Wireless Phones, GPS and Data Applications

James M. Conrad and Santosh Kolenchery
Ericsson, Inc., 7001 Development Drive, Research Triangle Park, NC 27709
(919) 472-6178, james.conrad@ericsson.com
(919) 472-9914, santosh@torrentnet.com

ABSTRACT

The Federal Communications Commission has specified that, after October 1, 2001, 50% of all wireless handset activations must provide Automatic Location Identification (E911). A user's position must be accurately conveyed to Emergency Services Authorities during a 911 call. Several methods of location determination can be implemented, including one that is handset-based, one that is network-based, or any variant in between. If the technology allows location identification with accuracy of tens of meters, then a plethora of location-based services can be realized. This location information can be sent by the handset for each service request, or can be stored in a network location. This paper examines the basics of E911, Global Positioning System (GPS), and Wireless Acœss Protocol (WAP). We will also suggest how location based services can access location information and provide services/content to the user.

Keywords: E911, GPS, WAP, Cellular, wireless, network.

1 INTRODUCTION

Today's users of cellular phones want more features and function. It is now no longer acceptable to have a phone that you can use to make calls, now the phone must have caller ID, integrated phonebooks, speed dialing, voice recognition/ dialing, and data capabilities. One prediction is that in the United States, between April 2000 and April 2001, 72 million phones will be sold which are data-capable, versus 45 millions PCs [1]. Similar trends are seen in Europe. Primary data access will be via an over-the-air mechanism called Wireless Application Protocol (WAP).

At the same time of this data capability, the Federal Communications Commission (FCC) has specified that, after October 1, 2001, 50% of all wireless handset activations must provide Automatic Location Identification (E911). The intent is that, when a cell phone user makes a 911 call, that cell phone's user information and exact location (within 50-150 meters) be conveyed to Emergency Services Authorities.

What if the WAP environment and position information were combined? What services could be provided to cell phone users? How would these services obtain the location information? What security risk does this pose? This paper describes the positioning mechanisms and possible methods of providing this location information to WAP services.

This paper is organized as follows: Section 2 describes the motivation for cell phone location, the E911 requirements mandated by the FCC. Section 3 describes several approaches that could be used for locating the position of a cell phone. Section 4 provides an introduction to the WAP standard. Section 5 offers suggestions of how the cell phone location, described in earlier sections, can be provided to WAP services. We present our conclusions in Section 6. We have even included a list of acronyms/glossary at the end.

2 THE MOTIVATION: E911

The FCC has outlined its mandates for Automatic Location Identification (ALI) and Automatic Number Identification (ANI) as applied to wireless handsets in [2,3]. These mandates are intended to encourage deployment of location determination of wireless handsets for the purpose of Emergency 911 services. ANI and ALI refer to the capability to automatically display, at the Public Safety Answering Point (PSAP), the caller's telephone number, the location of the telephone and supplementary emergency services information used to locate the wireless handset that is placing an E-911 call.

The FCC's wireless E911 rules require certain commercial wireless carriers to begin transmission of enhanced location information in two phases. Phase I of the FCC's E911 rules requires that a dialable number accompany each 911 call, which allows the PSAP dispatcher to call back if the call is disconnected or to obtain additional information. It also gives the dispatcher the location at the cell site that received the call as a rough indication of the caller's location.

Phase II of the FCC's wireless 911 rules allows the dispatcher to know more precisely where the caller is located, a capability called ALI. The E911 rules adopted by the FCC in 1996 required that ALI be provided for all 911 calls in a PSAP's area as of October 1, 2001. Only network-based ALI solutions were anticipated. In [4], the FCC revised its rules to permit phased-in compliance with Phase II for handset-based solutions for ALI.

Network Based ALI Schedule

For carriers employing network-based location technologies, implementation must be fully accomplished within 6 months of a PSAP request, with a revised rule requiring the carrier to deploy Phase II to 50 percent of callers within 6 months of a PSAP request and to 100 percent of callers within 18 months of such a request.

For network-based solutions, the FCC mandates the following performance standards for Phase II location accuracy and reliability: 100 meters for 67 percent of calls and 300 meters for 95 percent of calls.

