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Location, Location, Location

Executive Summary

We are all familiar with the Federal Communications Commission's (FCC) new rules for locating wireless E911 callers. On the back of a unanimous Commissioners' vote, the FCC roadmap for compliance is very clear, and the test beds are set up and ready to prove or disprove a technology's ability to meet the location requirements within the specified deadlines. So your network should be able to meet the E911 compliance milestones without any problems, correct? Perhaps not.

The measurements needed to meet the FCC rules will, over time, require the network operator to be able to provide emergency call accuracy within 50 meters (150 feet) horizontally for 80 percent of all emergency calls or alternatively provide a very precise "Dispatchable Location"—an accurate address, floor, and suite/apartment of the caller. This represents a blended mix of "live" emergency calls that for the first time include indoors as well as outdoors, rural, suburban, and dense urban area results. These metrics are averaged over the appropriate county (more than 3,000 across the country) in the market where they are measured. The rules represent a number of "firsts." For example, it is the first time a carrier's location performance is judged on the basis of "live" 9-1-1 calls, and it is the first time Public Safety Answering Points (PSAPs) are empowered to trigger an enforcement action. Let me delve into these "firsts" in more detail.

The "Live Call" requirement, applied to *all* 9-1-1 calls, implies that an appropriate percentage of embedded devices have to be capable of supporting the proposed FCC metric by April 2017, April 2018, etc. This further implies that devices capable of meeting the new rules need to start being sold by the beginning of 2017 to hit the appropriate deadlines. Given realistic handset lead times, this is not very far from today.

The Commission has also placed the E911 Call Centers (more than 6,000 across the country) in the unique position of being the "eyes and ears" of the Commission in terms of ensuring the carrier meets the new metrics. The E911 Call Center, aka the Public Safety Answering Point (PSAP), can request a carrier to supply the location performance data delivered within the PSAP's jurisdiction. If it does not meet the compliance metrics as laid out by the FCC, the PSAP can trigger a compliance action with the FCC. Therefore, a PSAP in urban Philadelphia or rural Idaho Falls, or for that matter in downtown Manhattan, can make the same request. The expectation is that there is uniform location performance for E911 calls throughout the wireless carrier's footprint.

The question is whether today's technologies of GPS and cell tower trilateration can meet those metrics. The answer is "probably" in rural areas, whereas indoor locations in urban and dense urban areas will likely require new device location approaches.

The silver lining in this new responsibility is that there are several technologies available. However, they need to be carefully assessed and decisions need to be made fairly quickly due to network and device lead times. A wrong decision can prove to be expensive from a switching cost perspective, potential compliance penalties, and worse, from a public relations perspective.

In assessing any technology some of the key parameters to be considered are:

- a) Does it meet the year six horizontal performance metric and year eight vertical metric today?
- b) What is the Total Cost of Ownership (TCO) of the solution?
- c) What is the reliability of such a service and what level of “Continuity of Service” can be expected from the solution?

The solutions currently at play are:

- a) The National Emergency Address Database (NEAD)
- b) Crowd-sourced Wi-Fi (as opposed to dedicated, or “managed” Wi-Fi)
- c) Observed Time Difference of Arrival or OTDOA-based solution (based on the LTE system)
- d) Metropolitan Beacon System (MBS)

The NEAD is a national database of Wi-Fi access points and their corresponding street addresses that can return a “Dispatchable Location” for the caller. Due to the voluntary nature of the database, privacy and cyber security concerns, and lack of broadband penetration in poorer communities (only 50 percent of the population is served by Wi-Fi), only a small percentage of calls are expected to be supported using this solution. Regardless, due to the carrier commitment during the formulation of the rules, this solution will be built.

Crowd-sourced Wi-Fi, a solution used in commercial wireless services to provide “Best Efforts” location, is expected to be a relatively inexpensive solution. Although its performance in urban areas is not yet fully known, it is well known that in poorer communities with high crime or elderly residents, where a large percentage of 9-1-1 calls are expected to originate, broadband/Wi-Fi penetration is so low that it is not expected to perform well, if at all, especially in cities such as Chicago and New York. Further, it will not work in times of natural disasters such as hurricanes and storms when the power goes out and 9-1-1 call volume is expected to surge! This system does not deliver accurate vertical information either. Despite the attractive initial cost factor and presence in some venues, crowd-sourced Wi-Fi is not expected to consistently deliver required performance levels across the country and completely fails the “reliability” and “continuity of service” performance requirements across an entire metropolitan market. Therefore it will likely be the more expensive long-term option both from a cost and a public relations perspective.

The OTDOA positioning solution is available as part of the LTE system, which at first glance seems highly scalable and potentially “free.” However, a closer examination reveals that it is far from free. In fact, OTDOA is expected to consume up to 4 percent of expensive LTE spectrum in each market, which equates to \$1–\$3 billion across the Top 50 markets per carrier!¹ What is worse is that it is not expected to meet the FCC’s location requirements on the ‘X-Y’ metric in critical urban environments and it

¹ Based on AWS-3 auction results of between \$163 and \$2.88 Price per MHz-POP (<http://www.fiercewireless.com/story/aws-3-auction-results-att-leads-182b-verizon-104b-dish-10b-and-t-mobile-18b/2015-01-30>)

certainly does not meet the 'Z' metric requirement. It also puts an enormous burden on the LTE system in terms of measuring cable delays, antenna siting, network design, "rebalancing" for location additions and or changes, etc. Thus it fails to meet performance and total cost of ownership considerations.

The Metropolitan Beacon System (MBS) from NextNav is a proven technology that provides both horizontal and vertical location for emergency callers. It has already passed multiple test beds from multiple parties (including the FCC's CSRIC) and it is being trialed by at least one major network operator. MBS is based on a dedicated network of location beacons or transmitters that are placed in precise locations around an urban area. A modified receiver must be added to each device to receive the network signal but it costs only pennies, and then the system functions much like the GPS system does in open spaces except that these beacons penetrate deep into buildings. The system uses 900-MHz radio spectrum that is licensed to NextNav, which builds and operates the Metropolitan Beacon System.

MBS has been operational in the San Francisco Bay Area market for several years now, and appears to be the one solution that can ensure your network is fully compliant with the new FCC location rules (Year six 'X-Y' metric and Year eight 'Z' metric) not only during field tests but after deployment in the top urban markets. The NextNav solution can help your network comply to the new indoor rules, requires no capex, and is expected to become less expensive as more operators sign on. MBS does require a network operator to instruct its device vendors to supply GPS chips with MBS capabilities baked into them in the wireless devices they deploy on the network.

So, the question is whether the operators will go with a proven solution that does not cost billions of dollars and has complete reliability and span of control, or risk going with a solution that could initially appear cheaper but is an unproven solution with known weaknesses and is expected to break down in many environments. The smart money says to go with what is available and proven today!

Regardless, the time to make a decision is now. Since the milestones are less than two years away and require an embedded base of devices to be available, networks to be built, and systems to be proven in the test bed, you cannot afford to wait!

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Will Carriers be Ready to Meet FCC Requirements of Phase III (Fourth Report and Order)?

Introduction

Typically the title of this paper is the mantra of real estate sales people, but in this case it is about finding the location of a wireless caller who dials 9-1-1 in an emergency. Some reports suggest that more than 60 percent of wireless callers cannot provide a 9-1-1 operator with a solid location. This unfortunate fact results in delays of emergency personnel arriving on the scene and, in some cases, can prove to be fatal. Dialing 9-1-1 was introduced in the United States in 1967 and the first cellular service (now more generically called wireless service) was available in 1981. As the number of wireless customers grew year over year, and the number of households that dropped their wired phones rose to today's 45 percent of all households², wireless E911 calls became the rule rather than the exception. As a majority of wireless calls now originate in buildings, the issue of pinpointing a wireless caller's exact location has become an urgent priority for Public Safety Answering Points (PSAPs) as well as the entire first responder community.

