# E911 Location Accuracy

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911 is a North American system that links emergency callers with public safety call centers. 911 was originally designed to support wired landline calls originating from a known location of record. As the use of mobile cellular phones has grown, the Federal Communications Commission has mandated that Enhanced 911 (E911) be implemented to provide location information of non-landline callers. Many of the techniques used to locate wireless 911 callers require that accurate locations of cellular antenna towers be recorded, and that the azimuthal alignment of sectored antennas be done precisely. In practice, the recorded locations of cellular antenna towers are often inaccurate and the azimuthal alignment of sectored antennas is often wrong. These errors if left uncorrected will lead to increased response times, increased loss of life, and negative economic impacts.

In February 2014 the Federal Communications Commission issued a Third Further Notice of Proposed Rulemaking (FCC 14-13) for "Wireless E911 Location Accuracy Requirements" as part of PS Docket No. 07-114. The Third FNPRM is based on recognition that the majority of 911 calls from wireless phones, and that Public Safety Answering Points (PSAPs) must have the ability to accurately identify location of the caller. The press release associated with the NPRM notes that in California, 73% of 911 calls are made from wireless phones. [1] With wireline phones, the service address is recorded by the provider and made known to the PSAPs – but this is not possible with wireless phones that are by definition not used in fixed locations.

The Third FNPRM is part of an ongoing effort by the FCC to impose requirements that wireless carriers, who operate as Commercial Mobile Radio Service (CMRS) providers, must adapt to shifting public safety needs in the face of wireless technology evolution. The FCC's E911 rules (47 C.F.R.§20.18 [2, 3]) require CMRS providers to make location information available to PSAPs based on the following standards:

- For network-based technologies: 100 meters for 67% of calls, 300 meters for 90% of calls
- For handset-based technologies: 50 meters for 67% of calls, 150 meters for 90% of calls

Requirements which would enhance existing standards to require greater accuracy (using any technique or combination of techniques) are being considered in the Third FNPRM. [3]

The dynamic nature of wireless phone usage means that the FCC's E911 rules have been designed to allow CMRS providers to select from a wide variety of location techniques, e.g. the best location technique for a dense urban core is different than one which works best in suburban or semi-rural locales. Handset-based location techniques in dense urban cores are adversely impacted by GPS signal blockage inside buildings, and GPS signal mirroring at street-level caused by shallow angle of incidence on tall building faces – a problem that is compounded by increasingly common use of low-E glass in "green building" construction. Network-based location techniques in dense urban cores are primarily affected by multipath – signals from the handset which reflect off surfaces and cause the location-sensing equipment to see multiple copies of the same uplink signal. [4] In rural areas network-based location techniques will fail if there are insufficient tower sites to obtain a location fix, and often a rural cell may be served by only one or two tower – not the three towers which are required to determine an accurate location.

FCC rules for E911 require that confidence and uncertainty data be provided to the PSAPS. CMRS providers must file their conformance verification procedures with the FCC, and the FCC recommends periodic conformance testing. Because wireless location accuracy can be greatly affected by multipath [4] the need for periodic conformance testing is critical in areas where construction and growth are actively occurring. However, costs for testing can be significant; ranging from $250 – $1,000 per base station (costs are 2012 US dollars). [5]

Location solutions are broken down into two classes: Network and Handset. Network Location relies entirely on CMRS provider infrastructure to determine location and can include techniques such as Received Signal Strength (RSSI), Observed Time Difference of Arrival (Downlink OTDOA), Angle of Arrival (AoA), Multipath Fingerprinting, and combinations of these. Handset Location relies on location information provided by, or cooperative analysis with, the user device and can include techniques based on Global Positioning System (GPS) coordinates, Assisted Global Positioning System (A-GPS), Enhanced Observed Time Difference (E-OTD), Enhanced Forward Link Triangulation (E-FLT, CDMA-only), and combinations of these.

