Albert-Ludwigs-University of Freiburg WS2009
Computer Networks and Telematics
Ad-Hoc Networks Seminar

Report on the subject:

"On the Pitfalls of Geographic Face Routing".
Y.-J. Kim, R. Govindan, B. Karp, S. Shenker, 2005

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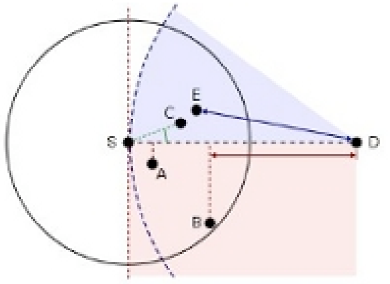
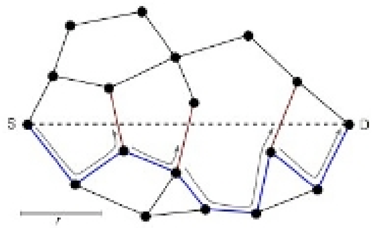
1. Introduction

In normal networking we are used to an idea that when we send packets from source to destination they are being routed using their network addresses. In *Geographic Routing* situation is somewhat different. We route the packets using their geographical coordinates.

For that purpose two basic approaches are used, namely *Greedy*(pic. 1) and *Face Routing*(pic. 2) as well as the protocols based on them. In *Greedy* message is being routed closer and closer to the destination node while only local information is being used in order to decide to which node it is better to send the packet from the current one. *Face Routing* however consists of two parts: *Planarization* and *Face Traversal*. The first one is used to compute a planar[1] graph out of the initial wireless connectivity graph. In order to understand what the second part means we need to take a look at the pic. 2, which shows the situation where we would like to move packet from node S to node D. *Face routing* simply moves the packet along the inner side of the faces of the graph with face changes occuring at the point where packet tries to cross the $[S, D]$ segment. Thus while moving the packet it tries to "keep as close as possible" to the $[S, D]$ segment(which is obviously the shortest distance between source and destination) but without crossing it.



[1] Pic1. Greedy: local info used - angle, distance etc



[1] Pic2. Face Routing: traversing in planar graph

Based on the afore-mentioned approaches there are various protocols for *Geographic Routing*. Such as: *GFG, GPSR, GOAFR+* family. These algorithms share the similar idea of using *Greedy* in the first place unless a radio "void" is encountered. E.g. packet reaches the node from which there is no neighbor with a shorter way to the destination. If such situation occurs then *Face Routing* is used to recover from it and then algorithms proceed again with *Greedy* once it can be used. If we summarize - protocols share 3 basic approaches: *Greedy forwarding, Planarization, Face Traversal*.

Authors of the paper [2] suggest that the weakest point of afore-mentioned protocols is planarization, which fails in realistic situation. Having unit-disk graphs[2] representing connectivity between the nodes is vital for successfull planarization. It is however not always possible to have unit-disk graphs in real wireless connectivity because of various reasons(e.g. radio blocking obstacles). Furthermore authors classify situations where planarization fails and classify pathologies caused by this problem, while suggesting face traversal rules that best match in case of unit-disk graph assumption violation.

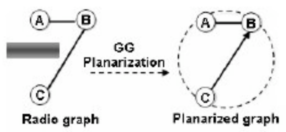
[1] A planar graph is a graph where edges intersect only at the endpoints.

[2] Unit-disk graph is a graph where each node is always connected to all other nodes inside its fixed radio range and never to the ones outside of it.

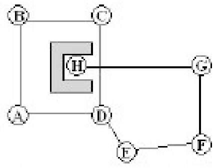
2. Planarization

This chapter discussess planarization in more detail. In order to construct a planar subgraph, algorithms like *GG(Gabriel Graph), RNG(Relative Neighborhood Graph), RDG(Restricted Deluney Graph)* are used. The main idea in all of them is to eliminate crossing links via so called "witnesses", which are nothing more than other neighbors lying in certain geometric region. Thus we eliminate cross link at the same time preserving connection(indirect) from A to B through a "witness". Each algorithm has its own way to determine the geometric region where "witness" must be situtated.

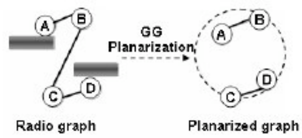
Since all of the afore-mentioned algorithms rely on unit-disk assumption, in case of its failure we can encounter 3 different problems in planarization, which are: *unidirectional links, preserved cross links and disconnected links*. We will take a look at each of these problems. Corresponding illustrations follow:



[2] Pic3. Unidirectional links



[2] Pic4. Cross links



[2] Pic5. Disconnected links

In order to understand how unidirectional links can occur let's take a look at pic. 3. Simple scenario is that due to obstacle C doesn't "see" A and therefore keeps CB link. Furthermore, node B has access to A and therefore removes its link BC considering A as a "witness". What we get is a "one-way" link from C to B.

