On the Effect of Location Inaccuracy on Geographic Face Routing in Wireless Networks

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1 Introduction

Geographic routing protocols ([1], [5], [6]) are very attractive choices for routing in wireless networks for several reasons. First, such protocols incur low route discovery overhead relative to flooding-based approaches, and hence conserve energy and bandwidth. Second, these protocols are stateless in the sense that nodes need not maintain per-destination information, and only neighbor location information is needed to route packets. In mobile networks with frequent topology changes, geographic routing can find new routes quickly by using only local topology information. For these reasons, geographic routing is expected to become the protocol of choice for many applications in wireless networks, for example in sensor networks it is proposed for data-centric storage [7] and distributed indexing [2]. Hence, it is quite crucial to develop a detailed understanding of the behavior of geographic routing for various practical settings and to evaluate its performance and (more importantly) its correctness in those settings.

Most geographic routing protocols use greedy forwarding as its basic mode of operation, where the next forwarding hop is chosen to minimize the distance to the destination. Greedy forwarding, however, fails in the presence of *voids* or *dead-ends*. In order to provide *correct* routing in the presence of dead-ends *face routing* has been proposed to route around the void. The most commonly used geographic routing protocols include greedy forwarding coupled with face routing.

The evaluations of all geographic routing protocols till date have assumed the availability of accurate location information. In practice (in systems that either rely entirely on GPS, or infer location using ad-hoc localization systems [3]), however, location measurement is often noisy and incurs some error. For example, many state-of-the-art techniques usually incur around 10% (of the radio range) or more in localization error. To our knowledge there has been no previous study on the effects of localization errors on the correctness and performance of geographic routing. This work attempts to fill that void.

In this work, we first analyze the pathologies that can arise in geographic routing protocols, in the presence of errors in node location. Our methodology for this analysis is novel: using an elaborate, micro-level analysis of geographic routing protocols, we provide detailed scenarios in which protocol correctness is violated when the location of a node is in error.

We then perform extensive simulations to evaluate and quantify the effects of localization errors on two prominent protocols that use face routing; GPSR [5] and GHT [7]. Our study shows that realistic localization errors can in fact lead to incorrect (non-recoverable) behavior and noticeable degradation of performance, more so for GHT than for GPSR. In some cases, more than 10% storage failure of sensor events can occur in the presence of 10% location error.

Based on our analysis and error classification we introduce a simple protocol fix that eliminates the most likely protocol errors and we evaluate the efficacy of our fix. Our simulations show near perfect performance for our modified geographic routing (for GPSR and GHT) even in the presence of significant localization errors.

2 Model

Our study focuses on the effect of inaccurate location errors on geographic routing. Thus, to capture this effect purely without interference from other factors, we assume a static and stable network (no mobility and no failures) without obstacles and with nodes having accurate and symmetric radio ranges. We also assume that nodes have consistent location information about other nodes, which means that a node estimates its location and announces it, and all nodes observe the same estimated location for that node.

3 Micro-level Analysis

We present scenarios that cause protocol errors, analyze the error conditions and bounds, and quantify the range of location inaccuracy under which these errors occur. We follow a systematic approach in creating the scenarios and analyzing them. This helps us realize a complete listing of the possible failures under the current model and assumptions.

We show scenarios where only a single node has inaccurate estimated location and all other nodes are accurate. These scenarios are helpful in understanding the causes and conditions for errors under minimal discrepancy, where everything is ideal except for a single node inaccuracy. Even with this relatively benign assumption, routing pathologies can occur in geographic protocols. (In the simulations, we study the effects of errors in random topologies, where all nodes have random inaccurate estimated locations).

A complete, efficient, geographic routing protocol consists of the following components: (a) greedy forwarding, (b) planarization, and (c) face routing (also called perimeter routing or planar graph traversal). Greedy forwarding alone *does not* guarantee the delivery of packets because of dead-ends. Face routing on a planar graph theoretically *does* guarantee the delivery of packets. For improved performance, face routing is typically integrated with greedy forwarding and is used as a way to overcome dead-ends when greedy forwarding fails. Wireless network connectivity is in general non-planar, this is why a planarization component is required to create a planar graph by using only a subset of the physical links during face routing. The correct operation of face routing requires the graph to be planar. *RNG* and *GG* are examples of algorithms that create a planar graph from the non-planar physical topology by selecting a subset of the links and using only those links during face routing. A desirable feature in these algorithms is that they are local (a node needs to know only its own and direct neighbors' locations) and run in distributed manner. The main idea is for a node to exclude an edge to a neighbor from the planar graph if there is another path through a different neighbor called *witness*. The witness (node *w* in Figure 1) should exist in a specific intersection area between the two nodes of the edge. These algorithms assume a unit graph (a pair of nodes is connected if and only if the distance between them is below a certain threshold), which is critical for the algorithm to be local. In face routing a packet keeps traversing planar faces, using the right-hand rule, getting closer to its destination.