In an effort to assist Public Safety with the issue of locating wireless callers, the Federal Communications Commission (FCC) passed its first location accuracy rules in 1996. As wireless technology matured and next-generation technologies were introduced, the FCC updated those requirements. Prior to the present rulemaking (Phase III Rules or the Fourth Report and Order), the last update was in 2010 (Phase II or "outdoor" E911). Since that time, the fourth generation of wireless services was introduced and the number of wireless devices skyrocketed. Thus the FCC passed another update that will, over time, accomplish better accuracy for both outdoor and indoor location and will also add a third (vertical) dimension to location. These new rules require carriers to locate wireless devices dialing 9-1-1 from inside buildings to within fifty meters (150 feet), and eventually to identify the floor of the building from which the call originates. These new rules are part of the move to Enhanced 9-1-1 services that will better equip PSAPs to serve the public.

An additional element of the rules that should be of concern to network operators is the monitoring and reporting requirement that for the first time enables PSAPs to challenge network operators for proof they are meeting the location requirements of the law. If one or more network operators are not providing the specified accuracy, the PSAP has the option to contact the FCC and request that it intercede to determine if the carrier is in compliance. Since there are more PSAPs (nearly 6000) than

² "Wireless Substitution: Early Release of Estimates from the National Health Interview Survey, July-December 2014", Stephen J. Blumberg, PhD and Julian V. Luke Division of Health Interview Statistics, National Center for Health Statistics.

there are counties (3100+), this means that even a small PSAP covering a very small population has the same right of verification as a PSAP in a dense urban area. However, dense urban areas, where most calls are made from indoors, remain the most challenging areas for E911 location performance and virtually all urban area PSAPs can be expected to closely track individual carrier performance across their areas. Network operators that may broadly meet FCC benchmarks for accuracy in the monitored areas may not, in fact, be able to meet the requirements in densely populated urban areas where most 9-1-1 calls come from inside buildings or on the street in deep urban canyons.

Given their “outdoor-only” performance requirements, previous FCC rules for locating callers are not sufficient to provide what the Public Safety community needs, and currently deployed location technology, primarily driven by a combination of base station trilateration and Global Positioning System (GPS) receivers in wireless devices, does not provide much if any precise location data when an emergency call originates from inside a building (well over 64 percent)³. Particularly in urban markets, even if the caller’s location is identified as a specific building, further resolution to the floor level is required to reduce Public Safety response times. In order to provide better location services, the FCC has passed new rules⁴ and regulations that affect every type of wireless emergency call being made today. But beyond the FCC’s new E911 rules, the Public Safety community itself needs the ability to locate its operating personnel inside a building during an incident to a level of location accuracy that exceeds that required by the new FCC indoor E911 rules.

New FCC Requirements and Timeframe for Implementation

Two major points need to be addressed by commercial wireless network operators in order to meet the FCC’s new wireless device (emergency caller) location benchmarks. The first is the consistent accuracy of the location information, particularly of in building location in urban markets (including, over time, elevation within multi-story buildings). The second is the timing for implementing these requirements. It is important to note that these new rules are to be implemented in stages and, based on recent FCC fines relative to E911 performance, penalties for not meeting the requirements could be harsh⁵. It is clear that regulators view this issue seriously, and the unanimous vote on location accuracy rules by the FCC Commissioners suggests that non-compliance and extension requests will be viewed critically.

The FCC’s rules and performance benchmarks take effect over a period of time and there are two ways to meet the requirements set out in the rules. The first is what is termed a “known dispatchable location,” which is defined by the FCC as a verified street address of the calling party plus additional information such as floor, apartment, suite number, or similar information that is necessary to positively identify the location of the caller reporting the incident. The second method of compliance is coordinate-based location requiring an increasing percentage (80 percent by year six) of emergency callers be located within 50 meters in the horizontal plane. By year six, the rules require network operators to determine caller location not only in the horizontal plane but also in the vertical plane in major urban markets. Therefore, the first step for network operators is to select an appropriate combination of location technologies that will enable them to meet the increasingly demanding

³ Survey conducted by Find Me 911 Coalition 4/2014 <http://www.prnewswire.com/news-releases/survey-of-9-1-1-dispatchers-finds-many-indoor-callers-cannot-be-located-on-wireless-phones-256539011.html>

⁴ FCC Wireless Indoor E911 Location Accuracy requirements <https://www.fcc.gov/document/fcc-adopts-new-wireless-indoor-e911-location-accuracy-requirements-0>

⁵ <https://www.fcc.gov/document/t-mobile-pay-175-million-resolve-911-outage-investigation-0>

horizontal location requirements over the next five years while keeping an eye on future vertical plane requirements.

Timing of the Rules

The FCC rules took effect in April 2015, with initial reporting obligations at eighteen months and initial performance compliance beginning at two years (40 percent of all live E911 calls) and escalating in horizontal accuracy benchmarks until year six (80 percent of all live E911 calls). As noted previously, these live call benchmarks must be met by either a sub-50 meter coordinate-based location fix or by an accurate address of the calling party (dispatchable location); although in the case of an address-based solution, the coordinate-based location must be reported as well. The determination of whether the coordinate-based location fix of each live call was accurate to within 50 meters or whether the address of the calling party was truly the correct “door to kick down” is not practical to assess or document for each live call. Therefore the rules require that each location technology (both coordinate-based and address-based) be tested in a representative test bed environment to establish how often they meet the accuracy objective (sub-50 meters, or correct address/room/floor/apartment of the caller).

Adding the vertical component to these requirements takes place in three stages. By year three, carriers must deliver uncompensated barometric pressure data to the PSAPs if available on the handset, and must work with Public Safety to develop a vertical accuracy standard to be approved by the FCC. By year six after rules issuance, vertical accuracy that meets the FCC’s approved standard (either by coordinate-based or dispatchable location-based methods) must be available in the top 25 urban markets. By year eight the approved vertical accuracy component must have been deployed in the top 50 markets. To provide a lasting technology solution, the network operators’ fundamental goal should be a suite of location technologies that consistently achieves an 80 percent rate of horizontal location accuracy, as well as a consistent vertical capability in urban centers.

There are some additional caveats for each of the rule categories: horizontal accuracy, vertical accuracy, and monitoring and reporting. The horizontal accuracy portion of the rules requires in year two that 40 percent of all emergency calls are located within 50 meters (this is not much time, especially if the chosen method requires modifications to mobile devices or standards development). In year three this percentage increases to 50 percent, in year five to 70 percent, and in year six to 80 percent. The percentage is based on all live E911 calls and carriers can use one or both approved address-based or coordinate-based methods. To make use of the dispatchable location (address-based) method means the essential enabler, the National Emergency Address Database (NEAD), will have been standardized, approved, completed, and put into operation by the carriers. This is a complex and time-consuming undertaking, but one that all national wireless carriers have committed to achieve. Smaller or rural carriers have more relaxed compliance deadlines based on their projected slower rollout of LTE/VoLTE (Voice over LTE).

For the horizontal and vertical accuracy aspects of these rules, beginning in mid-2016 there will be an independent test bed process currently targeted at San Francisco and Atlanta, wherein the performance of different location technologies will be established for each Alliance for Telecommunications Industry Solutions (ATIS)-designated morphology (urban/dense urban, suburban, rural). It is noteworthy that compliance will be measured on a county basis per the FCC rules, which results in highly urban counties such as Manhattan and Chicago requiring indoor location technology that can meet or exceed the high accuracy requirements without the advantage of “averaging out” with performance in more benign

suburban and rural environments. Also, a limited number of “monitored markets” that require overt compliance reporting have been identified as San Francisco, Denver, Chicago, Philadelphia, Manhattan, and Atlanta. PSAPs in other markets are empowered to require reporting of their market’s E911 call performance on a case-by-case basis, thus permitting individual call centers to evaluate local performance against standards on an ongoing basis and enable them to ask the FCC for assistance for any non-compliant operator.