Now let's consider cross links by looking at pic. 4. H is enclosed into radio wave blocking wall, such that C and D cannot see H and vice versa. G also doesn't see C and D and vise versa because of a long distance. In this case link CD will not be eliminated and will cross with HG.

Last but not the least - disconnected links in subgraph on pic. 5. Here A and C as well as B and D correspondingly cannot communicate due to the obstacles. C "thinks" that CB link can be eliminated since D might be used as a "witness". The same applies to BC link and witness A. In the end we have disconnected link between C and B in both directions.

In addition it is important to say that these problems can be caused not only by obstacles but also by the fact that nodes can incorrectly estimate their own location or due to transciever differences.

In order to avoid afore-mentioned problems the *Mutual Witness Protocol* was created. The basic idea is that nodes communicate between each other sending lists of their neighbors in order to identify mutual ones. As shown in [2] this approach however is not effective if unit-disk assumption is violated, turning one problem into another. According to the same paper tests were done in topology with 23 and 50 nodes using *GPSR* protocol with success rate showing number of nodes, which were able to communicate. Pure *GG* showed rather poor performance of 97.2% 68.2% depending greatly on the number of nodes. *GG* "equipped" with *MWP* discussed earlier, showed slightly better performance of 100% 87.8% correspondingly, cross links left, collinear ones introduced. The best results were achieved through using *CLDP* with *GG*. In both cases success rate was equal to 100%, which leads us to the discussion of *CLDP*.

Cross-Link Detection Protocol was suggested by authors of [2] and its basic idea is simple. For each node and all of its links protocol simply checks whether the link is not crossed by any other one. It works as follows. Node A sends a so called "probe" containing its coordinates and the coordinates of the other endpoint of the link - node B. We can denote coordinates of A as (x_a, y_a) and coordinates of B as (x_b, y_b) So now a line equation can be established to mathematically identify AB link: $\frac{x-x_a}{x_b-x_a} = \frac{y-y_a}{y_b-y_a}$(1). The probe is being sent to the other endpoint, from there probe travels in graph according to the right hand rule[3] until it reaches source node A again as illustrated on Figure 15 in [2]. At each node after B, before sending probe along its link an equation similar to (1) is generated to mathematically identify the link on which probe will now traverse. Afterwards all is needed is to check whether SLAE consisting of this equation and (1) has a solution, which would then mean that links intersect at some point. Depending on that information corresponding link might be eliminated. In case of multiple crossing links which can be common in realistic wireless network it is only neccessarry to probe link multiple times until no crossing links remain. But it might be necessary to probe both of the crossing links. It is important to mention that the tests were done on network with static nodes [3]. The question is however - what would be the performance of CDLP in non-static wireless network.

Face Traversal.

Face Traversal algorithms define the way for a packet to travel from one face of planar graph to another one until it reaches the destination. Common algoritms used for face changes are: *Best Intersection, First Intersection, Closest-Node Other Face Routing, Closest-Point Other Face Routing.* In all of the algorithms theoretically packet will be dropped only if face was traversed without crossing the point where face should be changed, which would mean that destination is disconnected. Authors of [2] state(depending on other papers) that only *Best Intersection* and *Closest-Point Other Face* algorithms seem to guarantee correct face changes if the subgraph is planar.

Another important thing to discuss are so called *Collinear Links.* They represent two or more links having overlapped regions. Such situation introduces difficulty for the right hand rule to produce correct results. Imagine 3 nodes A, B, C lying on the same line with their radio range big enough to reach each other. Thus we might have links AB, BC, AC, since nodes lie on the same line - all their links overlapp. Normally planarization would terminate necessary links if the unit-disk graph assumpion would hold as discussed earlier. In fact in real networking planarization can turn collinear link problem into an unidirectional link problem. Consider a case when B has an incorrect information about its own location and therefore cannot be rached by C. During planarization A eliminates link AC considering that B can be a "witness", at the same time C keeps CA link since it can't see B. Earlier it was mentioned that for an efficient planarization MWP or CDLP is required. Both of the approaches however may themselves introduce collinear links into the graph.

