

how it works

THE FCC'S WILLINGNESS TO LET MARKET FORCES DETERMINE WHICH E911 TECHNOLOGIES WILL SUCCEED IS A DOUBLE-EDGED SWORD. HOW SHARP IT IS REMAINS TO BE SEEN.

On the edge of geolocation

By Joshua Israelsohn, Technical Editor

WHEN FACED with an emergency, the first act of many people is to reach for the telephone, and for good reason. Three key presses away, trained PSAP (public-service answering-point) personnel quickly evaluate each situation and dispatch the appropriate emergency

services to the correct location. Complicating this task is the fact that callers often cannot supply complete and accurate location information (**Reference 1**).

Telephone systems that comply with E911 (enhanced-911) standards transmit ANI (automatic-number-identification) and ALI (automatic-location-identification) data to the PSAP as well as the voice signal. When a 911 emergency call originates from a residential wire-line telephone, the PSAP display indicates the caller's telephone number and address. But telephone-company equipment alone cannot provide the ALI data in two common cases.

The access interface to a PBX (private-branch-exchange) business-telephone system marks the boundary of the public-telephone network and, thus, the limit of telephone-company-provided location information. Blind to the PBX's internal geography, emergency-response personnel depend on the PBX-system-management software to provide up-to-date on-site location information for each PBX extension. With telephone extensions more closely associated with people than with fixed

positions, the location database requires an update each time the company reshuffles employee office assignments. As important as the location database is during, say, a medical emergency, keeping it properly updated and allowing appropriate access reduces to relatively straightforward database- and software-maintenance tasks.

YOU ARE (W)HERE

The more difficult case arises when an emergency call originates from a mobile phone. Of the roughly 190 million 911 calls made last year, some 50 mil-

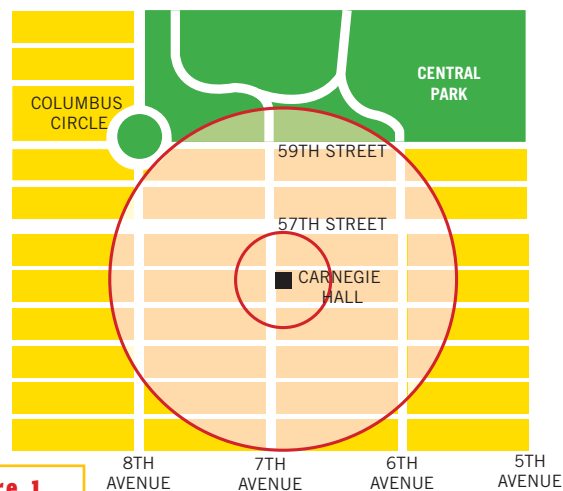


Figure 1

No time to play *Where's Waldo?* Network-based systems operating to FCC accuracy specifications may be unable to distinguish your location to better than a 16-block area in midtown Manhattan for 30% of all wireless enhanced-911 calls.

lion originated from mobile phones, and without ALI data from these calls, public-safety officials are concerned about the significant fraction of wireless callers unable to specify their location (references 1 and 2).

In response to those concerns, expressed in an environment of rapid growth in the wireless-telecommunications market, the FCC mandated wireless E911 in two phases. Starting in April 1998, the FCC's Phase I requirements direct wireless-service providers to supply PSAPs that request Phase I service with ANI data—the calling handset's telephone number—and the location of the base station servicing the call. As with the PBX, the access interface for a mobile call—in this case, the cell base station—marks the boundary of the public-telephone network. Generating this level of location information is not technically challenging, but the resultant location granularity is too coarse for a long-term emergency-service deployment strategy.

Phase II requirements, originally slated to begin a multiyear rollout on Oct 1, 2001, order mobile-telephone-service providers to supply ALI data to PSAPs requesting the service (Reference 3). The FCC mandate did not stipulate the "fixing" method to locate a mobile phone, and many technologies have developed in the competitive environment that the FCC's rulings allow. However, development and commissioning delays led to the current situation wherein all national wireless-service providers have petitioned the FCC for implementation deferments.

