Geolocation and Assisted GPS

Goran M. Djuknic and Robert E. Richton
Bell Laboratories, Lucent Technologies

Currently in development, numerous geolocation technologies can pinpoint a person's or object's position on the Earth. Knowledge of the spatial distribution of wireless callers will facilitate the planning, design, and operation of next-generation broadband wireless networks. Mobile users will gain the ability to get local traffic information and detailed directions to gas stations, restaurants, hotels, and other services. Police and rescue teams will be able to quickly and precisely locate people who are lost or injured but cannot give their precise location. Companies will use geolocation-based applications to track personnel, vehicles, and other assets.

The driving force behind the development of this technology is a US Federal Communications Commission (FCC) mandate stating that by 1 October 2001 all wireless carriers must provide the geolocation of an emergency 911 caller to the appropriate public safety answering point (see http://www.fcc.gov/e911/). Location technologies requiring new, modified, or upgraded mobile stations must determine the caller's longitude and latitude within 50 meters for 67 percent of emergency calls, and within 150 meters for 95 percent of the calls. Otherwise, they must do so within 100 meters and 300 meters, respectively, for the same percentage of calls. Currently deployed wireless technology can locate 911 calls within an area no smaller than 10 to 15 square kilometers.

GLOBAL POSITIONING SYSTEM

An obvious way to satisfy the FCC requirement is to incorporate Global Positioning System (GPS) receivers into mobile phones. GPS consists of a constellation of 24 satellites, equally spaced in six orbital planes 20,200 kilometers above the Earth, that transmit two specially coded carrier signals: L1 frequency for civilian use, and L2 for military and government use.

Assisted-GPS technology offers superior accuracy, availability, and coverage at a reasonable cost.

GPS receivers process the signals to compute position in 3D—latitude, longitude, and altitude—within a radius of 10 meters or better. Accuracy has increased substantially since the US government turned off Selective Availability, the intentional degradation of GPS signals, in May 2000. Because no return channel links GPS receivers to satellites, any number of users can get their positions simultaneously. GPS signals also resist interference and jamming.

To operate properly, however, conventional GPS receivers need a clear view of the skies and signals from at least four satellites, requirements that exclude operation in buildings or other RF-shadowed environments. Further, it takes a GPS receiver starting "cold"—without any knowledge about the GPS constellation's state—as long as several minutes to achieve the mobile station location fix, a considerable delay for emergency services. Finally, incorporating GPS receivers into trendy, miniature handsets raises questions of cost, size, and power consumption.

NETWORK-BASED GEOLOCATION

Geolocation technologies that rely exclusively on wireless networks such as time of arrival, time difference of arrival, angle of arrival, timing advance, and multipath fingerprinting offer a shorter time-to-first-fix (TTFF) than GPS. They also offer quick deployment and continuous tracking capability for navigation applications, without the added complexity and cost of upgrading or replacing handsets. These technologies also provide a business opportunity for network operators as exclusive providers of subscriber-location information.

On the downside, network-based geolocation provides far less accuracy than GPS, requires expensive investments in base-station equipment, and raises privacy concerns. For more on network-based technologies and their implementation, see http://www.cell-loc.com/, http://www.geometrix911.com/, http://www.trueposition.com/, and http://www.uswcorp.com/.

ASSISTED GPS

Compared to either mobile-station-based, stand-alone GPS or network-based geolocation, assisted-GPS technology offers superior accuracy, availability, and coverage at a reasonable cost. As Figure 1 shows, AGPS consists of

- a wireless handset with a partial GPS receiver,
- an AGPS server with a reference GPS receiver that can simultaneously "see" the same satellites as the handset, and
- a wireless network infrastructure consisting of base stations and a mobile switching center.

