Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, D.C. 20554

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In the Matter of	)	
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Wireless E911 Location Accuracy	)	**PS Docket No. 07-114**
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COMMENTS OF iPosi, Inc.

I. INTRODUCTION AND EXECUTIVE SUMMARY

iPosi, Inc. (www.iposi.com) is a private and GNSS/GPS based embedded location and timing technology company based in Denver Colorado with R&D labs in Boulder CO, including facilities at the University of Colorado. iPosi uses advanced signal processing and an embedded soft-core processor to extract extremely weak in-building GPS and GNSS satellite signals. From the iPosi client and network server, the system resolves the host device location and provides a continuous, accurate GPS timing reference to the host in which the iPosi client embeds. The company optimizes its client receivers for long term observations to overcome path distortion and other deleterious effects imposed by the GNSS channel. The solution thus enables highly sensitive, accurate and jam-resistant reception that overcomes the traditional limitations of indoor reception of GPS signals. To implement this solution, the company has developed a unique assistance method that exploits a common IP-Network connection that is a standard interface across all iPosi applications.

iPosi technology aims at solving indoor mobile location in a substantially different way than conventional mobile A-GPS location methods have exercised assistance methods to date. Instead of relying exclusively on location determination by detecting GPS signals in the mobile handset, iPosi instead brings to bear IP network delivered signal processing resources that in turn assist its embedded receivers to detect GPS signals 500-1000 times weaker than present day mobile-assisted GPS which relies on cellular network connectivity. When applied to solving indoor mobile location, the iPosi technology enhances standards-based proximity/cell association, or LTE OTDOA and 802.11 RTT and downlink ranging to work optimally which levers millions of indoor small cells to yield accurate and virtually instant interior mobile

location measurements. This provides handset or network determined locations to accuracies within a few meters in interior enterprise and public venues. These accuracies are also possible due to the relatively short range between the mobile and small cells that are increasingly used in office buildings, hotels, public venues, institutional settings such as hospitals, university campuses and shopping areas.

A. Why Seek an Indoor-Optimized Mobile Positioning and Timing Solution?

Mobile devices are most accurately located in outdoor or lightly obstructed areas using Assisted GPS or Assisted GNSS. Several billion devices use this technology today and is the standard by which all other location methods are compared. Indoor, especially inside buildings is the "last frontier" for mobile location. This is target for substantial commercial location services as well as E911. Outside the US countries with GNSS satellite navigation systems are looking to adopt emergency call systems based on using their respective GNSS perhaps in addition to GPS. This is testament to the power of GNSS and GPS as the primary mobile location method.

Outdoor infrastructure solutions according to the March 2013 CSRIC test bed report results fell short of reaching consistently either 67% or 80% yield for a 50 meter horizontal error. This was also made clear in the expert statements by a CSRIC committee person at the subsequent November 2013 CSRIC regarding the earlier March test report. Further, there are questions of commercial and technical feasibility that leave open how well any "outdoor-in" infrastructure method will handle true in-building location unless those areas are covered using indoor cells that work in unison with outdoor, or are network-grade 802.11 access points.

Two of the methods tested both involve hybrid terrestrial augmentation that use those signals to "in fill" signals in the absence of sufficiently strong indoor *mobile* A-GPS signals. One (AFLT) augmentation used the existing CDMA communication signals while the other used prototype purpose-built 900MHz terrestrial signals transmitted from beacons operating in a shared licensed/unlicensed band. The former method is already implemented in CDMA legacy handsets while the latter requires modification to mobile devices, a step which experts opine will take time to incorporate, perhaps years to implement broadly. These terrestrial augmentations are designed to provide additional power to penetrate buildings to assure the mobile can directly "hear" signals with sufficient level to yield a precise mobile location fix within the FCC OET 71 prescribed guideline of 30 seconds.

The findings of the CSRIC test were conclusive enough to question how much more outside infrastructure solutions can actually improve indoor location performance. Even granting more infrastructure deployment, such as more outdoor TDOA LMUs or micro/macro cells, limits exist that are not solely addressed by delivering more power relative to GPS signal power.

Aside from significant economic constraints these choices impose, outdoor cell towers (whose signals often traverse 500 to 5000 meters over or around urban/suburban terrain) face fundamental limits to deliver indoor mobile location accuracy due primarily to radio signal diffraction and multipath reflections. The ranging-signal sources are fixed, and thus one cannot reduce path errors without more terrestrial infrastructure beacons, unless one removes surrounding radio obstructions. There is also a controversy regarding the advantage of a separate, dedicated signal-ranging "overlay" solution compared to a similar downlink method

offered in forthcoming release of LTE OTDOA. The solution is a principled design and has precedent in GPS pseudolite and other commercial terrestrial augmentation location methods. The company proposing this method also deserves credit for showing via the CSRIC test bed the promise of vertical location by incorporating barometric sensors in both wireless infrastructure and mobile devices to address indoor vertical location determination. However, while the purpose-built method could theoretically provide a competitive alternative should OTDOA face delay, both require updating subscriber handsets in the final analysis. OTDOA is a global, standards-based downlink ranging technology that (as our analysis herein shows) also offers higher range-signal bandwidth to reduce certain multipath effects[1]; it uses a similar transmission power to the communication signals and avoids sharing the 900MHz band with legacy unlicensed systems that pose some interference risk.

Instead of attempting to resolve location exclusively within the mobile device, we seek to enhance and exploit the Small Cells migration and continue the current platforms of GPS-location and synchronization, exploiting a diverse set of current and future indoor wireless infrastructures incorporating GNSS/GPS, 802.11v and subsequent network synchronism, as well as LTE and LTE/OTDOA global technology standards. This approach reduces commercial time to market concerns which relate to among other things, avoidance of requiring specially modified handsets. It is also targeted to work optimally indoors, and is cost effective. Further, over the past 9 years there has been substantial growth in GNSS, which is anchored on GPS. There was in 2005 only GPS with 25 satellites and one civilian accessible signal, there are today over 60

[1] However, outdoor methods employing static transmission sites cannot eliminate multipath simply by increasing range-signal bandwidth, and are still subject to diffractive path elongation that are common in terrestrial wireless.

GNSS signals and will soon grow to over 100 satellite vehicles bearing in aggregate 300 civilian accessible signals. At virtually any point on Earth satellite sky-visibility is 4 or more times what it was a few years ago, and this important factor continues to increase.

This satellite-based feature creates more geometric diversity between the infrastructure Small Cells thus reduces terrestrial path reflection/diffraction elongation limitations to a high degree. Further, the iPosi solution exploits delivery of a continuously moving GNSS satellite signal set to enhance system availability, accuracy and reliability.

The iPosi solution works with existing GNSS, and terrestrial communication and mobile location industry standards such as SUPL and 3GPP LTE. To enhance delivery of mobile positioning inside buildings, iPosi technology enhances at least three standards-based mobile positioning methods: station almanac based cell proximity/association, LTE Release 9 featuring mobile downlink OTDOA ranging, and within the unlicensed domain, 802.11 round trip or downlink (e.g., 802.11v) time-of-flight options. The latter two categories of range-based methods use iPosi Small Cell time and local network synchronism. The cell association method is accurate for many purposes in either single cell deployment cases, or simply where the mobile is so close that proximity/association provides the more accurate solution.