Handset Based ALI Schedule

Regardless whether the carrier has received a PSAP request for Phase II deployment, the carrier must (Refer Section II of [4] for ALI deployment schedule requirements):

- By March 1, 2001, wireless carriers selecting a handset-based solution must begin selling and activating ALI-capable handsets.
- Ensure that at least 50% of all new handsets activated are ALI-capable no later than October 1, 2001; and ensure that at least 95% of all new digital handsets activated are ALI-capable no later than October 1, 2002. The requirement of the initial 50 percent benchmark applies to all new handsets, not solely to new digital handsets (para 42 and 45 in [4]).
- To satisfy FCC's phase II rules for roamers and other callers without ALI-capable handsets, carriers shall support Phase I ALI and other available best practice methods of providing the location of the handset to the PSAP.
- An ALI technology that requires new, modified, or upgraded handsets shall conform to general standards and be interoperable, allowing roaming among different carriers employing handset-based location technologies.

Once a PSAP request is received, the carrier must, in the area served by the PSAP:

- Within six months or by October 1, 2001, whichever is later, ensure that 100% of all new handsets activated are ALI-capable;
- Implement any network upgrades or other steps necessary to locate handsets; and
- Begin delivering to the PSAP location information that satisfies Phase II requirements.

Within two years or by December 31, 2004, whichever is later, undertake reasonable efforts to achieve 100% penetration of ALI-capable handsets in its total subscriber base.

For handset-based solutions the FCC mandates an accuracy of 50 meters for 67 percent of calls, 150 meters for 95 percent of calls.

E-911 Call Completion

The FCC has proposed that all mobile phones manufactured after the 9 months adoption of the Order in May 99, capable of operation in an analog mode, MUST incorporate a special procedure for processing 911 calls (para 87 in [4]). E-911 call completion requirements are described in detail in [4]. One of the following proposals may be adopted to comply with FCC mandates.

- Automatic A/B with Intelligent Retry
- Strongest Signal
- Selective Retry
- Alternate methods

3 POSITION DETERMINATION

The driving factor for incorporating location services on this phone is the FCC mandate to provide accurate user position in the case of emergency E911 calls. Location determination is also being considered as a product differentiator by leveraging the technology to provide value-added services to WAP enabled phones. In this section we briefly discuss the various technology alternatives proposed for ALI

The handset or the network can perform position determination measurements. The two alternative technologies are discussed below. Once the position determination measurements are completed, the position calculation may be performed at the handset or the network (i.e. by a position determination entity - PDE). The position determination solutions being considered to meet FCC mandates must be applicable to DAMPS, GSM and CDMA systems. In some systems such as CDMA, the inherent synchronization of the infrastructure with GPS time can be leveraged to provide accurate time estimates at the handset which aid in better performance of handset based position determination techniques.

Network based

In this approach the network is responsible to find the location of the mobile. All handset's involved in a call are monitored by a set of base stations. With a network based solution we observe the following:

- No change in handsets. The method works with legacy handsets, hence permits aggressive deployment.
- Poor performance in rural areas where infrastructure deployment is sparse.
- Requires significant investment in infrastructure development.
- The handset does not have to implement complex protocols to exchange assistance information or to report position determination measurements to the network.
- Because the measurements are distributed over multiple cell-sites there is increased network load due to synchronization and signaling.

The radio signal from the handset is observed at multiple base-stations. By measuring properties of the received signal, the PDE in the network is able to determine the position of the mobile. In the sections below we briefly discuss a few network based position determination solutions.

Measurement of signal attenuation: In this method, the location is determined by observing the received power from a handset at the receiving base-station. The transmitted power of the mobile must be known and a propagation model is applied to determine the distance of the handset from the receiver. This technique suffers from problems of selecting an appropriate propagation model for the environment and the requirement of continuous system tuning to compensate for changes due to weather and other environmental factors. Multipath effects also seriously degrade the performance of this method with the received power fluctuating even when the mobile is stationary.

Time difference of arrival (TDOA): In this technique discussed in [6],[7] and [8], 3 or more base-stations from separate cell sites, measure the time of arrival of signals from an handset by using an accurate timing source. The difference in arrival time of the signal from the handset at pairs of cell sites result in a hyperbola. By combining measurements at multiple cell site pairs, the intersection of the hyperbolae are calculated and the position of the handset determined.

