Impact of Location Inconsistencies on Geographic Routing in Wireless Networks

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ABSTRACT

Recently, geographic routing in wireless networks has gained attention due to several advantages of location information. Location information eliminates the necessity to set up and maintain explicit routes. These advantages allow scalability especially in dynamic and unstable wireless networks. However, no matter which technologies or techniques a location system uses, its measurements will have some amount of quantifiable inaccuracy depending on environment and system. These inaccuracies may affect the performance and even correctness of geographic routing. However, thus far, these impacts have not been studied in-depth. In this paper, we analyze the impact of location inaccuracy on geographic routing. Our study shows the significant impact of location inaccuracy on the performance of geographic routing in terms of packet drops, non-optimal paths and routing loops.

Categories and Subject Descriptors: C.2.1 [Computer - Communication Networks]: Network Architecture and Design - *network communications,wireless communication*; C.2.2 [Computer - Communication Networks]: Network Protocols - *protocol architecture, routing protocols*; I.6.5 [Simulation and Modeling]: Model Development - *modeling methodologies*

General Terms: Performance, Reliability, Verification, Algorithm

Keywords: Geographic Routing Protocol, Location Inconsistencies, Network Simulation, Performance Analysis

1. INTRODUCTION

Geogrphic routing[1,2] in ad hoc networks has been given attention recently due to its several merits against traditional topology-based routing. In geographic routing, the routing decision at each node is based on the destination's location contained in the packet header and the location of the forwarding node's neighbors. Geographic routing thus does not require the establishment or maintenance of routes. Hence, geographic routing allows routers to be nearly stateless. However, no matter which technology is used, location information has some inaccuracy depending on the localization system and the environment. Nodes could acquire the estimates of their locations from outside sources such as GPS[3]. GPS has inheretent inaccuracy. The alternative solution proposed is to design a location discovery algorithm that uses measurements of the distances between nodes and estimates of the locations of a small percentage of nodes to determine the locations. Distance measurement is also inherently noisy. Mobility during beacon interval may also induce location inaccuacy. Transient state of location information may induce inconsistent view of location information, which may result in serious problems in geographic routing. Furthermore, even if every node knows its own location, there is still a need for an underlying location discovery and dissemination service such as the Grid Location Service(GLS)[5]. Location errors and inconsistencies may also be introduced by location dissemination services. To our knowledge, this is the first in-depth study of the effects of location errors on geographic routing protocols. The rest of paper is organized as follows. In section 2, we briefly review geographic routing. Section 3 defines inaccuracy metrics. Section 4 shows the impact of location inaccuracy on geogrphic routing using simulation. Section 5 concludes our paper.

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2. BACKGROUND AND RELATED WORK

The most fundamental function of geographic routing is greedy packet forwarding[2]. Using greedy packet forwarding, a sender of a packet includes the position of the destination in the packet header. A sender sends a packet to the closest node to the destination within transmission range. Ideally, this process can be repeated through intermediate nodes until the destination has been reached. However, there are some situations in which greedy forwarding fails, which is called local maximum. Local maximum occurs when greedy forwarding faces a *dead end* and fails to find a path between a sender and a destination, even though one does exist. Currently, the most advanced scheme to address this local maximum is graph-based scheme with planar graph such as perimeter mode[2]. To prevent loops, constructing a plannar graph that does not have a cross edge among the nodes is the most important function. However, as we shall show, constructing a plannar graph poses great challenges in the presence of location inaccuracy.

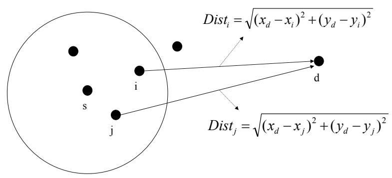

Figure 1: Distance between Node and Destination

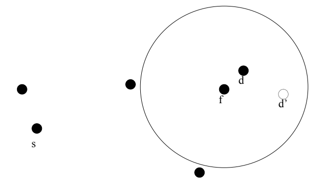

Figure 2: False Local Maximum

GPS is a common technique for localization. GPS introduces localization errors that depend on the receiver used. Those errors range from 1cm-100m. Reference beacons are used for localization in[4], where the accuracy increases with increased number of reference beacons and is a function of the radio range. The study cites 20 percent or more (of the radio range) as the mean localization error with high beacon deployment. We borrow from these studies to develop our location error model.

