Assisted GPS: A Low-Infrastructure Approach

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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.

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

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 receiver and the decoded satellite ephemeris and clock information. The receiver can therefore utilize weaker signals and also more quickly determine its position.

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.

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).

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

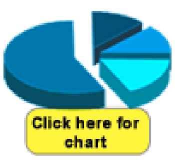

Figure 3 The time-to-first-fix (TTFF) is considerably reduced when a GPS receiver is assisted with data provided by a cellular telephone network as this test data shows.

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.

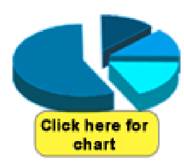

Figure 4 Since an assisted GPS receiver can work with weaker signals, additional range measurements are available to it which can result in increased positioning accuracy, as illustrated here.

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. 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.

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.

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 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.