Innovation

Assisted GPS

A Low-Infrastructure Approach

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Have you ever tried to use a GPS receiver indoors? Chances are, unless you were on the top floor of a wood-frame house and using a receiver with ample antenna gain, you couldn't get a position fix. GPS is a marvelous positioning tool but it does have some weaknesses, one of which is low signal power. And unlike cellular telephones, conventional GPS receivers do not work well, if at all, unless their antennas have a clear view of the sky. Although future GPS satellites will transmit signals with higher power, it will be a decade or more before the current constellation of satellites is fully replaced. In the meantime, how can GPS be used in skyscraper canyons, inside office buildings, and even in underground parking garages? Assisted GPS comes to the rescue! In this month's column, a team of researchers from the United States and Finland describe their approach for assisted GPS — one which does not require a huge infrastructure investment for service providers.

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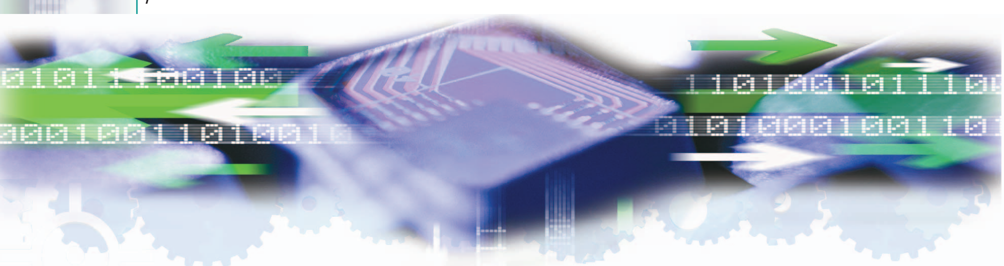


Cellular telephones with embedded GPS engines will be a reality for many in the near future. The development of these phones is being fuelled, in part, by the U.S. Federal Communications Commission's E-911 mandate requiring the position of a cell phone to be available to emergency call dispatchers. GPS cell phones will enable wireless location-based services (LBS), which are emerging as a new opportunity for mobile network operators to generate new revenues. All prominent industry analysts report a very steep growth in location-related services in the next few years. Services such as driving directions, identifying closest banks or restaurants, and tracking of people for safety or in emergency situations (via E-911 in North America and E-112 in Europe) are being deployed currently by wireless network operators.

LBS rely on some method of computing the user's location. One simple method uses the nearest cell tower as an approximate position; this method is called *Cell ID* and is currently used by operators that have already introduced commercial LBS. While Cell ID accuracy (the size of the cell tower coverage, normally several kilometers) is adequate for a number of applications, it is clearly not enough to meet the demands of applications such as E-911. Thus, advanced positioning methods that leverage mobile-network resources have been proposed. These techniques can be divided into network-based and handset-based solutions such as GPS and in particular, assisted GPS (AGPS).

In order to improve Cell ID accuracy, network-based positioning methods require the installation of hardware and software throughout the network and also in the cell phone. This means an "up front" investment by the network operator. Network-based methods improve on Cell ID accuracy but still do not satisfy all applications. Moreover, because they rely on the cellular signal to compute position, they are "cellular technology dependent" and therefore do not provide a good migration path to third generation (3G) systems (see sidebar).

AGPS is the most accurate of the methods, requiring only low infrastructure cost and allowing a direct migration path into 3G.

In this article, we describe an implementation of AGPS which requires absolutely no additional infrastructure from the service provider to be able to provide AGPS data to existing GPS terminals. We will discuss the main performance benefits from the user's point of view for the current handsets and also for the next generation.

In this implementation, we have chosen the Short Messaging Service (SMS) as a bearer for the GPS assistance data because it is a proven and available message format and is simple to use (see sidebar). SMS utilizes a low capacity channel and therefore restricts the number of bytes which can be sent. We have employed a compressed format of the aiding data which we will refer to as Compact Assistance Data (CAD).

This implementation can be considered a "pre-standard" — one suitable as a proof of concept and commercially viable in special applications. The source for assistance data is a worldwide reference network of GPS stations with sufficient coverage to track all GPS satellites at all times.

What is AGPS?