Ways to Meet the New Rules

Test beds are intended to establish the performance of location technologies in realistic environments from dense urban to rural by individual morphology, enabling the carriers to “map” the test bed performance to their commercial coverage in other markets. It is our opinion that wireless operators will be better off if the solutions chosen are similar, if not exactly the same. If, as it was with GPS for example, one of the successful methods under test requires a modification to devices, it makes more sense if all network operators select that option in order to speed delivery of compliant devices and drive down any associated costs.

As wireless carriers and other responsible entities seek to meet the new indoor E911 rules, there are a number of issues each company will have to weigh and use for technology evaluation. Their selection of a solution or multiple solutions will have to be the best fit for the carrier from a technology and total cost of ownership perspective, meet the FCC’s escalating near-term benchmarks as well as the demanding five/six year horizontal and six/eight year vertical deadlines, and satisfy the complete set of FCC expectations for accuracy, reporting, and service continuity within each PSAP’s service area. Particularly in difficult urban markets, carriers that delay their decisions and do not begin deployment of at least one if not more solutions soon will be surprised at how fast the first two and three-year implementation deadlines arrive (especially when one considers that it takes two to three years for turnover of a significant portion of the installed base of handsets). Neither of these deadlines offers carriers the ability to adopt a wait and see attitude.

When we discuss the total cost of ownership of solutions for meeting the FCC rules, we are not speaking only in terms of simple first financial costs of implementation. In some cases there may be hidden costs. For example, where one technology might aid in meeting the requirements with a minimum of direct costs, its implementation may be costly in terms of the amount of a carrier’s spectrum required to implement that particular technology. Other considerations might include using in-building Wi-Fi, but Wi-Fi is not able to provide carriers with assurances that each of the buildings within the top 50 markets can actually provide Wi-Fi access for the network operator. Some Wi-Fi systems are not only encrypted but are not available for any form of public access. And it lacks the ability to effectively resolve the accurate Wi-Fi Access Point (AP) in a multi-dwelling unit, and there is no guarantee that every floor and apartment within a building actually has a Wi-Fi AP. Particularly in lower income urban areas and among the elderly, roughly half of the population does not have wired broadband and a Wi-Fi access point.

It is also true as carriers delve into the FCC rules and available solutions that a total cost of ownership assessment will require solutions implemented to meet year two and three benchmarks also be capable of meeting year five and six benchmarks. No carrier can afford a network-wide rollout of suboptimal interim technologies that are unlikely to ensure meeting the benchmarks in later years. The use of test beds to help provide carriers with the location accuracy information they will need in order to make a decision is a positive concept, even if the FCC had not mandated their use. Simply gaining an

understanding of each technology's performance, particularly indoors in urban centers, is critical to deploying the appropriate technology solution and minimizing total cost of ownership. However, time to gather this test data is precious and the general performance of many of these technologies is already well understood. As time passes, if critical implementation decisions are delayed and cause benchmark deadlines to be missed, it cannot be simply assumed that the FCC will grant extensions to major network operators. Therefore, the timely selection of the proper mix of location technologies is critical to provide solutions that are cost effective in terms of direct costs, operational complexity costs, and associated spectrum usage costs, and they must also be able to meet challenging year six benchmarks.

As has been noted throughout, consistent and dependable technology performance in urban markets is paramount. While the 70 percent and 80 percent accuracy benchmarks in years five and six are often acknowledged to require significant improvement in current carrier performance, one critical aspect is often overlooked. As with prior Phase II outdoor location accuracy rules, the FCC required these performance benchmarks to be achieved on a county-by-county (and even PSAP-by-PSAP) basis, and further empowered each PSAP to obtain its individual performance data from each carrier as a safeguard to this requirement. The importance of this is obvious when assessing the impact of current carrier performance. GPS solutions alone may well achieve the year five and six benchmarks in rural and light suburban environments, particularly since it is likely that a substantial percentage of live 9-1-1 calls in these environments will be placed outdoors (and therefore, easily served by satellite-based solutions such as GPS).

However, the primary focus of the recent FCC rulemaking was to address performance in urban areas where GPS is obstructed and where a majority of calls originate indoors. By requiring county-by-county compliance, the FCC has ensured that carriers must deploy solutions in urban and dense urban areas that are appropriate to those environments and have proven dependable indoor urban performance. Further, if the carrier is interested in working with or partnering with FirstNet, the 700-MHz nationwide broadband network for Public Safety, it should be noted that FirstNet's in-building requirements for firefighters, EMS, and law enforcement personnel could well be even more stringent than the FCC rules. Finally, while it is doubtful that the FCC will relax its rules, there is the possibility it will review the data and impose even stricter requirements on the wireless industry in the future. Finally, both FirstNet and the broader Public Safety community will expect these critical urban solutions to work during major weather events and power outages. The FCC's continuing focus on E911 uptime and reliability is unlikely to diminish and, in fact, can be expected to heighten following any major natural disasters or weather events where E911 performance was impaired.

Leading Technologies for Compliance with the New Order

There are a number of ways to meet the FCC's new requirements when mobile devices are outside in a suburban or rural environment and some of the time even within urban canyons. All wireless devices today include GPS technology so location can be determined by receiving multiple GPS satellite signals. In addition, since it can take time for the GPS to sync on the satellites, especially from the cold start condition, operators are using cell site location, cell site triangulation, or other lower-accuracy location methods to augment GPS. It is clear that location information in the open, when GPS signals are available, coupled with the network's own augmentation, should be able to meet the new FCC rules for horizontal accuracy in rural and light suburban environments. It is not as clear how successful these systems are or will be indoors or in deep urban canyons where GPS is challenged. With the advent of more capacity-driven small-cell deployments, some degree of location improvement should occur in the

normal course of network densification. Will these denser small-cell deployments and 5G pico-cells be pervasive and sufficiently capable in time to help operators meet the FCC deadlines? Are they likely to be in a sufficient number of places and will they be sufficiently calibrated to know their precise location? The consensus answer is no, there will not be a sufficient number of small cells deployed to meaningfully help in meeting near-term FCC requirements.

Network operators must first improve their X-Y (horizontal) location measuring capabilities to be able to meet the FCC rules and then they must turn their attention to the real challenge facing those who provide wireless services in urban centers: How do you meet the FCC's rules regarding vertical accuracy or put another way, making wireless location three-dimensional. As mentioned above, by year three of the rules each wireless network provider must deliver both uncompensated barometric pressure to the Public Safety Answering Points and also submit the operator's plan to implement a vertical accuracy standard to the FCC for approval. By year six they must implement either the FCC approved standard or dispatchable location solutions of sufficient density within the top 25 urban markets. Alternatives and approaches for vertical solutions will be discussed later in this paper.

Technology Solutions

It is our belief that wireless network operators will need to deploy a combination of location technologies that either individually or collectively meet or exceed the FCC's rules first for horizontal and then vertical accuracy. While the nearest-term benchmarks require only horizontal accuracy, three years from April 2015 is not much time for a network operator to determine a vertical accuracy strategy and technology, nor is six years a long time to implement it.

There are only a few location technology solutions viable for use within the FCC's benchmark metrics and timeframes. Each needs to be assessed from a number of critical standpoints, including reliability, yield⁶, accuracy, and scalability, as well as total cost of ownership and whether it provides both vertical and horizontal solutions. Accuracy and yield must be determined through the independent test bed process and are an essential requirement, given that the later-year benchmarks (70/80 percent) allow little room for marginal accuracy or lower-yield solutions. While not an inherent part of the independent test bed process, the scalability, reliability, and "carrier-grade" aspects of the technology solution have long been an area of common concern among wireless carriers and the Public Safety community. As noted previously, solutions that rely on commercial power, widespread voluntary participation, and that have not been designed for diversity, redundancy, and robust operation must be viewed with caution. If they have uniquely desirable attributes (such as Dispatchable Location (DL) addresses), they may still play an important supportive role, but may be best viewed as supplementary rather than primary.