The scenarios we show represent incorrect edge removals by planarization causing disconnection, insufficient edge removals causing loops, cross-links, and destination inaccuracy causing routing failure to reach the destination. Although our focus in this work is on errors due to inaccurate geographic locations, similar errors could also happen for other reasons such as obstacles and non-ideal radio ranges.

We analyze the protocol components to show the possible errors that can happen. We describe precisely the geometric conditions under which face routing failures can arise as well as bounds for the these errors that cause face routing failure. For the detailed analysis, please see [8].

4 Fixes

Based on the micro-level analysis and validated by the simulations, we propose a fix that solves the most likely to occur problems. We noticed that a single problem causes most of the errors and has a very high probability comparable to other problems. This problem is the planar edge removals causing disconnections. From the planarization algorithm, an edge is removed from the planar graph when a witness is seen by a node (e.g., in Figure 1 node *u* removes edge (*u*,*v*) since there is a witness *w*). Disconnection happens when this witness is connected to the node removing the edge but not to the other node of the edge (*w* is connected to *u*, but not to *v*). Our solution for this problem is to *allow a node to remove an edge only if the other node of the edge sees the same witness* (i.e., both *u* and *v* need to see w in order for (*u*,*v*) to be removed)[1]. Based on this information sharing between neighbor nodes, incorrect edge removals are avoided.

5 Simulations

We use simulations to study the possibilities of errors happening in random topologies, in addition to their effects on performance. In arguing our case, we take the following position: *Since these errors are correctness errors that lead to non-recoverable persistent routing failures to reachable destinations, even small percentages of these errors are not normally acceptable in static and stable networks.* We first run simulations for both GPSR and GHT at different densities with relatively small localization errors that we believe represent the current state-of-the-art localization systems. Then we evaluate the fixes we introduced and show that they recover the most probable errors even with greater location inaccuracy.

The results show that even with relatively low location inaccuracy (1-10% of the radio range) the success rate is affected with higher reduction at low densities. GPSR can go below 97% (see Figure 2) and GHT below 90%. Adding the fix, the success rate at all densities is above 99.99% for GPSR and above 99% for GHT. This indicates that the simple fix added is good enough to fix almost all of the errors at least for the inaccuracy range of interest. This also shows that as we expected, planarization edge removal causes most of the errors (almost all of them in this range). The fix provides also great improvements and solves most of the errors at higher inaccuracy ranges (see Figure 3).

6 Future Work

In our future research we plan to investigate also pathologies that may arise due to node mobility or information inconsistency that may be caused by location dissemination protocols. Based on our analysis we are also encouraged to re-visit geographic-based systems and to design architectures that relax the assumptions of accurate location information.

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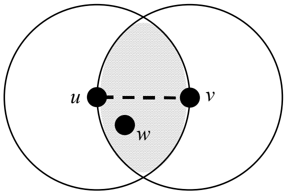

Figure 1: RNG planarization

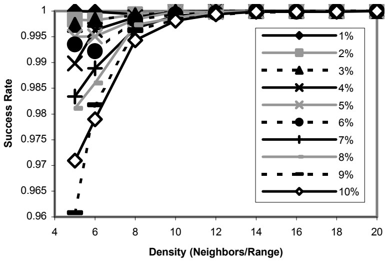

Figure 2: GPSR success rate at low inaccuracy ranges (1-10% of radio range)

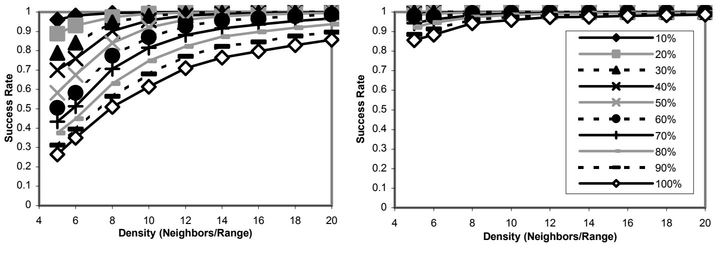

Figure 3: The success rate of GPSR at high inaccuracy ranges (up to the whole radio range) without (left) and with (right) the fix

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[1] A similar fix was suggested (but not evaluated) in [4] to cope with obstacles.