Authors of [2] introduce the concept of *small perturbation* of node positions as a solution to the problem of collinear links. The coordinates of each neighbor

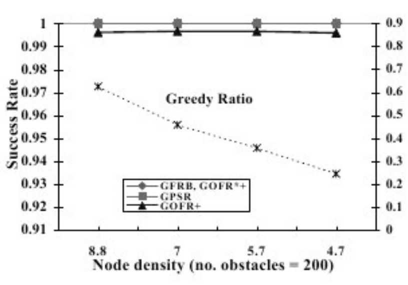
[3]Moving counterclockwise in a graph from one node to another.

at another endpoint of the link are being modified in such way that the link connected to it is rotated counterclockwise. This procedure is done for all links with different angles of rotation. In such way the collinearity is avoided between the links. The rotation angle is relative to the Euclidean length of the link. Thus a longer link gets bigger rotation angle. The additional condition is to keep the angle less than certain minimal angle θ_{min} between link's old position and any of the other links, which are located on the "counterclockwise side".

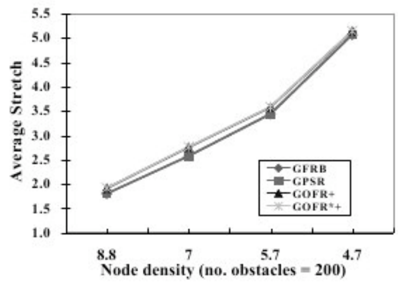
Although the described approach successfully eliminates collinear links, but it intrdoces position perturbations requires representation of a very small values of rotation angles, which is not always possible from the point of view of practical implementation. Therefore authors of [2] suggest a better approach. During packet traversal it is obviously necessary for the right hand rule to know the angle between the links, otherwise it won't be clear along which link packet should traverse. In case the links are collinear and therefore parallel we encounter an ambiguaty since it is unclear whether to consider the angle as 0 or 2π. The suggested approach works as follows. If the packet came from a link l_i, which belongs to the set L_c of collinear links then its Eucledian length is compared to that of collinear link l_j. If the first one is shorter then the angle is considered to be 0, otherwise 2π. If there are several collinear links for traversal then the link with the shortest length is chosen as a next hop.

Practical Experiments

In order to test the suggested ideas authors of [2] have held the following simulations. Four kinds of face change rules are used, named as FR-BI(Best Intersection), FR-FI(First Intersection), OFR(Closest-Node), OFR*(Closest-Point). Greedy was tested in combinatation with each of the face change rules, named GFRB, GPSR, GOFR, GOFR* correspondingly. 200 obstacles were randomly placed in the environment. Node density denotes average number of node's neighbors. For the construction of planar graph CLDP is used. Two basic values were measured: success rate and average stretch. The first one denotes percentage of successfully delivered packets from source to destination. The second one is used to measure average path stretch, which is a number of hops between source and destination divided by the minimal possible number of hops between source and destination. In other words value showing "path optimality". Topologies were generated each time randomly and results of experiments represent mean value between 50 such topologies. Following are the tables with those results:



[2] Pic6. Success rate & node density



[2] Pic7. Average stretch & node density

FR-BI and OFR* showed best results. OFR was almost as good as previous ones, having however 99.5% success rate by leaving some pairs of nodes unconnected. FR-FI showed the worst results. Afore mentioned tables show result from combining them with Greedy: GFRB, GOFR and GPSR all showed 100% success. Though FR-FI had a poor performance in combinaton with Greedy this situation seemed to be corrected. GOFR however seemed not to be able to recover from errors left by OFR. Average stretch of all algorithms showed almost equal results. This can be explained by the fact that in all of them a fallback-to-greedy mechanism is established. I.e. once packet recovers from a radio "void" situation algorithm proceeds with Greedy again.

Conclusion.

Based on work [2] we have identified problems that arise with planarization in non-ideal real networking and classified their types as well as discussed pathologies caused by those problems. We also had an overview of CDLP suggested by the authors of [2] for robust planarization and approaches for eliminating collinear links left after planarization. Then from planarization we turned to the problems caused by incorrect face changes and to solutions to them discussed in [2]. Theoretical conclusions then were prooved by observing experimental results in [2]. These results have shown that using CDLP, revised right-hand rule and Best-Intersection/Closest-Node rules for face change, it is possible to achieve robust geographic routing regardless of unit-disk graph assumption validity.

References

[1] http://en.wikipedia.org/wiki/geographic_routing, 2009-12-18.

[2] Y.-J. Kim, R. Govindan, B. Karp, and S. Shenker. On the pitfalls of geographic face routing. *In Proceedings of the 2005 joint workshop on Foundations of Mobile Computing*, 2005.

[3] Y.-J. Kim, R. Govindan, B. Karp, and S. Shenker. Geographic routing made practical. *In Proc. USENIX Symposium on Network Systems Design and Implementation*, May 2005.