Acquisition Scheme for a High Sensitivity Assisted GPS Receiver Considering Application Scenarios

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Abstract
Automatic location identification is required for emergency calls in Japan and many other countries. We proposed a fast acquisition scheme for an assisted GPS (AGPS) architecture that is based on a timing-synchronized mobile network. In this paper, the system construction considerations are discussed and analyzed for fast acquisition scheme.

1 Introduction

Universal market penetration makes cellular handsets one of the most popular platforms for positioning services. Furthermore, Enhanced 911 (E911), imposed by the United States FCC (Federal Communications Commission), is of crucial benefit during fires, break-ins, kidnappings, and other events where communicating one's location is difficult or impossible. The function for automatic location identification from an emergency call has also been made a requirement for cellular phones by the Japanese Ministry of Internal Affairs and Communications (April, 2007). Such mandates in turn require integrated positioning services in cellular communication networks. However, characteristics such as limited processor computational capability and the need for low power consumption present challenges to providing reliable and rapid positioning services to cellular phones. Assisted GPS (AGPS) technology has received a lot of attention as a potential method for meeting these demands. [1]

AGPS can enhance the performance of GPS operations through the wireless provision of assistance data. The GPS receiver downloads assistance data over a telemetry link (the standard cellular phone connection in cellular networks) from a server that can provide up-to-date satellite orbital location information, server's location, etc. It has expanded the capabilities of traditional receivers by reducing the time to first fix (TTFF) from approximately 30-40 seconds to less than 10 seconds in some situations. AGPS also enables high-sensitivity modes, which means the increased possibility of using GPS technology inside buildings where satellite access would otherwise be seriously curtailed. These advantages are essential for faster high-sensitivity positioning in urban canyons and indoors.

Our proposal is built on AGPS structure. From the cost standpoint, we wanted to use existing cellular networks to transmit assistant information. Therefore, we chose the timing-synchronized third generation (3G) network as our telemetry data link and devised a fast high-sensitivity acquisition scheme for an AGPS receiver of this type of network.

Conventional GPS receivers perform a two-directional search – C/A code and Doppler frequency - to acquire the right satellite and carrier in the initial acquisition stage. We previously proposed a fast C/A code search method [2] and a fast frequency search method [1] to perform a high-sensitivity and fast acquisition by using timing-synchronized network. In this paper, we are now focusing on the system construction considerations for implementing our fast high-sensitivity AGPS acquisition scheme based on the timing-synchronized cellular network. We discuss the communication method for transmitting a time-tagged navigation message data bit stream to make a long time correlation possible, which means we perform a fast high-sensitivity acquisition. Then, we analyze and compare service mode of providing a narrowed Doppler frequency search range by server or user. The frequency search range, computational load of the server and user, and the amount of data that is transferred via network are the issues of most concern.

The rest of this paper is organized as follows. Our proposal of wipe off navigation message data bit transition and a fast frequency search is briefly explained first. Then we present the system considerations of implementation.

2 Wipe off Navigation Message Data Bit Transition

2.1 System Description [2]

The system is composed of an assisting server, user handset, and network communication link, as shown in Fig. 1. The user is in the service area of the base station (cellular network). A navigation message is sent by the satellite at time T_s and received by the server and user handset at times T_r and $\tilde{T}_u$, respectively. Here, $\tilde{T}_u$ is an estimated value that includes a time error as shown in the figure, and d_{ss} is the distance from the satellite to the server. The approximate distance between the satellite and the user is $\tilde{d}_{us}$.