3. INACCURACY METRICS

In this section, we classify location inaccuracy into four metrics: Absoulte location inaccuracy, relative distance inaccuracy, absolute location inconsistency and relative distance inconsistency. Each of these metrics potentially has a negative impact on geographic routing in terms of packet drop, non-optimal path and routing loop. We do not assume any specific location system such as [5]. Instead, we focus on the general location inaccuracy that is incurred in any location system depending on its implementation and the deployment environment.

3.1 Absolute Location Inaccuracy

We define the absolute location inaccuracy for each node i as follows.

$$\text{Absolute Location Inaccuracy} =$$

$$\sqrt{(x_i - (x_i + \triangle x_i))^2 + (y_i - (y_i + \triangle y_i))^2} \quad (1)$$

where, $A_i(x_i, y_i)$ is the true location and $A_i(x_i + \triangle x_i, y_i + \triangle y_i)$ is the faulty location. Absolute location inaccuracy is the distance between the true location and the faulty location. A possible problem of absolute location inaccuracy is packet drop due to wrong neighbor node information. Absolute location inaccuracy may induce relative distance inaccuracy, absolute location inconsistency and relative location inconsistency. We define each of terms in the following sections.

3.2 Relative Distance Inaccuracy

In figure 1, the distance between node i, node j and the destination node d can be calculated as follows.

$$Dist_i = \sqrt{(x_d - x_i)^2 + (y_d - y_i)^2} \quad (2)$$

$$Dist_j = \sqrt{(x_d - x_j)^2 + (y_d - y_j)^2} \quad (3)$$

Then the true relative distance is defined as follows.

$$\triangle Dist = Dist_i - Dist_j \quad (4)$$

Greedy forwarding algorithm selects node i if

$$\triangle Dist < 0 \quad (5)$$

which means i is closer to the destination than j. However, greedy forwarding may fail if high relative distance inaccuracy exists. That is, a forwarding node may select a node which is not the closest to the destination within its radio range. Before we define relative distance inaccuracy, we define distance inaccuracy between node i and the destination d and between node j and the destination d as follows.

$$Dist_{i-error} =$$

$$\sqrt{((x_d + \triangle x_d) - (x_i + \triangle x_i))^2 + ((y_d + \triangle y_d) - (y_i + \triangle y_i))^2} \quad (6)$$

$$Dist_{j-error} =$$

$$\sqrt{((x_d + \triangle x_d) - (x_j + \triangle x_j))^2 + ((y_d + \triangle y_d) - (y_j + \triangle y_j))^2} \quad (7)$$

Then, the relative distance inaccuracy is defined as follows.

$$\triangle Dist \cdot \triangle Dist_{error} \leq 0 \quad (8)$$

where,

$$\triangle Dist_{error} = Dist_{i-error} - Dist_{j-error} \quad (9)$$

Possible problems of relative distance inaccuracy include higher packet drop rate due to false local maximum and non-optimal routing path due to wrong greedy decision.

3.3 Absolute Location Inconsistency

We define absolute location inconsistency as follows.

$$\text{Absolute Location Inconsistency} = \sqrt{(x_k^i - x_k^j)^2 + (y_k^i - y_k^j)^2} \quad (10)$$

where (x_k^i, y_k^i) is the location of node k as perceived by node i and (x_k^j, y_k^j) is the location of node k as perceived by node j. Absolute location inconsistency represents the difference of the same target locations perceived by two nodes. One potential problem of high absolute location inconsistency is the false local maximum within the range reachable to the destination. An example of absolute location inconsistency is illustrated in figure 2. Sender node s includes the destination location in packet header as location d. However, a

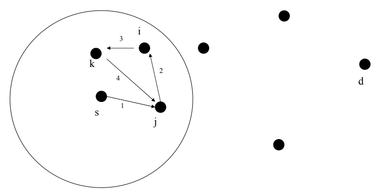

Figure 3: Multi-hop Routing Loop

forwarding node, f, at the last hop perceives the destination at a different location d'. If distance between the d' and d is greater than the distance between f and d, false local maximum occurs.

If global addressing is not available (or not used, as in some sensor networks) and the geographic routing algorithm relies only on the location information, there is a high probability that the packet cannot be delivered to the destination when absolute location inconsistency is high with high node density in radio range since the forwarding node cannot find a neighbor node closer to the destination than itself. Absolute location inconsistency may induce relative distance inconsistency, which is explained next.