Applying iPosi GNSS/GPS signal processing, the company has demonstrated vertical GNSS/GPS accuracy error levels into Small Cell nodes inside challenging building environments to less than three meters allowing a sufficient number of measurements to occur within a day or so of initial cell installation. Since the Small Cells are stationary and networked, this small error provides a source of independent elevation calibration to continuously reference and counteract barometric MEMs sensor drift (which can reach tens of meters) and ultimately calibrate nearby

mobiles whether on the same, or adjacent floors. Fusing GNSS capability with a built-in inexpensive mobile-grade barometric sensor into the Small Cell can provide enough accuracy to meet the FCC's proposed 3-meter vertical accuracy requirement, and will serves as an important improvement to general, everyday indoor location services or applications.

B. Small Cell Market and as a Pervasive Platform for Indoor Location

Accurate indoor location and synchronous timing at indoor Small Cells (also referred to as Pico- or Femtocells and Carrier Grade or Enterprise Grade WiFi) are already required by both current and coming generations of Small Cells. The vast majority of Small Cell installations occur indoors. 4G LTE Small Cell commercial launch is underway, and most Small Cells produced going forward, will be based on either or both WiFi and LTE/LTE-A. Enterprises will deploy both in many cases, including ultra-high bandwidth dual band WiFi (2.4 and 5GHz) to increase spectrum capacity with the least cost.

There are currently more than 4 M licensed spectrum Small Cells deployed, and another five million plus enterprise/institutional grade WiFi Small Cells are added each year. The combined market has evolved beyond a threshold of acceptance, and is now proceeding toward upgrading indoor communication density and coverage offering more quality control indoors by enterprise and consumers as the ultimate CMRS end-users. Density increases in Small Cell support leads to more devices and greater bandwidth usage that will stimulate new services such as indoor location. 95% of Small Cells are estimated to be deployed indoors, and consumer demand stems from offering distinct service improvements (including location services) relative to pure outdoor macro/microcellular networks. Small Cells also complement alternative indoor

infrastructure such as DAS and work with conventional outdoor infrastructure to provide seamless mobile bandwidth and location.

For these and other reasons we propose in this response to this NPRM that Small Cells be considered as the primary tool to deliver accurate indoor mobile E911 location. Logically, Small Cells go where the demand for indoor service is high, and subscribers are plentiful, thus is the economically most efficient way to cover where indoor E911 calls are likely to happen. We submit that the FCC can best advance broad adoption by building owners and occupants of high accuracy location-capable Small Cells by making 3D location capability into Small Cell equipment an FCC type acceptance criterion. Most small cells already require GNSS/GPS timing and thus offer a low, incremental cost solution to also support accurate indoor E911 location, including calibrating accurate mobile barometric pressure for accurate vertical z-axis location.

The NPRM asks for broad and specific comments or answers on a variety of indoor location topics across policy, technical feasibility, cost, and timely delivery of indoor location technology.

Among the broader conclusions we set forth: mobile indoor location accuracy of +/-50m 80% is feasible, and vertical accuracy of +/-3m 80% is tenable using close tolerance design methods, *provided in both cases* Small Cell systems are supported by iPosi technology. The iPosi technology enables location and precise timing for each Cell, and also provides GNSS/GPS-grade precise timing to extend precise mobile ranging indoors to determine mobile location. This solution is described in detail later. This approach is scalable in that it can be installed in virtually any kind of building, in any rural to dense urban area or region, and earlier

generations are today installed in a large numbers of US buildings. Forecasting any extent of indoor coverage is dependent on many factors, but we can state categorically that the FCC's goal of reaching highest accuracy standards within 5 years is consistent with global Small Cell deployment trends, opening of new spectrum bands for Small Cell systems by the FCC and its international counterparts, the availability of new location standards such as OTDOA Release 9 that provide indoor mobile location for commercial applications, and customer acceptance of Small Cell networks provided they are simple and inexpensive to install.

II. The Commission Should Mandate 50 meter horizontal accuracy with 80% yield over a 5 year time period and incorporate this as part of its equipment type acceptance criteria

The Commission in this NPRM reported location accuracy results of CSRIC that were questionable though encouraging all parties to meet a 50m/80% (by the 5th year) horizontal accuracy compliance requirement. They also reported that "The *CSRIC Indoor Location Test Bed Report* observed that all three vendors participating in the test bed were in the process of making improvements to their location technologies." The NPRM also states "Verizon notes that '*indoor small cell deployments, WLAN location information, and hotspot or femtocell technologies, all of which can be designed with a very small coverage area, have the potential to provide very accurate location information*'". The iPosi technology, which embeds into Small Cells, can solve the problem of limited accuracy indoors for horizontal and vertical position.

A. Horizontal 50m Indoor Accuracy with 80% Yield is Achievable

iPosi provides an IP network assisted GPS/GNSS receiver that achieves -175dBm sensitivity for fixed devices substantially beyond current autonomous and assisted GPS receiver technology. The extreme sensitivity accounts for up to nearly 50 dB of building loss and is provided through long integration methods and which requires comprehensive GPS assistance. This technology achieves horizontal fixed location accuracy of 5 m and an RMS, or 67%, and for more challenging cases is within 20 meters. Further detail is presented in the technical report section below based on both simulations and actual in-building experimental data results. The simplest and most direct way to use this for mobile device location is to use it in conjunction with a small cell. The iPosi technology when embedded in Small Cells will autonomously, without user or installer intervention, locate the small cell.

As the Commission reports Verizon in an earlier proceeding, once a mobile device is associated with the small cell due to its known proximity, it can report with low error the mobile location based on adopting the same location as the Small Cell. Since enterprise and public venue Small Cells are conventionally placed 60 m apart (even closer according to industry sources), the location uncertainty becomes the sum of the location error of the small cell and coverage range of the small cell to the mobile [c.f. Tech report ref 2]. One caveat is the case where the indoor mobile may not be served by the nearest small cell but, as seen in the report, this is actually a relatively small issue. In Section 6, we show that for 60 m inter-cell separation, the 80% of error is still less than 46 m using *only* proximity/association; the probability for 35m separation is well within 100% yield with horizontal error <50m.

Therefore we conclude from our work including the analyses below that the Commission can rationally expect indoor horizontal position error to be <50m for 80% yield within a 5 year

time frame provided it make this requirement in locales served by Small Cell systems, and that it effect 3D location capability through mandating it as part of a small cell equipment type acceptance process.

B. Indoor Cell LTE OTDOA enabled with iPosi technology improves accuracy

In the NPRM it was noted by the Commission:

"Finally providers assert that the deployment of LTE networks will be accompanied by improvements in location technology that could drive improved performance for both indoor and outdoor calls, but they also express concern about whether they can realistically meet the proposed requirements based on currently available technology."

In the iPosi technical report we also show how a located LTE small cell can provide LTE OTDOA location accuracy improvement once located by iPosi. In this scenario once the small cells are autonomously located, they can be used to provide the LTE OTDOA ranging signals using the PRS (positioning ranging signal) exactly how it is done outdoors today. In the report section 7, we provide an analysis which demonstrates that the expected performance is within 20 m uncertainty for (relatively conservative) 60m inter-cell separation environments.

III. Network, Small Cell Implementation Costs and Handset Modification

A. Network upgrade dependencies

The NPRM seeks comments on the cost and difficulty of upgrade of an indoor network to accommodate new location technology.