The assisting server collects information that includes the navigation message data arrival times T_r and the navigation message data stream itself. Since the server and satellite positions are known on the server side, the distance d_{ss} from the satellite to server can be calculated. Thus we can derive T_s using Eq. (1), where c is the speed of light.

$$T_s = T_r - \frac{d_{ss}}{c} \tag{1}$$

The T_s information and navigation message data sequences are then sent to the user. Here, remember that the user handset and server are timing-synchronized. The user uses the position of the base station (cellular network) as his approximate position; thus, the approximate distance $\tilde{d}_{us}$ between the satellite and the user is known. The approximate arrival time of the navigation message $\tilde{T}_u$ is estimated by using this distance and T_s provided by the server. We calculate $\tilde{T}_u$ as follows.

$$\tilde{T}_u = T_s + \frac{\tilde{d}_{us}}{c} \tag{2}$$

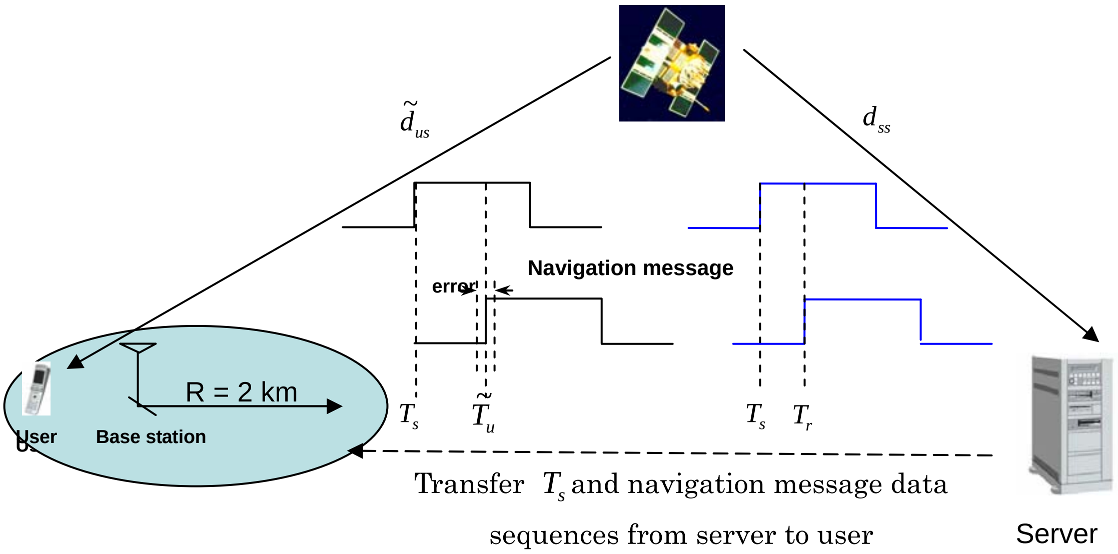

Figure 1. System structure

Finally, by referring to the estimated time $\tilde{T}_u$ and the navigation message data stream, the polarity changes caused by the navigation message can be removed. Thus, the navigation message can be wiped off, and this enables long coherent integration during the acquisition stage. The sensitivity of acquisition is proved.

2.2 Application Scenario

We propose that the server broadcasts the navigation message data bit stream and corresponding start time of this stream via a timing-synchronized cellular network. If we assume the time of the correlation performed by user is 1 s, 50 bits of navigation data and start time T_s of every bit will be broadcasted by the server. Because Doppler also effects C/A code length, if we perform long time correlation, start time error will be accumulated, which decreases long time correlation gain. To avoiding lost of correlation gain, transferring start time T_s of every navigation message bit is necessary.

Since a time-tagged navigation message is broadcasted, the data transfer delay time will not affect the correlation process conducted by the user's handset.

3 Fast Frequency Search

3.1 Frequency Uncertainty Issue

In an acquisition process, the frequency difference between the received and locally generated signals for each satellite are caused by the motion of the satellite, the local reference oscillator error, the position uncertainty, and the user motion uncertainty. The Doppler shift caused by the motion of the satellite can be calculated if the ephemeris or almanac and receiver's location are known. The sensitivity of the Doppler shift to initial position uncertainty is about 1 Hz/km [3]. Since we assume the service area of base station (cellular network) is 2 km, maximum position uncertainty is 2 Hz. The user motion uncertainty is so small for a cellular user that we can ignore it. The local reference oscillator uncertainty is typically 1,575 Hz/ppm [4] or more accurate, and it is by far the most dominant effect of the components mentioned above. Because oscillator error can be calculated from its accuracy and we ignore user motion uncertainty, we need the Doppler and position uncertainty information to estimate the frequency uncertainty.