3.4 Relative Distance Inconsistency

We define distance inaccuracy perceived by node i as follows.

$$\triangle Dist^{i}_{error} = Dist^{i}_{i-error} - Dist^{i}_{j-error} \qquad (11)$$

In addition, we define distance inaccuracy perceived by node j as follows.

$$\triangle Dist^{j}_{error} = Dist^{j}_{i-error} - Dist^{j}_{j-error} \qquad (12)$$

Then relative distance inconsistency is be defined as follows.

$$\triangle Dist^{i}_{error} \cdot \triangle Dist^{j}_{error} \leq 0 \qquad (13)$$

One potential problem of relative distance inconsistency is formation of routing loop. Node s thinks that node j is the closest node to the destination within the transmission range and sends the packet to j. In turn, node j thinks that node i is the closest node to the destination and send a packet back to the node i and this continuation results in routing loop. There can be multi-hop relative distance inconsistency even though there is no relative distance inconsistency between two direct neighbor. Figure 3 illustrates multi-hop routing loop. Sender node s sends a packet to node j. Then, node j sends a packet to the node i and node i sends a packet to the node k. Node k sends the packet back to node j and so on , forming a multi-hop loop.

4. SIMULATION RESULT

We perform extensive simulations in NS-2 to investigate the impact of location inaccuracy on geographic routing. We use 250m of radio range and Gaussian distributions (with zero mean) with different standard deviation (0 - 50m) to

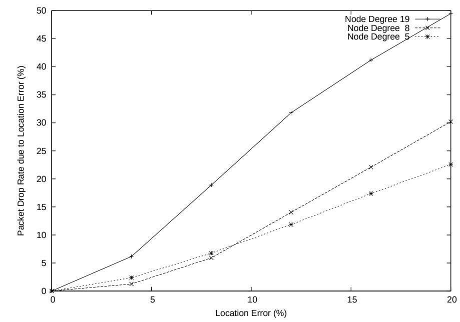

Figure 4: Impact of Location Inaccuracy and Node Degree on Packet Drop Rate

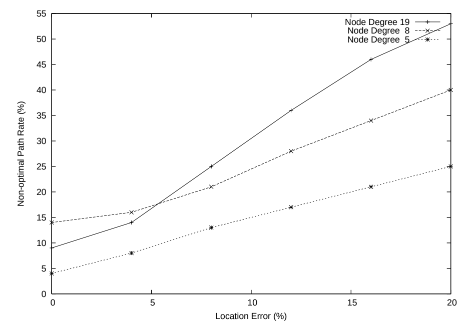

Figure 5: Impact of Location Inaccuracy and Node Degree on Non-optimal Path

generate location inaccuracy. Different node degree (5,8,19) which is the number of neighbor nodes within transmission range in the area of 1350m $\times$ 1350m is used. Traffic sources are 30 nodes. Location inaccuracy is added to true location. In our simulation, location error is represented as the fraction of standard deviation over radio range. We averaged 5 simulations. We perform simulation on greedy mode without local maximum resolution first, then we perform simulation of perimeter mode of GPSR as a case study of local maximum resolution. Figure 4 shows the effect of node degree and location error on packet drop rate. By carefully analyzing the simulation traces, we observe that the main reason for packet drop is false local maximum. A packet is forced to drop if there is no local maximum resolution mechanism under false local maximum situation. Even if there is local maximum resolution, longer detour is inevitable and local maximum resolution itself may also have some problem with location inaccuracy, The reason for higher packet drop in dense network is the higher probability of false local maximum within the destination range due to absolute location inconsistency that was explained earlier in section 3.3. Figure 5 shows the non-optimal path rate. There is higher non-optimal path rate in dense network reaching up to 53 percent. This shows the more frequent relative distance inaccuracy in dense network resulting in more non-optimal paths. In our simulation routing loops occurred because of relative distance inconsistency. Figure 6 shows that packet drop due to loop. There is more probability of relative distance inconsistency in sparse network, resulting in more routing loops. Single hop loops and multi-hop loops occurred in our simulation.