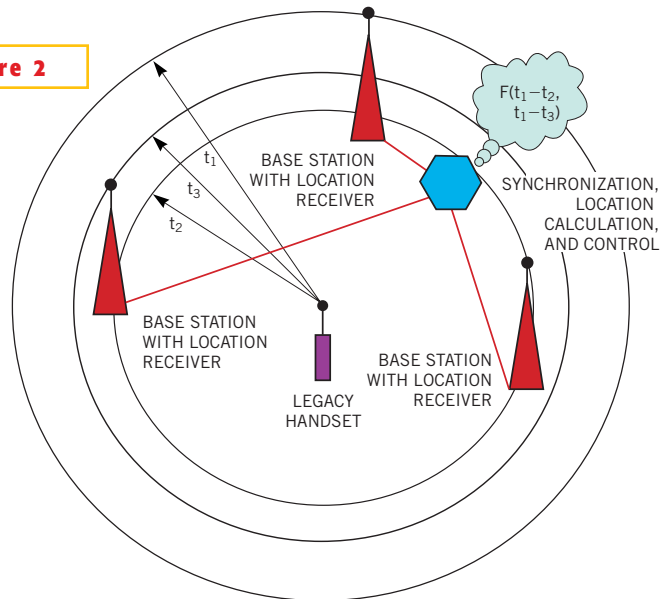
Fixing methods fall into three categories: Network-based systems use base-station equipment to calculate location data from measurements of the mobile phone's signal. Handset-based systems determine their location from signals they receive from fixed-position transmitters. Hybrid systems combine handset- and network-based methods and try to mitigate some of the disadvantages of both.

It is commonly held that network-based methods work best in urban settings, where cell densities and overlaps are high, and handheld methods shine in rural settings, particularly where cells are arranged in linear arrays with little overlapping. This view reflects a reasonable assessment of some but not all technologies in both categories.

FINDING A MOBILE NEEDLE IN A WIRELESS HAYSTACK

The FCC requires network-based-location systems to deliver ALI within a tolerance of 100m for 67% of calls and 300m for 95%. At first glance, this level of performance may seem fairly accurate. But, in terms of a potential search area, network-based systems leave a location uncertainty larger than many users would want to stake their lives on. Were you standing, say, in front of Carnegie Hall (Seventh

Figure 2



TDOA (time-difference-of-arrival) systems use the difference in signal-arrival times between pairs of base stations to determine a unique location.

Avenue just south of 56th Street) in Manhattan, a network-based E911 location system operating within FCC specifications would be unable to determine your location to much better than 16 large city blocks 30% of the time (Figure 1).

Several network-based methods can determine the location of a mobile phone to within the established tolerances. TDOA (time difference of arrival) measures the difference between signal-arrival times between pairs of base stations (Figure 2). The calculation-and-control hardware converts a time difference into a constant distance from the corresponding pair of base stations, which describes a unique hyperbolic curve. With data from three base stations taken as the difference of two pairs, two intersecting hyperbolas determine a unique location in two-space (Reference 4). TDOA base stations require synchronization on the order of 100 nsec, generally implemented with GPS (global-positioning-system)-disciplined clocks (references 5 and 6).

TOA (time-of-arrival) systems use absolute arrival times instead of time differences. With a constant propagation velocity, signal-transit times correspond directly to distance (Figure 3). TOA data from one base station gives a circular locus. Data from two base stations narrow the solution to two points. The third base station's data removes the ambiguity and fixes the mobile phone to a specific location. As with TDOA, TOA systems require well-synchronized base stations. An arrival-time measurement error results in a proportional rang-

ing error of about 300m/ μ sec.