A similar position determination can be performed when the handset measures the signals from multiple cell sites. TDOA applied to the uplink (i.e. network based) is also referred to as time of arrival and when applied to the downlink, it is called Observed Time Difference (OTD), which is a handset-based solution. For time of arrival, the mobiles are required to be active and there may be interruption in the voice call.

Multipath causes multiple copies of a transmitted signal that are received at an antenna contributing to error in a TDOA system. The overlapping multipath components distort the shape of the original signal and the group delay, causing the TDOA system difficulty in accurately determining the point in the signal to be measured by all receivers. Certain geometries caused by the base stations and the handset participating in measurements may result in poor performance. This is especially true if the base stations are far apart causing large angles to be subtended at the handset. Geometric Dilution of Precision refers to the degradation in accuracy due to the geometry of the receiving antennae relative to the handset. Geometric Dilution of Precision is a multiplier on measurement errors.

Angle of Arrival (AOA): The AOA technique discussed in [7] and [8] determines the direction of arrival of a handset's signal at the cell site. This is achieved by observing the phase difference of the received signals at a calibrated antenna array mounted on base stations. These measurements are repeated at multiple cell sites. Knowing the AOA, the base station can generate a circle where the handset is likely to be located. Therefore, AOA requires at least two base stations be available to determine the location of the handset by calculating the intersection of two circles.

This technique is ideally suited for tracking continuously transmitting mobiles. The performance degrades as the mobile moves away from the base-station. Multipath effects also seriously degrade performance of AOA measurements.

TDOA + AOA: This method combines both TDOA and AOA to achieve better performance. One example of this is the coverage of a rural highway where the cell site arrangement often is in a line along the highway. TDOA-only systems must overcome increased propagation loss for three-site reception.

Handset Based

In handset-based solutions, the handset is modified to perform position determination signal measurements. These may be signals from base-stations such as pilot signal in CDMA systems [9] or from satellites such as in GPS [6] and [11].

- Legacy handsets cannot support handset-based solutions.

- Accuracy is very good compared to network based solutions drives handset costs, however this may reduce as the technology matures.
- Poor performance of GPS in urban areas due to shadowing (buildings etc.). Other schemes such as E-OTD fare better because of dense infrastructure.
- Very good performance in rural areas of GPS.
- E-OTD performance suffers in rural areas because of sparse infrastructure.

Global Positioning System (GPS)

The GPS satellite system consists of 24 satellite vehicles (SVs) broadcasting radio navigation signals. This is sufficient to provide a clear view of at least four satellites at all times (one satellite is required to acquire time, once position is establish and four satellites are required for a complete four dimensional solution (latitude, longitude, altitude, and time). There are two spread spectrum code Course Acquisition broadcast on the L1 carrier (1.575 GHz) and Precision, (P) broadcast on both L1 and L2 (1.227 GHz) carriers. P-code is encrypted and for military use only. Commercial GPS receivers discussed in this article utilize Course Acquisition codes. Refer [6] and [11] for more details on GPS.

The GPS receiver goes through the following steps during position determination.

- Acquisition - Acquire satellite signals
- Synchronization and demodulation - Capture NAV messages from satellite
- Pseudorange measurement - Measure pseudorange to all satellites.

Position computation - determine position and clock offset of receiver based on satellite position, satellite clock, pseudoranges, satellite clock corrections, ionospheric, tropospheric propagation delay corrections and Doppler shift of received signal.

The receiver produces the Course Acquisition code sequence for a specific SV with some form of a Course Acquisition code generator. The receiver slides a replica of the code in time until there is correlation with the SV code. As the SV and receiver codes line up completely, the spread-spectrum carrier signal is de-spread and full signal power is detected. A phase locked loop that can lock to either a positive or negative half-cycle (a bi-phase lock loop) is used to demodulate the 50 HZ navigation message from the GPS carrier signal. The same loop can be used to measure and track the carrier frequency (Doppler shift) and by keeping track of the changes to the numerically controlled oscillator; carrier frequency phase can be tracked and measured.

The receiver PRN code start position at the time of full correlation is the time of arrival of the SV PRN at receiver. The delay multiplied by the speed of light gives the pseudorange. This pseudorange is offset from the actual range by an amount determined by the clock bias at the receiver (offset of receiver clock from actual GPS time).

