrives at the destination. If source and destination are located in different quadrants then the source node sends the data to its immediate neighbor closest to the entry point into the highest-level quadrant in which the destination node resides. As the data traverses the quadrant boundaries the location information about the destination becomes more specific until eventually the data arrives at the destination's quadrant and is routed using precise location information.

For example, consider the situation when N_1 from quadrant **Ac2** sends data to node N_4 in quadrant **Bb4**. In this case N_1 will send the data to the node closest to quadrant **B**. Eventually, the data will reach an intermediate node in, let us say, quadrant **Ba2**, which will have more precise location information about N_4. Specifically, the intermediate node in quadrant **Ba2** will have the location of N_4 recorded as quadrant **Bb**. Similarly, when data arrives at an intermediate node in quadrant **Bb1**, the forwarding information will state that N_4 is located in quadrant **Bb4**. Eventually the data will arrive at some intermediate node in quadrant **Bb4**, at which time it will be forwarded according to precise location information.

It is possible that the data may reach an impasse, i.e., a blocked route, in which the current intermediate node has no neighbors besides the node from which the data arrived. In this case, the forwarding algorithm backtracks to the previous node which forwards the data to the next closest neighbor on the path to the destination. GRP allows recursive backtracking all the way back to the source node such that if an intermediate node receives a backtrack request and there are no more neighbor nodes to try, then in an attempt to find an alternative route, it forwards the packet back to the node from which it originally arrived. If the source node receives a backtrack packet and it has no more neighboring nodes to try, then it is determined that there is no path to the destination and the data is discarded.

To create forwarding tables, GRP also relies on flooding. Initially, GRP performs a network wide flooding to discover location information of all the reachable nodes in the network. After initial route discovery, GRP periodically conducts limited flooding in order to update the forwarding tables. GRP initiates limited flooding based on node movement, i.e., whenever a node moves a set distance or crosses a quadrant boundary. The area of the limited flooding is determined based on the quadrant boundary that was crossed. For example, if the node did not cross the quadrant boundary, that is, the limited flooding was initiated based on the distance traveled, then the flooding is restricted to the node's quadrant only. If the node crossed a quadrant boundary, then the flooding is performed in the highest level quadrant which is common to the quadrants on each side of the boundary. For example, if a node crosses the quadrant boundary between **Aa2** and **Ab1**, then the flooding will be limited to quadrant **A**. The route discovery messages received outside the flooding area are discarded. Finally, in order to keep location information about its immediate neighbors up-to-date, GRP requires every node to broadcast periodic hello beacon messages [13].

III. SIMULATION SET-UP

We compared the performance of LAR, GeoAODV, and GRP protocols using OPNET Modeler version 16.1 [12]. The network topology in our study contained 50 WLAN nodes randomly placed within a 1500 meters x 1500 meters area. We examined scenarios with 2, 5, 15, and 30 randomly selected communicating nodes. The communicating nodes began data transmission 100 seconds after the start of the simulation, which itself ran for 300 seconds. The nodes in the network moved according to the Random Waypoint model with pause time computed using exponential distribution with the mean outcome of 10 seconds. We examined the performance under two sets of scenarios: (1) all the nodes in the network are stationary and (2) all the nodes in the network travel with the speed 20 meters per second. Summary of individual node configuration presented in Table 1.

TABLE 1: SUMMARY OF NODE CONFIGURATION

Configuration Parameter	Value
Channel Data Rate	11 Mbps
Transmit Power	0.001 Watts
Packet Reception Power Threshold	-95 dBm
Start of data transmission	normal(100, 5) seconds
End of data transmission	End of simulation
Duration of simulation	300 seconds
Packet inter-arrival time	exponential(1) second
Packet size	exponential(1024) bytes
Mobility model	Random Waypoint
Pause Time	exponential(10)
Destination	Random

The geographical location-based routing protocols examined in our study were configured as follows. In LAR scenarios, individual nodes distributed their precise location information once every second. We set α and β parameters of LAR distance protocol to 1 and 0, respectively. GeoAODV protocols were configured to have the initial value of the flooding angle set to 90 degrees. After each failed round of route discovery the value of flooding angle was increased by 90 degrees, until it reached 360 degrees, at which point GeoAODV morphed into regular AODV protocol. GRP was configured to perform a single initial flood. Limited flooding was triggered whenever a node traveled 250 meters or crossed the boundary of a 375 meters x 375 meters quadrant, i.e., the network area was divided into four GRP quadrants. The remaining configuration attributes were set to their default values.

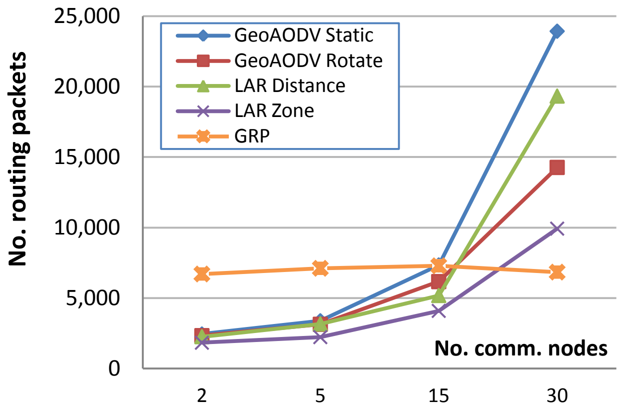

Figure 6: Routing traffic sent when nodes travel at 20 m/s

IV. Analysis of Results

The results collected in our study suggest that the reactive protocols generate less control traffic than GRP in scenarios where the nodes are moving around and there are less than 30 traffic generating sources. However, GRP performed better in all scenarios with stationary nodes and in scenarios with 30 communicating nodes. A summary of collected simulation results is presented in Figures 6 and 7.

