A Performance Comparison Study of Two Position-Based Routing Protocols and Their Improved Versions for Mobile Ad Hoc Networks

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Abstract. The high-level contribution of this paper is a detailed simulation based analysis of the performance of two well-known position-based routing protocols - Greedy Perimeter Stateless Routing (GPSR) and the Geographical Routing Protocol based on Prediction (GRPP) and their improved versions to handle perimeter forwarding. The two strategies adopted to improve the performance of position-based routing protocols and better handle perimeter forwarding are: Destination-node Location Prediction (DNP) and Advanced Greedy Forwarding (AGF) approaches. We use a scalable location service scheme, referred as Hierarchical Location Service (HLS) to periodically disseminate the location information of the nodes in the network. The simulations were conducted in ns-2 under different conditions of network density, node mobility and offered traffic load. Performance results indicate that with a slightly larger location service overhead, the improved versions of GPSR and GRPP based on DNP and AGF yield a relatively lower hop count, end-to-end delay per data packet and a larger packet delivery ratio.

Keywords: Mobile Ad hoc Networks, Position-based Routing, Greedy Perimeter Stateless Routing, Geographical Routing Protocol based on Prediction, Simulations.

1 Introduction

A mobile ad hoc network (MANET) is a dynamic distributed system of wireless nodes that move independently of each other. The operating transmission range of the nodes is limited and as a result, MANET routes are often multi-hop in nature. Any node in a MANET can become a source or destination, and each node can function as a router, forwarding data for its peers. MANET routing protocols can be classified into topology-based and position-based protocols. Topology-based protocols are either proactive or reactive in nature. Proactive routing protocols determine and maintain routes between any pair of nodes irrespective of their requirement. The reactive on-demand routing protocols determine a route only when required. As the network topology changes dynamically, reactive on-demand routing has been preferred over proactive routing [3][6].

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Position-based routing protocols do not conduct on-demand route discovery to learn and maintain routes. Instead, forwarding decisions are taken independently for each data packet at every forwarding node (including the source) depending on the position of the forwarding node, the intermediate nodes and the destination. Normally, the source includes its estimated location information of the destination in every data packet. The position-based routing protocols are mostly designed to choose the intermediate forwarding nodes that lie on the shortest path or close to the shortest path from the source to the destination. Greedy Perimeter Stateless Routing (GPSR) [7] and Geographical Routing Protocol based on Prediction (GRPP) [4] are two-well known examples of position-based routing protocols. Each node is assumed to know the locations of its neighbors through periodic beacon exchange. The effectiveness of the position-based routing protocols depends on the accuracy of the destination location information included in the header of the data packets, method adopted for disseminating location information and the method adopted to learn the latest location information of the destination node. In this research work, we assume the source uses the Hierarchical Location Service (HLS) [8], a robust and scalable location service scheme proposed for MANETs. The source node queries the responsible cells (in a region of the network) of the HLS at a certain time period uniformly distributed in the range $[0\ldots MaxT_{update}]$ where $MaxT_{update}$ is the maximum time period between successive destination location update searches. The source node includes the recently learnt location co-ordinates of the destination in the header of the data packets. The shorter the time between consecutive location update searches by the source node, the more accurate will be the location prediction and shorter will be the hop count. But, this advantage comes at the cost of a higher cellcast (broadcast within the responsible cells) control message overhead in frequently querying the HLS about the latest location of the destination. Due to the limited queue size at the nodes, a higher control message overhead to query HLS can also result in dropping of the data packets.

The rest of the paper is organized as follows: In Section 2, we provide a brief overview of the position-based GPSR and GRPP routing protocols and their improved versions. Section 3 presents the simulation conditions used to compare the GPSR and GRPP routing protocols and their improved versions and explains the simulation results observed for different conditions of network density, node mobility and offered traffic load. Section 4 draws the conclusions.

2 Review of Position-Based Routing Protocols

Position-based routing protocols do not go through a network-wide route discovery process, but attempt to forward the data packets from a source to the destination using the position information of the destination included in the data packet headers and the knowledge of the nodes about the positions of other nodes in their local neighborhood. Two well-known examples of position-based routing protocols are the Greedy Perimeter Stateless Routing (GPSR) protocol [7] and the Geographical Routing Protocol based on Prediction (GRPP) [4].