Assisted GPS describes a system where outside sources, such as an assistance server and reference network, help a GPS receiver perform the tasks required to make range measurements and position solutions. The assistance server has the ability to access information from the reference network and also has computing power far beyond that of the GPS receiver. The assistance server communicates with the GPS receiver via a wireless link. With assistance from the network, the receiver can operate more quickly and efficiently than it would unassisted, because a set of tasks that it would normally handle is shared with the assistance server. The resulting AGPS system, consisting of the integrated GPS receiver and network components, boosts performance beyond that of the same receiver in a stand-alone mode.

There are three basic types of data that the assistance server provides to the GPS receiver: precise GPS satellite orbit and

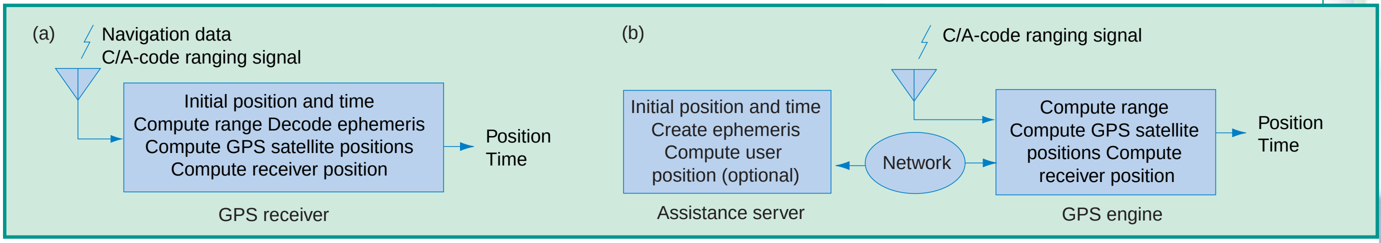


FIGURE 1 A stand-alone GPS receiver (a) must search for satellite signals and decode the satellite navigation messages before computing its position – tasks which require strong signals and additional processing time. A cellular telephone network can assist a GPS receiver (b) by providing an initial approximate position of the receiver and the decoded satellite ephemeris and clock information. The receiver can therefore utilize weaker signals and also more quickly determine its position.

clock information; initial position and time estimate; and for AGPS-only receivers, satellite selection, range, and range-rate information. The assistance server is also able to compute position solutions, leaving the GPS receiver with the sole job of collecting range measurements. Figure 1 shows the architecture of AGPS implementation compared to conventional GPS.

AGPS Implementation

An example of a GPS-equipped cell phone already on the market is the Benefon Esc! This phone features a core dual-band Global System for Mobile Communications (GSM) 900/1800 engine for wireless communications, a SiRF-enabled GPS receiver for precise positioning and personal navigation, mobile maps, Friend-Find, and Mobile Phone Telematics Protocol (MPTP) among the other standard GSM functions.

One of the phone's most innovative features is its ability to download topographical, street or city, nautical, or personal maps suitable for use at any time directly via a laptop computer, home PC, or from the Internet. The phone's user interface allows various operations, from waypoint navigation to locating a friend using SMS and MPTP to exchange location information.

The Benefon Track, a sister product to Benefon Esc!, uses the same platform for communications and positioning but has a user interface tailored for professionals who work alone and individuals desiring personal security through location knowledge.

One of the most important features in the Benefon Track is a dedicated emergency button located clearly at the top of the phone. This button activates a procedure that instantly initiates a location message and a voice call to a user-definable number. This phone also features a wide range of special telematics functions such as tracking, condition check, and status messaging which all use position

Cell Phones: Generation Next

The cellular communications industry has gone through several generations of systems since the first commercial cellular networks were introduced in the early 1980s. The first networks to be implemented were based on analog principles. Limited testing of one of the first analog systems – the Advanced Mobile Phone Service (AMPS) began in North America in 1978 using the 800 MHz band. Commercial AMPS services started here in 1983 and are still operating. Various analog systems entered service in Europe and elsewhere during the 1980s.

In an effort to increase network capacities and to more easily provide additional services to cell phone users such as fax, data communications and text messaging, digital networks were developed. These second generation systems made their first appearance in Europe. Europe had nine incompatible analog systems making roaming between systems difficult if not impossible. Planning started in the early 1980s to develop a standard which would lead to the creation of a single Europe-wide digital mobile service with enhanced voice and text features (Short Messaging Service) and easy roaming. This system was called GSM, initially for Groupe Speciale Mobile, the name of the study group which developed the standard, but it now stands for Global System for Mobile Communications. GSM started operations in Europe in 1991 and its use has now spread worldwide including a recent introduction in North America. Most systems in Europe operate in the 900 MHz band while in North America, the 1.9 GHz band is used.