The technology proposed by iPosi requires a small cell network, typically an LTE/WCDMA dual mode small cell device, or a WiFi device. Some experts opine these technologies will fuse into integrated devices to aggregate or bond RF channels between the LTE and 802.11 based technologies. We current reference our network profile and cost based on a baseline Small Cell LTE architecture.

As the Commission is no doubt aware, LTE is designed to be a synchronized network and uses either FDD or TDD access to provide the highest available wireless access network throughput and highest spectrum efficiency. LTE FDD cells require time synchronism within 1.5 µsec to 0.5µsec (the latter is LTE-A, and supports carrier aggregation). To meet this timing performance, fixed broadband operators involved with back hauling small cell traffic must install both expensive and time consuming infrastructure upgrades in order to reach the 1.5 usec time or phase accuracy transfer objective. Equipment suppliers in discussion with iPosi believe these methods are ultimately growth constraining in that they are expensive, time consuming, some involving external timing references or separate GPS rooftop antennas. Finally, the wireless operators deploying Small Cells seek service level agreements regarding warranted levels of "over the top" network delivered synchronization performance which the fixed operators are not prepared or equipped to sign. Their networks are continuously increasing performance but also accept traffic that systematically is also more asymmetrical thus requires more intermediate network elements to compensate in the timing solution just to warrant strict performance criteria.

Many Small Cells today are also equipped with some GPS capability to address E911 or eliminate the cited-above packet synchronization dependencies. However, these use modules that are barely better than autonomous (non-assisted) GPS. Exemplary versions of these Small

Cells today provide an external cable and GPS antenna in case the end-subscriber is unable to get the GPS to sync, and thus could place an external GPS by a window. This presents an installation burden on customers and to operators seeking a more "plug and play" Small Cell deployment solution.

For enterprises, and only in cases where the building owner makes roof and vertical riser access available, the alternative of roof-top antenna installations can add $1,500-3,500 plus potential site lease charges.

By contrast, iPosi operates an assistance network using a much more tolerant grade of packet synchronism with tolerances between hundreds to thousands of microsecond time transfer precision to acquire then transfer very fine time from GNSS. Further, this is only required during a relatively brief period (a few seconds to minutes) to acquire the first fix to launch the iPosi client. Thus unlike maintaining a continuous packet synchronism service, the iPosi method uses less fixed (back haul) network resources and avoids onerous SLAs.

B. Small Cell Location and Synchronization: Incremental Cost Approach

The NPRM seeks cost analysis for the new location technology.

Since consumer small cell devices by mandate already have a GPS receiver, some with external antennas, the iPosi assisted solution provides a higher performance solution cost at similar or lower cost. The iPosi embedded small solution is equivalent in hardware to a self-contained GPS device because both an iPosi GPS receiver, and a standalone GPS receiver have a GPS RF front-end and a baseband signal processor usually containing hardware correlators.

C. No Mobile Device Hardware Modification Required

The NPRM seeks responses on requirements to modify mobile devices in order to enable new location technology. There is no hardware change needed to assume the Small Cell location using the proximity/association method. Location by association is actually done today in handsets through database look-ups off WiFi SSID's. The location uncertainty is higher, since this technique in essence forms a circular area the radius of which can be varied to reduce uncertainty by estimating range using received signal strength (RSSI). As presented later in this report indoor proximity/association is accurate to meet the FCC horizontal accuracy based on developing an automated and monitored location fix for fixed devices relying on location by association.

For more precise indoor location, 4G LTE handsets have or will have LTE OTDOA location enabled though one must expect a handset changeover process not dissimilar to Phase II A-GPS. However, there is no additional costs we are aware of allocated to LTE OTDOA and is expected to be used generally, not only for use with small cells.

Handset OTDOA capability consists of upgraded software thus is less invasive than mobile hardware modifications.

D. Mobile Time to First Fix (TTFF)

iPosi's assisted GPS/GNSS is a relatively fast time to initial or first fix within a few seconds to minutes at threshold sensitivity environments. It then will continue and take another 24-48 hours operating in the background to reach optimal accuracy after first installation. Accuracy transfers to the mobile position using the base to mobile solutions discussed herein.

As shown in the technical report section, the fixed location solution is able to continue improving over a few days even in the most obscured in-building sites. Given that the host device position is fixed it can be periodically refined or updated as a background task to prioritize host processing resources optimally. This location is fixed and known by the iPosi server available to the mobile or any other participating network location entity or client, or trusted E911 database. Thus no time is added to locate the mobile and, in the case of location by association, no ranging and location measurements are required. The initial OTDOA ranging process is sub-second, and can be extended to provide a real time update during the call. Thus time to access the E911 caller location for mobiles in these Small Cell environments will typically be faster compared to outdoor positions.

IV. 3m vertical accuracy at 80% is achievable within 5 years

A. Enhanced 3D Indoor Location by Small Cell and GNSS/GPS/Barometric Hybrid Methods

We support in principle the Commission's proposal to achieve a +/-3 meter vertical accuracy standard within 5 years with 80% yield. +/- 3 meter vertical accuracy is the more difficult to achieve due to factors set forth elsewhere in this Comment. Therefore, we urge the Commission not to mandate a set timeframe for compliance until more field testing is performed to establish broad, realistic vertical performance and related yield statistics. As with horizontal accuracy standards, we again urge the Commission to mandate the vertical accuracy standard as part of its type acceptance process for Small Cells.

Often stated in the record, most buildings are constructed having 3 to 4m elevation between floors which sets a desired upper bound distance on the z-axis error tolerance. We

would recommend that this mandate contemplate a programmed offset elevation factor to take into account the difference between a ceiling mounted small cell (about 2.75m above floor) and the mobile (1.5m above the floor or ground is a common reference) to enhance system accuracy. We would also note that the 3-meter criterion expresses an error from the true elevation, thus the error allows a 6 meter elevation width from an assumed 1.5m caller elevation. Thus it is possible to have plus or minus one adjacent floors be reported with a 3 meter error tolerance.

An important premise for setting forth a 3 meter specification stems from the testing in one urban CSRIC test bed building over two days. This deserves further examination in light of the many factors that affect vertical accuracy when examining the use of barometric pressure sensing across millions of US buildings, widely varying climate and interior building conditions.

Such a review requires analysis of the accuracy of available commercial grade mobile sensors, and the accuracy limitations imposed by transferring pressure references from broadly available outdoor sites or stations to use to calibrate mobiles located indoors. There is also need to have a reliable elevation reference independent of barometric sensing that is automated, to verify (or informally, a "sanity check") the reported interior small cell and E911 caller mobile elevation as well as provide measurement uncertainty limits. Finally, there should be call record provisions to enter where building owners seek it the floor number or other designation.

B. Vertical Accuracy of Barometric Sensors

High quality, low cost MEMs based sensors now are in major brands of mobile devices and can provide excellent relative accuracy (that is, the on-board sensor can accurately detect a change in mobile elevation with precise of less than a meter). We are aware of at least three

brands of MEMs based sensors designed or targeted to work in mobile devices and mobile network equipment.