Greedy Perimeter Stateless Routing (GPSR) [7] is a position-based ad hoc routing protocol in which there is no flooding-based route discovery to determine source-destination routes. The source periodically uses a location service scheme (like HLS) to learn about the latest location information of the destination and includes it in the header of every data packet. If the destination is not directly reachable, the source node forwards the data packet to the neighbor node that lies closest to the destination. Such a greedy procedure of forwarding the data packets is also repeated at the intermediate nodes. In case, a forwarding node could not find a neighbor that lies closer to the destination than itself, the node switches to perimeter forwarding. With perimeter forwarding, the data packet is forwarded to the first neighbor node that is come across, when the line connecting the forwarding node and the destination of the data packet is rotated in the anti-clockwise direction. The location of the forwarding node in which greedy forwarding failed (and perimeter forwarding began to be used) is recorded in the data packet. We switch back to greedy forwarding when the data packet reaches a forwarding node which can find a neighbor node that is away from the destination node by a distance smaller than the distance between the destination node and the node at which perimeter forwarding began. GPSR requires each node periodically (for every one second, in this paper) broadcast a beacon containing its latest location information to its neighbors.

The perimeter forwarding approach of GPSR has been observed to generate wasteful loops when the destination node moves away from the location co-ordinates included in the header of the data packets [10]. To counter the looping problem and to increase the packet delivery ratio when the destination node moves out of its original location, a destination node-location prediction (DNP) approach has been proposed in [10]. According to DNP, each node, before forwarding a data packet based on the location information of the destination in the packet header, searches its neighbor list for the destination node. If the destination node is in the neighbor list, then the data packet is directly forwarded to the destination node. A further advanced improvement to position-based greedy forwarding called Advanced Greedy Forwarding (AGF) has been proposed in [9]. According to AGF, each node manages to collect the list of nodes in its two-hop neighborhood through the exchange of neighbor lists during periodic beacon broadcast in the one-hop neighborhood. In AGF, each node, before forwarding a data packet based on the location information of the destination in the data packet header, searches for the destination in its one-hop and two-hop neighbor lists. If the destination is in the one-hop neighbor list, the data packet is directly forwarded to the destination (in this case AGF reverts to DNP). If the destination is only in the two-hop neighbor list and not in the one-hop neighbor list, the data packet is forwarded to the neighbor node (of the destination) in the one-hop neighbor list.

The Geographical Routing Protocol based on Prediction (GRPP) [4] is a novel approach of deciding the next hop node at a forwarding node, based on the current and future positions of the forwarding node and its neighboring nodes with respect to the ultimate destination node of the data packet. Based on its own movement and the periodic beacons received from its neighbors, each node learns the location of itself and its neighbors at the current time instant t (say, in seconds) and predicts the location of itself and its neighbors for the next 3 seconds (i.e., at time instants t+1, t+2 and t+3). Let I be the intermediate node from which a data packet needs to be forwarded so that it can reach its ultimate destination D. For every neighbor node N of I, I computes the distances d_{IN}^{t}, d_{ND}^{t}, d_{IN}^{t+1}, d_{ND}^{t+1}, d_{IN}^{t+2}, d_{ND}^{t+2}, d_{IN}^{t+3}, d_{ND}^{t+3} between itself and N and between N and D for the current time instant t and for each of the next three seconds. The location of the destination D is assumed to be fixed for the current time instant and for each of the next three seconds. Only the location of the forwarding node *I* and its neighbors are predicted. The forwarding node *I* chooses the next hop as the neighbor node *N* such that the sum $d_{IN}^{t} + d_{ND}^{t} + d_{IN}^{t+1} + d_{ND}^{t+1} + d_{IN}^{t+2} + d_{ND}^{t+2} + d_{IN}^{t+3} + d_{ND}^{t+3}$ is minimized. GRPP is an improvement over the Ellipsoid algorithm [11] that considers only minimizing the sum $d_{IN}^{t} + d_{ND}^{t}$ while choosing the next hop node at the intermediate forwarding node *I*. Both GRPP and the Ellipsoid protocols aim to select the next hop node as the node that lies closer to the straight line joining the forwarding node and the destination. By also considering the predicted locations of the neighbor nodes to determine the next hop, GRPP selects stable links (links having positive increase in the signal strength between consecutively transmitted packets) in the presence of node mobility. Like the original version of GPSR, GRPP also relies on the co-ordinates of the destination location information in the data packet header to apply the above described procedure to determine the next hop.