In North America, digital service began in 1992 with the conversion of some AMPS analog channels to digital using Time Division Multiple Access (TDMA), a technique which assigns specific time slots to different transmissions on the same frequency channel, interleaving the signals and thereby increasing the capacity of the channel. (GSM also uses TDMA.) Digital AMPS, or D-AMPS, features a maximum data rate of 9.6 kilobits per second and supports Internet Protocol data transmissions over the Cellular Digital Packet Data (CDPD) service. In 1995, a different digital technique was introduced by some North American network operators: Code Division Multiple Access (CDMA). CDMA encodes transmissions from different users on the same frequency using spread spectrum techniques – the same frequency sharing approach used by GPS.

Wireless 3G systems will offer high-speed data transfer capabilities comparable to those currently available on wired networks — speeds of at least 144 kilobits per second. This high-speed service will permit a wide range of enhanced multimedia services to the mobile user including permanent access to the Web, interactive video, and CD-quality sound. In addition, 3G systems will offer a high degree of commonality of design permitting global roaming. 3G systems will be based on packet switching technology rather than the circuit switching used by 2G systems. Circuit switching networks initiate and then maintain an open connection between users for as long as it's needed. Packet switching is a digital communications technique in which digitized voice or data is subdivided into small units (packets) and relayed through sites in a network along the best route available between the source and the destination. Packets from different sources can be interleaved for transmission on the network and are reassembled at the destination. Packet switching increases network capacity and efficiency.

3G systems will not be with us for several years. In the meantime, 2.5G systems are being introduced to bridge the gap between second and third generation systems. These systems feature higher data rates than second generation systems to provide services such as the General Packet Radio Service (GPRS) which is currently being added to GSM systems.— R.B.L.

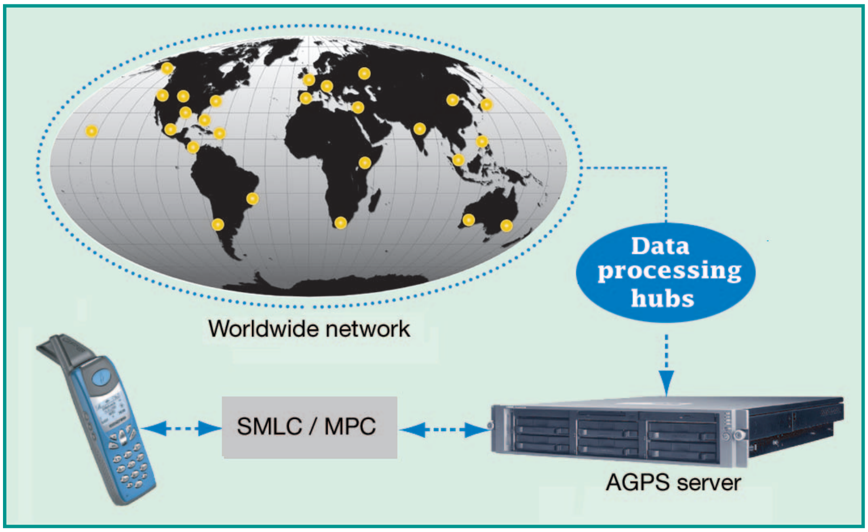


FIGURE 2 Assisted-GPS requires a worldwide tracking network for obtaining the navigation messages of all satellites and data processing hubs along with a server which feeds data to a Serving Mobile Location Center (SMLC) or Mobile Position Center (MPC) operated by a network service provider. Data is sent to individual cell phones using Hypertext Transfer Protocol (HTTP) and the Short Messaging Service (SMS).

as a key element. Both of the phones have support for enhanced Cell ID-based network positioning which is combined with GPS to provide users a hybrid positioning capability.

Initial User Groups

Many people benefit from a system that gives them their position and communicates it to a service or call center. Many applications discussed today address wide-spread acceptance of LBS in the consumer market. Yet many of the LBS providers are not ready to support these large-scale commercial services. Therefore, we have targeted our AGPS phones to customers who currently support location information and to users looking to combine the functionality of a cell phone with a GPS receiver for recreational use.