C. System Error Budget: MEMs Barometric Sensor Accuracy Requirements

To assess feasibility of a 3 meter vertical error requirement, we gathered and tabulated information from three major semiconductor vendors' relative and absolute accuracy performance based on their published sensor datasheets. Only one, Vendor B, appears to offer a grade of absolute error that does not exceed the Commission's proposed 3 meter vertical error, but we note even this low absolute error value virtually exhausts the 3 meter error budget, a budget that must include other sensor accuracy and indoor air-column effects discussed later.

We evaluated two cases, where both mobile and fixed station both use the same higher performance sensor (since both are indoors, they can each achieve least error) as well as assess cases when the mobile and calibration station use different performing sensors. Since two of the three devices have absolute error values of 1.0 to 1.2 hPa, which represents the equivalent of an 8.3 to 10m elevation error, thus neither of these in their current form can support a 3 meter error tolerance without further compensation or refinement. Therefore, the only case left is to analyze both mobile and indoor reference station's use of the Vendor B sensor (or any other with same grade of accuracy).

Using Vendor B's performance figures, we calculate that the combined error for absolute error impact for the two mobile and station barometric sensors will be 3 meters for an 80% vertical accuracy yield. However, reaching this stringent error tolerance also requires that both sensors

have exposure to the same interior vertical air-column, a design factor covered below in more detail.

Table: Commercial MEMs Barometric Sensor Relative and Absolute Errors

	Relative Error (Vendor datasheet)	Absolute Error (Vendor Datasheet)
Vendor A	0.12 hPa	1.2 hPa
Vendor B	0.10	1.0 (0-80 C) 0.2 (20-60 C)
Vendor C	0.15	1.0

Note: 1.2hPa error is equivalent to a 10m elevation error at sea level

D. Challenges of Calibrating Barometric Altitude from Outside Major Buildings

Methods have been proposed and limited test bed results were made using barometric pressure sensing referenced in the Vertical Location Information section of the subject Location Accuracy NPRM[2]. One company participating in the CSRIC Test Bed evaluated a mobile test prototype and then externally calibrated the mobile sensor by using their proprietary barometric reference stations which also provided 2D range signals. The test process used a relatively time-constrained route starting at the building entry then ascended or descended across several floors. It is presumed that updates were made within the prototype mobile device as it ascended or descended during the run, which is a testament to the *relative* accuracy of MEMs sensors. Further, though we cannot say with certainty the test appears to invoke self-calibration at the point of physical entry into the building. The test then took two routes over two consecutive days

[2] Paragraphs 71, 73, 74 introduce barometric sensing to obtain z-axis elevation in mobile devices

and reported errors to within 2.9 meters for 90% yield of all test samples of interior vertical measurements.

We believe as a threshold case, the CSRIC test was fair for relatively benign climatic environment case and for a limited mobile use-case, that is, the mobile subscriber took a confined route for relatively limited time. We wondered if the CSRIC reported results will support a more general use-case where mobile subscribe might enter the building several hours before an E911 call might be made. Does this not require all mobiles to continuously calibrate? We also did not see consideration given to cases where or when there are differences between indoor and outdoor barometric pressure which could be substantial relative to the 3 meter error budget and cannot be "calibrated out" without an interior, same or adjacent floor pressure reference.

Also to be considered in tight tolerance design is an error factor that arises when two same or different make sensors perceive different responses to identical measurement stimuli (i.e., the term "make tolerance(s)"). Some commercial MEMs sensors according to data sheets and our tests could register as much as 10-20 meters variation even though both are responding to the same ambient pressure.

For 3 meter close tolerance design, we also submit for public safety and other reasons a need for an independent elevation measurement and integrity tests to ensure calibration remains true to the changing indoor environment. Such a capability could be implemented within Enterprise grade Small Cell networks that offer redundant sensors across Small Cells occupying the same floor, thus all at a common elevation.

Finally, given the Commission's latest vertical accuracy proposal premised on the test bed indeed one building, we also wondered if the 3 meter error can be realized in climates not represented by the San Francisco test bed. If a distinct interior/exterior air-column effects exist they potentially are to different degrees depending on climate or building type. This could induce a unique vertical measurement error that (in combination with the sensor errors discussed above) adds uncertainty to the overall vertical error budget.

Turning first to available industry reports, we found that researchers recently evaluated mobile barometric MEMs sensor technology for its use in mobile environmental and user behavior intelligence, including reduced motion artifacts and floor and floor-change detection[3]. This research reports that conditions prevalent in modern higher rise buildings will have substantial pressure differences and thus impact accuracy limits necessary to maintain the 3 meter objective. Simply put, when the calibration pressure reference transfers from a source outside the building, it is only accurately referenced if the mobile seeking calibration is also outside and is exposed to the same air environment.

In this technical report, the researchers took interior measurements across seven buildings in Singapore to investigate barometric sensor usage for a variety of user behavior and intelligence applications. Over several consecutive days they observed Singaporean building interior pressure difference of 3 to 4 hPa (equivalent to about 24 to 32 meter variation) that almost uniformly repeated over daily periods using stationary mobiles with different makes of

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[3] Muralidharan et al, "Barometric Phone Sensors – More Hype than Hope!", ACM HotMobile' 14, February 26-27, 2014, Santa Barbara, CA, ACM 978-1-4503-2742-8.

barometric sensors. An excerpt[4] of their findings regarding interior environmental conditions and technical observations follows:

> "We expect the use of the barometer for indoor height/floor estimation to be a non-obvious exercise, principally because indoor environments have several distinct artifacts that we do not observe outdoors. In particular, we can envision the following artifacts:
>
> - Buildings are often pressurized and climate controlled (more specifically, in the context of Singapore, air-conditioned). As a consequence, we expect the humidity and temperature indoors to be quite distinct from that outdoors. Also, the pressure-gradient indoors may not follow a simple relationship, as the building pressure on different floors may be regulated by different air-conditioning units or controllers.
> - The floor heights of buildings are typically in the range 2.5- 6.0 meters, which may be well within the range of measurement error of the smartphone-embedded barometer sensor. So, while a 20 meter variation in height estimation may be inconsequential for GPS, it may translate into an error of 8 or more floors inside a building.
> - The floor heights of buildings are not only different, but are non-uniform (even within the same building). In particular, our empirical studies showed that the heights of lower level floors (notably the entrance lobby) are often larger, and even the heights of otherwise homogeneous floors (e.g., the 4th and 5th floors of a campus building) show unexpected construction-specific artifacts."

To evaluate generality of the researchers' claims, we sought relevant building environmental engineering sources -- principally ones from North America so as to have similar climate and construction -- for guidance on in-building pressure differentials relative to outdoor pressure barometric pressure.

E. Pressure Differentials in- and outside Interior-Sealed Buildings

[4] Ibid, page 2.

The N. American research[5][6] from building environmental design and engineering firms reveal that in-building air pressure differences do vary and depart substantially from the outside pressure despite standing at the same elevation. This is primarily due to the nature of modern building design which forms an environmentally sealed shell, thus insulating temperature and humidity from the outdoors. This appears to be a consistent practice across many modern US urban and suburban structures. Based on these environmental engineering reports pressure differences can vary across just a few adjacent floors[7] as well as between the vertical span of lower to upper floors. Pressure difference factors take into account the height of the building, thermally induced "stack effects", climate, HVAC air-handling distribution and outlet points, fire/smoke system ventilation design to name some of the factors cited.