A GPS receiver must acquire GPS satellite signals first to perform pseudorange measurements. The following uncertainties affect the time to first fix of the receiver that has a significant impact on the latency in obtaining position information:

- Visible satellite uncertainty - If this is not available, the receiver is forced to scan for all satellites, thereby increasing the time to first fix considerably. The receiver requires the knowledge of approximate position of the receiver, approximate time and almanac (which is usually valid for a year) to determine the visible satellites. This is called warm start.
- Course Acquisition code phase uncertainty - 1023 chips or 1 ms. The receiver must search through all code phases (in sequence or in parallel) to determine the code phase of the SV signal.
- Frequency uncertainty - 5 kHz due to Doppler shift caused by relative motion of the satellite and the user.
- Frequency uncertainty - +/- 30 kHz due to 20-ppm oscillator drift in the receiver. This can be corrected by calibrating the frequency, using the signal locked to the base station

Additional information provided to a GPS receiver (in the form of Acquisition Assistance from the network) alleviates time to first fix performance of a GPS receiver.

The SV position estimates are computed by the receiver in XYZ, based on the ephemeris data sent by each SV. Receiver position is computed from the SV positions, the measured pseudo-ranges (corrected for SV clock offsets, ionospheric delays, and relativistic effects), and a receiver position estimate (usually the last computed receiver position). Position is determined from multiple pseudo-range measurements at a single measurement epoch. Four satellites (normal navigation) can be used to determine three position dimensions and time. The position of the receiver is where the pseudo-ranges from the set of SVs intersect. Position dimensions are computed by the receiver in Earth-Centered, Earth-Fixed X, Y, Z (ECEF XYZ) coordinates. Time is used to correct the offset in the receiver clock, allowing the use of an inexpensive receiver clock. Velocity is computed from change in position over time, the SV Doppler frequencies, or both.

Factors contributing to location error include:

1. Precision of pseudorange derived from code measurements has traditionally been about 1% of chip length - 3 m.
2. Radial velocity of satellite - ≈ 0.9 km/s, travel time of signal - ≈ 0.07s. Correction - ≈ 60m.
3. Geometric dilution of precision. Dilution of precision indicates when the satellite geometry can produce the most accurate results. The lower the number of dilution of precision the better the accuracy. They are multipliers on the standard deviation of pseudorange measurement errors. E.g.:- If Horizontal dilution of precision = 2.0 and horizontal accuracy is 25m (67%), the horizontal accuracy becomes 50m (67%)
4. The data from this table:

Table 1: Major factors affecting accuracy.

Error factor	*Typical error in meters*		*Corrected by*
	Standard GPS	*DGPS*	
Satellite Clocks	1.5 m	0 m	Clock correction parameter in NAV message
Orbit Errors	2.5 m	0 m	Ephemeris information
Ionosphere	5.0-7.0 m	0.4 m	Ephemeris information and DGPS
Troposphere	0.5-0.7 m	0.2 m	Ephemeris information and DGPS
Receiver Noise	0.3-1.5 m	0.3 m	No correction
Multipath	0.6-1.2 m	0.6 m	No correction
Selective Ability	24-30 m	0 m	No correction

The following table gives the resulting accuracy for standard GPS.

Table 2: Accuracy for standard and DGPS.

	Typical Position Accuracy	
	Standard GPS	*DGPS*
Horizontal	50 m	1.3 m
Vertical	78 m	2.0 m
3-D	93 m	2.8 m

Observed Time Difference (OTD)

The OTD solution [8] uses time difference between the control signals broadcast by the base stations and observed at the handset, to calculate its position. With OTD, the handset monitors the signal from at least three base stations, the serving base station and two adjacent base stations. The handset observes the TDOA of the three base stations, whose positions are known and fixed. These measurements are used to triangulate the position of the mobile. This requires handset modifications, but requires less positioning infrastructure support than time of arrival.

In certain systems, such as CDMA, the handset transmitter power is controlled by the base station. This makes time of arrival measurements difficult. Measurements can be easily made at the handsets because the signal from the base station is constant and is at higher power levels. In OTD, the position determinations can be performed even when the mobile is idle.