One target market is comprised of people who work in dangerous jobs (such as security guards), people who work alone (such as field engineers), and people who are more commonly in need of assistance (such as nurses and health care workers). These professionals and others like them benefit from being able to locate someone immediately from a remote location and for the workers to be able to request assistance by pressing a single button. These actions are made possible by exact location obtained by using the GPS receiver with assistance and network positioning in those areas which are not covered by stand-alone GPS.

Another market targeted by our products includes companies which have field personnel and cell phones and location information for workforce management. Examples of these companies are those with service personnel such as heating repair technicians who make many calls in different locations during a single business day. This same technology applies equally well to dispatch-driven services. The phones provide a communications link to give instructions and new tasks. Location knowledge improves the efficiency of the moving workforce.

In the future, field personnel can be equipped with a sophisticated PMG (Professional Mobile Radio over GSM) feature allowing them to use cell phones like "walkie talkies" using the emergency button as a push-to-talk switch.

Assistance Data

Global Locate owns and operates a worldwide reference network which continuously tracks the GPS satellites and logs the satellite tracking information into the reference hub. This tracking network allows us to predict satellite orbit and clock information for many days into the future. This information can then be used for AGPS. This feature of the network removes the reliance on the broadcast ephemerides and allows access to satellite orbit and clock data, in standard formats, not just for the current epoch but for times into the future. For example, a phone could request the orbit and clock data during off-peak times for the following day. This reduces the network traffic for assistance data during peak hours and provides the user with an all-day capability for location services without requesting assistance data. This concept can be easily expanded to many days of operation.

Figure 2 shows the assistance data system architecture. Global Locate provides the reference network and the hub for archiving the information. MSLocation Oy (a Finnish location services company) provides the server that receives requests from the phone, requests information from the Global Locate hub, then sends the SMS messages with orbit, clock, position, and time information.

Why AGPS?

AGPS architectures increase the capability of a stand-alone receiver to conserve battery power, acquire and track more satellites, thereby improving observation geometry, and increase sensitivity over a conventional GPS architecture. These enhanced capabilities come from knowledge of the satellite position and velocity, the initial receiver position, and time supplied by the assistance server.

The received GPS signals are shifted in frequency due to the relative receiver-satellite motion. This is the so-called Doppler frequency shift. The receiver must find the frequency of the signal before it can lock onto it. Knowledge of the satellite position and velocity data and the initial receiver position reduces the number of frequency bins to be searched because the receiver directly computes the Doppler frequency shift instead of searching over the whole possible frequency range. Satellite position and velocity data are computed from the orbit and clock data provided by the assistance server. The initial receiver position can come from Cell ID techniques or any other available source of information. Reducing the number of frequency bins which must be searched to acquire the signal reduces the time-to-first-fix (TTFF).

Shorter Wait. TTFF is further reduced because the receiver no longer has the task of decoding the navigation data bits, a task that takes tens of seconds. Instead, the assistance server provides the satellite orbit and clock parameter values to the receiver. Shorter TTFF results in reduced power consumption because the system does not have to wait for the GPS receiver to decode the navigation data for each visible satellite. If the receiver had to decode the ephemeris from the broadcast message, it would take a minimum of 18 seconds after acquiring the signal, assuming that it did not drop or lose any data bits. In practice, TTFF (when decoding ephemeris data) is in the range of 20-60 seconds for environments where the receiver has an unobstructed view of the sky. If the environment is harsh, such as an urban canyon or even indoors, the receiver may take much longer to recover the data bits, if it can recover them at all.

Greater Sensitivity. Increased receiver sensitivity is directly related to the TTFF and the number of frequency bins which must be searched to find a satellite signal. Because the receiver has fewer frequency bins to search in an AGPS architecture, it can dwell in each bin for longer periods of time. This additional dwell time increases the sensitivity of the receiver, so that it can use signal strengths below the conventional thresholds to make range measurements. In addition, when the higher sensitivity is required, the navigation data bits would be difficult if not impossible to decode. Therefore, this technique allows the use of satellite data which would have otherwise been unavailable.