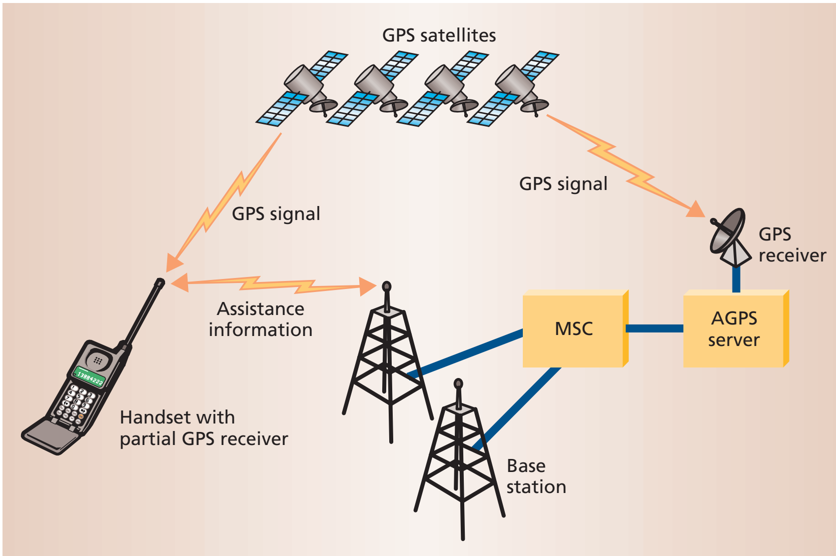

Figure 1. Assisted-GPS concept. The main system components are a wireless handset with partial GPS receiver, an AGPS server with reference GPS receiver, and a wireless network infrastructure consisting of base stations and a mobile switching center (MSC).

The network can accurately predict the GPS signal the handset will receive and convey that information to the mobile, greatly reducing search space size and shortening the TTFF from minutes to a second or less. In addition, an AGPS receiver in the handset can detect and demodulate weaker signals than those that conventional GPS receivers require. Because the network performs the location calculations, the handset only needs to contain a scaled-down GPS receiver.

By distributing data and processing, as well as implementation costs, between the network and mobiles, AGPS will optimize air-interface traffic. It is accurate within 50 meters when users are indoors and 15 meters when they are outdoors, well within federal guidelines and an order of magnitude more sensitive than conventional GPS. Further, because users share data with the network operator, AGPS lets them withhold data for privacy reasons while the operator can restrict assistance to service subscribers.

Reduced search space

Because an AGPS server can obtain the handset's position from the mobile switching center, at least to the level of cell and sector, and at the same time monitor signals from GPS satellites seen by mobile stations, it can predict the signals received by the handset for any given time. Specifically, the server can predict the Doppler shift due to satellite motion of GPS signals received by the handset, as well as other signal parameters that are a function of the mobile's location.

In a typical sector, uncertainty in a satellite signal's predicted time of arrival at the mobile is about ±5 µs, which corresponds to ±5 chips of the GPS coarse acquisition (C/A) code. Therefore, an AGPS server can predict the phase of the pseudorandom noise (PRN) sequence that the receiver should use to despread the C/A signal from a particular satellite—each GPS satellite transmits a unique PRN sequence used for range measurements—and communicate that prediction to the mobile.

The search space for the actual Doppler shift and PRN phase is thus greatly reduced, and the AGPS handset receiver can accomplish the task in a fraction of the time required by conventional GPS receivers. Further, the AGPS server maintains a connection with the handset receiver over the wireless link, so the requirement of asking the mobile to make specific measurements, collect the results, and communicate them back is easily met.

After despreading and some additional signal processing, an AGPS receiver returns back "pseudoranges"—that is, ranges measured without taking into account the discrepancy between satellite and receiver clocks—to the AGPS server, which then calculates the mobile's location. The mobile can even complete the location fix itself without returning any data to the server.

Sensitivity assistance

Sensitivity assistance, also known as *modulation wipe-off,* provides another enhancement to detection of GPS signals in the handset receiver. The sensitivity-assistance message contains predicted data bits of the GPS navigation message, which are expected to modulate the GPS signal of specific satellites at specified times. The mobile station receiver can therefore remove bit modulation in the received GPS signal prior to coherent integration. By extending coherent integration beyond the 20-ms GPS data-bit period—to a second or more when the receiver is stationary and to 400 ms when it is fast-moving—this approach improves receiver sensitivity.