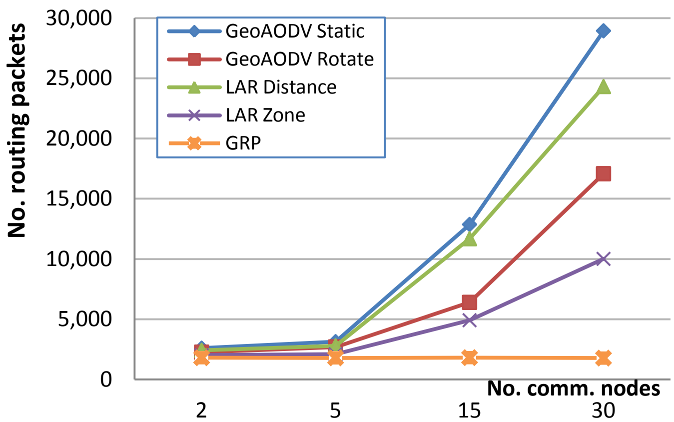

Figure 7: Routing traffic sent when nodes are stationary

GRP performs route discovery during initialization and based on the node movement. However, the number of communicating nodes is not tied in any way to the amount of control traffic generated by GRP. This is clearly reflected in collected results: the number of routing packets generated by GRP remains more or less the same in respect to the number of communicating nodes. However, GRP generates significantly more control traffic in scenarios with mobile nodes than when the nodes are stationary. This happens because in scenarios with stationary nodes GRP generates control traffic only upon initial network-wide route discovery and during periodic "pinging" of neighboring nodes; while when the nodes move around GRP performs additional route discoveries whenever the nodes travel a certain distance or cross quadrant boundaries.

The reactive protocols initiate route discovery whenever there is data to send but route to destination is unknown. Thus, their performance directly relates to the number of traffic generation sources. As the number of communicating nodes increases so do the frequency of route discoveries and the total number of routing packets sent into the network. Collected results suggested that LAR zone protocol generates the least amount of control traffic while GeoAODV rotate is a close second. Even though LAR zone performs the best it relies on the assumption that the GPS location and traveling velocities of all the nodes in the network are readily available, while GeoAODV makes no such assumption and distribute location information during route discovery. Thus, even though GeoAODV rotate generates slightly more control traffic than LAR zone, it may be a better choice in certain environments.

We compared the length of the path taken by the data packets when routed using the proactive GRP protocol and reactive location-aided protocols. The length of the path taken when using GRP was about twice as long as that of any reactive protocol. This phenomenon is most likely due to the greedy nature of GRP: intermediate nodes route the data packet to the next hop node that is closest to destination and backtrack if an impasse is encountered. GRP does not maintain the next hop id in its routing table; instead, the routing tables store the location information. Effectively, GRP performs some limited route discovery while forwarding the data: it tries to find the next hop which is closest to destination and is a part of the path. This results in occasional detours and backtracks which extend the length of the path. Reactive protocols examined in this study actually find the shortest path to destination before forwarding the data. That is why the path length for all examined reactive protocols is about the same and significantly shorter than that of GRP.

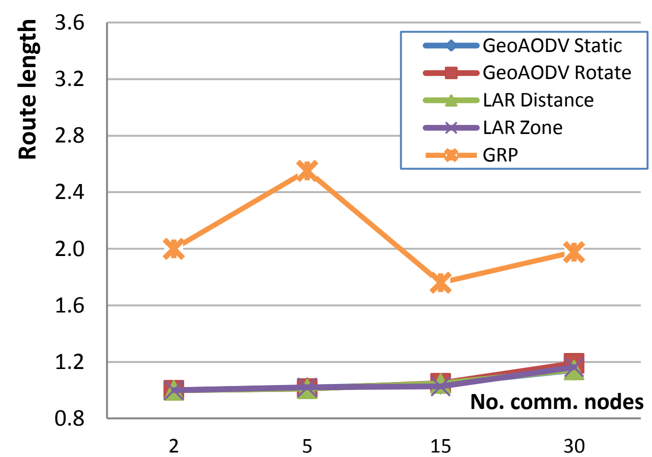

Figure 8: Route length when node travel at 20 m/s

V. Conclusions

This paper compares the performance of reactive and proactive geographical location–aided routing protocols for MANETs through simulation using the OPNET Modeler ver. 16.1 software package [12]. Collected results suggest that proactive protocols will generate less control traffic in the network environment where the nodes are stationary. This occurs because once proactive protocol collects routing information it does not need to be updated very frequently, since the routes remain the same. On the other hand, reactive protocols perform route discovery every time there is data to send. However, in environment where the nodes constantly move, reactive protocols perform better due to the fact that proactive protocols will have to update routing information proportionally to the node movement, while reactive protocols update routing information only when there is data to send. However, a more detailed study of this phenomenon is needed.

Currently, we are investigating other aspects of the reactive protocols which might affect their performance. In particular, we are looking into various optimizations of the GeoAODV protocol in respect to the initial value of the flooding angle and how the flooding angle is expanded after initial failure to find a route. Similarly, we are examining the possibility of improving LAR distance by dynamically adjusting values for α and β and modifying LAR zone to extend the request zone after route discovery failures. Finally, we plan to expand our study by comparing the performance of other proactive routing protocols, such as the Greedy Perimeter Stateless Routing (GPSR) protocol [6].

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