Customer Satisfaction. Although discussions of TTFF and navigation data bits are compelling to engineers, the real reason for implementing AGPS is customer satisfaction when using location or E-911 services. With AGPS, the position can be computed more quickly, on the order of a few seconds. If the position solution took minutes, as is common with warm starts in conventional GPS receivers, the consumer might become frustrated while waiting and wonder whether there was anything wrong with the phone. The typical cell phone consumer has grown accustomed to applications which work in a few seconds. Location services should behave the same way to gain customer acceptance beyond those already familiar with, and accustomed to, the performance of GPS receivers.

Infrastructure Requirements

SMS is currently available in most cellular networks and supports store and forward low data rate messaging services. The General Packet Radio Service (GPRS) is the next generation of mobile messaging and is available in the so-called 2.5 Generation (2.5G) cellular systems. GPRS provides packet data services ("always on") with rates comparable to a 56 kilobit per second modem.

In the next generation of cell phones, 3G, data rates will be even higher in order to provide services such as streaming video, streaming audio, and high speed Internet access. 3G features "bandwidth on demand" depending on the quality and type of service the customers requests with data rates up to 2 megabits per second. 3G services are not yet available from the handset manufacturers, but the standards are being finalized and services are planned to start within the next few years.

Our AGPS system uses SMS because of the widespread availability of the service. SMS data rates and latencies provide adequate performance for AGPS purposes. However, special considerations were required to accommodate satellite orbit and clock information into the SMS constraints.

SMS Data Compression

Our worldwide reference network, hub, and server infrastructure tracks the GPS satellites, computes current and predicts future satellite orbit and clock information, and provides that orbit and clock data to AGPS systems. The tracking network provides the raw tracking information to the hubs, as shown in Figure 2. Global Locate provides algorithms that convert raw orbit and clock information into an ephemeris-like format compatible with ICD-GPS-200C ephemeris propagation equations.

What is SMS?

The Short Messaging Service (SMS), also called the Short Message Service, is a feature of digital cellular telephone networks which permits the transmission and reception of brief text messages using a mobile phone. It debuted in the early 1990s with the inauguration of Global System for Mobile Communications (GSM) networks in Europe. Messages may be up to 160 characters in length for languages based on the Latin alphabet and up to 70 characters for non-Latin alphabets such as Arabic and Chinese. Binary messages, including data for phone applications, may also be exchanged via SMS. Each binary message is typically limited to a length of 140 bytes.

SMS is simple to use. You type a message on the phone keypad, cycling through the characters assigned to each key to select the one desired. Some phones have special dictionaries which attempt to predict which word you're trying to spell. Once the message is composed, you specify the phone number of the recipient and send it. The recipient sees the message displayed on his or her phone. What if the destination phone is switched off when a message is sent? SMS is a store-and-forward system. The messages go via a messaging center and each network has one or more such centers to handle SMS messages. The center will store the message until delivery can be made – typically for as long as 72 hours. Confirmation of receipt can be requested assuring the sender that the message has been received.

Some networks permit messages to be exchanged between phones and the Internet permitting limited e-mail capability.

SMS messages can be sent or received at the same time as a voice or data call is in progress since SMS uses a signaling path (one of the auxilliary channels used by the network to register the phone as active, notify a user of an incoming call, synchronize communications, facilitate cell handoffs, etc.) rather than the voice or data channel.

In addition to person-to-person messaging, SMS is used to notify a cell phone user of new voice or fax or e-mail messages waiting to be read. In fact, voice mail notifications account for a vast majority of SMS traffic. SMS is also used to broadcast share prices, sports scores, weather, flight information, news headlines, lottery results, and even jokes and horoscopes. SMS can be used to remotely monitor machines, to read meters, and to notify a distributor that a vending machine is empty. Using GSM's Subscriber Identity Module security features, SMS can be used to pay bills. SMS can support virtually any application requiring short bursts of data.

SMS is wildly popular in Europe, particularly among young people. The GSM Association estimated that in December 2001 alone, approximately 30 billion SMS messages were sent over GSM networks.