Finally, as with any technology decision, total cost of ownership is a key metric for carrier evaluation. Some solutions require ongoing network operational costs, such as retiming base stations, surveying base station locations, antenna locations, cabling lengths, and other measures that drive hidden manpower and operational costs. Some require ongoing database maintenance and validation, while others use up carrier bandwidth or spectrum, thus forcing premature network upgrades, cell splitting, and even spectrum acquisition. Another requires compliant GPS chipsets, which may not entail significant costs, but does require involvement of the handset supply chain. These various factors and

⁶ Percent of time there is a location fix

how they weave together into an attractive and sustainable E911 location strategy need to be considered.

It is important to realize that the FCC’s expected 50-meter (150 feet) horizontal accuracy benchmark percentages are based on a blended mix of the performance of all live 9-1-1 calls. This blend will be calculated by taking the percentage of live emergency calls located using each particular location technology (such as GPS, GNSS, OTDOA, MBS, DL, etc.), then attributing the accuracy each of the technologies has demonstrated in the test beds for the given morphology/environment, and “blending” or averaging them over the area being evaluated (state, county, individual PSAP, etc.). Although the compliance test beds scheduled for 2016 should provide definitive accuracy percentages, prior independent testing through the FCC’s CSRIC advisory group gives a general view of the range of expected outcomes. The Alliance for Telecommunications Industry Solutions (ATIS) and the CTIA—The Wireless Association working groups are completing the specific testing and reporting details, but certain key findings are unlikely to change.

One element everyone agrees on is that the challenges for E911 location accuracy reside almost exclusively in urban markets, and that rural and light suburban areas of the country can likely be well-served by existing location technologies, particularly satellite-based technologies such as GPS and GNSS (which uses signals from other satellite constellations in addition to GPS satellites). While the FCC compliance test bed process will be required to validate GPS performance (both indoors and outdoors), prior FCC Communications Security, Reliability and Interoperability Council (CSRIC) testing and carrier outdoor testing would indicate that 80+ percent accuracy within 50 meters is achievable in rural areas as well as in smaller structures in light suburban environments. Because the FCC benchmarks entail “blending” of all live E911 calls by the location technologies that were used, areas that achieve a high percentage of GPS fixes (rural/suburban) will achieve their objectives much more easily than areas where GPS is challenged (urban/dense urban).

Therefore, the “mix” of technologies used is critical in determining the final blended accuracy percentage that the carrier can claim to achieve. If high-accuracy GPS is blended with lower-accuracy base station trilateration methods such as Advanced Forward Link Trilateration (AFLT, or more recently OTDOA), it will be imperative that a very high percentage of live calls use GPS-only. It is fairly straightforward how averaging of accuracy numbers works out. For example, if GPS’s underlying accuracy is above 80 percent and accounts for 80 percent of the E911 location fixes while a less accurate fallback technology accounts for 20 percent of the location fixes, the blend would incorporate both the percent of fixes and their tested accuracy:

Component Location Tech	Suburban Call Distribution (A)	Suburban Test Bed Calls w/ <=50m Accuracy (B)	Suburban Accuracy (C=A X B)	Total Accuracy (Total C)
GPS	80%	90%	72%	75%
AFLT	20%	15%	3%	
Total	100%	NA	NA	(Target >80% in year 6)

Note that GPS and AFLT perform better in Suburban than in Urban environments. In a real scenario, any given county will contain its own unique mix of environments.

While GPS is expected to account for a very high percentage of outdoor calls, and even a substantial percentage of rural/suburban indoor calls, both its accuracy and its yield have proven to drop dramatically when tested indoors in urban areas. So for urban environments, consider instead a situation where only 50 percent of live calls were served by GPS. It becomes immediately apparent that any alternate technology deployed must achieve similarly high accuracy capabilities or the high blended benchmark percentages simply cannot be achieved:

Component Location Tech	Urban Call Distribution (A)	Urban Test Bed Calls w/ 50m or Better Accuracy (B)	Extended Accuracy (C=A X B)	Total Accuracy (Total C)
GPS	50%	80%	40%	45%
AFLT	50%	10%	5%	
Total	100%	NA	NA	(Target >80% in year 6)

Note that GPS and AFLT perform better in Suburban than in Urban environments. In a real scenario, any given county will contain its own unique mix of environments.

Note: Advanced Forward Link Trilateration (AFLT) is a technology that does not use GPS. The phone itself takes measurements of signals from nearby cell sites and reports the time/distance readings back to the network. This normally requires signals from at least three different cell sites. The LTE-compliant version of this approach is Observed Time Difference of Arrival (OTDOA), which is expected to provide somewhat better accuracy but falls far short of GPS-level accuracy. In addition, the yield of both AFLT and OTDOA fall far short of 100% in urban areas (85-90 percent in CSRIC testing of AFLT).

The test beds will be used to prove and/or disprove a technology’s ability to meet all of the FCC requirements by morphology. However, as in any tests, the results may not map well to all other markets. Therefore, the FCC in its Monitoring and Reporting Phase of the rules not only requires test bed data to be collected and reported, and live E911 call data to be reported for six monitored markets, it also requires carriers to certify that their technology deployments in other markets are consistent with those in the test beds and monitored markets. Further, the new FCC rules give any PSAP the right to request current performance data for its coverage area so it can determine the overall location accuracy performance of wireless network operators within its local area. If the system’s performance is below that permitted in the FCC rules, the PSAP must first bring the shortfall to the attention of the wireless carrier, but thereafter has the right to request FCC enforcement to bring the performance into line.

The FCC, 9-1-1 community, carriers, and vendors have all worked diligently to provide a set of rules that can be met and that will provide a new and important layer of location. Now it is up to each wireless network operator to select location solutions to meet the FCC’s new rules. In order to ensure they will be able to meet year three horizontal accuracy rules, as well as those looming in year six for both horizontal and vertical (vertical accuracy implemented in the top 25 markets), operators will have to act soon to decide which set of technologies will meet their needs and fit into their financial and operational budgets.

Vertical Requirements and Approaches

While the initially proposed FCC rules included a specific three-meter accuracy requirement for vertical along with near-term performance benchmarks, the final rules require wireless carriers to work with the industry at large over the next three years to determine whether the desired three-meter objective is achievable and if not, to establish the most accurate objective achievable. In lieu of specific vertical accuracy requirements in the near term, beginning in year three the FCC requires that uncompensated barometric pressure data available in handsets with barometric sensors be delivered to PSAPs as a “pressure reference” that might be useful to first responders searching for a caller. Since a large percentage of smartphones now include barometric pressure sensors, this interim approach is required as a first step to providing accurate vertical location information.

The CTIA sponsored an industry wide working group assessing various methods of providing vertical (Z-axis) location information. Thus far, only dispatchable location (room/suite/floor address) and locally compensated barometric pressure sensors have shown promise in establishing vertical location. Similar to the 2012 CSRIC III tests, vertical accuracy testing is also expected to be included in the planned independent test beds being established for horizontal accuracy testing. The industry test bed process hopes to assess various vendors’ approaches to accomplishing this necessary compensation and to determine what accuracy metrics are reasonably achievable. Public Safety and the FCC’s desired results are that the industry would be able to achieve the objective “3m” performance that would peg the location of the caller to the floor number. The “sub-3m” results from the 2012 CSRIC testing suggest that accuracy near this level should certainly be considered an aspirational goal at a minimum.

As an alternative, the FCC rules suggest that a sufficiently dense registration of dispatchable location access points in a NEAD database can be used to fulfill the vertical accuracy objectives for E911 calling. FCC rules indicate that a market that has registered address/access points equal to one quarter of the population (i.e., one address for every four people) will qualify as providing vertical accuracy. It should be noted that this alternate approach for demonstrating vertical accuracy is premised on the definition of dispatchable location, which indicates that the database address is validated as the room/suite/floor (hence, vertical location) of the caller in the multi-story structure. Test Bed confirmation (or invalidation) of this premise may well determine whether dispatchable location alone can be relied upon for providing vertical location.