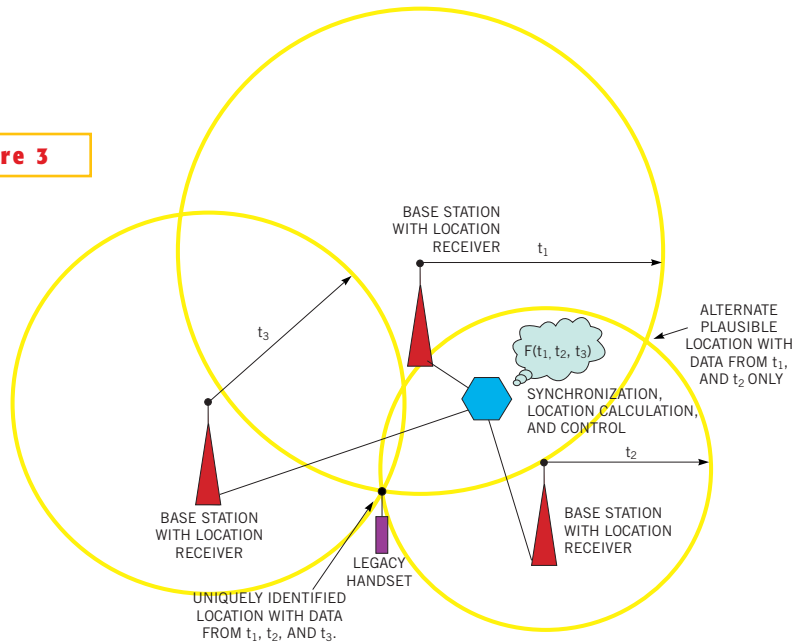
AOA (angle of arrival) is an alternative location method that eliminates the need to tightly synchronize geographically remote base stations. AOA systems use antenna arrays to determine a signal's incident angle (Figure 4). The system requires a minimum of two base stations to fix a mobile phone's location. But adding and aiming arrayed antennas brings additional base-station cost beyond that of the location receivers and calculation-and-control hardware. Like TDOA and TOA systems, AOA systems require a line of sight between the mobile phone and the base-station antennas to operate at their full accuracy and must distinguish between the direct signal and multipath interference in less than optimum environs.

A fourth network-based system uses multipath interference to take advantage of the fact that the world rarely changes shape, even on a local level. The multipath-fingerprint method compares an incoming signal with a database of locations and their multipath "fingerprints" (Figure 5). When installing a multipath-fingerprint system in a region, a test vehicle must visit each catalogued site to "ping" the system. The system records and characterizes the multipath signal deriving from the test ping for later comparison. Construction or other events that alter the multipath landscape force the location service provider to resurvey the region. Location accuracy depends on the number of distinct sites in the database for an area and the extent to which the local topography results in uniquely identifiable multipath images.

Multipath-fingerprint technology—the only single-site geolocation method—has successfully passed field trials. Ironically however, in rural areas where single sites are most prevalent and where this method might be most attractive, distinctive multipath signatures are least likely to occur.

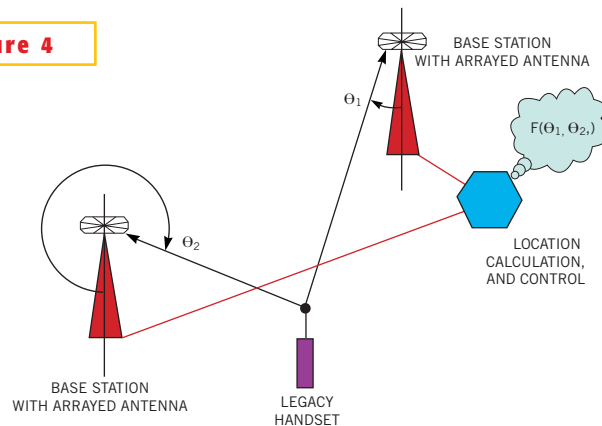
None of the network-based methods offer optimum location accuracy for all types of terrain. They are, however, collectively attractive for several reasons: They work with current handset models, which can dramatically speed the introduction rate of geolocation-related services, including so-called value-added services that many service providers look toward to pay for the required base-station upgrades. Network-based methods also allow location services to operate seamlessly as mobile phones roam out of their home region. With base-station equipment providing the required processing capability, pure network methods do not affect the mo-

Figure 3



A radio signal's fixed propagation rate provides a ranging method for TOA systems. The intersection of three ranging circles gives the unique location of the wireless handset.

Figure 4



AOA (angle-of-arrival) systems require only two base stations. An ambiguous case arises, however, when the two base stations and the mobile phone form a straight line. Relative signal-strength measurements can aid the ranging calculation.

bile phone's size, cost, design complexity, or power usage.