4 WIRELESS APPLICATION PROTOCOL

WAP is an industry standard established by the WAP Forum, a consortium of many wireless and computing companies. The WAP forum states:

> *WAP specifies an application framework and network protocols for wireless devices, such as mobile telephones, pagers, and personal digital assistants. The specifications extend and leverage mobile networking technologies (such as digital networking standards) and Internet Technologies (such as XML, URLs, scripting, and various content formats) [12].*

Ericsson, Nokia, Phone.com, and other companies established WAP to provide a common standard early in the development of wireless data, instead of their own competing implementations. Other companies were invited to join and participate.

The WAP programming/architecture model is based on the World-Wide Web (WWW) model. One difference is that WAP adds a gateway with encoders and decoders between the client and server (see Figure 1). The flow of requests and data follows this sequence:

1. The client (typically a micro-browser in the cell phone handset) requests information. This is typically via an encoded message, perhaps simply a numeral representing a selection from a menu. Complete URLs (like www.stiquito.com) could also be typed.
2. The encoded request is send via the air interface to a base station, and then to an Internet gateway. The gateway will decode the request into a common WWW request (i.e. HyperText Markup Language, JavaScript) and pass the request through the Internet to a content server.
3. The content server will take the WWW request and serve it, typically supplying content is a standard WWW format. The server may also supply content in a wireless format (i.e. using Wireless Markup Language or Wireless Markup Language Script).
4. The content is passed back to the gateway, where it is encoded for delivery to the handset. The data packet is sent from the gateway to the wireless base station and then over the air interface to the handset.
5. The handset will display the content on its display screen.

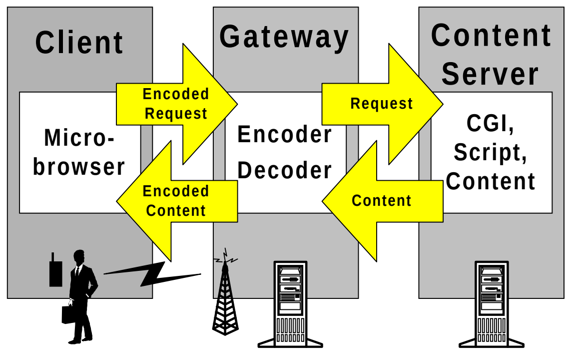

Figure 1: WAP Programming Model [12]

As you can imagine, the content must be concise yet valuable, since the memory capabilities of a handset are limited and the screen size is VERY small.

5 PROVIDING LOCATION TO WAP SERVICES

The FCC has mandated Automatic Location Identification, but they have allowed the handset manufacturers, infrastructure providers, and wireless service providers the flexibility to determine the best (and most cost effective) solution. Nonetheless, by October 1, 2001, a handset's position will be available. One can imagine the many services that could be available to a user if his position is conveyed to content providers:

- Weather forecasts can be immediately provided, without the user entering zip codes or city names.
- A user can request a list of specific types of restaurants within a certain radius of his current position.
- A detailed driving map can be provided based on current position and desired destination (which could have been previously stored as a "book marked" location).
- A "date-finder" application could try to match two people with similar personality profiles who are located in close proximity.

The disadvantages of location information can include:

- One's precise location can be used by companies or government agencies (or worse yet, spouses!), alerting them to possible inappropriate activities or insurance risks.
- Service providers could pass location information to advertisers, who could then barrage a user with advertisements from stores in close proximity.

The protocol for transmitting location information to PSAPs and content servers relies on the approach taken by the wireless industry for generation of the location. There are three options of location generation and storage:

1. Location is generated at the handset and the information retained in the handset only. This requires additional GPS hardware, computing resources, antennas, memory, and power than typical handsets (hence, a greater cost).
2. Location is generated and stored at the network side. This will require additional radio and computing resources of the wireless network, depending on the frequency of location computations.
3. Location is generated at the handset, and sent to the wireless network/gateway for temporary storage. This frees the wireless network of computing resources, but still keeps the disadvantages of the handset.

There are three approaches on the frequency of location generation:

1. Update continually. This method will either consume a vast amount of computing time (and power) in the handset, or a vast amount of computing resources in the wireless network infrastructure.
2. Update only on request of information. Although this saves power, if the location mechanism has a long time to first fix or the location has changed a great amount since the last location generation, then this may take too long for FCC mandates or the users patience.
3. Update at a frequency between 1 and 2 above.

