Carrier Choices in Location
The System Integrator's View

by Mario Proietti

Wireless carriers face a variety of challenges in implementing Phase II E911 and location-based services. In many cases, innovations chosen years earlier to provide increased capacity, call security, or improved voice quality now work in opposition to the goals of the location system designer. For example, frequency reuse in cellular and personal communications systems (PCS) networks generates propagation effects and interference, causing signal attenuation and multipath that the location system designer must now overcome or at least mitigate. Similarly, other features and implementation of the wireless network and its air interface will also influence location system design.

GPS on the other hand was designed, built, and tested from the beginning as a location system. It presents few of the network-based system challenges, although it does have shortcomings of its own that have influenced vendors and carriers in proceeding with its implementation.

Further complicating the picture, many carriers have more than one air interface. Some interfaces may soon be obsolete (AMPS and TDMA in particular), and carriers have partially migrated to different interfaces. However, as Federal Communications Commission (FCC) E911 requirements will take effect before they can complete these migrations, they must find compliant solutions for all their operative interfaces.

The cost of implementing E911 location systems is substantial, and each technology choice presents its own cost structure. While both network-based and assisted GPS (AGPS) technology entail expensive purchases and upgrades of hardware and software, network-based solutions require installation of location determination equipment in the infrastructure, typically at every cell site. Although AGPS infrastructure additions are relatively modest, subscribers must acquire new specially-equipped handsets. In either case, carriers are now fully realizing the large burden they face to manage and operate the location systems at necessary performance levels.

TechnoCom works with carriers operating AMPS, GSM, CDMA, TDMA, and iDEN air interfaces who are using, or at least have explored, all the available location technologies. In this necessarily brief overview, I will first outline environmental and network impacts on location system design, then review the implications of each air interface for network-based and handset-based solutions.

Environmental and Network Effects

A variety of factors can influence network performance. This section discusses the most important of these.

Multipath & Propagation. Multipath reflections can result from fixed objects (buildings, hills, mountains) or from moving objects in the vicinity of either the mobile set or the base station. These reflections distort the raw measurement and, if excessive, lead to unusable angular measurement distortions in angle of arrival (AOA) systems and time measurement distortions in time difference of arrival (TDOA) systems. In general, no satisfactory method exists for making use of severely distorted measurements. The location algorithm must identify and eliminate them. Signals with minor distortions are usable if the distortions are somewhat random in nature. The "noise" in these measurements can be filtered during the course of the tracking process to yield more accurate position results.

The effects of multipath resulting from objects moving in the propagation path (perhaps other vehicles moving in the vicinity of the mobile set) are random in nature and can often be reduced by filtering. Fixed objects in the vicinity of a stationary mobile set produce multipath distortions that are not noisy and therefore not easily filtered. If the mobile set is moving, however, then these reflections take on a "random nature" and the signal may be filtered and used for greater accuracy. For this reason, moving mobile set tracks will tend to be more accurate overall than location fixes of stationary sets.

Site Density and Geometry. Location sensor density and geometry are extremely important for obtaining acceptable location fixes. In general, AOA techniques require sensor information from at least two sites to obtain a location, three to estimate the quality of a location, and four to identify and reject severely corrupted data from one site. TDOA, at the sites or in the handsets, requires sensor information from a minimum of three, four, and five sites for the same capabilities.

The geometry of the site infrastructure also affects the quality of the fixes, and geometric dilution of precision (GDOP) plays an important role. An extreme example of poor geometry is found along (relatively) straight highways between major cities. In these cases, cell sites are often located in a string near the highways, providing cellular/PCS coverage only to the highway (see Figure 1). An AOA location system with sensors located only at the sites will only locate a mobile set as being between two highway sites — perhaps less information than simply knowing the serving sector! TDOA systems will only locate the mobile set as being along a hyperbola intersecting the highway — better information if one can assume the mobile set is on the