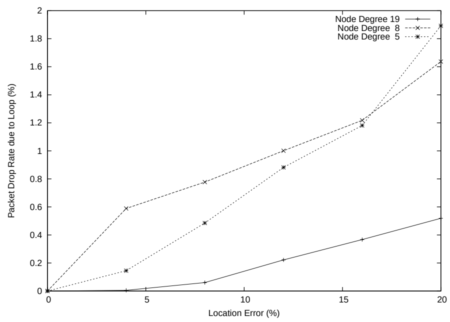

Figure 6: Packet Drop Rate Due to Routing Loop

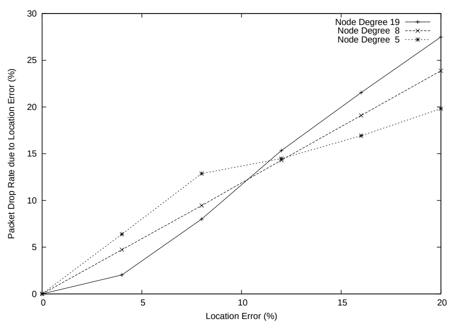

Figure 7: Packet Drop Rate Due to Location Inaccuracy in Perimeter Mode

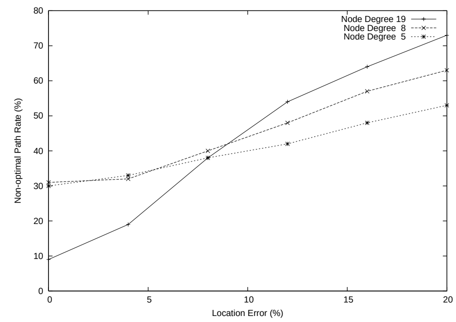

Figure 8: Non-optimal Path Rate in Perimeter Mode

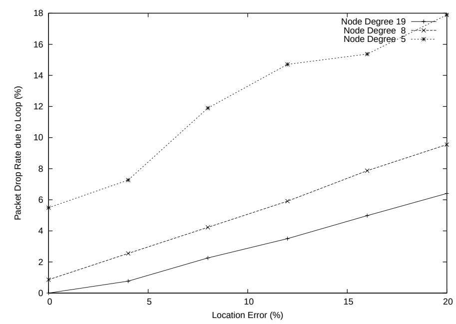

Figure 9: Impact on Loop in Perimeter Mode

Local maximum resolution is one of the most important issues in geographic routing. As a case study, we selected local maximum resolution from well-known greedy perimeter stateless routing (GPSR)[2] protocol. We perform simulation to study impact of location inaccuracy on perimeter mode in GPSR. Figure 7 shows the packet drop rate due to location inaccuracy. As inaccuracy increases in perimeter mode, dense network shows higher drop rate. However, in lower location error, sparse network shows higher drop rate. This occurs because there is higher probability of disconnection between nodes with even small location inaccuracy in sparse network. Figure 8 shows non-optimal path rate. Notice that non-optimal rate is higher in sparse network even when location error is small. This is because there is higher probability of local maximum in sparse network resulting in detour path. In figure 9, we can see that more routing loops happen in sparse network because of high relative distance inconsistency. One interesting result in this graph is that routing loop occurs in perimeter mode of GG graph even without location error. This is due to network disconnection and is not considered a protocol error per se.

5. SUMMARY AND CONCLUSION

In this paper, we have introduced a classification of location errors identifying four location inaccuracy metrics: (1) absolute location inaccuracy, (2) relative distance inaccuracy, (3) absolute location inconsistency and (4) relative distance inconsistency. Using extensive NS simulations, we conducted studies on greedy forwarding and perimeter mode routing. We observed the following impacts of location inaccuracy on geographic routing.

(I) For greedy forwarding, packet drops occur mainly because of (a) routing loops caused by relative distance inconsistency and (b) no-route within destination caused by absolute location inconsistency. The packet drop rate is affected by the node degree. Non-optimal path is caused by relative distance inaccuracy. Relative distance inaccuracy causes wrong greedy neighbor selection. In addition, relative distance inaccuracy causes false local maximum which invokes local maximum resolution. Non-optimal path is affected by node degree.

(II) Location inaccuracy affects the correctness of graph-based local maximum resolution scheme. Our analysis of the perimeter mode of GPSR shows that in the presence of location inaccuracy, the planar graph is highly unlikely to be constructed correctly. Furthermore, location inaccuracy degrades performance of perimeter mode in terms of optimal path. These observations indicate a pressing need to re-visit the design of geographic routing protocols to be robust to location errors.

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