BUILDING A SMARTER NEEDLE

FCC Phase II requirements allot handset methods half the error tolerance of network methods—50m for 65% of 911 calls, and 150m for 95% of calls. Handset-based systems add cost and take up board space—neither of which is freely available in the highly competitive handset market. And unaided, handset-based geolocation methods can take longer

to lock and fix a mobile phone's position than do network-based methods. But they allow service providers to share some of the cost burden with handset owners and, in the case of GPS-based systems, take advantage of the sophisticated navigational infrastructure already in place and maintained by the US government. Perhaps most important to the dialing public, the tighter FCC accuracy requirements for handset methods result in a fourfold reduction in the emergency-response search area. In rural locales, where good visual landmarks may be few and far between and where terrain can make finding someone difficult, particularly at night, this improvement can make a critical difference in emergency-response times. In this same environment, poor cell geometries and overlaps challenge most network-based methods.

In addition to GPS, the handset-based methods garnering the most support are two variations on TDOA. Using the E-OTD (enhanced-observed-time-difference) method, handset circuits measure the relative TOA of signals from multiple mutually asynchronous base stations. As with network-based TDOA, the handset location is fixed by trilateration—a technique that computes coordinates based on distances from known points, as is done in surveying.

E-OTD systems use both the OTD (observed time difference)—the interval between signals from two base stations—and the RTD (real time difference), which is a measure of the base station's synchronization error provided by a ground-based LMU (location-measurement unit). The GTD (geometric time difference) that the trilateration computation uses is the difference between the OTD and the RTD.

As with the network-based TDOA method, a constant GTD between a pair of base stations describes a hyperbola. Two intersecting hyperbolas generated from three base stations taken as two pairs describe a unique position.

Another way of computing location by E-OTD is similar to the TOA network-method. Here, the handset tracks the arrival times of signals from three base stations and reports them to the LMU. The LMU calculates the handset location from the handset data, LMU-based arrival-time measurements, the clock-synchronization errors, and the known distance between the LMU and the base stations.

CDMA (code-division multiple-access) mobile-phone networks use the A-FLT (advanced-forward-link-trilateration) method. A-FLT takes advantage of the fact that, unlike GSM, CDMA is a synchronous system. A-FLT uses the phase delay between pairs of pilot signals for ranging. As with the other

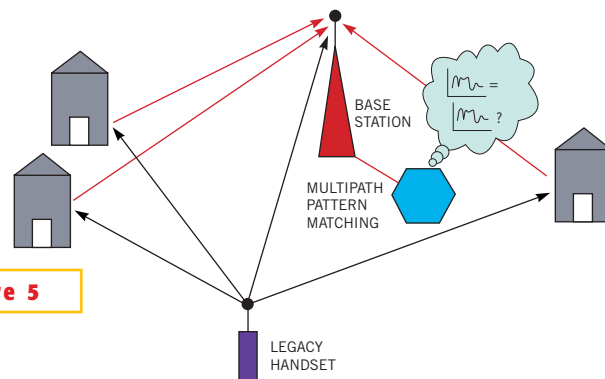


Figure 5

The multipath-fingerprint method turns the tables on interference and uses a traditional nuisance noise source as a location identifier.

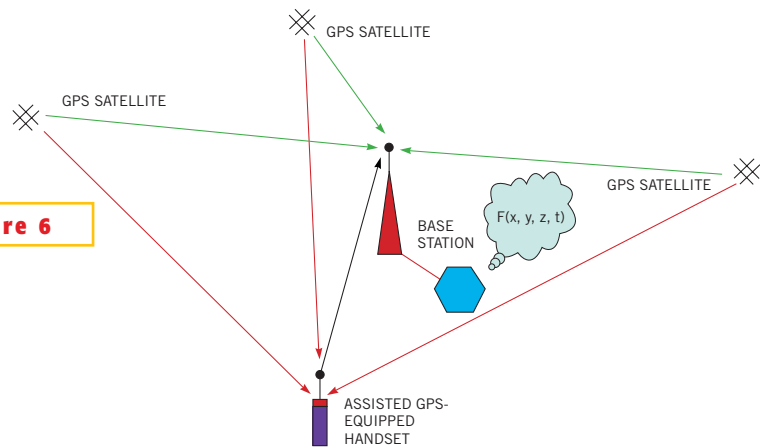


Figure 6

The base-station processor in an A-GPS system can reduce the time to lock and fix a handset's location from about a minute to just a few seconds.