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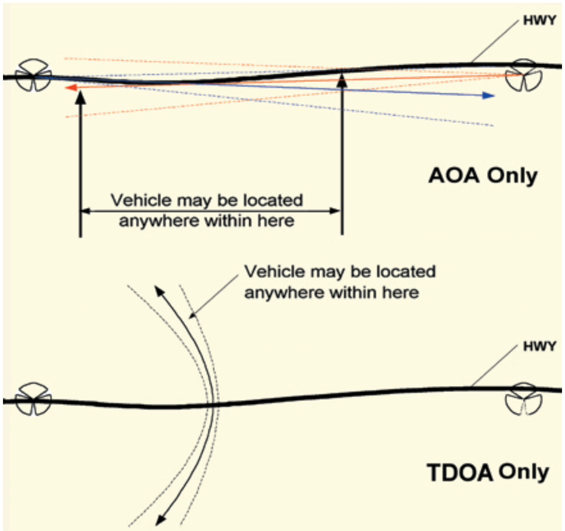
TechnoCom Corporation integrates location technologies into wireless networks, products, and software, and works with wireless carriers to enable E911 and location-based services. <www.technocom-wireless.com>



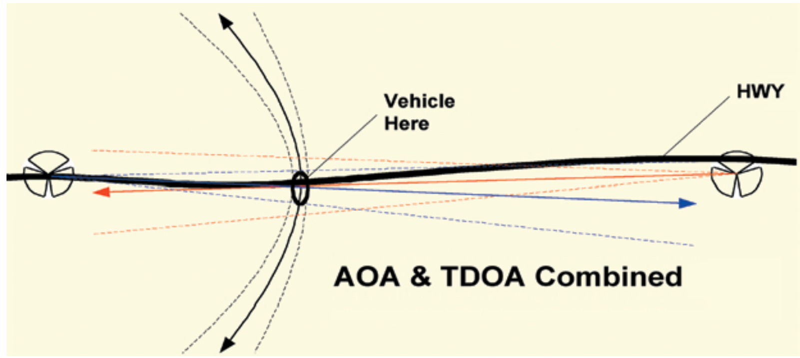


FIGURE 1 Geometrical dilution of precision by typical cell site placement along highways

highway and not on a nearby farm-to-market road. Even this would require a unique algorithm for use only in these areas. A combined AOA/TDOA system could provide location services under these circumstances.

Antenna Sectorization. In most urban and suburban areas, cellular/PCS systems divide sites into sectors to increase capacity. At some of these sites, especially in urban areas, the antennas are placed down the sides of buildings since high placement of the antennas would create an interference problem. Location systems may also require sectorizing to mitigate interference resulting from dense cell site placement and accompanying close frequency reuse. This need not be a major issue for TDOA systems, as they can use the same sectored antennas as the cellular/PCS systems.

Sectored antennas for AOA measurement (if required) may be difficult to add to some existing cell sites, due to space or other physical limitations, or zoning restriction on adding antennas in some localities. Careful antenna placement is required to insure that reflections from the buildings on which they are mounted are kept to a minimum.

Topography & Morphology. The performance of sensor systems for location is more sensitive to the topography and morphology of the covered area than cellular/PCS systems. Reflections from hills and buildings are not nearly as detrimental to cellular/PCS conversation as they are to location systems. Indeed, the cellular system in urban canyons relies on these reflections to extend coverage down streets where a direct path from the mobile set to the cellular antennas is not possible. This problem can be mitigated somewhat by an adequate density of sites and careful algorithm design.

RF Interference. RF interference can cause severe errors in AOA systems and can erode the measurement accuracy of TDOA systems. The same precautions taken to mitigate the effects of interference in cellular/PCS systems are necessary for location systems. Location systems may have to detect and identify color codes or other channel indicators to be able to separate the desired signals from interference. The inability to successfully detect known/expected parameters could be used as an indicator of the presence of significant interference, and in turn used to filter out the resulting measurements.

Indoor Operations. Aside from the obvious problems of higher path loss, the signal emanating from (or propagating into) a building may present a more diffuse nature due to multiple reflections within the building. The quality of fixes obtained from mobile sets located within buildings is likely to be less accurate than for outdoor locations.