While the market penetration of "Smartphones" allows increased use of Handset Location, the continued use of "Legacy Handsets" (older GSM and CDMA devices) requires that Network Location techniques also be available. It's estimated that in the US (as of Q2 2014) less than 85% of AT&T user handsets and less than 75% of Verizon user handsets can be classified as "Smartphones", and these legacy handsets are incapable of providing or cooperating in Handset Location techniques. In terms of approximate numbers, this means that there are more than 18 million AT&T subscribers and more than 24 million Verizon subscribers in the US which must rely on the PSAPs being able to provide accurate Network Location when placing 911 calls. [6] Even smartphones with Handset Location capability cannot provide location information if a GPS lock cannot be obtained due to signal blocking and signal

scattering situations which often occur in dense urban areas, so Network Location is still often needed to service E911 calls made from even the most modern smartphone.
Network Location techniques rely on accurate placement and alignment of provider infrastructure. Observed Time Difference of Arrival (OTDOA) uses calculations based on a set of hyperbolas where some of the serving tower antennas serve as foci in the hyperbolic curves. The intersection of the hyperbolas provides the location of the handset. [4] The non-linear equation which defines these curves is given as:

$$R_{i,1} = \sqrt{(X_i - x)^2 + (Y_i - y)^2)} - \sqrt{(X_1 - x)^2 + (Y_1 - y)^2)} \ \textit{where:}$$

- $R_{i,1}$ *is the range distance between the first base station and the ith base station*
- $(X_i, Y_i)$ *is the location of the ith base station and* $(x, y)$ *is the location of the handset*

When we plot the hyperbolic equations, we observe that variations in recorded location of the tower antenna(s) affect the calculated position of the handset. This extent of this effect can range from problematic to catastrophic. In Figures 1 & 2 we consider a case where the placement of tower antennas is fairly even around the target handset. Recorded location errors of 30 – 50 meters are not uncommon for tower antennas, and some rooftop sites have the sectors of the antenna system located around the building perimeter – often a few hundred feet apart – so it's possible that three estimated locations based on measurements from a single rooftop site could be grossly wrong in three different ways. Target location errors will tend to be approximately twice the tower antenna location error, resulting in E911 location errors of up to 100 meters – well outside the FCC-defined accuracy guidelines for even current E911 location. In cases where the emergency call is being made from a person who is capable of interacting with first responders, an error of up to 100 meters may result in an extended time to contact. If the emergency call is being made from a person who is incapable of responding (e.g. a person who loses consciousness after dialing 911), or by a person who is being threatened while in a dense crowd, then 100 meters inaccuracy may be significant.

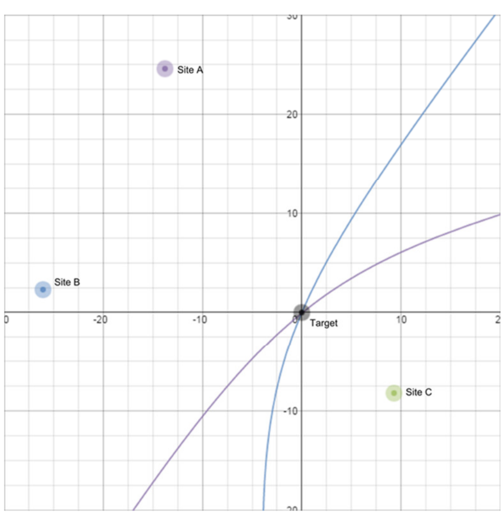


*Figure 1 – Accurate OTDOA (Urban)*

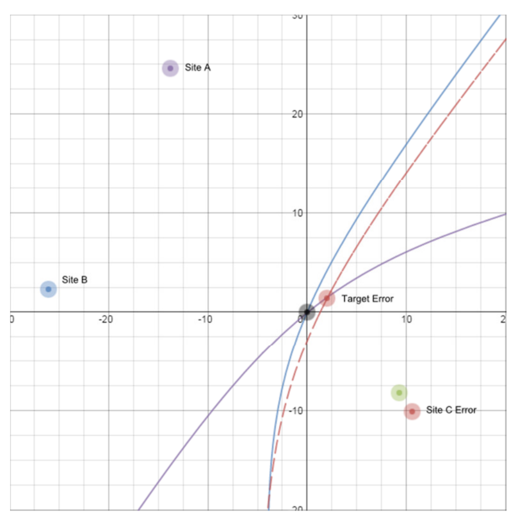


*Figure 2 – Error in recorded location slightly skews OTDOA*

In Figures 3 & 4 we consider the case where tower antennas placement results in unfavorable hyperbolic geometries.  This may occur for example in sparse suburban or rural areas where tower antennas are distant and located along similar azimuths as observed from the handset.  In this case, the hyperbolic curves are nearly coincident and thus recorded tower antenna location errors are multiplied – a location error of 15 – 30 meters could result in a handset location error of over 500 meters.  A call for help from a hiker fallen into a ravine, a car driven down an embankment, or a victim rendered unconscious may not be easily found – resulting in the need for additional first responders and reducing response time.