Sensitivity assistance provides an additional 3-to-4-dB improvement in receiver sensitivity. Because some of the gain provided by the basic assistance—code phases and Doppler shift values—is lost when integrating the GPS receiver chain into a mobile phone, this can prove crucial to making a practical receiver.

Achieving optimal performance of sensitivity assistance in TIA/EIA-95 CDMA systems is relatively straightforward because base stations and mobiles synchronize with GPS time. Given that global system for mobile communication (GSM), time division multiple access (TDMA), or advanced mobile phone service (AMPS) systems do not maintain such stringent synchronization, implementation of sensitivity assistance and AGPS technology in general will require novel approaches to satisfy the timing requirement. The standardized solution for GSM and TDMA adds time calibration receivers in the field—location measurement units—that can monitor both the wireless-system timing and GPS signals used as a timing reference.

Table 1. Advantages and disadvantages of geolocation technologies.

Location technology	Pros	Cons
Mobile-station-based stand-alone GPS	Little or no additional network equipment Works with all mobiles Privacy not an issue (user controlled) Location capability remains in absence of wireless coverage or network assistance	New handsets Little or no indoor coverage Fails in radio shadows Considerable increase in handset cost and complexity Additional battery consumption Long time to first fix System upgrades limited by deployed handset base
Network-based systems	No added mobile-station complexity or cost Works with all mobiles Short time to first fix Maps and databases increase accuracy of location fix Continuous tracking capability for navigation applications Business opportunity for network operators as exclusive providers of subscriber-location information	Inferior accuracy Additional investments in infrastructure, with very high up-front costs Difficult network installation and maintenance User privacy questionable
AGPS	Superior accuracy, availability, and coverage Short time to first fix Maps and databases increase location accuracy if processing done in network Minimal impact on battery life Implementation cost shared by mobiles and the network System evolves with network upgrades Location data shared between users and network operator—users can withhold data for privacy reasons, and operator can restrict assistance to subscribers of service Air-interface traffic optimized by distributing data and processing between network and mobiles	Network assistance increases signaling load Interoperability between network and mobiles requires additional standards, delaying deployment New or upgraded handsets needed for initial deployment

Hybrid solutions

Many factors affect the accuracy of geolocation technologies, especially terrain variations such as hilly versus flat and environmental differences such as urban versus suburban versus rural. Other factors, like cell size and interference, have smaller but noticeable effects. Hybrid approaches that use multiple geolocation technologies appear to be the most robust solution to problems of accuracy and coverage.

AGPS provides a natural fit for hybrid solutions because it uses the wireless network to supply assistance data to GPS receivers in handsets. This feature makes it easy to augment the assistance-data message with low-accuracy distances from handset to base stations measured by the network equipment. Such hybrid solutions benefit from the high density of base stations in dense urban environments, which are hostile to GPS signals. Conversely, rural environments—where base stations are too scarce for network-based solutions to achieve high accuracy—provide ideal operating conditions for AGPS because GPS works well there.

Even providers who favor mobile-station-based solutions view the current lack of handsets with location capabilities as a major obstacle. Proponents of network-based solutions regard the obstacle as insurmountable.

Considering the advantages and disadvantages of each approach, summarized in Table 1, we believe that AGPS, augmented with elements from other location technologies, is the solution to which most wireless systems will ultimately converge. Such hybrid solutions offer superior location accuracy and the most potential cost-effectiveness. AGPS is also being standardized for all air-interfaces, which will prove critical for the technology's widespread deployment.

Goran M. Djuknic is a member of the technical staff at Lucent Technologies, Bell Laboratories. He received a PhD in electrical engineering from the City University of New York. Contact him at goran@lucent.com.

Robert E. Richton is a distinguished member of the technical staff at Lucent Technologies, Bell Laboratories. He received an MS in physics and chemistry from Stevens Institute of Technology, Hoboken, N.J. Contact him at richton@lucent.com.

Editor: Upkar Varshney, Department of CIS, Georgia State University, Atlanta, GA 30002-4015; voice +1 404 463 9139; fax +1 404 651 3842; uvarshney@gsu.edu