Non-GPS Horizontal Location Technologies under Consideration

As noted previously, GPS/GNSS are expected to serve a key role, particularly in rural and suburban areas, as part of every carrier’s E911 location strategy. In addition to GPS/GNSS, three primary technology approaches are under active consideration.

- In-building Wi-Fi (both crowd-sourced Wi-Fi and registered Wi-Fi as part of a dispatchable location database - NEAD)
- OTDOA, Observed Time Difference of Arrival (in conjunction with Cell ID and GPS)
- MBS, Metropolitan Beacon Systems (either standalone or hybridized with GPS)

In exploring each of these in turn, rather than speculate on detailed performance results that will be quantified by independent test beds, we will focus on the broader attributes that should be considered by any network operator in establishing deployment plans.

In-Building Wi-Fi/BTLE (Address-Based or Coordinate-Based)

The address-based, dispatchable location approach (NEAD).

During the FCC rulemaking process, much attention was drawn to the concept of Dispatchable Location (DL) as an address-based approach to providing the PSAP with the location of an E911 caller. Based on favorable experiences with the wireline ALI (Automatic Location Identification) address of E911 callers, Public Safety considers the address of the correct “door to kick down” to be the gold standard for emergency dispatch. However, in a wireless environment where the location of the caller is not tied to a specific address, PSAPs have relied instead on coordinate-based approaches that identify an area on the map where the caller is located (with the size of the area directly related to the accuracy of the location technology solution). Hence, technologies that provide a very small search area (less than 50 meters) are desirable, particularly in urban environments where larger search areas become problematic.

Many detailed discussions among Public Safety, carriers, and the FCC eventually resulted in an agreed definition of dispatchable location to be the caller’s validated street address, with additional information such as apartment, suite, room, floor of the calling party. While the definition is clear, the technical approaches possible to meet the definition are less so. The primary challenges associated with dispatchable location solutions fall into a number of categories, including:

- Mismatch between static access point address and mobile caller address
- Voluntary nature of registering access points
- Complexity and ongoing database integrity
- Privacy and Security of management of the database
- Limited broadband and access point density in low-income urban areas
- Outage susceptibility during severe weather/power conditions

Of these issues, the most immediate is that addresses can only be appended to static points, such as Wi-Fi access points, and these addresses typically only identify the “general vicinity” rather than the address/room/suite/floor of the caller as required to be a dispatchable location. To more fully understand this as well as the other challenges of dispatchable location, a brief description of the intended implementation process is needed.

The carriers have committed to create a National Emergency Address Database (NEAD) that would allow the voluntary registration of civic locations (addresses) associated with various deployed reference points (predominantly Wi-Fi access points, but also Bluetooth Low Energy (BTLE) beacons when available). This tabular database correlates Wi-Fi Media Access Control (MAC) addresses with the known address of the access point (or BTLE beacon equivalent). While this registration process is voluntary, it is likely that some amount of bulk registration may occur by uploading the current deployment/billing records from cooperating ISPs (likely including wireline affiliates of wireless carriers). While some validation/scrubbing of these bulk registrations will be required (and certainly some mechanism to achieve consumer privacy opt-in concurrence as well), the bulk input process will likely provide an initial base of address-correlated reference points in the NEAD database.

However, these records would not automatically include access points behind government or private enterprise firewalls, which are not available for public use, and the specific location that is normally not known to the carrier. This becomes particularly problematic when dealing with large multi-story structures under common management (hotels, office buildings, government locations, etc.). In these

instances, voluntary registration efforts of the extensive web of access points beyond the initial ISP installation are required.

The key issue here is that any handset calling E911 will likely see a significant number of Wi-Fi access points, only a fraction of which will have been registered with an address in the NEAD (depending on the eventual success of voluntary registration and cross-correlation of individual access point MAC addresses). Even if large numbers of access points are registered, there is no guarantee that the calling party's device will be located in the same room/suite/floor as the access point. In fact, it is probable that the two will not be collocated. Anyone simply accessing the Wi-Fi settings on their phone in an apartment complex or office building will immediately detect numerous access points on different floors, apartments, and even buildings. Additionally problematic is the fact that newer Wi-Fi access points generally contain large numbers of different MAC addresses, often separately correlated to which spectrum band, Wi-Fi radio, or protocol is being used. An access point could easily have a particular MAC appropriately correlated but have a different MAC in use or visible to the calling party. These inherent disparities between access point location and caller location are currently not resolved and are under active debate.

After the initial upload likely to occur from cooperating ISPs, the issue of voluntary participation and scalability rapidly emerge as an ongoing issue. The voluntary nature of the effort does not give confidence in the eventual result, and further, the accuracy and validity of this data becomes problematic, particularly as individuals and enterprises move and change location on an ongoing basis. This is truly a massive data-entry, data-integrity, and cyber-security issue where reliability and accuracy are at odds with the voluntary, best-faith efforts of the public at large.

The accuracy of matching the address/suite/room/floor of the static reference point to the actual address/suite/room/floor of the caller will require validation through the test bed process. However, even when deployed at scale, it is unknown what fraction of test calls in the test bed process would correctly identify the dispatchable location of the caller, and hence, what portion of any dispatchable location fixes from live E911 calls could be appropriately attributed to meeting the benchmark percentages.

Dispatchable location is a great objective, but it is very challenging. Thus separating the political necessity of the deployment of the NEAD from its likely contribution to an 80 percent accuracy metric, especially over time if the data is not refreshed on a constant and consistent basis, is critical. Beyond the extent to which a NEAD/dispatchable location solution can contribute to the FCC benchmarks, there remain significant concerns regarding reliance upon public Wi-Fi access points for mission-critical emergency services. This technology/reliability frailty must be taken into account both with NEAD implementations and with any crowd-sourced, coordinate-based Wi-Fi usage. It has been a long-standing concern shared by both carriers and the Public Safety community that continuity of service for mission-critical services is imperative. It is also a well-known fact that emergency calling spikes during snowstorms, hurricanes, and other power-outage situations. Unfortunately, it is an acknowledged frailty that Wi-Fi access points cease to operate during power outages, essentially blinding first responders during a time when demands are most critical.

A more subtle point is that low-income urban areas have significantly lower wired broadband penetration and Wi-Fi access points according to the Pew Research Center⁷ only 54 percent of

⁷ ⁶ <http://www.pewinternet.org/2013/08/26/home-broadband-2013/>

Households with income less than \$30,000 have broadband, which means that nearly half the population does not. Similarly, only 43% of the elderly, greater than 65 years of age have broadband/Wi-Fi at home. Hence, any E911 location solution built on ubiquitous availability of Wi-Fi access points will provide significantly poorer performance in low-income urban areas and for the elderly communities where E911 usage is proportionally much higher. While not directly related to the FCC's performance benchmarks, it is a sensitive subject for many regulators, government agencies, and consumer advocacy organizations. Providing superior E911 location service to suburbs and affluent urban areas and inferior service to the urban poor is not a desirable outcome, regardless of the lack of initial intention for that outcome.

Coordinate-Based (Crowd-Sourced) Wi-Fi

Beyond the planned creation of the address-based NEAD database, a number of companies provide horizontal location estimates based on an internal database of Wi-Fi access points and associated signal strengths. These databases do not purport to expressly know the specific location of individual Wi-Fi access points, but instead rely on the observed signals of visible access points that large numbers of handsets "see" (and report) while their Wi-Fi capability is activated. By "crowd-sourcing" this large number of observed inputs, the database provider can specify a presumed location consistent with prior inputs. Some companies provide this as a specific service (an example would be True Position's SkyHook service), while others use the information as part of their own internal marketing and commercial efforts. Most particularly, Apple and Google provide the capability to their commercial clients as part of their App stores and e-commerce platforms).

