An Overview of Geographic Routing in Mobile Ad Hoc Networks

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Although geographical routing in MANETs is fairly new, the idea of geographical forwarding is simple to the degree that one can only lay claim to discovering, not inventing, it. So much so, in fact, that the first paper to specifically mention geographical routing does so in passing [19].

The idea of using GPS in geographical routing is extensively covered in [18], and no doubt was one of the applications considered by the creators of GPS (cf. [5]).

On a topic discussed in this section, [6] is widely cited as the first study to mention the shortcomings of *greedy forwarding*, but this author presently does not have a copy of the report for verification.

1 MFR (1984)

Takagi and Kleinrock's excellent paper *Optimal Transmission Ranges for Randomly Distributed Packet Radio Terminals* [19] is actually about power management in packet radio networks. They solve the problem of finding the optimal transmission range for a randomly distributed packet using slotted ALOHA or CSMA. If the transmission range is fixed, choosing the value they prescribe results in the maximum expected progress per forward towards the destination.

They describe a routing algorithm called MFR (most forward within R), where the source forwards packets to the neighbor whose projection along the line connecting the source and destination is greatest, even if the source is closer. The transmission radius is fixed and the source is assumed to know the position of the destination.

The case where the transmission power is adjustable is considered in [8]. A system with directional antennas but fixed transmission power is considered in [4]. Other aspects of the same algorithm are analyzed in [10].

2 LAR (1998)

Ko and Vaidya's *Location-Aided Routing* (LAR, [14]) is not a protocol *per se*. Rather, it is an optimization that can be used in conjunction with flooding algorithms to "limit the search for a new route to a smaller 'request zone' of the ad hoc network".

Starting from the unreasonable premise that the location of the destination is always known, the authors simply state that packets should be forwarded only among nodes in which the destination belongs (the *expected zone*.) The expected zone encapsulates the area the destination is expected to be in, given its average velocity and the elapsed time since it was last sighted. More realistic mobility models are not considered.

Realizing that the *expected zone* may not contain the forwarding nodes, the authors define the *request zone* so the existence of a path to the destination can be guaranteed. The proposed request zone turns out to be rectangular, with the source in one corner, and the expected zone of the destination in the other. Then two schemes using this expected zone are offered. The first scheme forwards only to nodes inside the rectangle, otherwise it discards packets. The second scheme is more lax and continues to forward packets on the condition that some progress is being made towards the destination. This 'progress' can be negative; all that is required is that the relaying node be "at most δ farther"' from the node preceding it. This may occasionally result in packets being forwarded outside of the rectangular request zone.

3 DREAM (1998)

The *Distance Routing Effect Algorithm for Mobility* (DREAM, [2]) by Basagni *et al.* is an unthought through attempt at designing a geographical routing protocol. The paper puts forth the valid observation (the 'distance effect'), which states that "the greater the distance separating two nodes, the slower they appear to be moving with respect to each other. Accordingly, the *location information* in routing tables can be updated as a function of the distance separating nodes without compromising routing accuracy." Yet this is common knowledge, even in fixed networks, and is one of the reasons why hierarchical routing works [13].

The forwarding rule shows resemblance to that of LAR: the *expected zone* of the destination is calculated given the destination's position and velocity. The *request zone* is then the smallest wedge containing the request zone, with the source at its tip (cf. figure 1, [2]). Packets are forwarded to every neighbor in the request zone, for multi-path routing. The problems of what to do if the sender has no location information, or if no neighbors are in the request zone, are deliberately avoided. The 'recovery' algorithm is flooding.

DREAM periodically broadcasts control packets containing the position of the node they have been sent by. The *life time* of a control packet is based on the distance the packet has traveled from its sender. The 'distance effect' is realized by sending short-lived control packets more often than long-lived ones, similarly to many hierarchical algorithms [9]. The authors acknowledge that "a sender may experience a long delay in waiting for the route to be computed. Furthermore, there is no guarantee that the route obtained is usable, since in the meanwhile some of the nodes in the route may have moved out of transmission range."

The paper's real fault lies in its far-fetched statements. The requirement for the routing table to contain an entry for all the other nodes is too strict; the algorithm should fail gracefully for fixed-length tables. The claim that the algorithm is "inherently loop-free" is obviously wrong, because the algorithm is not fully defined. The claim that "we can derive a probabilistic guarantee of finding a node in a given direction" is vacuous because the proffered expressions are not evaluated, nor approximations made, nor even educated guesses formed. Finally, the liberal use of the word *optimization* is disconcerting, because nothing is optimized.

