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(General article)

Position Based Routing Technique: Greedy Perimeter Stateless Routing for Wireless Networks

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Abstract

We present Greedy Perimeter Stateless Routing (GPSR), one of the best examples of position based routing. GPSR is a routing protocol for wireless datagram networks that uses the positions of routers and a packet's destination to make packet forwarding decisions. GPSR makes greedy forwarding decisions using only information about a router's immediate neighbors in the network topology. When a packet reaches a region where greedy forwarding is impossible, the algorithm recovers by routing around the perimeter of the region. By keeping state only about the local topology, GPSR scales better in per-router state than shortest-path and ad-hoc routing protocols as the number of network destinations increases. Under mobility's frequent topology changes, GPSR can use local topology information to find correct new routes quickly. We describe the GPSR protocol, and use extensive simulation of mobile wireless networks to compare its performance with that of Ad Hoc On Demand Distance Vector Routing (AODV). Our simulations demonstrate GPSR's scalability on densely deployed wireless networks.

Keywords: *VANET, Distance Vector, Link State, Ad hoc Network, Automation*

1. Introduction

In networks comprised entirely of wireless stations, communication between source and destination nodes may require traversal of multiple hops, as radio ranges are finite. A community of adhoc network researchers has proposed, implemented, and measured a variety of routing algorithms for such networks. The observation that topology changes more rapidly on a mobile, wireless network than on wired networks, where the use of Distance Vector (DV), Link State (LS), and Path Vector routing algorithms is well established, motivates this body of work.

DV and LS algorithms require continual distribution of a current map of the entire network's topology to all routers. DV's Bellman-Ford approach constructs this global picture transitively; each router includes its distance from all network destinations in each of its periodic beacons. LS's Dijkstra approach directly floods announcements of the change in any link's status to every router in the network. Small inaccuracies in the state at a router under both DV and LS can cause routing loops or disconnection *(zaumen, w., and garcia-luna aceves, (sept. 1991)).*

The two dominant factors in the scaling of a routing algorithm are:

- The rate of change of the topology.
- The number of routers in the routing domain.

Both factors affect the message complexity of DV and LS routing algorithms: intuitively, pushing current state globally costs packets proportional to the product of the rate of state change and number of destinations for the updated state.

We propose the aggressive use of *geography* to achieve scalability in our wireless routing protocol, Greedy Perimeter Stateless Routing (GPSR). We aim for scalability under increasing numbers of nodes in the network, and increasing mobility rate. As these factors increase, our measures of scalability are:

- Routing protocol message cost: How many routing protocol packets does a routing algorithm send?
- Application packet delivery success rate: What fraction of applications' packets are delivered successfully by a routing algorithm?
- Per-node state: How much storage does a routing algorithm require at each node?

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Networks that push on mobility, number of nodes, or both include:

1. Ad-hoc networks: Perhaps the most investigated category, these mobile networks have no fixed infrastructure, and support applications for military users, post-disaster rescuers, and temporary collaborations among temporary associates, as at a business conference or lecture *(haas, z., and pearlman (sept. 1998), johnson, d. B., and maltz (1996))*
2. Sensor networks: Comprised of small sensors, these mobile networks can be deployed with very large numbers of nodes, and have very impoverished per-node resources *(chandrakasan, a., amirtharajah, r., cho, s., goodman, j., konduri, g., kulik, j., rabiner, w. And wang (may 1999),kahn, j. M., katz, r. H., and pister, k. S. J. (aug 1999))*. Minimization of state per node in a network of tens of thousands of memory-poor sensors is crucial.
3. "Rooftop" networks: Proposed by Shepard *(shepard (aug. 1996)*, these wireless networks are not mobile, but are deployed very densely in metropolitan areas (the name refers to an antenna on each building's roof, for line-of-sight with neighbors) as an alternative to wired networking offered by traditional telecommunications providers. Such a network also provides an alternate infrastructure in the event of failure of the conventional one, as after a disaster. A routing system that self-configures (without a trusted authority to configure a routing hierarchy) for hundreds of thousands of such nodes in a metropolitan area represents a significant scaling challenge.