Vertical positioning is almost without exception very difficult to perform accurately since all the sensors are more or less located in one plane (that of the Earth's surface). It is unlikely that present technologies will be able to differentiate between the floors of a building. Even with GPS-based solutions, vertical position determination is not adequate for this purpose.

Air Interface Effects on Network Solutions

Each air interface poses different challenges for location system design.

AMPS. In Advanced Mobile Phone System (AMPS) networks, it is relatively easy to determine the mobile identity of a caller and the number being called, since both pieces of information are transmitted on the air without encryption. The availability of all call parameters over the air makes it possible to implement stand-alone network-based location systems (AOA or TDOA) without any coordination with either the carrier or the wireless infrastructure manufacturer. Hence, the wide availability and demonstration of AMPS-based location system solutions.

TDMA. In contrast to the analog AMPS networks, American National Standards Institute Standard 136 (ANSI-136) Time Division Multiple Access (TDMA) and the other digital air interface standards at least include provisions for hiding this information from the casual observer of control channel transmissions. The privacy and other network control complexities inherent in digital networks present additional challenges to the location system designer.

In TDMA's case, these include: no network synchronization among base stations, and time measurement and alignment too coarse for location purposes. Thus, the location system must process and interpret specific random access and voice channel bursts, have proper synchronization, and implement a subset of TDMA message processing.

GSM. AOA, TDOA, and their hybrids can be applied to Global System for Mobile communications (GSM) networks. Specific performance depends on ability to cope with and process the waveforms specific to GSM.

To avoid the abundance of design and development issues for a GSM network-based location system, and to

Carrier Choices by Air Interface

	AMPS	TDMA	GSM/iDEN	CDMA
Network-based	TDOA/AOA AT&T, Cingular Verizon	TDOA/AOA AT&T, Cingular	TDOA/AOA	TDOA/AOA
Handset-based			AGPS Nextel	AGPS Sprint, Verizon
Hybrid		MNLS	E-OTD AT&T, Cingular	AFLT Sprint, Verizon

Some carriers have multiple interfaces across their network.
Carrier-filed announcement with FCC   Other/pending choices under exploration by carriers

take advantage of handset capabilities supporting timing/handoff (GSM's time advance feature offers an inherent time-measuring mechanism that could be exploited for location purposes), attention in the GSM community has centered around "handset-assisted" location schemes, particularly Enhanced Observed Time Difference (E-OTD).

GSM characteristics affecting network-based solutions include: potentially more accurate location but a more complex radio design to process across multiple bursts; inherent time measurement still too coarse for location; extremely flexible network configurations add complexity to location system design.

CDMA. By its nature, Code Division Multiple Access (CDMA) lends itself to TDOA applications. The success of TDOA depends on how accurately the base stations are synchronized, or how accurately timing offsets may be quantified by the location system.

Even more so than with GSM, network-based location systems must contend with CDMA reverse-link power control. For the reverse link, access channel power and initial power on the reverse traffic channel depend on received power measurements made by the mobile station (MS). With CDMA's tight power control, it is unlikely that multiple base stations (three or more are desirable) will be able to consistently detect a signal from the MS.

Due to these limitations, pilot TOA measurement at the handset for a methodology called forward link triangulation (FLT) shows better promise. A significant benefit of this approach is that pilot channels are transmitted at a constant power typically much higher than that of the paging and traffic channels. This method's success also depends on precise synchronization of the base stations or the ability for the location system to carefully monitor and compensate for their relative timing offsets and drift.

One concern with FLT is that current handsets do not offer adequate phase measurement resolution required to achieve reasonable accuracies. Upgrades to the handset are needed to achieve the location accuracy specified by E911 requirements.