In one of the reports, starting without wind pressure effects, 16-60 story buildings were modeled and reported interior air pressure in-to-outdoor difference reaching 0.95 inches[8] of water relative to outdoor pressure (equivalent to a +/- 8 meters altitude error) if the calibration reference were outdoor and outside the interior air-column while the mobile seeking accurate vertical measurement is inside.

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[5] Jayalerian, M., PE, Executive Vice President of Environmental System Design, "High Rise Building Air Pressure, Infiltration & Stack Effect Theory and Impact on Indoor Environment", presentation at 2012 Spring Seminar Chicago Committee on High Rise Buildings, June 14, 2012. Link: http://cchrb.homestead.com/Members/Presentations/2012_Seminar_Jalayerian.pdf

[6] Quirouette, R., "Air Pressure and the Building Envelope", 2004, retrieved March, 2014, link: http://www.cmhc.ca/en/inpr/bude/himu/coedar/upload/Air-Pressure-and-the-Building-Envelope.pdf

[7] Jayalerian, page 31 is one example

[8] Jayalerian, page 7

When general climatic impact conditions are taken into account, even a relatively modest 15 MPH wind force can further raise differential pressure gradients and induce an error of 1.4 inches of water[9], equivalent to 33 m elevation for a 60-story building. Similar effects and errors are seen in that study's modeled buildings which consider structures starting at 16 stories[10].

Aggregating the immediately available research, it appears safe to say there is substantial evidence that unless interior reference stations that are best incorporated into Small Cells are deployed the 3-meter vertical accuracy will be unattainable across many modern high-rise buildings.

We propound elsewhere that interior pressure sensing should be a type acceptance criterion and incorporated into Small Cell devices. This would have benefit to customers, operators, equipment producers and best meets the Commission's intended regulatory aims.

1. Elevation Calibration Solutions: Promise of GNSS Measurements for Interior Building Elevation and Barometric Sensor References

To achieve a vertical elevation reference, we propose that the GPS/GNSS be used as a primary or co-primary reference alongside manually-entered floor designation value (e.g., "Floor Number 6") to cross-reference elevation of the interior calibration function located in Small Cell devices. In our technical report in section 6.1 we presented simulations of GPS signals with all signals precisely at a uniform, worst case threshold power of -175dBm. This simulation resulted

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[9] Jayalerian, page 8

[10] Jayalerian, page 29

in a vertical error of <3m for 80% of the trials after 20 days of measurements using the iPosi design.

To obtain results in actual field cases, we conducted extensive vertical measurements in the Engineering Center complex on the campus of the University of Colorado which has similar if not more challenging conditions compared to urban or suburban buildings. To establish ground truths, we verify the elevation using accurate GPS survey instrument taken from the roof and transferred using laser ranging finding into test points within the building. Significantly, our measured results in Section 6.2, Figure 12 showed in the Engineering Complex at the University of Colorado underground basement that the vertical accuracy error is within 1 m after 25 hours of cumulative server-processed measurements and observation time. In the lecture room on the top floor, (a less difficult location) the results are shown in section 5.2, Figure 15 the vertical error is 1 m within 31 hours.

In both cases of basement and lecture room readings, the iPosi solution offers improved indoor accuracy. While there can be in certain indoor areas limit to the attainable accuracy, the 3m goal appears tenable or promising based on tests to date though requiring 5-10 days of Cell post installation time to process observations.

The company is in the process of entering the CSRIC test bed and plans in conjunction with the work group to develop a test plan and protocol suitable for Small Cell based measurements that then transfer or provide multi-lateralization position measurements to indoor mobiles.

V. Specific, Selected NPRM Questions and Comments

A. iPosi supports Interim Milestones for Accuracy Yield, but the Commission's Proposed Timeline is Likely Too Aggressive to Fairly Meet All Stakeholders' Requirements

The FCC asks comments on the time frame for transition between the 67%-tile and 80 %-tile for horizontal and vertical accuracy yield standards. This appears to be part of a larger question balancing urgency to deploy against ensuring what is deployed is effective.

iPosi believes that the time frames proposed of 2 years to increase yield from 67% to 80% for horizontal, and for vertical escalate in the same fashion at 3 years is structurally a good approach by building an interim, progressive milestone. However, the timeframes are both very aggressive given a number of program management interests and issues ranging from Test Bed administration to compliance standards to work through across a large equipment and services eco-system. This FCC's approach positively recognizes that the technologies will improve over time; it gives all involved parties time for adoption of new technology to mature. These positive factors outweigh time for the sake of time and 2 years to implement when looking at the Phase II compliance experience may likely too tight.

B. iPosi supports setting an indoor long term accuracy requirement

The FCC asks for comments on "…replacing the current handset- and network-based accuracy requirements". The NPRM states "We also seek comment on how to formulate a long-term requirement with an increased degree of location accuracy, sufficient to identify the caller's specific address, floor level, and suite/room number within a building."

The question and background is understandable, but iPosi believes that identifying individual suite or room numbers and cubicle or booth numbers will be virtually impossible to manage on a large scale. Room or cubicle "move/add/changes" are very transitory since these change often with the needs of the building floor tenants, new tenants or owners whose continuous cooperation would be a critical to ensure a high quality and always current floor map. This poses serious IT challenges.

We do believe more permanent information references such as the building address, floor count and other permanent information is helpful to locating victims unable to reliably self-report their position.

We would also suggest that once inside the building, technology exists to lever the Small Cell networks that allows first responders in emergencies to also access the same network and location assets (akin somewhat to an authentication or access subscriber white list). This enables the same Small Cell network that functions and locates on behalf of the mobile caller to function and locate the responder within the same environment thus guide the responder toward the E911 caller's position without needing precise floor maps. This method provides an intelligent way to connect and correlate the radio and sensor based position information from the E911 mobile to the responder's own intelligent device, both operating in the same radio network environment.

This could be developed as an on-screen application to electronically direct responders to the caller's position in cases where the caller is not be discovered immediately. This electronic method of connecting on the floor-wide network provides guidance independent of physical floor map or layout to potentially hasten rescue.

Such an approach is enabled by gathering and comparing the same 3D location references as the caller's device used to report position and using the same network, cells and ranging helps locate by following direction based on a heading formed between the first responder and the caller coordinates.

This also applies to ensuring the right floor by referencing the Small Cell vertical sensor and correlating that with the responder's intelligent device also with a similar sensor to form a differential measurement comparison that reveals how close and how to get closer to the E911 caller efficiently and without strict interior map dependencies.

C. iPosi Supports Nationwide Standard Indoor Location Accuracy

The FCC proposes that the location requirement be set to a common standard nationwide, just as citizens expect all location, navigation systems to act regardless of region. iPosi agrees there may be important variations between rural and dense urban structures that warrant flexibility in certain adoption timelines. However, building interiors where ever they are seem to be relatively consistent across virtually all jurisdictions, and morphologies. Applying in-building networks consists of relatively similar radio illumination and coverage principles, thus again Small Cells can provide a high quality and uniform approach benefitting all jurisdictions and end-users in those different jurisdictions who tend to expect modernity over regional variations.