Traditional shortest-path (DV and LS) algorithms require state proportional to the number of reachable destinations at each router. We will show that geographic routing allows routers to be nearly stateless, and requires propagation of topology information for only a *single hop*: each node need only know its neighbors' positions. The self-describing nature of position is the key to geography's usefulness in routing. The position of a packet's destination and positions of the candidate next hops are sufficient to make correct forwarding decisions, without any other topological information.

We simulate a network that uses 802.11 radios to evaluate our routing protocol. We consider topologies where the wireless nodes are roughly in a plane. Finally, we assume that packet sources can determine the locations of packet destinations, to mark packets they originate with their destination's location. Thus, we assume a location registration and lookup service that maps node addresses to locations *(C. Lochert, H. Hartenstein, J. Tian, D. Herrmann, H. Füßler, and M. Mauve,(June 2003)*. Queries to this system use the *same* geographic routing system as data packets; the querier geographically addresses his request to a location server. The scope of this paper is limited to geographic routing. We adopt IP terminology throughout this paper, though GPSR can be applied to any datagram network.

In the following sections, we describe the algorithms that comprise GPSR, measure and analyze GPSR's performance and behavior in simulated mobile networks.

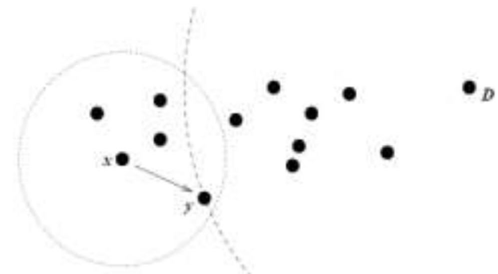

Figure 1 Greedy forwarding example. *y* is *x*'s closest neighbor to *D*.

Algorithms and examples

We now describe the Greedy Perimeter Stateless Routing algorithm. The algorithm consists of two methods for forwarding packets: *greedy forwarding*, which is used wherever possible, and *perimeter forwarding*, which is used in the regions greedy forwarding cannot be.

Greedy Forwarding

As alluded to in the introduction, under GPSR, packets are marked by their originator with their destinations' locations. As a result, a forwarding node can make a locally optimal, greedy choice in choosing a packet's next hop. Specifically, if a node knows its radio neighbors' positions, the locally optimal choice of next hop is the neighbor geographically closest to the packet's destination. Forwarding in this regime follows successively closer geographic hops, until the destination is reached. An example of greedy nexthop choice appears in Figure 1. Here, *x* receives a packet destined for *D*. *x*'s radio range is denoted by the dotted circle about *x*, and the arc with radius equal to the distance between *y* and *D* is shown as the dashed arc about *D*. *x* forwards the packet to *y*, as the distance between *y* and *D* is less than that between *D* and any of *x*'s other neighbors. This greedy forwarding process repeats, until the packet reaches *D*.

Greedy forwarding's great advantage is its reliance only on knowledge of the forwarding node's immediate neighbors. The state required is negligible, and dependent on the density of nodes in the wireless network, not the total number of destinations in the network. On networks where multi-hop routing is useful, the number of neighbors within a node's radio range must be substantially less than the total number of nodes in the network. The position a node associates with a neighbor becomes less current between beacons as that neighbor moves. The accuracy of the set of neighbors also decreases; old neighbors may leave and new neighbors may enter radio range. For these reasons, the correct choice of beaconing interval to keep nodes' neighbor tables current depends on the rate of mobility in the network and range of nodes' radios. We show the effect of this interval on GPSR's performance in our simulation results. We note that keeping current topological state for a one-hop radius about a router is the minimum required to do *any* routing; no useful forwarding decision can be made without knowledge of the topology one or more hops away.

