

Mobility-Induced Location Errors and its Effect on Geographic Routing in Ad Hoc Networks: Analysis and Improvement using Mobility Prediction

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In anticipation of broader use of GPS and other localization schemes, geographic routing is becoming a very attractive choice for routing in mobile ad hoc networks. Geographic routing (e.g., *GPSR*) provides drastic performance improvement over existing ad hoc routing protocols, where the packet forwarding decision is solely based on the locations of neighbors and the destination node at the moment of forwarding. Geographic routing has been shown to be correct and efficient with *exact* location information. The effect of *location errors* on geographic routing, however, has not been studied before. This effect is exacerbated with node mobility. In addition, most (if not all) previous studies on geographic routing have used the random waypoint mobility model that ignores movement correlation among nodes.

In this study we provide the first study to (1) understand the effect of inaccurate location information caused by node mobility on geographic routing protocols under various mobility models, and (2) provide remedies for the identified problems. We evaluate our proposal through *ns-2* simulations of the greedy perimeter stateless routing protocol, *GPSR*, using the *IMPORTANT* mobility tool.

Analysis on the effect of node mobility

Three of the main factors that greatly affect the performance of geographic routing protocols include:

(a) The freshness of location information: It is not possible to avoid the time gap between the measurement of a location and the time when the information is actually looked up for routing decision due to the time spent for the delivery of location information and the time passed before the received information is used. The freshness of position information is one of the most important factors that may cause degrees of error in cached location information,

(b) The speed of mobile nodes in the network: Each mobile node can move at a different speed and the maximum node speed is considered as another critical factor deciding the level of inaccuracy.

(c) The mobility pattern of mobile nodes: If the node movement exhibits a different pattern, the effect of node mobility on the geographic routing protocol will be different. Four different mobility models are adapted in our work: Random waypoint (*RWP*), Freeway (*FWY*), Manhattan (*MH*) and Reference Point Group Mobility (*RPGM*).

To estimate the effect of inaccurate location information caused by node mobility on the geographic routing protocol, we conducted simulations with *ns-2* varying the beacon interval and the maximum speed of mobile nodes for each mobility model. *GPSR* is selected for our simulation because it uses greedy forwarding with face routing that are generally accepted schemes for geographic routing in sensor networks. Fifty nodes are placed randomly in 1500m x 300m field and the combination of beacon intervals of 0.25, 0.5, 1.0, 1.5, 3.0, 6.0 sec and maximum node speed of 10, 20, 30, 40, 50 m/sec are simulated. To filter out the noise in simulation results, five different scenarios are generated for each distinct parameter setting and the results represents the average value.

We introduce several metrics to evaluate the performance of the routing protocol in several aspects. (1) *Successful Delivery Rate (SDR)*: the number of packets successfully delivered to the destination node over the total number of packets transmitted. (2) *Wasted Transmission Rate (WTR)*: the number of transmission efforts made for dropped packets during the delivery over the total number of packet transmission. (3) *Number of Lost Link (LLNK)*: the number of lost link problem observed during the packet forwarding.