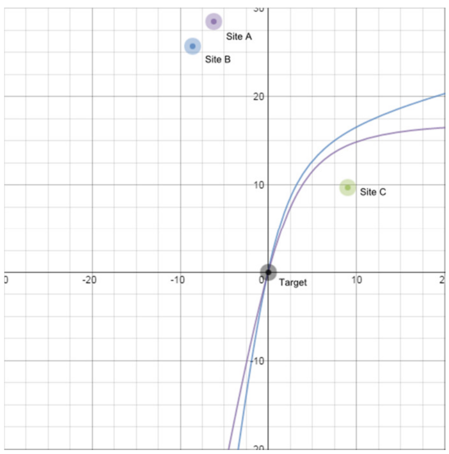


*Figure 3 – Accurate OTDOA (Rural)*

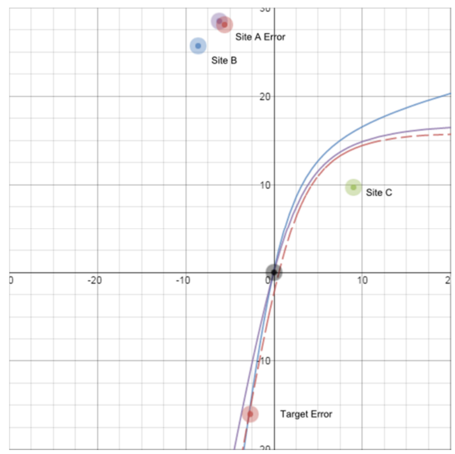


*Figure 4 – Error in recorded location greatly skews OTDOA*

Because the OTDOA technique is limited, E911 deployment may require the use of additional techniques such as Angle on Arrival (AoA) to meet FCC requirements.  When used in conjunction with OTDOA, AoA can reduce uncertainty and decrease response time to contact.  Combined AoA + OTDOA systems require installation of additional equipment in the form of specialized antenna arrays. Commonly referred to as "triangulation" – standalone AoA requires at least three tower antenna sites, and AoA + OTDOA requires at least two tower antenna sites and works best with three or more.

Obviously the accuracy of the AoA directional data is heavily dependent on proper azimuthal alignment of the tower's AoA antenna array.  Figure 5 shows accurate alignment and the target fixed at the graph origin.  Figure 5 shows inaccurate alignment of just one base station with commensurate skewing of the target.  Clearly in accurate alignments of multiple towers would further degrade accuracy, likely resulting in not meeting FCC mandates.  Errors in recorded tower antenna location will also reduce accuracy and result in increased response times.