As noted, services reliant on uncontrolled and unmanaged public Wi-Fi networks cease to operate during power outages (when emergency calling volumes dramatically increase). Additionally, their accuracy and effectiveness is predicated on a high density of Wi-Fi access points, which have only modest penetration in lower income areas. Finally, their accuracy is predicated on constant recalibration based on crowd-sourced usage present in highly trafficked retail locations but less so in the upper levels of high-rise office complexes and other non-retail environments.

Even if reliability aspects of these commercial Wi-Fi systems could be improved, the carrier has to certify it can deliver consistent performance across its entire network – from the streets of Manhattan to the inner cities in Baltimore or Chicago. Additionally, some of these systems are tied to the type or brand of handset being used (e.g., Google's Android platform). Covering all makes of handsets will require a number of different service providers, and the performance of each system must be validated through the independent test bed process. Since the varied implementation and capabilities of these systems drive varying accuracy results, any live calls from such a system will need to identify the underlying source of the fix (Apple, Google, SkyHook, or other source of the calculation). These parties might act as "trusted agents" and take responsibility for the associated accuracy, but at a minimum, the carriers themselves must certify that the deployment of each of these systems (density, Wi-Fi protocol approach, etc.) is consistent in all markets, not simply in the two test bed markets or in the six monitored markets. And, of course, none of these systems deliver the vertical information that will eventually be required.

Recapping Use of Unmanaged Public Wi-Fi for either Dispatchable Location (Address-Based) or Crowd-Sourced (Coordinate-Based) Location

- The MAC address database must be assembled and then updated on a regular and consistent basis, and the associated addresses must be validated.
- With rare exception, during power outages and natural disasters Wi-Fi access points typically cease to operate.
- Some access points are “hidden from view” and may not be available for location use.
- Low-income urban areas and the elderly (approximately 50 percent of the population) are expected to have limited density of Wi-Fi access points. Therefore the population with the greatest need will likely be the most vulnerable.
- Civic addresses associated with Wi-Fi MAC addresses are not necessarily the same as the address of the E911 caller (room/suite/floor).
- Crowd-sourced, coordinate-based systems do not attempt to provide vertical location, only horizontal.
- Crowd-sourced, coordinate-based systems do not offer span-of-control and thus it is not directly possible to guarantee performance from market to market (unlike a cellular system, which is managed end-to-end).
- Voluntary participation for registering and correlating civic addresses to MAC addresses makes widespread participation (and therefore accuracy) in the NEAD uncertain at best.
- Responsibility for the integrity and accuracy of the correlated addresses rests with the voluntary party (consumer/retailer/business) registering the address rather than with the wireless carrier.
- The NEAD represents a massive cyber-security and privacy undertaking that essentially has to support any party entering their information but also must secure and protect the information reliably.

While dispatchable location, particularly if bulk registered (subject to consumer privacy concerns and approvals) by cooperative ISPs such as Verizon FIOS, ATT U-Verse, Comcast XFINITY, etc. holds the promise of providing an address in the near vicinity of an E911 caller for some portion of calls, it is unlikely that a high percentage of these addresses would constitute the actual room/suite/floor of the caller. The lack of redundancy during power outages, cyber-security concerns, and the scarcity of coverage in low-income urban areas further overhang any decision to rely solely on public Wi-Fi systems for urban indoor location requirements.

Observed Time Difference of Arrival (OTDOA)

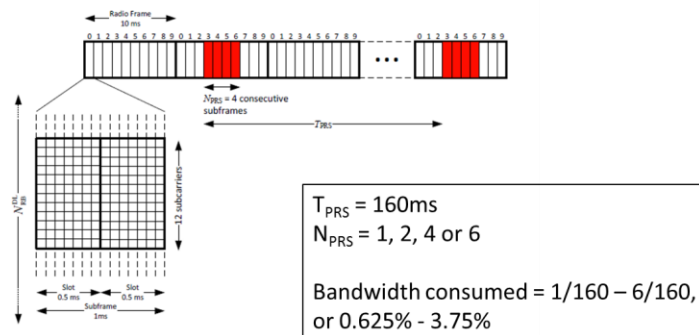
In assessing OTDOA there was little published data available regarding the actual performance of the technology or the total financial cost to implement. The following information regarding OTDOA was obtained from many different sources including a Qualcomm White Paper published in June of 2014 authored by Sven Fischer.⁷ Since this document was published prior to the FCC Rules, it does not reference the rules or their accuracy requirements and does not, therefore, provide any method for determining whether OTDOA will meet FCC requirements.

However, there is enough information being provided by both Qualcomm and a network operator or two to come to broad conclusions. For example, when Verizon responded to the request for comments to the FCC docket on this issue (07-114) in May 2014, it made the following statement on page 18: “Indeed, based on discussions with vendors and experience with the legacy A-GPS system, Verizon expects that O-TDOA performance as applied to VoLTE alone would represent up to a 20 percent improvement over AFLT in similar environments in a few years – which, as noted above, would not achieve the proposed 50m/67 percent level within the time periods proposed in the FNPRM.” In reality,

the results for OTDOA based on that statement would put OTDOA in dense urban areas somewhere close to 160-meter accuracy 80 percent of the time, which is totally incompatible with the 50 meter required metric.

It is important when evaluating any technology to understand how the system operates, the result (proven in tests), and true costs both in terms of funds required for implementation and deployment, and any other cost factors. Technically, OTDOA uses outbound Positioning Reference Signals (PRS) at each cell site and each sector that uses cell sector capacity in the downlink direction (from the base station down to the device). Each user device then receives these signals. The device receives multiple PRS signals from different cell sites or cell sectors (typically at least four). The device measures the distance to the towers and trilaterates to determine the location of the mobile.

There are also several identifiable costs associated with the OTDOA solution. First is the installation cost since the equipment required is over and above a normal LTE base station installation. More importantly, there is a hidden cost that may not be noted by many looking at the OTDOA solution. That cost is the LTE data-carrying capacity consumed by this technology. The amount of network capacity used by OTDOA can account for a capacity loss of between 0.625 percent up to 3.75 percent in a 10-MHz downlink. As an example, if we consider the latest spectrum auction prices, if a carrier owned 100 MHz of spectrum in a market such as Chicago, the price per Pop/MHz was about \$6. This translates into about \$100 million for only that market, across the Top 50 markets it translates into approximately \$1-\$3 billion per carrier. In reality, this is a cost of the technology that must also be factored into the total operational cost of the system since it means less network capacity and perhaps the installation of more cell sites to offset the loss in high traffic areas.



Source: "Observed Time Difference of Arrival (OTDOA) Positioning in 3GPP LTE", Sven Fischer, Qualcomm, 2014.



Bandwidth consumed = $1/160 - 6/160$,
or 0.625% - 3.75%

Source: "Observed Time Difference of Arrival (OTDOA) Positioning in 3GPP LTE", Sven Fischer, Qualcomm, 2014.

There are also the ongoing costs of network changes and modifications to take into consideration. Commercial wireless networks are not built and then left alone. There is a near constant addition of full macro, pico, and micro cells sites and Distributed Antenna Systems (DAS). With each site or network modification, the network needs to be recalibrated and OTDOA capabilities retested, and the network database that provides the calculations must then be updated. Further, as more networks move to HetNets and 5G, operators are off-loading their users to Wi-Fi and soon LTE-Unlicensed (LTE-U) in order

to handle the increased demand for broadband services. This too presents an issue, as these Wi-Fi access points are not part of the OTDOA system so will not assist in finding device locations.

Based on the prior CSRIC testing of AFLT, as well as carrier deployment and testing of OTDOA to date (both informal characterizations and formal filings with the FCC as noted above), it does not appear that OTDOA can be expected to achieve accuracy levels in urban areas that are anywhere near the FCC benchmarks, particularly by years five and six. In suburban areas, it is possible that a combination of high-accuracy GPS and lesser-accuracy OTDOA may suffice, particularly if dispatchable location technologies are also deployed aggressively. In urban and dense urban environments, a larger percentage of calls will not be able to use GPS, thus it is unlikely that OTDOA's accuracy performance shortfalls will be able to be overcome. Further, these urban and dense urban areas are the very areas where spectrum and LTE capacity is of greatest value and can least afford to be allocated to location accuracy instead of commercial traffic.