In this paper, we study the original versions of GPSR and GRPP and also apply DNP and AGF to improve the performance of both GPSR and GRPP. The improved versions are referred to as GPSR_DNP, GPSR_AGF, GRPP_DNP and GRPP_AGF.

3 Simulation Environment and Performance Results

We use ns-2 (version 2.28) [5] as the simulator for our study. We implemented the GPSR, GRPP protocols and their improved versions GPSR_DNP, GPSR_AGF, GRPP_DNP and GRPP_AGF in ns-2. The network dimension used is a 1000m x 1000m square network. The transmission range of each node is assumed to be 250m. The number of nodes used is 25 and 50 nodes representing networks of low and high density respectively. Initially, nodes are uniformly randomly distributed in the network. The maximum time period ($MaxT_{update}$) between successive location update queries sent by a source node to the Hierarchical Location Service for the position-based routing protocols is chosen to be 20, 80 and 200 seconds. For a given value of $MaxT_{update}$, the time period between two successive queries launched by the source node towards the responsible cells (of the HLS) for the latest information about the destination location is uniformly distributed within the range [0… $MaxT_{update}$].

Traffic sources are constant bit rate (CBR). The number of source-destination (*s-d*) sessions used is 15 (indicating low traffic load) and 30 (indicating high traffic load). The starting timings of these *s-d* sessions are uniformly distributed between 1 to 50 seconds. The sessions continue until the end of the simulation time, which is 1000 seconds. Data packets are 512 bytes in size and the packet sending rate is 4 data packets/second. For each node, we made sure that the node does not end up a source for more than two sessions and/ or not as a destination for more than two sessions. The node mobility model used in all of our simulations is the Random Waypoint model [1]; the values of the maximum velocity of a node, v_{max}, used are 5, 30 and 50 m/s representing scenarios of low, moderate and high node mobility respectively.

We measure the following performance metrics for the routing protocols under each of the above simulation conditions. Each data point in Figures 1 through 8 is an average of data collected using 5 mobility trace files and 5 sets of randomly selected 15 or 30 *s-d* sessions, depending on the simulation condition.

- *Control Messages Overhead*: It is the sum of the destination location update search cellcast messages received by the nodes in the network, computed over all the *s-d* sessions of a simulation run.
- *Hop count per path:* It is the average hop count per path, time-averaged over all the *s-d* sessions.
- *End-to-end delay per packet*: It is the average of the delay incurred by the data packets that originate at the source and delivered at the destination.
- *Packet Delivery Ratio*: It is the ratio of data packets delivered to the destination to the data packets originated at the source, computed over all *s-d* sessions.

3.1 Control Message Overhead

We measure the control message overhead as the number of destination location update search messages received by the nodes in the network. Note that we measure the control message overhead as the number of control messages received by the nodes in the network, rather than the number of control messages transmitted. This is because the control traffic is broadcast in nature.

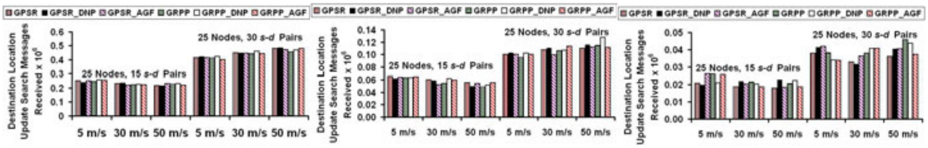

Fig. 1.1. $MaxT_{upd}$ = 20 sec **Fig. 1.2.** $MaxT_{upd}$ = 80 sec **Fig. 1.3.** $MaxT_{upd}$ = 200 sec

Fig. 1. Control Message Overhead (25 Node Network)

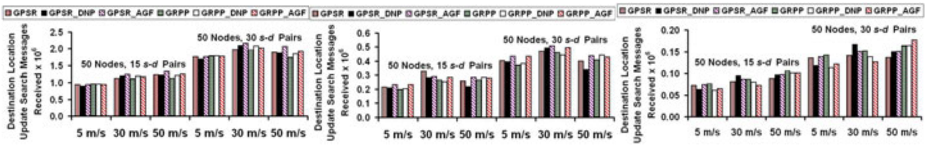

Fig. 2.1. $MaxT_{upd}$ = 20 sec **Fig. 2.2.** $MaxT_{upd}$ = 80 sec **Fig. 2.3.** $MaxT_{upd}$ = 100 sec

Fig. 2. Control Message Overhead (50 Node Network)