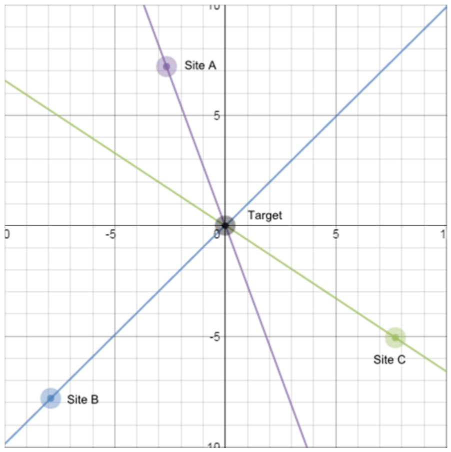


*Figure 5 – Accurate AoA*

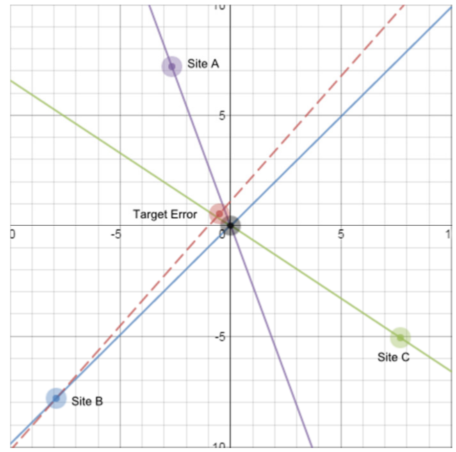


*Figure 6 – Error in azimuth alignment skews target*

Target location inaccuracy caused by incorrect tower antenna location data for OTDOA systems and/or inaccurate azimuthal alignment for AoA systems has real consequences above and beyond not meeting FCC E911 mandates. In 2001 a study conducted by Columbia University in the Salt Lake City area found that, on average, a one minute reduction in emergency medical (EMS) response time equates to a 17 percent decrease in the likelihood of 90-day mortality. [7] 90-day Mortality is the medical standard for measuring effectiveness of treatment or intervention, and refers to the rates at which patients receiving EMS intervention for catastrophic medical conditions (heart attack, stroke, major trauma from vehicular accidents, etc.) are likely to be alive 90 days after the EMS intervention. Improved EMS response time is directly correlated to reduced rates of 90-day mortality. Approximately 25 million people call for an ambulance each year. [8] Using rough but reasonable assumptions, it can be estimated that improved location accuracy which results in reducing EMS response time by one minute can result in saving over 10,000 lives annually. Aside from the humanitarian aspect, the US Department of Transportation’s guidance on the “Economic Value of a Statistical Life – 2014” is given at US$9.2 Million. [9] Thus improving EMS response times by one minute through better E911 location accuracy has a societal monetary benefit of over US$92 billion.

The problem of tower antenna misalignment is very real. An audit conducted in the first half of 2013 found that 2,541 out of 6,046 antennas were out of tolerance. 27% of the antennas were 4 – 10 degrees out of tolerance, and shockingly 15% of the antennas were more than 10 degrees out of tolerance. Clearly the E911 Network Location data provided by these problematic sites would be less than useless – it would be grossly misleading and ultimately very costly in both humanitarian and financial terms.

Sunsight Instruments offers test solutions for E911 system integrators, site contractors, and communication shops. Sunsight’s Antenna Alignment Tool (AAT) has the ability to measure and record latitude and longitude to within 30 centimeters – 3 times more accurately than competitive instruments. When used to align the azimuth of a sectored cellular antenna, the Sunsight AAT provides ±0.3° RMS (and less than ±1.0° based on 3 standard deviations aka “R99”) a 2.5 times increase in accuracy over competitive instruments.  Using Sunsight's industry-leading technology to ensure proper azimuth alignment and record more accurate antenna location data for PSAP and RF databases will help ensure that E911 cellular location systems will work upon commissioning, will require fewer periodic adjustments, and will be less likely to need costly and time-consuming system troubleshooting and retesting.

*Sunsight Instruments AAT-30 quickly measures and records antenna location, azimuth, tilt, and roll to ensure accurate E911 location.*

*AAT Classic, previous Sunsight Model.*

Providing PSAPs with a highly accurate database of tower antenna location is critical to meeting FCC mandates for E911 system performance.  Accurate azimuthal alignment of antennas is also critical to ensuring system performance.  Improving antenna position data capture is one of the solutions to improving E911 Network Location based determinations.   Achieving both success metrics will provide citizens with a system that better serves an increasingly mobile community with accuracy and lowered public safety response times.

About the Author

David Witkowski is the founder and Principal Consultant of Oku Solutions, a firm specializing in market-entry and business development for the wireless industry.  Over a career spanning 30 years David has held positions of leadership and responsibility in the wireless and telecommunications industry at companies ranging in size from Fortune 500 multi-nationals to early stage startups.

David serves as President of the non-profit Wireless Communications Alliance, as an advisor to the Carnegie Institute of Technology Dean's Council at Carnegie Mellon University, and as a member of the Wireless Communications Initiative committee for Joint Venture Silicon Valley.  David is a Senior Member in the Radio Club of America, and a Senior Member in the IEEE.  He obtained his BSEE from University of California with a study emphasis on modulation theory and RF/wireless design.

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