There are four major uses/scenarios of location information:

1. During E911 calls, the location information should automatically be sent to the PSAP. The information would be continually updated through the call, if it changes (like during a call in a moving car).
2. During a WAP session with a trusted content server, location could be sent automatically to the server for each individual request.
3. During a WAP session with a non-trusted content server, location could be sent to the server only after the server requests it and the user approves the transfer.
4. A user should be able to display his location through the handset's user interface at any time. The location will have to be sent to the handset if it is not generated there.

There are currently confidential discussions among most parties in the wireless industry relating to the best and most cost effective method to implement the FCC mandates. Any solution should take into account the FCC mandates, handset cost, computing resources, security concerns, and business opportunities raised in this paper.

6 CONCLUSIONS

There are several methods to determine a cell phone's location, based on a GPS receiver, a network algorithm, or a hybrid of the two. Using WAP, location can be provided to content servers, and valuable information conveyed to the user.

A mechanism to determine a cell phone's location within 50-150 meters WILL be available no later than October 1, 2001. The FCC mandate for Automatic Location Identification can serve as a business opportunity for the wireless industry to provide accurate, valuable services to the user community. The industry must now determine the best (and likely the most cost effective) mechanism to provide this information to PSAPs and content servers. This information, however, can be misused, and the industry must set guidelines to ensure the security and integrity of a user's location.

7 REFERENCES

[1] www.wap.com/share/osas/cache/artid50005.html

[2] Enhanced 911 Emergency Calling Systems, FCC, Docket No. 94-102, Adopted May 13 1999, Released June 9 1999.

[3] Revision of Commissions Rules to Ensure Compatibility with RM-8143, Enhanced 911 Emergency Calling Systems, Report and Order AND Further Notice in Rulemaking, FCC, CC Docket No. 94-102, Adopted June 12, 1996, Released July 26 1996.

[4] Revision of Commissions Rules to Ensure Compatibility with RM-8143, Enhanced 911 Emergency Calling Systems, Third Report and Order, FCC, CC Docket No. 94-102, Adopted September 15 1999, Released October 6 1999.

[5] Revision of Commissions Rules to Ensure Compatibility with RM-8143, Enhanced 911 Emergency Calling Systems, Second Report and Order, FCC, CC Docket No. 94-102, Adopted May 13 1999, Released June 9 1999.

[6] www.trueposition.com/tdoa.htm

[7] www.trueposition.com/forum.htm

[8] www.ncs.gov/n6/content/technote/tnv5n2/tnv5n2.htm

[9] Mobile Station-Base Station Compatibility Standard for Dual-Mode Spread Spectrum Systems, TIA/EIA-95-B (IS-95B), TIA/EIA, SP-3693-1.

[10] *Understanding GPS: Principles and Applications*, Elliott D. Kaplan - Editor, Artech House Publishers, ISBN: 0-89006-793-7, 1996.

[11] *GPS: Theory and Practice*, B. Hofmann-Wellenhof, H. Lichtenegger, and J. Collins, Springer Wien NewYork, 4th Revised Edition, ISBN: 3-211-82839-7.

[12] Wireless Application Protocol Architecture Specification, WAP Forum, Ltd., Version 30-April-1998 (www.wapforum.org).

8 Other References

[13] PN4535, To be published as IS-801, TIA.

[14] www.glue.umd.edu/~skant/project621.html#_Toc469904820

[15] http://www.utexas.edu/depts/grg/gcraft/notes/gps/ephxyz.html.

[16] Enhanced Wireless 9-1-1 Phase II, TIA/EIA, PN-3890

[17] Beyond Enhanced Wireless 9-1-1 Phase II, TIA/EIA, PN-4288

[18] www.geometrix911.com/e911.html

9 Acronyms, Glossary

ALI	Automatic Location Identification
ANI	Automatic Number Identification
AOA	Angle of Arrival
CDMA	A cell phone transmission technology
DAMPS	A cell phone transmission technology
DGPS	Differential Global Positioning System
FCC	Federal Communications Commission
GPS	Global Positioning System
GSM	A cell phone transmission technology
HTML	HyperText Markup Language
NAV	Navigation messages
OTD	Observed Time Difference
PSAP	Public Safety Answering Point
SV	Satellite vehicle
TDOA	Time difference of arrival
URL	Uniform Resource Location
WAP	Wireless Application Protocol
WWW	World-Wide Web
XML	Extensible Markup Language