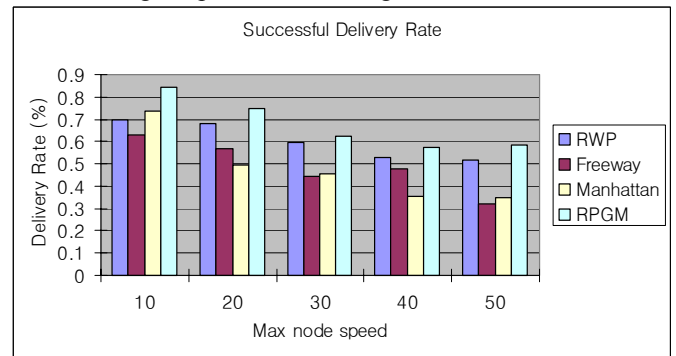


Fig1. SDR varying maximum node speed

Figure 1 shows the effect of node speed on the performance of *GPSR* routing protocol. The performance drops as the maximum node speed increases, but the amount of performance drop is different for each mobility model. *MH* and *FWY* model shows the biggest performance drop and *RWP* performs well with increased maximum node speed. Average number of *LLNK* is consistently low for *RPGM* (~812 *LLNKs*) than other mobility models (ranging from 2,366 to 2,586 *LLNKs* on avg), and this explains the better performance of *RPGM* in general. In our simulations, we find that the number of packets delivered via less-than-optimal hops, calculated before the actual routing, increased from 5.9 at speed 10 to 19.4 at speed 50 while the ratio of successful packet delivery decreases with high node mobility. This can be considered as a positive effect of node mobility, where destination node moves towards the source, and this result somewhat supports the necessity of the second part of our suggested (*MP: mobility prediction*) scheme following in next section.

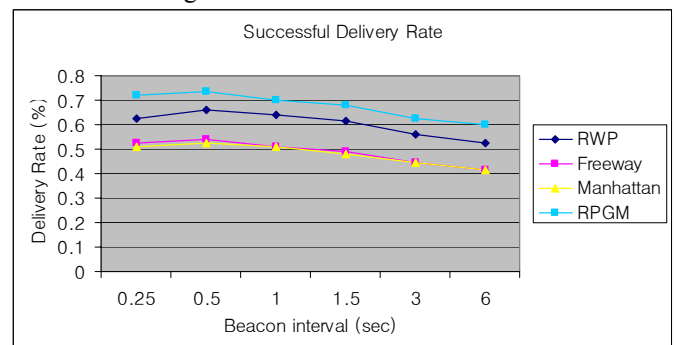


Fig2. SDR varying beacon interval

The simulation result on effect of using different beacon interval is presented in figure 2. The Performance drop caused by longer beacon interval is smaller (~12.7 in SDR) than per-

formance drop by increased node mobility (~28.6). The performance of geographic routing protocol GPSR is better when the beacon interval is 0.5 instead of 0.25 in the aspect of every metric (SDR, WTR and LLNK) in general. By analyzing drop reasons, we could see that beacon interval (bint) 0.25 shows much more drop caused by IFQ, means more congestion in the network, than bint 0.5 while other drops reasons, such as RTR_TTL, RTR_CBK, RTR_NRTE, IFQ_ARP, RTR_LOOP, show just a little more drop with bint 0.25. This result teaches us that too frequent beacon can be the reason of performance drop as well as the cause of network resource (including energy of nodes) wastage.

Identified problems caused by node mobility

Inaccurate location information caused by node mobility incurs bad performance of geographic routing protocol as we can see in our simulation results. We could identify two main situations which account for the lowered performance curve. Case [1]: Greedy forwarding mode in GPSR always forwards a packet to the neighbor that is located closest to the destination node. Each node searches its neighbor list to find a node that meets this condition and forwards a packet to this selected next hop neighbor. However, the selected next hop node may not exist within the radio range while it is listed as a neighbor due to node mobility or asymmetry in transmission range. Lost link problem happens in this case, and we name this as LLNK problem. Case [2]: With GPSR, the packet is forwarded towards the coordinate of the destination stored in the packet header, and identification of a node is not important in greedy forwarding. When a destination node moves away from its original location and another becomes a node located closest to the original coordinate of the destination, it is misunderstood as local maximum situation by GPSR, and perimeter mode forwarding is used, and packets get dropped if the destination node doesn't come back to original location. Perimeter forwarding generates wasteful loops in this situation, and we call this LOOP problem in the rest of this paper.

MP: Improvement on geographic routing

We introduce mobility prediction (MP) scheme to geographic routing protocol, which is not requiring any additional communication or serious calculation. Suggested mobility prediction scheme is composed of two prescriptions to identified problems.