Although SMS is an integral component of GSM networks, it has been adopted as the text messaging protocol on other types of digital cell phone networks including those using different flavors of time division multiple access (TDMA) and code division multiple access (CDMA) – the techniques used by most North American digital cell phone networks. Even so, SMS has been slow to catch on in the United States and Canada. This might be because of the widespread use of home computers and conventional e-mail and the relatively low cost of wired telephone and Internet services compared to Europe. Another deterrent is the restrictions that some North American networks currently impose on SMS users. For example, some networks only permit the reception of SMS messages. And some only permit the exchange of messages between users on the same network. However, national and international SMS roaming between networks, like that already available for voice transmissions, is under development. Also, some North American cell phone companies are converting their TDMA networks to GSM — a move which will facilitate the full use of SMS messaging capabilities. — R.B.L.

For this application, the satellite orbit and clock information is compressed to best utilize the SMS messaging capability. This process of tracking the GPS satellites and computing orbit and clock data allows us to provide assistance data to the AGPS-equipped phone in a standard format while providing the best possible validity periods into the future.

The limiting factor on SMS messages is the overall length of about 140 bytes (accepted by most services, but length limitations vary by provider). Therefore, the satellite orbit and clock data must be organized to fit into these 140 byte blocks.

To send the full broadcast ephemeris content for each satellite in view would take one SMS message per satellite, resulting in 8-12 SMS messages per set of assistance data (assistance data is only provided for those satellites which should be in view from the initial location). However, we reduced the overall size of this data set by using a unique CAD scheme which fits orbit and clock information from three satellites into a single SMS message in addition to the initial position and time information. Therefore, assistance data takes 3-4 SMS messages instead of the 8-12 required to broadcast the full uncompacted data set.

The CAD compression scheme utilizes 138 bytes for the satellite orbit, clock, initial position, and time data. The additional two bytes are used to manage the message count and message sequencing. Each SMS message contains a full set of satellite information for the satellites included in the message, providing a robust architecture in the event a subset of the messages was lost. For example, in the event that 1 out of 4 SMS messages was dropped, satellite orbit and clock data for up to 9 satellites would still be available.

This robust and compact method to communicate with the AGPS receiver is a pre-standard implementation. With the advent of GPRS and 3G messaging services, the requirement for extremely compressed assistance data will diminish. However, a robust method of ensuring that an adequate subset of information is available to the AGPS receiver will still be required to provide the customer with the best location-based service experience.

Further Reading

For previous *GPS World* articles on AGPS, see:

- "Wireless-assisted GPS: Keeping Time with Mobiles" by J.T. Syrjärinne, Vol. 12, No. 1, January 2001, pp. 22-31.
- "GPS Reference Networks' New Role: Providing Continuity and Coverage" by P. Enge, R. Fan, and A. Tiwari, Vol. 12, No. 7, July 2001, pp. 38-45.
- "Indoor GPS: The No-chip Challenge" by F. van Diggelen and C. Abraham, Vol. 12, No. 9, September 2001, pp. 50-58.

For further information on the authors' assisted-GPS approach, see

- "Indoor GPS Technology" by F. van Diggelen and C. Abraham, presented at the Cellular Telecommuni-cations and Internet Association's *CTIA Wireless Agenda 2001 Conference*, Dallas, Texas, May 14-18, 2001. <http://www.globallocate.com/downloads.html>
- "Global Locate Indoor GPS Chip Set and Services" by F. van Diggelen in the *Proceedings of ION GPS 2001, the 14th International Technical Meeting of the Satellite Division of The Institute of Navigation*, Salt Lake City, Utah, September 11-14, 2001.

For further details on the Short Messaging Service, see

- MobileSMS.Com <http://www.mobilesms.com/>.

For an in depth discussion of cellular telephone technology, see

- *Cellular and PCS: The Big Picture* by L. Harte, S. Prokup, and R. Levine, Mc-Graw Hill, New York, 1997.
- "Cellular Telephone Basics" by T. Farley <http://www.privateline.com/ Cellbasics/Cellbasics.html>.

Phone Modifications Required

The handsets we used to test our approach include a GPS receiver as an integral part of the phone. However, we had to modify the phone in several ways to upgrade it to an AGPS system. We modified the phone firmware to request assistance data via the SMS, convert the data from the SMS format to one compatible with the GPS receiver, and to load this data to the GPS receiver. Therefore, we recreated that data structure in the firmware based on the assistance data received via SMS. Location information can be extracted from the phone in three ways: through display as latitude and longitude, through the phone's National Marine Electronics Association (NMEA) 0183 port or by using MPTP wirelessly over SMS. Similarly the phone could be remotely configured for various operating modes by using MPTP.