TDOA methods, A-FLT phase-delay measurements from two pairs of base stations describe a unique location by means of intersecting hyperbolas.

Perhaps the most common geolocation technology is the GPS. The large, established run rate for GPS receivers has motivated significant reductions in the size, cost, and power budget for these radios. However, the time-to-first-fix for an uninitialized autonomous GPS receiver is about a minute—far too long for E911 service. A-GPS (assisted GPS) uses base-station equipment to transmit data across the wireless network that allows the handset to fix its location within a few seconds (Figure 6). The base stations provide time, satellite Doppler data, and the GPS code-phase search window. The handset uses this information to significantly reduce the GPS acquisition time. Once the handset captures the GPS data from the satellite constellation, it can

further speed its location calculation and reduce its own computational load and battery drain by transmitting the data to a network-based location processor.

Shadowing is a known problem with GPS-navigation systems. Though GPS can offer good location accuracy, it is likely that E911 location systems will use the method in conjunction with others to ensure at least 150m accuracy in urban canyons. This strategy is similar to the one that navigation systems use with inertial sensors to track positions through areas in which the vehicle is shadowed from the one or more satellites of the requisite GPS complement.

WHERE DOES THAT LEAVE US?

Despite delays implementing E911 Phase II geolocation services, the FCC still anticipates full compliance by the current deployment deadline of the end of 2005 (**Reference 2**). Standards committees for 2G wireless systems are lining up behind specific location technologies. For example, CDMA will use A-GPS and A-FLT. GSM systems, on the other hand, will use A-GPS and A-FLT, possibly in conjunction with network-based TOA.

A number of questions remain unanswered.

Among them are technical issues, such as how disparate E911 geolocation systems will contend with roaming handsets without a network-based fallback method, which the FCC has not mandated. Wireless-location technologies also raise operational issues for PSAPs accustomed to ALI data appearing in street-address format. Wireless E911 systems report handset locations in terms of geographic coordinates, which allow the system to describe arbitrary locations. More sophisticated display technologies may be required at PSAPs before emergency-service dispatchers can work seamlessly with mixed wire-line and wireless ALI data. The FCC can direct wireless service providers to add Phase II capability; PSAPs, free from the FCC's scheduling mandates, must be able to make use of the data to complete the information path. It appears that the PSAPs and their suppliers are lagging behind—an issue not lost on the Cellular Telephone and Internet Association, a trade group that represents service providers (**Reference 7**). Lastly, location privacy and the commercial use of a caller's location information outside of emergency situations raise public-policy questions directly tied to wireless-geolocation technologies. □



REFERENCES

1. *Report Card to the Nation: The Effectiveness, Accessibility and Future of America's 911 service*, National Emergency Number Association, 2001.
2. Sugrue, Thomas J, "Testimony before the Subcommittee on Communications, Committee on Commerce, Science, and Transportation, US Senate," Wireless Telecommunications Bureau, FCC, Oct 16, 2001.
3. "FCC Wireless 911 Requirements," Fact sheet, FCC, www.fcc.gov/e911/factsheet_requirements_012001.txt, 2001.
4. "Overview of 2G LCS Technologies and Standards," Motorola, 3GPP TSG SA2 LCS Workshop, LCS-010019, London, January 2001.
5. "Meeting E911 Requirements With Network-Based Solutions," Trimble Navigation Limited, 2001.
6. Israelsohn, Joshua, "How it works: time," *EDN*, March 15, 2001, pg 46.
7. Allen, Gary, "Wireless E911 forum as presented at NENA 2001 Conference," reporting remarks by Kathryn Condello of the CTIA. www.dispatch-monthly.com/nena2001/wireless_forum.html.