To perform fast frequency search, the user can get necessary information by using different method according to system construction. For example, the Doppler information can be calculated and provided to user by server, or be calculated by user him/herself from almanac data. We discuss application scenarios in the following section.

3.2 Application Scenario

We assume three kinds of service mode according to various system construction requirements, and the performance is compared in Table 1.

The cellular phone user knows his approximate position, the approximate distance between the server and user can be computed. The server can calculate its Doppler shift for all satellites and transfers this information with its location to the user. The user estimates his frequency search range using the knowledge of the distance from the server (1 Hz/km), position uncertainty (2Hz) and the local reference oscillator frequency uncertainty f_{osi}. The search frequency is expressed as

$$F_{search} = (f_{IF} + f_{DS}) \pm (1Hz/km + f_{osi} + 2) \tag{3}$$

The search frequency F_{search} is centered on the summation of the user's receiver intermediate frequency f_{IF} and server-estimated Doppler frequency $f_{Doppler}$: $(f_{IF} + f_{DS})$, and the frequency uncertainty is $\pm(1Hz/km + f_{osi} + 2)$.

Table 1. Three Application Scenarios

Doppler	Server-based calculation	User-based calculation	Network-based calculation
Frequency uncertainty	$\pm(1Hz/km + f_{osi} + 2)$	$\pm(f_{osi} + 2)$	$\pm(f_{osi} + 2)$
Communication	Broadcast	Broadcast	Bi-direction
Search range	Wide	Narrow	Narrow
Server computational load	Medium	No need	Heavy
User computational load	Medium	Heavy	No need
Amount of data transferred	Server's Doppler & location	Almanac data when required	User's Doppler & location

3.2.1 Server-based calculation

Since the satellite is moving, the server frequently needs to calculate and update the server's Doppler frequently. However, this is common information for all users, so the computational load of the server is medium compared to the other two scenarios. The user receives f_{DS} from the server and calculates his/her Doppler search range by referring to the distance between the user and server. The computational load of the user is also medium. The data transferred via the network is server's Doppler and location information.

3.2.2 User-based calculation

If the server broadcasts the almanac data to the user, the user handset can calculate the Doppler f_{DU} without the information from the server. The search frequency is expressed as equation (4)

$$F_{search} = (f_{IF} + f_{DU}) \pm (f_{osi} + 2) \tag{4}$$

The computation on the server side is not needed. However, the user has to calculate the satellite's position and consequently the Doppler frequency. The computational load of the user is the heaviest of the three kinds of scenarios. The transferred data via the network is almanac data.

The frequency uncertainty is $\pm(f_{osi} + 2)$, which is less than that in scenario 1. The user does not need to communicate with the server after receiving all the almanac data at once and can predict its accurate Doppler for one week using the latest almanac data. The demerit here is that the user computation load is heavy and time-consuming.

3.2.3 **Server calculates Doppler for user handset**

The user handset transmits its approximate location to the server. The server calculates user's Doppler f_{DU} and returns it to the user. The search frequency is expressed as equation (4)

$$F_{search} = (f_{IF} + f_{DU}) \pm (f_{osi} + 2) \tag{4}$$

The computational load of the server is determined by the number of users who will use the service. The user's computational load is lightened the most. The transferred data via the network are user's location and user's Doppler.

The frequency search range is the same as that in scenario 2, although there is a transfer delay that delays the acquisition start time. The number of users' requests that a server can deal with is limited by the server's processing capability. Bi-directional communication is needed, which makes the user to wait for arriving of f_{DU} information.

4 Conclusion

We discussed the implementation issues for the proposed fast AGPS high-sensitivity acquisition scheme. The system considerations for the server's function are analyzed in the process of broadcasting time-tagged navigation message data bits, which are used to wipe off navigation messages and thus makes a long time correlation possible. A Doppler calculation service mode is analyzed to reduce the search range of the frequency. Three application scenarios were listed out for comparing their merits and demerits, such as the server, the user's computational load, and the amount of data transferred via network.

In the future, a real system construction experiment will be carried out to confirm the validity of the proposed scheme.

References

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