4 GPSR (1999)

The *Greedy Perimeter Stateless Routing* algorithm (GPSR, [12]) by Karp and Kung presents a solution to resolving the *dead-end problem* problem. This is an issue with stateless greedy geographical algorithms (e.g., MFR, LAR, DREAM, GRA). *Greedy* refers to their inability to look ahead, leading packets into dead ends. *Stateless* refers to their lack of memory about the route, so they continue to repeat the same mistakes. "When a packet packet reaches a region where greedy forwarding is impossible, the algorithm recovers by routing around the *perimeter* of the region".

Based on [3], GPSR appears to be the first complete protocol to tackle this problem. [1, ch. 4], a later work, also covers 'obstacle avoidance', but remarkably contains no bibliography, so the source of inspiration is unclear.

Another major novelty in this paper is its inclusion of a sophisticated *location management* subsystem. Borrowed from [16], this subsystem allows each node to intelligently track the position of the other nodes, allowing Karp and Kung to reasonably assume that the location of the destination is known.

The greedy routing algorithm simply forwards packets to the neighbor nearest to the destination. This scheme is applied until the destination or a dead end (local maximum) is reached. In the latter case, *perimeter routing* takes place.

Perimeter routing involves planarizing the network graph, such as in [15, 3]. The suggested planarization types are *Relative Neighborhood* and *Gabriel* (described in the paper.) Once the distributed planarization in complete, packets are forwarded along the perimeter as explained:

> Perimeter forwarding is only intended to recover from a local maximum; once the packet reaches a location closer than where greedy forwarding previously failed for that packet, the packet can continue greedy progress toward the destination without danger of returning to the prior local maximum.
>
> When a packet enters perimeter mode at node x, GPSR forwards it along the face intersected by the line $\overline{xD}$ [D: destination]. x forwards the packet to the first edge counter-clockwise about x from

> the line $\overline{xD}$. This determines the first face over which to forward the packet. Thereafter, GPSR forwards the packet around that face using the right-hand rule.
> [In a disconnected graph,] GPSR will greedily forward a packet for potentially many hops before the packet loops ... and is recognized as undeliverable. If the majority of unreachable destinations lie beyond the boundary of a single face, undeliverable packets may concentrate on that face of the network graph.

Beacons, jittered by half a period to avoid collisions, are piggybacked onto every data packet. It is suggested that transceivers operate in *promiscuous mode*, which has the undesirable consequence of rapidly draining energy.

Simulation results indicate that GPSR performs favorably compared with DSR, with $5-10\%$ of DSR's overhead, close to perfect delivery rates and path length optimality.

5 SLURP (2000)

Woo and Singh's *Scalable Location Update-based Routing Protocol* (SLURP, [20]) is different from the other protocols in this section. It is more like the hierarchical routing algorithms used in Mobile IP networks in which each node is associated with a 'home', responsible for keeping a pointer to its current location.

A central feature of SLURP is its mapping of a node ID to a region ID. This static, many-to-one mapping should be independent of network size, transparent to mobility, known to all nodes and such that every region has the same node density. The authors use modular arithmetic as an example.

When a node moves across regions, it informs its home region by multicasting. If the home region is unpopulated at that time, all eight surrounding regions are informed, etc. All nodes are aware of the other nodes in their region.

Inter-region routing is done by MFR without backwards progression [19]. Intra-region routing is done by DSR [11].

Numerous optimizations are suggested, a scalability analysis is presented, followed by simulation results.

6 Conclusion

Judging by the literature, little progress has been made since MFR [19]. For the most part, the use of geographic information has been limited to local decisions (e.g., which neighbor to forward to), without due attention to the rest of the network.

The reason for the primitiveness of current geographical routing algorithms is that the location management systems on which this class of algorithms critically depends have yet to reach maturity. It is not coincidental that a great many routing protocols assume that the position of the destination is known; for knowledge of position is tantamount to solving the routing problem.

As noted in [12], geographical information is another card for extracting scalability, alongside caching and hierarchy.

For surveys and performance comparisons see [7, 17].

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