In fact, we could make GPSR's beacon mechanism fully reactive by having nodes solicit beacons with a broadcast "neighbor request" only when they have data traffic to forward. We have not felt it necessary to take this step, however, as the one-hop beacon overhead does not congest our simulated networks. The power of greedy forwarding to route using only neighbor nodes' positions comes with one attendant drawback: there are topologies in which the only route to a destination requires a packet move temporarily *farther* in geometric distance from the destination *(FINN, G. G. (Mar. 1987), KARP, B. (July 1998).*

A simple example of such a topology is shown in Figure 2. Here, *x* is closer to *D* than its neighbors *w* and *y*. Again, the dashed arc two paths, (x→y →z→D) and (x→w→v→D), exist to *D*, *x* will not choose to forward to *w* or *y* using greedy forwarding. *x* is a local maximum in its proximity to *D*. Some other mechanism must be used to forward packets in these situations.

Figure 2 Greedy forwarding failure. *x* is a local maximum in its geographic proximity to *D*; *w* and *y* are farther from *D*.

The Right Hand Rule: Perimeters

Perimeter forwarding is used where greedy forwarding fails. It means when there is no next hop closest neighbor to the destination is available then perimeter forwarding is used. Perimeter forwarding uses nodes in the void regions to forward packets towards destination. The perimeter forwarding used the right hand rule. In "*right hand rule*" *(ko, y., and vaidya (Aug. 1998)*, the voids regions are exploited by traversing the path in counterclockwise direction in order to reach at specific destination. When a packet forward by source node, it forwarded in counterclockwise direction including destination node until it again reached at the source node. According to this rule each node involved to forward packet around the void region and each edge that is traversed are called perimeter. Edges may cross when right hand rule finds perimeter that are enclosed in the void by utilizing *"heuristic approach" (KO, Y., AND VAIDYA (Aug. 1998)*. Heuristic has some drawbacks besides it provides maximum reach ability to destination. The drawback is that it removes without consideration of those edges which are repeated and this may cause the network partitions. To avoid this drawback another strategy is adopted that is described below.

Planarized Graphs

When two or more edges cross each other in a single graph is called planar graph. "*Relative Neighborhood Graph (RNG)"* and "*Gabriel Graph (GG)" (KO, Y., AND VAIDYA (Aug. 1998))* are two types of planar graphs used to remove the crossing edges. Relative neighborhood graph (RNG) is defined as, when two edges intersect with radio range of each other and share the same area. For example, x and y are the two edges that share the area of two vertices x and y. The edge x, y are removed by using RNG because another edge from x towards v is already available.

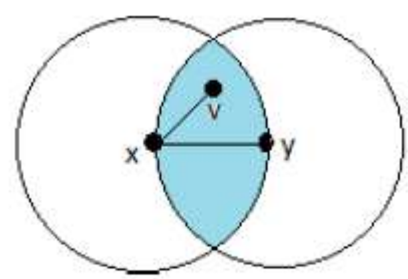

Figure 3 Example of RNG

Gabriel Graph (GG) is used to remove only those crossing edges which are in between the shared area of two nodes having the same diameter as the other nodes have. Figure 4 depicts GG:

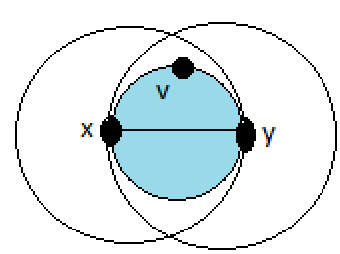

Figure 4 Example of GG

Figure 4 shows that the midpoint diameter is less than the diameter of node x or node y. Thus the edge from the x, y cannot be removed. So there is less network disconnection in the GG as compared to RNG.

Features of GPSR

GPSR combines the greedy forwarding with the perimeter forwarding to provide better routing decision on both full and planarized network graph by maintaining neighbor"s information in the location table. For the forwarding decisions in perimeter mode GPSR packet header include the following distinct characteristics ***(****ko, y., and vaidya (aug. 1998))*.

- Gpsr packet header has the flag identity that is used to identify whether packet is in greedy forwarding or in perimeter forwarding.
- It contains destination node physical address.
- GPSR packet header also contains location of packet in the perimeter mode and the location of the new face to take a decision whether to hold the packet in the perimeter mode or to return it to the greedy mode.
- GPSR also have the record of sender and receivers address of the packet when the edge"s crosses in the new face.