D. iPosi Supports a Representative Test Bed and leads to Inputs for FCC Type Acceptance Standards

The FCC asks "…we propose the institutionalization of an indoor location accuracy test

bed for purposes of demonstrating compliance with these requirements and ask about other approaches to validating compliance." At the same time, in Paragraph 97, the NPRM also recognizes that CSRIC is developing a test bed not currently intended to create certification.

iPosi believes that the location accuracy technology should become part of indoor deployed Small Cell acceptance procedures, adding to the current type acceptance of these devices today. To this end, the CSRIC test bed provides engineering level criteria and important input to generate certification and test specifications used in equipment type acceptance.

There is need to diversify the CSRIC test bed to include indoor based location technology and Small Cell platforms in which the location technology embeds.

We also believe that the test bed should be controlled to be ensure that the equipment or systems tested scale in the same fashion they are tested.

Given the reality of a fixed set of known building sites in the CSRIC test bed almost any location technology of interest could be "tuned" to work optimally in those particular selected test sites. Whether tuned or not, it is important to ensure that the resources that met the performance criteria in the test bed are deployed to the same extent elsewhere to ensure test bed results are representative.

E. iPosi supports use of small cells as the Primary Solution for Indoor Location

In paragraph 64, the FCC asks comments "…would provide incentives to providers to leverage existing investments in implementing technologies in the near-term

to facilitate their efforts to meet a long-term accuracy requirement?"

iPosi believes this question requires several parts that all work together. First, Small Cell platforms provide with suitable 3D technology built in can provide all the key elements to host indoor location solutions, across both licensed and unlicensed, and new shared spectrum services contemplated in the upcoming 3.5 GHz shared spectrum proceeding. Small Cells are an emerging low cost method of improving cellular and wireless coverage for general indoor environments and provides increased subscriber density using increasing data rate services, and location. The small cells are a natural avenue to providing indoor location taking advantage of their high signal strengths and the existence of the LTE OTDOA standard.

Second, this equipment is increasingly demanded by wireless subscribers and is installed increasingly under the control of those subscribers who uses these systems daily on their own property. Therefore, wireless subscribers in effect have at least some and could be argued dominate control over the grade of location accuracy based on their decision to purchase qualified or certified wireless access network equipment for their buildings or offices. This suggests they, not the operators are in charge of location accuracy deployment decisions. This presumes that the CMRS entities offer network compatible equipment capable of meeting the FCC indoor location requirements.

F. iPosi Supports a Fair "Trigger" and Continuous Improvement Concepts

The FCC seeks in paragraph 60 comments "regarding alternatives to using the effective date of rules as the trigger for the timeline to comply with proposed indoor location accuracy

requirements. For example, to address potential uncertainty in the development of technology, should we consider initiating the compliance timeline only after the test bed administrator certifies that a technology has met the proposed accuracy standards in the test bed?"

iPosi recommends developing test bed rules to ensure continuous improvement and innovation in location technology and is a process that avoids discriminating or exclude new technology entrants from access to the bed resources.

If required to obtain commercial adoption through a Test Bed gaited Type Acceptance process, iPosi also believes there be ensured fair access to related wireless operator network resources related to the same CSRIC type test bed testing process, or network resources remote from the test bed that are used to otherwise perform compliance or certification tests. In our experience these steps can consume much time given the limited time that is the premise or implication of the trigger question. These and other related steps ensure that any new entrant is treated fairly in obtaining a route to commercial acceptance.

Respectfully submitted,

iPosi, Inc.

By:__/s/_____

Richard Lee

CEO and President
iPosi Inc.
1127 Auraria Parkway
Suite 604
Denver
Colorado
303 475 2493

By:__/s/_____

Christopher N. Kurby

Sr. Vice President of Engineering
iPosi Inc.
1127 Auraria Parkway
Suite 604
Denver
Colorado
630 347 9102

Dr. Eric Derbez

Chief GPS architect
iPosi Inc.
1127 Auraria Parkway
Suite 604
Denver
Colorado
303 547 8120

May 11, 2014

APPENDIX: TECHNICAL REPORT

Version 2.0

E911 NPRM Technical Report

In support of iPosi, Inc. Comments in Matter of FCC PS Docket No. 07-114

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Revision history

Revision		Update
1.0	Final draft, carried over	5/10/2014
2.0	Public version	5/11/2014

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GLOSSARY

3GPP	Third Generation Partnership Program
AWGN	additive white Gaussian noise
C	carrier power
CU	University of Colorado
dB	decibel
dBi	decibel isotropic
E911	Enhanced 911
EIRP	effective isotropic radiated power
FCC	Federal Communications Commission
GHZ	gigahertz
GPS	Global Position System
KHz	kilohertz
Km	kilometer
LOS	line of sight
LTE	Long Term Evolution
MHz	megahertz
m	meter
ms	milliseconds
NLOS	non-line of sight
N_0	noise power spectral density
ns, nsec	nanosecond
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
OTDOA	LTE Observed Time Difference of Arrival
P_r	received power
PRS	LTE Positioning Reference Signal
ppm	parts per million
RF	radio frequency
Rx	receive

1 iPosi Enabled Small Cell Indoor Location for E911

iPosi has embedded technology that determines the GPS/GNSS location and timing for IP-connected devices, including fixed Small Cells. iPosi uses a proprietary, advanced version of assisted GPS/GNSS to deliver timing, frequency, network location and other relevant satellite or network based intelligence into its embedded receivers using conventional IP networks in order to acquire a position with high sensitivity, multipath and diffraction deterrence, and high anti-jam immunity to work accurately deep inside buildings where traditional, lesser sensitive forms of GPS reception are denied.

After iPosi enabled Small Cells are installed, the iPosi technology enables accurate interior location directly to indoor mobile devices using one or more standards-based methods. There are two ways that iPosi technology underpins and enables indoor mobile location suitable for E911 and other services. The first method is by in-the-art proximity/association where the position of the indoor Small Cell's 2 or 3D position is infers or estimates position of nearby mobiles. The second and generally more accurate method uses relatively newer LTE OTDOA Release 9. This later 4th Generation LTE standard enables and deploys purpose-built location ranging signals, known (in the standards) as Position Reference Signals (PRS) from each surrounding eNodeB Cells. When combined, these provide relatively high precision radio ranging (provided cell node timing is relatively accurate) measurements from the Small Cells surrounding any LTE Release 9 indoor mobile device. Similar time-of-flight methods exist within the 802.11 standards for WiFi access points that are also enabled by the iPosi embedded client providing it the same location and timing solution as LTE. iPosi plans to also comment and feature this in another Commission action, the Final NPRM regarding 3.5GHz shared spectrum rulemaking. The Commission seeks the equivalent 3D location performance in that proceeding which overlaps this E911 NPRM.

Both the association and ranging methods significantly reduce indoor mobile time-to-fix (compared to conventional AGPS) to about one second, and thus can even enable mobile location updates during the E911 call to confirm caller location in real time. This capability moreover can eventually help automate PSAP situation analysis by invoking precisely nearby

security assets, such as cameras, security door access, etc. aided by receipt of this fine-grained indoor mobile location.

1.1 Location by Indoor Small Cell Proximity/Association

With proximity methods the mobile position using the nearest serving Small Cell will limit the mobile horizontal position error to 10-30 meters based on the communication range between adjacent cells and building layout. This limits the position uncertainty greatly in contrast to the "outside-in" wide area macrocellular-based range methods tested in the March 2013 CSRIC report [1]. We will show later that following current industry installation practices this method alone will be within the Commission's proposed horizontal accuracy requirements. (We also are aware of the time to market and time to installation criticisms some have raised regarding dependence on Small Cell deployment. We deal with that objection elsewhere in the Comments.)