First, a *neighbor location prediction (NLP)* scheme is introduced as a solution to the LLNK problem. The current location of a neighbor node is estimated based on previous beacon information received. The last beacon time of a neighbor needs to be stored together with its previous location for each node, and the estimated location of a neighbor is calculated for each routing decision as follows. When a node receives a new beacon packet, the latest speed of a neighbor node is calculated individually for each coordinate x and y . If we denote the coordinate x , y , and the beacon time of previous beacon as (x_1, y_1, PBT) and the same information for the last beacon as (x_2, y_2, LBT) , the latest speed of a node S_x and S_y are:

$$S_x = (x_2 - x_1) / (LBT - PBT) \text{ and } S_y = (y_2 - y_1) / (LBT - PBT).$$

The current location of a given neighbor node (X_{est}, Y_{est}) can be estimated with following formula:

$$X_{est} = x_2 + S_x * (Current\ Time - LBT)$$

$$Y_{est} = y_2 + S_y * (Current\ Time - LBT)$$

Each node knows its own radio range and does not forward a packet to a neighbor node which is currently located outside of its transmission range based on the estimated position to

avoid LLNK. With NLP, LLNK problem caused by asymmetry in transmission range between neighboring nodes can be also addressed. By using estimated neighbor location attained from this simple calculation, the LLNK problem identified from previous simulation is greatly reduced for every mobility model in our simulation. The percentage of drop in number of LLNK is as follows: RWP (17.5%), FWY(15.2%), MH(14.3%), RPGM(6%).

Second part of our mobility prediction scheme is a solution to the LOOP problem, which is turned out to be the most serious problem in greedy forwarding routing scheme. A great number of packets get dropped even when those are delivered to a neighbor node of the destination node. Packet drop after forwarding it to a neighbor of a destination node is the most undesirable thing to do with packet routing because it means more wastage of energy and bandwidth in the network.

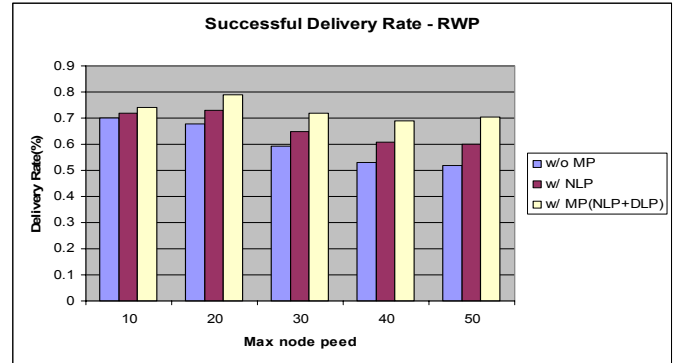


Fig3. Successful Delivery Rate (SDR) with different schemes

To avoid this kind of problem and to increase the chance of packet delivery for the case when the destination node is moved out of its original, destination location prediction (DLP) is proposed as a second part of MP. With DLP, each node searches its neighbor list for the destination node before it makes a packet forwarding decision based on the position information of the destination it knows. If the destination node exists in its neighbor list, it forwards the packet to the destination node regardless the remaining distance to the destination location indicated in the packet.

With MP (NLP plus DLP), the amount of wasted transmission (WTR) is reduced 18.6% for RWP, 37.2% for FWY, 15.2% for MH, 16.45% for RPGM and the SDR levels up even with higher mobility and longer beacon interval cases as figure 3 and figure 4 show.

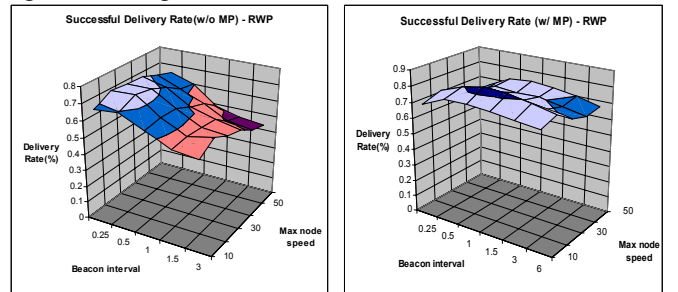


Fig4. Performance improvement with MP (w/ diff speed, bint)

Future work

Mobility prediction scheme will be updated and introduced for the location services as well as other forwarding strategies than GPSR. The location information of a node provided by GPS will be also adjusted with mobility prediction scheme and the relationship between node density and the performance of geographic routing protocol will be investigated for each mobility models.