The control messages considered for performance measurement are the destination location search cellcast messages in the responsible cells in the case of GPSR, GRPP, GPSR_DNP, GPSR_AGF, GRPP_DNP and GRPP_AGF. The control message overhead incurred by the position-based routing protocols (illustrated in Figures 1 and 2) depends on the value of $MaxT_{update}$ and the number of *s-d* pairs. For a given number of *s-d* pairs, the lower the value of $MaxT_{update}$, the larger the control message overhead and more accurate is the destination location information included by the source in the header of the data packets. Similarly, for a given value of $MaxT_{update}$, the larger the number of *s-d* pairs, more source nodes would initiate destination location searches and larger is the control message overhead. We observe a tradeoff between the control message overhead and the percentage of packets delivered. For a given offered data traffic load, the smaller the $MaxT_{update}$ value, the larger will be the percentage of packets delivered with the position-based routing protocols and vice-versa (refer Figures 7 and 8 for packet delivery ratio).

We do not take into account the periodic beacon exchange overhead incurred while measuring the routing control message overhead. These routing protocols require periodic beacon exchange among neighbors in order to learn about the positions and mobility of the neighbor nodes. In this paper, we have set the beacon exchange interval to be 1 second. The reason for the omission is that we want to only consider control messages whose scope for transmission and reception is larger, i.e., either within the cells of a HLS region or network-wide. Though we do not measure the number of beacons received at the nodes, we do take into consideration the presence of beacons and other control messages in the queues of the nodes and thus consider their impact on packet delivery ratio and end-to-end delay per data packet.

In the case of GRPP, GPSR and their improved versions, after each destination location update search, each source node, independently, uniformly and randomly selects a waiting time value from the range [0… $MaxT_{upd}$ seconds] and initiates the next destination location search process. By doing so, we avoid the situation of having all nodes simultaneously and periodically broadcasting (cellcasting) their location query message updates, which would trigger congestion at the nodes.

3.2 Hop Count per Path

In Figures 3 and 4, we observe that the hop count incurred by GPSR and its improved versions is smaller than that GRPP and its improved versions. As the routing protocols simulated in this paper do not take the queue size into consideration while determining the routes, the hop count of the routes for each protocol is independent of the offered data traffic load. The hop count of the routes chosen by GPSR and GRPP are somewhat influenced by the dynamics of node mobility.

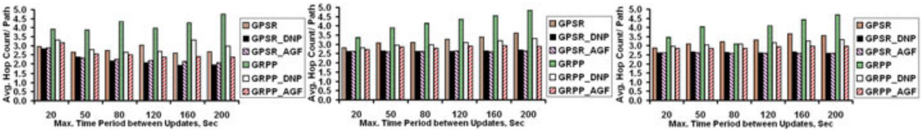

Fig. 3.1. $v_{max} = 5$ m/s **Fig. 3.2.** $v_{max} = 30$ m/s **Fig. 3.3.** $v_{max} = 50$ m/s

Fig. 3. Average Hop Count per Path (25 Node Network and 15 *s-d* Pairs)

For a given value of $MaxT_{update}$, the percentage of data packets getting forwarded through perimeter routing for GPSR increases as the maximum node velocity increases. With perimeter routing, due to the lack of nodes lying on a straight line path connecting the source and the destination, packets get forwarded on a path around the straight line. As more data packets get forwarded through perimeter routing, the average hop count of the paths for a session increases. The hop count of GPSR routes increases with node mobility and with increase in the value of $MaxT_{update}$, for a given offered data traffic load.

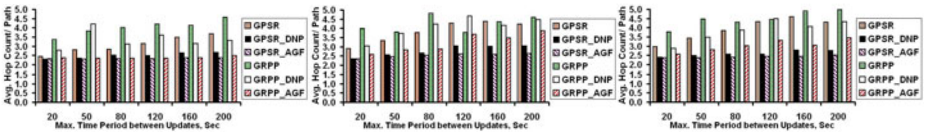

Fig. 4.1. v_{max} = 5 m/s **Fig. 4.2.** v_{max} = 30 m/s **Fig. 4.3.** v_{max} = 50 m/s

Fig. 4. Average Hop Count per Path (50 Node Network and 30 *s*-*d* Pairs)

The hop count of GRPP is higher than that of GPSR by a factor of 20 to 50%. The main reason for this increase in the hop count for GRPP is that while forwarding a data packet towards the destination, the forwarding node chooses the next hop node as the neighbor node that exists (i.e., currently exists and predicted to exist for the next three seconds) closer to the straight line joining the forwarding node's location and the location of the ultimate packet destination, as specified in the data packet header. The hop count would have minimized if the forwarding node chooses the next hop node as the neighbor node that is closer to the destination (similar to the GPSR approach). But, GRPP adopts the "stay on the line through a sequence of stable links" approach to maximize the chances of a data packet reaching the ultimate destination, even if the tradeoff is a higher hop count.