There are two practical E911 related limitations of proximity based positioning. One is determining the vertical location of the mobile, unless the Small Cell and mobile both have barometric sensors to provide a vertical location measurement. We therefore advocate elsewhere the Small Cell have both GPS/GNSS vertical reference capability, and capability to manually enter the building designated floor level. We believe there is merit in both methods to cross-check and assure the highest information consistency and thus highest location reliability for critical applications such as rescuing E911 callers inside high rise buildings. In some rescue situations, the physical elevation provides a distinct value that floor designation may not convey. The other limitation is that proximity in essence provides a location that represents a circular zone based on a maximum estimated communication range. This will often suffice. We believe that if accompanied with a receive signal strength indication this creates a more targeted position. The best solution is multi-lateral ranging where multiple small cells are deployed, and we understand through industry supplier discussions that a rule of thumb is to deploy 4-8 small cells per floor to achieve needed bandwidth and coverage capabilities balanced against the number of devices and employees or visitors served.

1.2 Radiometric Ranging to using LTE Rel. 9 OTDOA in Indoor Small Cells

To increase indoor location accuracy further (relative to proximity/association), new standards within LTE and 802.11 standards use principles of radio ranging by sounding the channel in with specialized position references signals in either a one way, or outbound and return (round trip) methods.

We expect the 3GPP OTDOA downlink PRS signal in accordance with the LTE Release 9 standard will be a good choice for Small Cell indoor mobile location services. The new element here is iPosi provides automated self-surveyed node locations and precise timing , the latter to sharply reduce range path measurement errors, time slot interference and multi-lateral ranging biases or variation across the indoor Cells that each broadcast a precisely timed downlink PRS. To examine the nature of indoor multi-lateral error, the total location error is a function of two independent factors: 1) the Small Cell position error (or uncertainty), and 2) the ranging OTDOA error created by either time variations among the surrounding Small Cell eNode B downlink signal triggers, or multipath or diffractive delay spread, the latter factor due to the imprecise estimation of arrival time due to dominant signal arrival delay where the direct path is attenuated.

2 Technical Report

The next part of our Comments introduces some of the key concepts behind both the iPosi GPS/GNSS location technology its application in enhancing LTE OTDOA PRS for mobile location. We also cover the nature and quantify indoor path propagation, propagation loss models, and range detection accuracy to see how well OTDOA performs based on simulation, analysis results, and field measurements from an archetype building interior -- in this case using the space of the former law school library that is undergoing renovation. This area provided a relatively similar floor, wall and ceiling elements to replicate the inside of urban buildings.

3 Small Cell system

3.1 Small Cell layout

Small Cells are normally associated with indoor cellular coverage and are generally considered as WCDMA and LTE dual mode devices. Equipment manufacturers recommend using in-door propagation simulation tools in a way to optimize or maximize data rate, in-building coverage to wireless end-customers. The ITU-R M.2135 [2] describes using a co-linear array of Small Cells or indoor hotspots that are installed along an imaginary line with cells spaced 60 meters apart. Our feedback from network equipment manufacturers indicates that Small Cells are typically placed closer than the ITU specification. The model of indoor Small Cells follows the outdoor cellular model as shown in Figure 1. Based on discussions with network equipment vendors and intelligence on size of building floor layouts we believe that Small Cells are more likely to be 35 m apart, and placed in a triangular fashion versus the ITU collinear array. We analyzed both configurations to contrast expected indoor location accuracy.

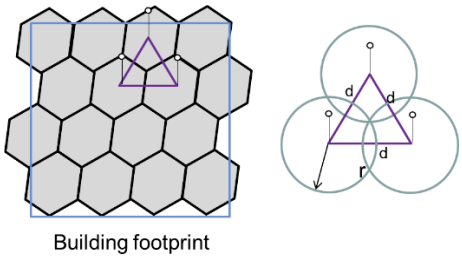

Figure 1. Typical Indoor Small Cell Grid Layout

In the table below we show the Small Cells parameters from the ITU-R M.2135 for the analysis and simulation of location performance except in certain instances where we believe these are more representative of industry practice in the year 2014.

3.2 Small Cell parameters

Table 1. Summary of LTE OTDOA Indoor Simulation Parameters

Parameter	**Value**	**Source**
Inter-cell distance cases	60 m 35m	ITU-R Report M.2135 Inter-cell distance based on 2014 network vendor feedback
Base antenna height	6 m, i.e. on ceiling	ITU-R Report M.2135
Mobile antenna height	1.5 m	Assumed based on industry practice
eNodeB Transmit power	21 dBm	ITU-R Report M.2135
Frequency (mid-point for modeling)	3.5 GHz	ITU-R Report M.2135
Base antenna gain	0dBi Omni antenna	ITU-R Report M.2135
Mobile antenna gain	-6 dBi	Assumed more representative indoor (though 0dBi used by the ITU)
BTS noise figure	5 dB	Commonly used in industry link margins for BTS
Path loss model	Path loss = LOS/Free space +16dB (10dB clutter margin plus 6 dB fading due to floor reflection) And ITU-R M.2135	Assumed by iPosi ITU-R M.2135

3.3 Path Loss Modeling

To compute performance of the LTE OTDOA ranging signal path estimation performance with transmission of the LTE PRS symbol, we seek the mobile receiver SNR, when applying the parameters in Table 1. We considered several path loss models. The models are:

- Free space compensated for LOS from a 1.5m antenna height to a 6m antenna height
- Free space plus ground reflection
- An approximation of the free space plus ground reflection which is modeled as free space with 6dB more loss
- The ITU-R M.2135 LOS model, which uses a simple LOS free space path loss factor
- The ITU-R M.2135 NLOS model for median path loss

Each of these modeling cases are plotted below in Figure 2.

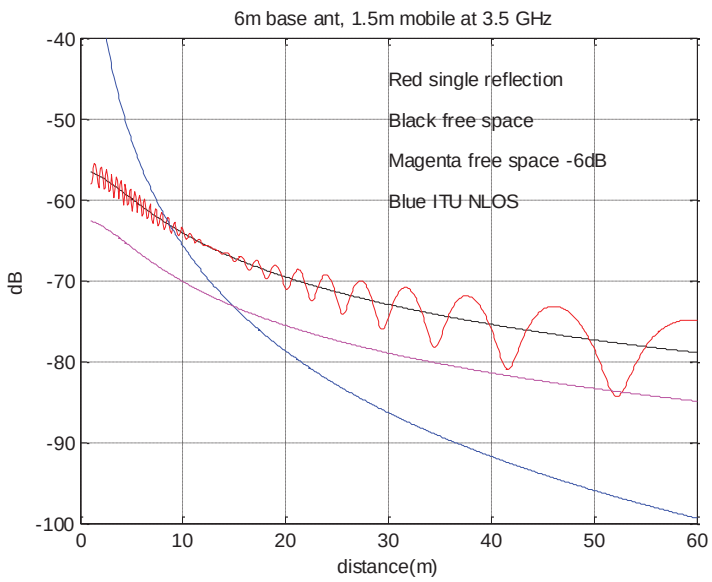

Figure 2. Path Loss Models for Small Cells

When the ITU-R NLOS model is used, we include an additional loss of 6.48dB to account for the difference between the median power and the 90% tile as a result of the 4dB lognormal sigma of the ITU report.