OTDOA Recap

- Added expense per base station over and above usual communications operation to calibrate the equipment and maintain the calibration to achieve baseline location performance.
- Additional cost to build and maintain an accurate database of OTDOA capabilities, including timing and surveyed location (for antenna configurations, cable lengths, and other detailed information for each cell site).
- Allocating expensive LTE spectrum for sub-optimal position location function. In the Top 50 markets alone, OTDOA use of between 0.625 – 3.75 percent of network capacity absorbs spectrum value in the range of \$1-\$3 billion dollars for each carrier. This hits hardest in urban areas where OTDOA is not expected to perform well but also consumes the most valuable spectrum.
- Networks are not static in nature; therefore, constant updates are needed to the OTDOA databases that calculate the location of the emergency caller.
- OTDOA makes no attempt to provide vertical location, regardless of accuracy.
- OTDOA's expected accuracy is unlikely to meet FCC performance benchmarks, at least in urban and dense urban areas, although suburban performance may be acceptable.

Terrestrial Beacon System and Metropolitan Beacon System (TBS and MBS)

The 3GPP standards body is currently completing standards for two different types of Terrestrial Beacon Systems (TBS), targeted specifically at indoor location. The first is radio network-centric and is intended to provide a complement to OTDOA with essentially "location-only" transmitters. Similar to OTDOA, however, this network-centric approach would also use spectrum or network capacity that otherwise would be used for revenue-earning LTE capacity in addition to a whole new network dedicated to location for each carrier. The second approach is a radio network-independent implementation where beacons do not use the sites or spectrum of any cellular or wireless network (essentially an "overlay" network, much like GPS). With standardization through 3GPP, any provider or network operator could deploy its own TBS system on its own dedicated spectrum, or multiple carriers could share a common overlay network.

Currently in the United States, only one TBS operator has deployed using the network-independent approach and it refers to its system as a Metropolitan Beacon System (MBS). MBS operates on its own

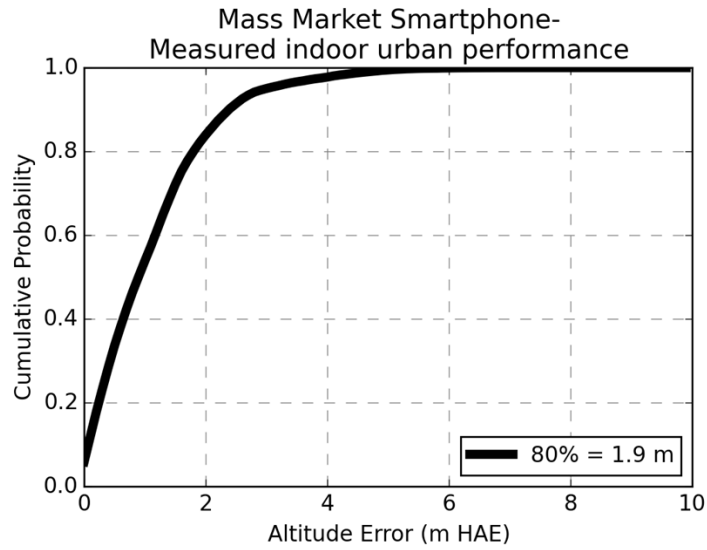
licensed spectrum from dedicated transmitter sites optimized for location accuracy. This system, operated by NextNav, was the system tested in the FCC-sponsored CSRIC tests of late 2012. In those tests, MBS demonstrated relatively high accuracy in indoor environments (under E911 calling conditions) as well as high yield, in all tested morphologies. MBS was also the only technology to have demonstrated “floor” (<3m) level vertical capabilities. Given its hybrid nature, MBS can be deployed to augment GPS (or even OTDOA) in urban areas where FCC accuracy benchmarks will be most difficult to achieve.

In order to understand how MBS/TBS works, it is important to understand how GPS works. There are 24 GPS satellites in the air, and when a device is in the open it will “see” multiple satellites and measure relative timing and distances to determine the location of the device. Provided the GPS receiver in the device sees four or more satellites, a fairly accurate location (in the 10-20m range) can be achieved. MBS works in the same fashion except that the beacons (essentially terrestrial satellites) transmit precisely timed signals from towers that are strategically located around each metropolitan area. Not only are the locations sited to provide the best radio coverage, each one is surveyed and documented to ensure a known horizontal and vertical position. Unlike Wi-Fi or a cellular wireless network that changes over time, once MBS is installed and tested for coverage and timing, it remains in place largely unchanged.

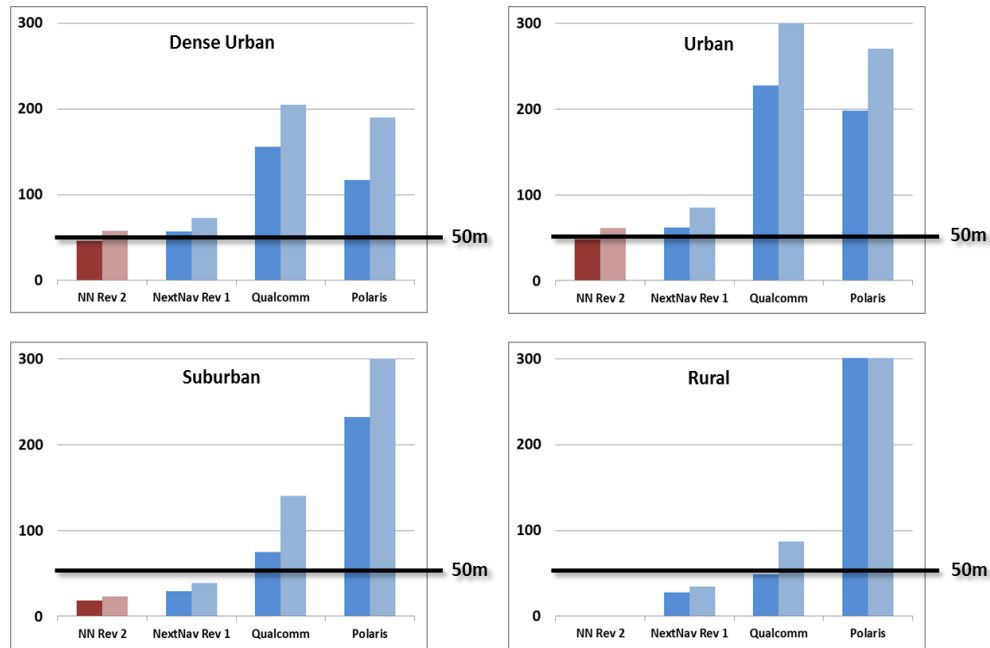
NextNav’s radio beacons are located in the 900-MHz spectrum band, which has good in-building penetration. Each site is surveyed to account for system timing delays (transmitter, connectors, cabling, etc.) to achieve consistent timing accuracy. Overall MBS timing accuracy averages two to three nanoseconds (compared to OTDOA’s 100+ nanoseconds), which is important since each nanosecond of timing differential equates to one foot of location accuracy differential. Each beacon also listens to adjacent beacons to ensure they remain in close timing synchronization. As a managed network, each beacon has redundant transmitters as well as battery backup such that system operation continues during power outage conditions. Unlike GPS (or OTDOA, Wi-Fi, or other location systems), MBS also transmits local weather and barometric calibration information in addition to its location timing and ranging signals. This vertical calibration or compensation data is an inherent part of MBS, and is used by barometric sensors inside receiver handsets to convert raw barometric pressure to vertical altitude.