We also observe that for a given offered data traffic load and node mobility, the hop count of GRPP paths in networks of high density is 10 to 25% more than that of the GRPP paths in networks of low density. The advantage is a relatively higher packet delivery ratio (by a factor of 10 to 20%) for GRPP in high-density networks when compared to low-density networks. In high density networks, there are greater chances of finding a source-destination path with all the intermediate nodes located on or closer to the straight line joining the source and the destination. GRPP prefers to go through such "stay on the line" paths (which can have more intermediate nodes) rather than paths that connect the source and destination with the minimum required number of intermediate nodes, but the intermediate nodes are located far away from the straight line joining the source and destination locations.

The hop count of the GRPP routes in networks of moderate and higher node mobility is 15 to 35% more than the GRPP hop count incurred in networks of low node mobility. This could be attributed to the fact that at the time of forwarding a data packet using GRPP, the forwarding node attempts to choose a next hop node as the neighbor node that would be connected to it for the immediate future so that the data packet sent to the neighbor node does not get lost due to the neighbor node suddenly moving away. In order for a forwarding node to choose a neighbor node with which a stable link is predicted to exist at least for the immediate future, the forwarding node and the neighbor node should be either moving towards each other or be moving parallel to each other separated by a smaller distance.

The DNP and AGF versions are observed to be very effective in reducing the hop count per path incurred by the original versions of both GPSR and GRPP. Both DNP and AGF are effective strategies to avoid routing loops encountered with the original versions of GPSR and GRPP. If the destination node is located in the one-hop neighborhood (in the case of DNP and AGF) or is located in the two-hop neighborhood (in the case of AGF), a data packet is forwarded to the destination node (if located in the one-hop neighborhood) or to the neighbor of the destination node (if located in the two-hop neighborhood) and is not forwarded based on the destination location co-ordinates in the data packet header.

3.3 End-to-End Delay per Data Packet

Figures 5 and 6 illustrate the end-to-end delay per data packet for all the routing protocols. GPSR and its improved versions incur a lower end-to-end delay per data packet for all simulation conditions. In networks of low density and high offered traffic load, almost all the nodes play the role of intermediate nodes for at least one *s-d* session and each node acts as source or destination for at least one session.

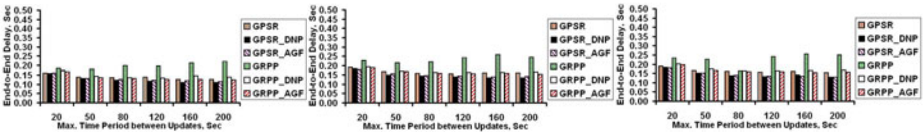

Fig. 5.1. $v_{max} = 5$ m/s **Fig. 5.2.** $v_{max} = 30$ m/s **Fig. 5.3.** $v_{max} = 50$ m/s

Fig. 5. Average End-to-End Delay per Data Packet (25 Node Network, 15 *s-d* Pairs)

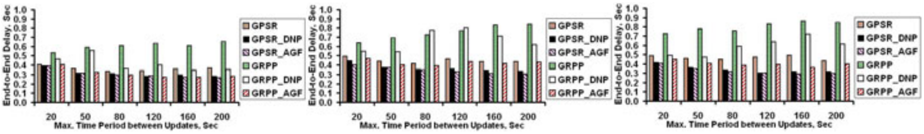

Fig. 6.1. $v_{max} = 5$ m/s **Fig. 6.2.** $v_{max} = 30$ m/s **Fig. 6.3.** $v_{max} = 50$ m/s

Fig. 6. Average End-to-End Delay per Data Packet (50 Node Network, 30 *s-d* Pairs)

For position-based routing protocols, the delay per data packet decreases as we use higher values of $MaxT_{update}$. But, the decrease in the delay per data packet is not proportional to the increase in $MaxT_{update}$ value. For a given offered data traffic load and node mobility, the decrease in the end-to-end delay per data packet is by factors of 20-30% (for low density networks) and 10-15% (for high density networks) when the $MaxT_{update}$ value is increased from 20 seconds to 200 seconds. The relative decrease in the magnitude of the difference is attributed to the increase in the route discovery control message overhead (route discoveries and route maintenance/ repair) for LPBR as we increase the offered data traffic load and/or node mobility.

