

Mobile User Locating Mechanism Based on Network Latency

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Abstract- A mechanism for the positioning of mobile user location is presented in this paper. Based on the three-point problem from land surveying, this positioning mechanism makes use of network delay to estimate user locations by trigonometry and analytical geometry. Location-sensitive wireless services and applications can be provided without the need of obtaining access to the physical layer information such as signal strength, time of arrival (TOA), angle of arrival (AOA) or adding GPS (Global Positioning System) hardware. It also provides better protection for user privacy by user initiation mechanism. The novel concept of virtual location based on network latency is introduced to investigate the relative topologies among mobile users and position-known servers.

I. INTRODUCTION

Research about positioning a mobile user has been extensively studied. With the emerging location-aware application [1-4], it becomes more and more important to provide a low cost and effective mobile positioning mechanism.

Traditionally, there are two categories of mobile user locating mechanisms: utilizing radio signal information and Global Position System. Mobile user location is typically determined by utilizing radio signal information such as radio signal strength, TOA (time of arrival), or AOA (angle of arrival) [5,6]. Several signal measurements from different base stations with the knowledge of geographical location of base stations can determine the mobile user location. Global Position System (GPS) estimates the location by signals arriving angles and time differences from multiple satellites.

However, the radio signal-based technologies require access to physical radio information and information about base station locations. It requires that cellular system operator is willing to provide base station location information and handset hardware support. GPS brings the integration issue between GPS and mobile device. It results in higher cost, more power consumption, and larger size. To use radio signal-based techniques, Internet Content Providers (ICP) have to acquire accesses to physical layer information if they want to provide location-aware services. In many cases, it is difficult to obtain the access or its cost is very high. Adding GPS to the mobile device may also increase the cost.

In this paper, we describe a novel framework for positioning mobile user location for the next generation wireless Internet. The user locating mechanism is based on measuring network latency from a mobile user to position-known reference nodes. Based on the three-point problem from land surveying, this positioning method makes use of network delay to estimate user locations by trigonometry and analytical geometry. This paper is organized as follows.

Section II describes the positioning algorithm. Section III presents the simulation and performance evaluation. Analysis and discussion are presented in Section IV, followed by conclusion in Section V.

II. SYSTEM ARCHITECTURE

A. Virtual Location

The “virtual location” concept is introduced. Fig. 1 shows the locations of mobile devices and reference servers on virtual reference plane and physical geographical plane respectively. Virtual reference map in the sense of network latency is generated to locate mobile users.

On virtual map, distance between two nodes is defined by network delay latency. We denote that node A is the nearest neighboring node to the other node B if and only if the network latency between node A and B is less than the network latency from B to any other nodes. Near-far relationship and the virtual location on “virtual reference map” are built upon this statement. If the network latency is highly correlated to the geographical distance, the virtual location is highly correlated to geographical location.

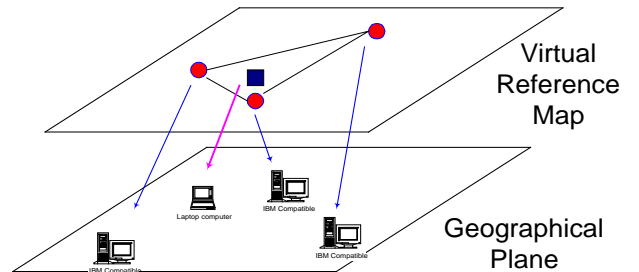


Fig. 1. Virtual location concept

B. Basic Algorithm

The basic algorithm to locate a newly added node is to measure the network latency from the new node to three reference nodes with known locations. The new location is computed by this information.

Consider Fig. 2, there are three position-known reference nodes $P1(x_1, y_1)$, $P2(x_2, y_2)$, and $P3(x_3, y_3)$. The values of network latency r_1 , r_2 , and r_3 from an unknown-position node $U(x, y)$ to $P1$, $P2$, and $P3$ can be measured.

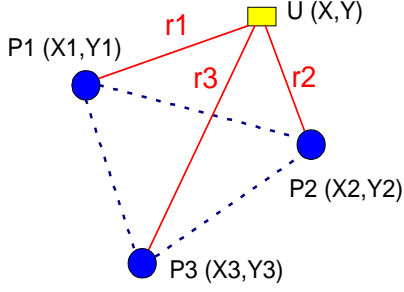


Fig. 2. Basic Algorithm of mobile user locating

The position of the new point $U(x, y)$ is determined by (1) using the known values $(x_1, y_1), (x_2, y_2), (x_3, y_3), r_1, r_2, \text{ and } r_3$

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = r_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = r_2^2 \\ (x - x_3)^2 + (y - y_3)^2 = r_3^2 \end{cases} \quad (1)$$

Specifically, the solution of (1) is readily computed as (2). The unknown position (x, y) is represented by known reference values $x_1, x_2, x_3, y_1, y_2, y_3$ and measured values r_1, r_2, r_3 .