We also had to make minor modifications to the phone software to interface the phone to the SMS server and the Global Locate network. The assistance data is available in Hypertext Transfer Protocol (HTTP) format and is bit packed for immediate packing into the SMS messages. MSLocation provided the interface between the SMS messages and the Global Locate server. Additional software was added to the phone processor to unpack the assistance data from the SMS messages and convert that data into an ICD-GPS-200C data format.

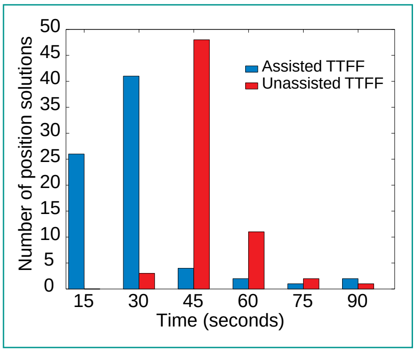


FIGURE 3 The time-to-first-fix (TTFF) is considerably reduced when a GPS receiver is assisted with data provided by a cellular telephone network as this test data shows.

MSLocation provided the initial position for use in the AGPS aiding data. This initial position is based on Cell ID, time slot, sector information, and cell tower location. The combination of GSM-network-based position solutions and AGPS provides a strong partnership for an optimal combination of technologies to provide location information.

AGPS Performance

We have tested the performance of our AGPS approach for TTFF and position accuracy. We conducted the testing in both open and urban environments. TTFF was measured relative to the time when the assistance data was received at the phone and power consumption was monitored during the testing.

Special software was loaded into the phone to clear the memory of the GPS receiver prior to requesting a position solution. In these tests, the GPS receiver memory would be cleared and the assistance data requested. After the assistance data was converted to the format for the receiver, the position computation was requested. This test configuration used power directly from the phone battery and the built-in GPS antenna.

Figure 3 compares TTFF performance using AGPS assistance data and when decoding the navigation data from the satellite broadcast. We collected the data for this particular test using on outdoor rooftop antenna. The AGPS performance provides typical TTFF of 30 seconds compared to about 48 seconds for decoding the navigation data. This is a significant performance increase which directly impacts customer acceptance and usability of AGPS technology. It is also interesting to note that decoding the ephemeris takes 18 seconds (900 bits divided by 50 bits/second = 18 seconds).

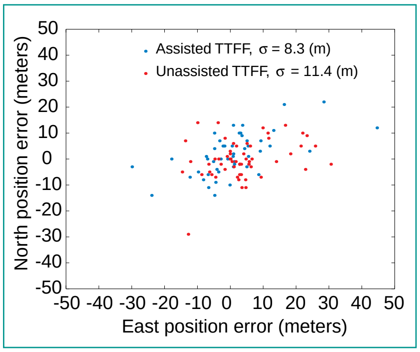


FIGURE 4 Since an assisted GPS receiver can work with weaker signals, additional range measurements are available to it which can result in increased positioning accuracy, as illustrated here.

Figure 4 shows the output position performance for the position computed using both broadcast ephemeris and AGPS assistance data compressed over the SMS data link. The resulting one-sigma accuracy shows a slight improvement relative to that using broadcast orbits.

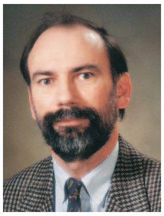
Future Enhancements

GPRS when available will provide a more efficient medium for transmiting AGPS assistance data over the network in comparison to today's SMS or circuit switched data.

When handsets are upgraded with the latest GPS chip technology, true indoor GPS performance will become a reality. ◍

Manufacturers

The Global Locate worldwide tracking network uses **Trimble** (Sunnyvale, California) 12-channel, survey-grade reference receivers. The **Benefon** *Esc!* and *Track* cell phones feature an embedded GPS receiver manufactured by **u-blox AG** (Thalwil, Switzerland) using the **SiRF Technology, Inc.** (San Jose, California) *SiRFstar* chipset.



"Innovation" is a regular column featuring discussions about recent advances in GPS technology and its applications as well as the fundamentals of GPS positioning. The column is coordinated by Richard Langley of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick, who appreciates receiving your comments as well as topic suggestions for future columns. To contact him, see the "Columnists" section on page 4 of this issue.