The delay per data packet incurred by GRPP could be as large as 1.5 – 2.0 times to that incurred by GPSR. This could be due to paths of larger hop count chosen by GRPP. The DNP and AGF versions of GRPP reduce the delay significantly by routing the data packet through shortest paths as and when possible. The reduction in the delay per data packet incurred with GRPP_DNP and GRPP_AGF in comparison with that incurred using GRPP could be as large as by a factor of 1.5 – 2.2.

3.4 Packet Delivery Ratio

Figures 7 and 8 illustrate the packet delivery ratio achieved. The packet delivery ratio of GRPP, GPSR_AGF and GRPP_AGF is the largest in most of the simulation conditions. This is attributed to the "stay on the line through a sequence of stable links" path selection approach of GRPP and the effective one-hop/two-hop neighborhood based destination location identification approach of AGF.

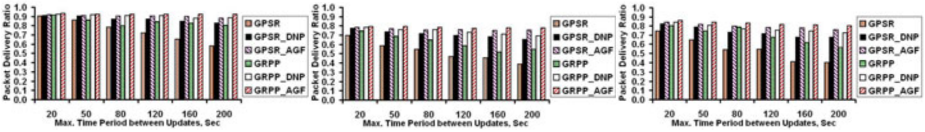

Fig. 7.1. $v_{max} = 5$ m/s **Fig. 7.2.** $v_{max} = 30$ m/s **Fig. 7.3.** $v_{max} = 50$ m/s

Fig. 7. Average Packet Delivery Ratio (25 Node Network, 15 *s-d* Pairs)

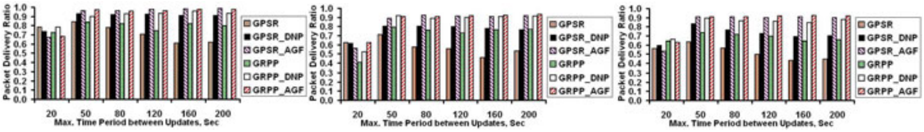

Fig. 8.1. $v_{max} = 5$ m/s **Fig. 8.2.** $v_{max} = 30$ m/s **Fig. 8.3.** $v_{max} = 50$ m/s

Fig. 8. Average Packet Delivery Ratio (50 Node Network, 30 *s-d* Pairs)

The packet delivery ratio of GPSR is about 5 to 15% less than that of GRPP. Note that the packet delivery ratios for GPSR and GRPP decrease with increase in the value of $MaxT_{update}$. This is attributed to the lack of accurate information of the destination location as the time period between two successive destination location update searches increases. As a result, data packets are subjected to more of perimeter forwarding and routing loops and hence get dropped eventually. On the other hand, the DNP and AGF versions of both GPSR and GRPP are not much affected by the value of $MaxT_{update}$ because they rely on locally finding the destination node based on the neighborhood information collected during the per-second periodic beacon exchange. This is attributed to the relative reduction in the HLS cellcasting overhead incurred as part of the destination location update search process and availability of more space in the queue of the nodes for forwarding the data packets.

4 Conclusions and Future Work

We compared the performance of GPSR, GRPP protocols and their improved versions GPSR_DNP, GPSR_AGF, GRPP_DNP and GRPP_AGF. We ran extensive simulations (in ns-2) by varying the network density, node mobility and offered data traffic load. We observe a tradeoff between the packet delivery ratio and the destination location search overhead in the case of the position-based routing protocols. As the maximum time period between two successive destination location searches is reduced, the accuracy of destination location information included in the data packet header is increased leading to an improvement in the packet delivery ratio. But, this is achieved at the cost of a higher destination location search control message overhead. Nevertheless, the DNP and AGF versions of GPSR and GRPP could yield relatively larger packet delivery ratios and still incur a lower control message overhead. The improved versions, GPSR_DNP and GPSR-AGF yield routes with a lower hop count and delay per data packet for most of the scenarios. GRPP and its improved versions yield a relatively higher packet delivery ratio compared to GPSR and its improved versions. As future work, we will evaluate the performance of the position-based routing protocols with other MANET mobility models and also compare them with respect to energy consumption per node and node lifetime.

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