GPSR also have several distinct characteristics that are if the packet is in perimeter mode then its location address is compared to forwarded node address and if distance to location and destination node is less then packet it switched to greedy mode to forward packet towards destination. GPSR discard those packets that are repeatedly forwarded as destination for such packets are not in range. The packets in perimeter mode never send twice through the same link if destination is in range. Overall GPSR is an efficient example of the position based routing that uses the geographic location of nodes and reduced usage of routing state on each node.

Issues in GPSR

Besides GPSR certain characteristics, it suffers from several drawbacks. Greedy forwarding measured as unsuitable for the vehicular networks where the nodes are highly mobile and the node may not be able to maintain its next hop neighbors information as the other node may gone out of range due to high mobility. This can lead to data packets loss. The second problem may occur during beaconing mechanism that beacons may lost due to channel destruction or bad signal. This problem can lead to removal of neighbor information from location table *(Lochert, C., Mauve, M., Füßler, H., and Hartenstein, (Jan. 2005)* GPSR uses planarized graphs as its repair strategy where greedy forwarding fails. But these graphs perform well in the highway scenario due to their distributed algorithms *(C. Lochert, H. Hartenstein, J. Tian, D. Herrmann, H. Füßler, and M. Mauve,(June 2003))*. These graphs does not perform well in such environment of vehicular communication where a lot of radio obstacles involves, in addition to this their distributed nature may lead to certain partition of network and may lead to packet delivery impossible. Hence there is need of such position based routing protocols, which merge position information with the road topological structure in order to make possible vehicular communication in presence of radio obstacles.

Future work

In wireless network community VANET received attention of many researchers due to its unique nature. Although amount of research has been devoted to the various routing issues in VANET but still there are some areas that need more attention. Due to time constraint, we only focused on traditional ad hoc and position based routing protocols but still there are some areas in these routing protocols that need more attentions.

- Other performance metrics such as end-to-end delay, average routing overhead and packet delivery ratio etc should be measure for both topology based and position based routing methods in VANET.
- Secure routing is one of the challenging areas. Due to the unsecure and ad hoc nature of VANET, there is prone to several security attacks that may lead to devastating consequences. So security attacks should be investigated with respect to different attacks in VANET.
- Several other routing methods such as broadcast, geocast and cluster based routing methods can be consider for the evaluation of routing protocols in VANET.
- New algorithms should be proposed to provide reliable QoS for safety and comfort applications in VANET.
- Different position based routing protocols should be evaluated in real environment of VANET to check their efficiencies in real situation.

Conclusion

We examined reactive ad hoc routing protocol AODV against position based routing protocols i.e. GPSR and A-STAR and found that the performance of AODV suffers from the high speed of nodes, radio obstacles and sudden change in position of nodes in VANET. So high speed of nodes and involvement of radio obstacles are major challenges for traditional ad hoc routing protocols that makes them unsuitable for VANET. We found that position based routing protocols shows better results than traditional ad hoc routing protocols in VANET. We evaluated two position based routing protocols that are GPSR and A-STAR in two different scenarios of

VANET. GPSR outperforms AODV completely in both highway and city environments of VANET. While GPSR affected with the involvement of obstacles in the large city environments. On the other hand A-STAR outperforms both GPSR and AODV in city environments of VANET. As A-STAR uses the anchored based street information to find the routes in large city environments, therefore it is not an alternative for highway scenarios. So we realized that A-STAR is scalable for such environments of VANET where numbers of nodes are higher and radio obstacles involved, while GPSR is reliable for direct communication among nodes. Furthermore, all position based routing protocols cannot deal with all various environments of VANET. From the conducted study, we suggest that position based routing protocols are more promising than traditional ad hoc routing protocols for VANET. Although position based routing is scalable for VANET but it is hard to suggest any single routing protocol that can deal with different scenarios of VANET. The selection of a single routing protocol is hard in VANET because the protocol performance depends on vehicle speed, driving environment etc that may vary from one environment of network to another.

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