E911, in Short

AFLT	Advanced Forward Link Trilateration
AGPS	Assisted Global Positioning System
AMPS	Advanced Mobile Phone System
AOA	Angle Of Arrival
BSS	Base Station System
CDMA	Code Division Multiple Access
CRDB	Coordinate Routing Database
DGPS	Differential Global Positioning System
EOTD	Enhanced Observed Time Difference
FLT	Forward Link Trilateration
GMLC	Gateway Mobile Location Center
GSM	Global System for Mobile communication
iDEN	Integrated Dispatch Enhanced Network
LMU	Location Measurement Unit
MNLS	Mobile-Assisted Network Location System
MPC	Mobile Position Center
MS	Mobile Station
MSC	Mobile Switching Center
PDE	Position Determining Entity
PSAP	Public Safety Answering Point
SMLC	Serving Mobile Location Center
TDMA	Time Division Multiple Access
TDOA	Time Difference of Arrival

Air Interface Effects on AGPS Solutions

The design of an AGPS solution requires

- a methodology to transfer the assistance and measured information between an AGPS-equipped handset and a location processor within the network
- handset designs incorporating AGPS capability
- integration of message transfer protocols into a carrier's network.

Theoretically, such implementation is feasible for any air interface, but practically the process may not be cost-effective for systems that lack an inherent data communications capability between the handset and the network. Implementation for any of the three digital networks is much easier than for AMPS.

AMPS. Due to AMPS' analog nature, inserting data into the voice channels is problematic without additional equipment at either end of the call path. Given the implementation difficulties and the transition plans to digital networks, few if any vendors or carriers will invest in design and development of handsets and network components that may be soon obsolete.

TDMA. The AGPS technology is applicable to TDMA networks, but major carriers plan to phase out TDMA and convert their networks to GSM or CDMA. Meanwhile, the industry proposes to use network-based solutions or hybrid solutions such as the mobile-assisted network location system (MNLS) that utilizes signal strength measurements performed at the handset that are normally reported to the network for handoff processing. Investment in AGPS incorporation at the handset is unlikely given the planned migration.

GSM. Several vendors have proposed AGPS for GSM, and some handset manufacturers have announced efforts in this direction. No technical issue prohibits such integration at this point. Carriers may shortly have the option of using AGPS in place of or in conjunction with E-OTD in much the same way that AGPS and FLT are already being used in CDMA networks.

CDMA. AGPS for CDMA is currently operational in some markets, with full scale deployment planned. CDMA solutions also include AGPS combined with an FLT variant called Advanced FLT (AFLT). AFLT requires handsets to have upgraded pilot channel phase measurement capabilities and messaging functionality for reporting the measurements to a location processor (PDE) in the network. In the combined solution, AFLT augments AGPS where an insufficient number of satellites are visible by the handset for an AGPS-only fix.

For sample performance data of AGPS for CDMA, see the accompanying Qualcomm-authored article.

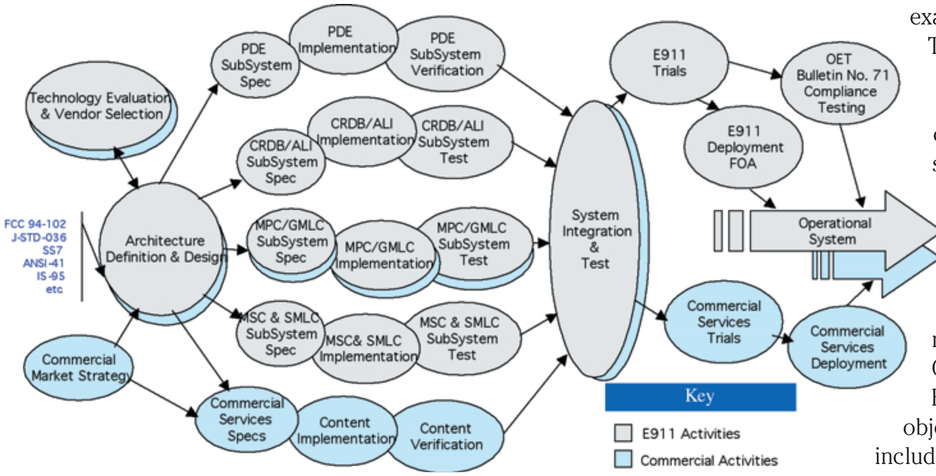


FIGURE 3 E911 implementation roadmap

Implementation Roadmap

Figure 3 depicts the TechnoCom process to implement wireless E911 in carrier networks, used with four of the top five carriers.