To support the FCC’s CSRIC trials in 2012, NextNav built out its MBS network in the San Francisco Bay area, and has subsequently been testing MBS location technology with at least one network operator as well as other interested parties. Since the network in the Bay area remains operational, several months ago we were given the opportunity to test-drive NextNav’s MBS. We went to a hotel with a device capable of receiving the signals from the beacons and a tablet showing the layout of the building.

The tests were conducted on the ground floor and on multiple floors while walking down the inner hallways, a really tough area in which to provide coverage. As we walked the halls, down the emergency stairways, and then down the elevator to the ground floor, the system tracked our every move to within a few feet. What surprised us most was that during the elevator ride up and down the device tracked the floors as fast as the elevator was traveling.



Below are some of the test results from the CSRIC tests that were submitted to the FCC. Ongoing tests with network operators are underway and continue to prove out the system and its accuracy.



Technology	Yield by Morphology
MBS Rev. 2	DU: 99%, U: 97%, SUB: 99%
Qualcomm gpsOne	DU: 86%, U: 91%, SUB: 91%
Polaris RF Pattern Matching	100%

It should be noted in the above test results that there are no reported results for NextNav in the rural portion of the test. While test results for rural areas were collected they are not shown here, since MBS technology is not really applicable to rural environments. The FCC's rules require providing vertical accuracy in the top 25 markets by the end of the sixth year, and in the top fifty markets within an eight-year period. Therefore, the FCC understands the need for vertical accuracy is far greater in urban areas than in rural areas of the country.

What Is Needed to Make Use of an MBS Network

Since the MBS network beacons transmit signals that are similar to GPS signals, the baseband and correlators of GPS chips can be used to compute MBS position fixes. Several chip manufacturers are currently modifying their standard GPS chips to incorporate MBS capability, such that dedicated MBS chips are not required to receive an MBS signal. However, NextNav's beacons transmit in the 900-MHz portion of the spectrum, which is not currently employed for GPS. Therefore, incorporation into handsets requires a 900-MHz Radio Frequency (RF) path as well as a compatible GPS chip (or GPS functionality within an LTE or connectivity chip). This process is quite similar to ongoing GPS chipmakers adding additional satellite constellations, such as GLONASS, to their chips. Fortunately, while selecting a compatible GPS chip and ensuring access to a 900-MHz RF path requires engagement and design support from the handset manufacturer, there are minimal handset cost implications (<\$0.25) to the hardware Bill of Materials (BOM).

Once the device is equipped it can be located to within only a few meters (both vertically and horizontally) indoors in urban locations, exceeding the FCC's new rules and providing the level of accuracy long sought by the Public Safety community. As noted, several chip vendors are already adding MBS to their proven GPS Integrated Circuits (ICs) and more are expected to join the MBS effort in the near future. The fact that MBS does require a compliant GPS chip in devices means that once a network operator has chosen to make use of MBS (the network operator does not need to deploy MBS, that is done for them), the network operator does need to ensure that new devices added to their network include MBS-compliant GPS capability.

System Costs

Unlike OTDOA, making use of MBS requires no spectrum or capital investment on the part of a network operator. It does, of course, require a service agreement with NextNav, and at this point we have not attempted to assess the reasonableness of ongoing MBS contractual expenses. However, since this is an "overlay" network and can thus serve all covered carriers from a single network, the more network operators that utilize a common MBS network, the more the overall system cost can be shared among them. Participation by multiple carriers would also drive volume of MBS-compliant chipsets and handsets, thus speeding the reduction of present estimated costs from a few cents per device to virtually nothing as handset volumes increase.

NextNav has been actively engaged with the 3GPP standards body with support from multiple wireless carriers, chipset manufacturers, technology providers, and the broader FCC, E9-1-1, and Public Safety communities. Once standardized and available in compliant GPS chips, the ability of MBS to achieve both vertical and horizontal accuracy benchmarks in the indoor urban environments that are the most difficult makes it an attractive complement to existing GPS capabilities that excel outdoors and in rural and light suburban environments.

MBS Recap

- As an overlay network, wireless carriers do not burden their network operations or RAN modifications and upgrades with timing and location ranging maintenance requirements.
- MBS can meet not only the FCC's horizontal benchmarks in critical urban environments, but also provide vertical location capabilities as an inherent part of the system.
- MBS-compliant GPS chips are required in each device. However, there are commercial GPS chip vendors already offering this option for 2016 delivery.
- Incremental handset costs for MBS capability are currently estimated at pennies per unit, trending to near zero as volumes build in the future.
- The MBS network is static and managed/maintained by the MBS provider, thus minimizing operational changes and recalibration to the RAN network.
- MBS is a carrier-grade managed network, with transmitter redundancy and battery backup, thus providing agreed upon performance assurances to participating carriers.
- Contractual charges for MBS service must be negotiated with the MBS provider, but may be shared between multiple participating carriers.
- When standardized, the Terrestrial Beacon technology will be available under normal IP licensing terms to all parties so the operator can be assured that any capable infrastructure vendor can make the beacon equipment (and any operator could install and maintain an MBS network if desired).

When looking at all of the choices available to meet the new FCC emergency location rules, it would appear to make sense to adopt a technology that does not impact the RAN network, is built and maintained by a known third party, is predictable in performance, and that can already meet the FCC benchmarks, including the vertical requirements for years six and eight. It is also possible that this technology will truly meet the needs of the Public Safety community with no additional expense to the network operator.

Conclusions

Network operators are facing the FCC's escalating performance benchmarks and have sufficient knowledge of the performance attributes of current location technologies (Assisted GPS (A-GPS), GNSS, AFLT, and OTDOA) to know that meeting year five and six horizontal benchmarks in most urban markets is not possible without significant performance improvements from new technology solutions. Even year three benchmarks represent a significant challenge for current technologies in counties or PSAPs with significant urban populations. Some network operators are already deeply involved in testing the various technology options, but regardless of which technology a wireless provider chooses, the decision time is drawing close when financial, system, and device planning must be completed and the chosen technology rolled out in time to meet the deadlines.

While some portion of calls may benefit from new dispatchable location approaches, the voluntary nature of Wi-Fi access point registration makes scaling difficult and even if widely deployed, does not provide the service continuity and reliability normally associated with Public Safety services. Using MBS to augment existing GPS solutions in urban markets does require new handsets to contain MBS-compliant GPS chips, but doing so provides a robust, carrier-grade solution for both horizontal and vertical E911 location requirements, and could provide valuable network and commercial Location-Based Service (LBS) opportunities as well. An MBS solution does not require any internal network

investment for new hardware and/or software and it is not prone to obsolescence due to outdated databases or new cell sites being added and not correctly integrated into the system. While GPS remains the ideal solution for rural and suburban location services, there remains a delay in startup time from a cold start. Verizon and other carriers using CDMA technology (3G) were able to minimize this delay by employing AFLT technology until the GPS locked onto the satellites.

Other than the obvious observation that GPS is provided for free by the government and MBS requires an ongoing service fee, technically, MBS has all of the advantages of the GPS system and none of the drawbacks. There is no wait time before the system is ready to provide location data and it works in urban canyons and deep into buildings as well as outdoors. It has proven to meet the FCC's strictest location requirements and is seen by the Public Safety community as providing the accuracy needed to better protect those who are inside buildings during an incident.

There are a number of technologies vying for a chance to prove they can meet the FCC's new rules. Some may be able to from the start but with no assurance that the database or other hardware and software needed to keep them working will be updated. OTDOA and other on-network solutions add costs to the commercial network both when adding it to the system and in the loss of network bandwidth. Wi-Fi, even with a database, will not be reliable enough to satisfy the FCC's rules in the short term or any new rules required by the Public Safety community in the future.

MBS, in conjunction with GPS/GNSS, is proven to more than meet the requirements now and well into the future. As an overlay network, it is a hands-off type of location service when it comes to network operators having to make sure it stays up and running, and is added into all of the network expansions. NextNav is an off-network, terrestrial GPS system designed for urban canyon and urban building location services. It has been proven to work and it is coming to a network near you soon.

Andrew M. Seybold