$$\begin{aligned} x = & [(x_1^2 - x_2^2 + y_1^2 - y_2^2 - r_1^2 + r_2^2)(2y_1 - 2y_3) - \\ & (x_1^2 - x_3^2 + y_1^2 - y_3^2 - r_1^2 + r_3^2)(2y_1 - 2y_2)] \div \\ & [(2y_1 - 2y_3)(2x_1 - 2x_2) - (2y_1 - 2y_2)(2x_1 - 2x_3)] \end{aligned} \quad (2)$$

$$\begin{aligned} y = & [(x_1^2 - x_2^2 + y_1^2 - y_2^2 - r_1^2 + r_2^2)(2x_1 - 2x_3) - \\ & (x_1^2 - x_3^2 + y_1^2 - y_3^2 - r_1^2 + r_3^2)(2x_1 - 2x_2)] \div \\ & [(2y_1 - 2y_2)(2x_1 - 2x_3) - (2y_1 - 2y_3)(2x_1 - 2x_2)] \end{aligned}$$

C. Generating Reference Map

Two stages are employed to locate users. The first step is generating virtual reference map among servers. Then mobile users are located on the virtual reference map. The reference map generating procedure is described as follows.

First, choosing arbitrary three servers as the first three reference nodes initializes the virtual reference map. Then iteratively adding one arbitrary server to the known map expands the virtual reference map. Three reference nodes $P1, P2, \text{ and } P3$ are arbitrarily chosen to be the initial references from all reference nodes. Network latencies between each pair of the nodes are measured and denoted by

$d1, d2, \text{ and } d3$. On virtual reference map locations of these three initial reference nodes are assigned $(0,0), (r_3,0)$, and $(\frac{r_3^2 + r_2^2 - r_1^2}{2r_3}, \sqrt{r_2^2 - (\frac{r_3^2 + r_2^2 - r_1^2}{2r_3})^2})$ respectively (shown in Fig. 3).

Then the basic algorithm is used to add the remaining reference nodes to the virtual map iteratively. The distances from a to-be-chosen reference node $U(x,y)$ to the three initial reference nodes $P1, P2, \text{ and } P3$ are measured. The basic algorithm mentioned in previous section is used to determine the virtual location of the $U(x,y)$. We repeat this step until all reference nodes are added to the virtual reference map. The virtual reference map can be stored distributed or in a central server. It is updated periodically to meet the topology changes and background traffic variation.

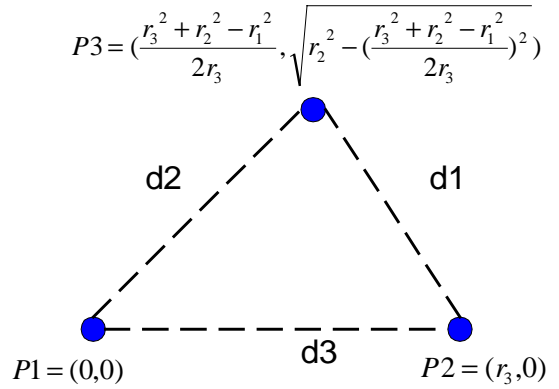


Fig. 3. Generating initial reference map

D. Locating Mobile User

The basic algorithm is used to determine the user location. Mobile node first downloads the virtual reference map. Then it finds three reference nodes $P1, P2, \text{ and } P3$ as reference, and measures the network distance to these nodes. By using the basic algorithm, a mobile node locates itself on the virtual reference map.

We can also estimate mobile speed and accelerating rate by recent location changes and the time difference. This information predicts future user moving direction and location. Hence it can assist service provider to provision handoff to future-serving server and thus improve the quality of service for real-time multimedia applications.

III. PERFORMANCE

Various simulations were performed to assess the algorithm. As shown in Fig. 4 a mobile user moves on the geographical plane. The virtual location is computed accordingly. The left window illustrates the geographical map. The right window illustrates the virtual reference map. User movement is depicted in square, and reference servers

are denoted in circle on physical plane and in star on virtual plane.

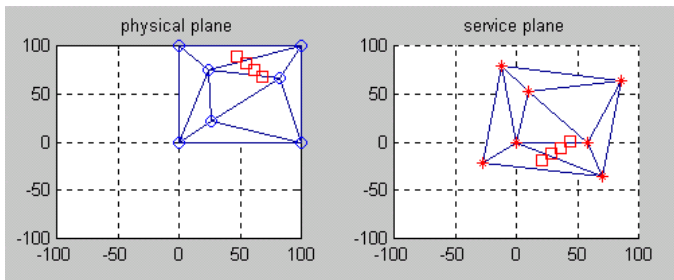


Fig. 4. Simulation program

If the network distance is equal to the geographical distance, the virtual plane location is the rotated version of the physical plane. The location scheme does not have information about orientation. When the geographical distance is not highly correlated with network distance, the virtual map will be a scaled and distorted version of geographical map.

Performance is evaluated by the error rates in estimation the nearest base station in different scenarios. Fig. 5 illustrates performance with different mobile speed and different background traffic variation. In Fig. 6, performance with different reference node density is shown.