We begin with technology trials and vendor evaluations: definition and design of E911 and commercial services in which a carrier may be interested, predictive coverage and accuracy analysis, and in-field trials using TechnoCom's LocationSafe suite of tools. Trials normally do not include all subsystems present in an operational location network; therefore upon selection of a technology, the carrier initiates an intensive design effort starting with the architecture and subsystem specification development.

After technology and vendors are selected, the architecture and system is defined to fit the carrier's unique environment and ensure compliance with FCC and other standards, including the Telecommunications Industry Association/Electronics Industry Association Joint Standard 36 (J-STD-036) and ANSI standard 41. Subsystem specs are critical to the successful interoperability of E911, as the network contains many new elements or nodes with new software and technology: mobile switching center (MSC) upgrades or serving mobile location center (SMLC), automatic location identification/coordinate routing database (ALI/CRDB), mobile position center (MPC) or gateway mobile location center (GMLC), and position determining entity (PDE — location technology).

These nodes may represent six or more vendors. Many carriers have multiple air interfaces and may also be on a partially completed migration path to different interfaces. So the complexity of the undertaking grows.

We support the carriers in design, development, test, integration and application of J-STD-036, which defines the messaging protocol required to support emergency call transfer to public safety answering points (PSAPs) for Phase II E911 location systems. Our InterOps Safeguard software isolates network problems and emulates network components that may not be ready. We implement and verify MPC, MSC, and PDE subsystem(s)' functional, interface, and performance capabilities.

Testing. After interoperability system testing is completed in the carrier's lab, the in-market trial begins and tests the full handset-to-PSAP (dispatcher) solution, examining accuracy, timing, and yields.

TechnoCom software may emulate the PSAP (or dispatcher) function so as not to interrupt the live 911 system. We work with the carrier to implement a comprehensive cell site calibration process to optimize system performance.

As part of first market implementations, we develop a test plan for evaluation of the deployed system. The test plan is based on detailed carrier requirement, standards-based test plans, and FCC's Office of Engineering and Technology (OET) Bulletin No. 71 guidelines. It covers specific objectives pertaining to the location technology, including:

- Accuracy of the location fixes as a function of propagation environment
- Reliability and repeatability of the location fixes as a function of propagation environment and system loading
- Interoperability of deployed technologies, if any.

Deployment. The complexity of broad market-by-market deployment differs by location technology. Each solution (including AGPS) requires accurate cell site surveying and development of a base station database (or almanac) containing key parameters. Maintenance, calibration, and testing are required to maintain the system, and ongoing testing must ensure continued OET Bulletin 71 (FCC requirements) compliance. TechnoCom supports the carrier in planning related to the initial trials with PSAPs, reviews the requirements set forth by the carrier and PSAPs, and formulates a project plan to meet the carrier's desired timeline.

Location-based services. Some bubbles in the roadmap contain blue shading, indicating activities required for commercial location-based services (LBS). Carriers plan to offer these services following E911 implementation and are simultaneously laying the groundwork for LBS — or at least thinking of the implications. For international carriers who have no requirements for E911, but who are deploying commercial LBS, this becomes the primary focus.

Conclusion

In summary, no single location technology is right for all carriers. Technical factors, such as the air interface, cell site configurations, and propagation environments, all affect the choice of location technology and its resulting performance.

Business considerations also weigh heavily. Carriers are considering wireless migration strategies as they plan for 3G and other service enhancements. They are also looking ahead to determine which location technology will suit their move into commercial location-based services. They are resolving these issues as they address the immediate goal of meeting FCC mandates.

In light of the realities, most carriers are doing their due diligence and moving forward carefully. And rightfully so. Given the importance of E911, we cannot expect anything less. ⊕