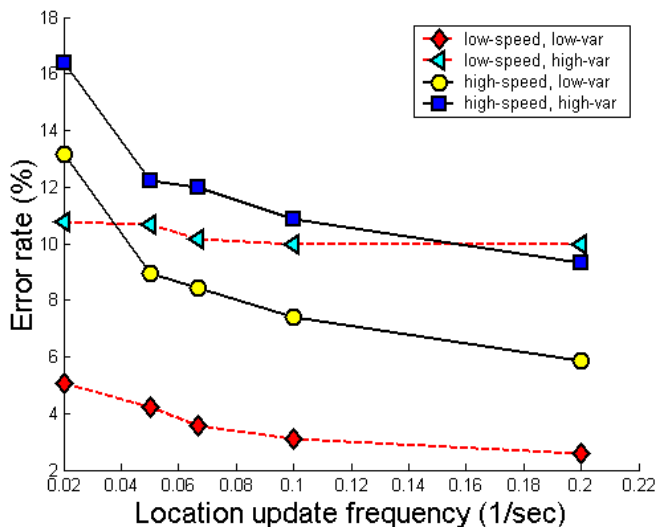


Fig. 5. Error rate for different mobile speed and background traffic load variation

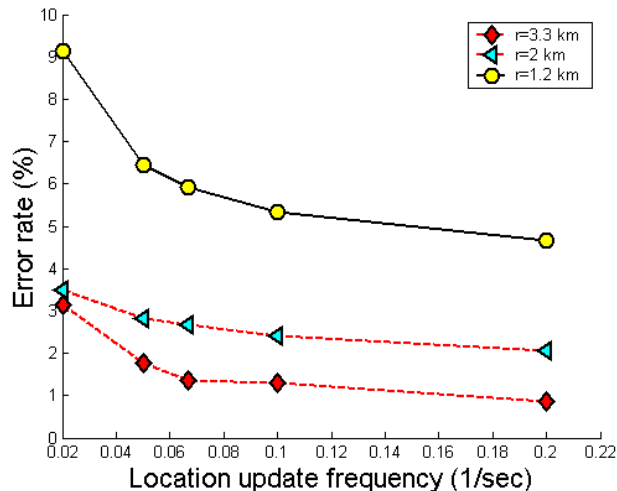


Fig. 6. Error rate for different reference node density

As illustrated in Fig. 5, background traffic variation affect the algorithm significantly. The lower the background traffic variation, the better the algorithm performs. It also shown that high-speed mobile user results in higher error rate. In Fig. 6, r denotes the average distance between reference servers. We found that reference nodes in higher density make the error rate of the estimated nearest reference node higher. However, if we use the error distance as the performance metric, it will have different result. Apparently, location update frequency is one of the key factors influencing on the performance. The accuracy and overhead will be always a tradeoff.

IV. DISCUSSION

There are several ways to make user-positioning schemes more effective. [7] First, we can choose the reference nodes intelligently. We can choose the frequent serving servers or the latest serving server as the reference node to locate user after user turn off the service for a while. Second, utilizing the information of user movement pattern can reduce the location update frequency and achieve acceptable accuracy. For example, we can estimate the user moving speed to classify users as pedestrians, low-speed vehicles, high-speed vehicles, or being idle. Then we can update the location of user moving in high speed more frequently and use the virtual reference map with broad coverage but low resolution.

In order to make our algorithm scalable, a hierarchical architecture is introduced to produce maps with different resolutions and coverage. We first use map with low resolution but large coverage to determine the rough location. Later, a map with high resolution but small coverage is used to locate the user more accurately. The hierarchical architecture and the number of nodes in different layers could be a future research topic.

The proposed location scheme reduces the privacy concern of information about a person's whereabouts. In our algorithm, mobile clients initiate the locating process. With the software parameter settings, users can turn-off the location support application. Moreover, the location map

databases only store the information about the distribution of servers instead of users. There is no database storing user location information. In addition, the user location information, which is provided to location-aware applications, only includes the rough locations of user instead of exact geographical locations. Users can be benefited from the location information based on measure of network performance and their privacy will not be infringed by providing their virtual locations.

In urban area, LOS (Line-of-sight) radio path is not widely available from base stations. Traditional radio signal-based location techniques may not perform so well. GPS system performance is limited by building shadowing. The proposed algorithm will not be affected in these situations.

The locating algorithm provides the best geographical user location accuracy when the network latency is highly correlated to the geographical distance. Enterprise networks without heavy background traffic is a good scenario to deploy this algorithm. Homogeneous mobile ad hoc networks, in which network nodes possess similar computational and network capability, could also obtain accurate location information.

V. CONCLUSION

The locating algorithm provides user location information in the sense of network latency. It performs well in scenarios with low background traffic and slow mobile movement. The location information obtained can be used in the applications, which only needs network latency information or does not need very accurate geographical information. For those location-aware applications, which require very high accuracy of geographical location information, GPS-assisted systems should be used. The proposed scheme provides a novel way to obtain mobile user location information at low-cost.

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