Each of these model cases assumes there is no strong multipath signal (that is near the amplitude of the direct signal) that would skew, lengthen the path that is detected and estimated at the receiver.

The ITU-R M.2135 also provides a model of the probability of a pure LOS signal from the Small Cell to the mobile as seen in Figure 3. This implies that the area of NLOS signals composed of strong indirect rays is small when we consider a 35 m indoor inter-cell distance separation.

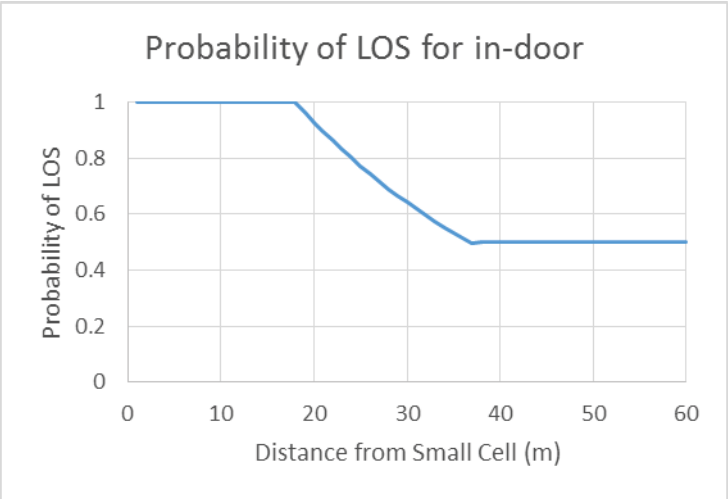

Figure 3. ITU-R M.2135 Indoor LOS Model

Next we consider the case of a strong delayed ray in the following analysis and simulations.

4 LTE OTDOA Indoor Analysis

4.1 LTE PRS Signals

LTE provides down link ranging signal for location estimates in the form of a PRS (positioning reference signal). This signal is illustrated in Figure 4. Each column represents a single symbol time of 1/15000 sec and each row represent a subcarrier of 15 kHz separation as described in the standards specification [3].

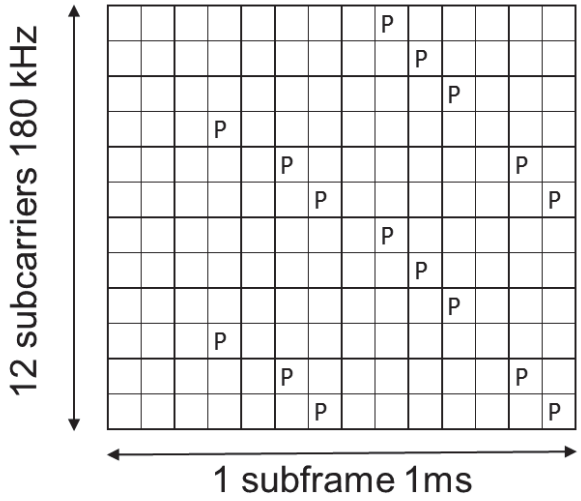

Figure 4. PRS Pattern of PRS Elements

The subcarriers when grouped together create much larger signal bandwidth. In the analysis provided here we consider LTE BW's of 1.4MHz, 10 MHz and 20 MHz these channel bandwidths do not use all the available subcarriers, some are left for guard bands as seen in the table.

Table 2. LTE configuration parameters

Channel Bandwidth [MHz]	**1.4**	**10**	**20**
Number of resource blocks (N_RB)	6	50	100
Number of occupied subcarriers	72	600	1200
Effective bandwidth of subcarriers (MHz)	1.08	9	18
IDFT(Tx)/DFT(Rx) size	128	1024	2048
Sample rate [MHz]	1.92	15.36	30.72
Samples per slot	960	7680	15360
PRS elements	12	100	200

4.2 LTE OTDOA Range

4.2.1 Accuracy and SNR Trade-Off

Next we estimate the OFDMA PRS range accuracy performance versus SNR using the time of arrival estimate. There is no simple closed form method of computing the time of arrival error so we apply the Cramer-Rao bound (CRB) method, which is referenced in [4]. The CRB describes an estimate of the best possible performance and while this over estimates the performance it does provide an analytical measure of performance that is useable for these analysis purposes.

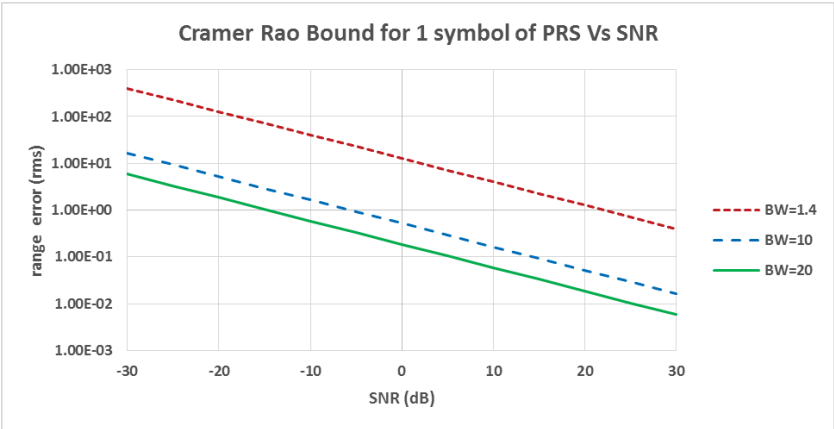

Figure 5. LTE PRS performance estimate

Since the CRB over estimates the error performance the curves of Figure 5 are increased by a factor of 10 when used in the range calculations. For example, if the SNR of 0dB is used, then for 1.4 MHz signal bandwidth, the range error increases from 11 meters to 110 m.

The curves in Figure 5 assume there is no ultimate limit of range accuracy, that is, as long as the SNR increases the range error reduces. This is not true as there often are other factors that reduce limit range measurement estimation performance. One major factor is the sampling rate of the ADC (analog to digital converter). This places time quantization error range for a single PRS measurement, that is, with no averaging over multiple intervals.

Using the 20MHz LTE BW the sample rate from Table 2 is 30.72 MHz or a time quantization of 32 nsec for a +/- time estimate results in an error of 16 nsec. At speed of light, this represents an

uncertainty of +/- 4.9 meters. If we assume this is distributed uniformly over the +/-4.9 m region this yields a 2.8 meters rms (67%) result. The composite rms error taking into account both the SNR and time resolution factors becomes:

$$d_{total_err} = ({d_{PRS_err}}^2 + {d_{resolution_err}}^2)^{1/2}$$

4.2.2 Overall Range Accuracy

Next we estimate the range accuracy using the computed SNR as a function of distance from the Small Cell using the parameters in Table 1and the path loss models of Figure 2 including the noise and resolution error. We used the ITU –NLOS path loss model with and without the 90%-tile correction factor along with 20 MHz bandwidth link parameters. Here we see that for an inter-cell distance of 60 meters, and even beyond, the OTDOA distance error becomes mostly limited by the ADC resolution (represented by the solid line) and the ultimate result remains very close to 2.8 meters rms.

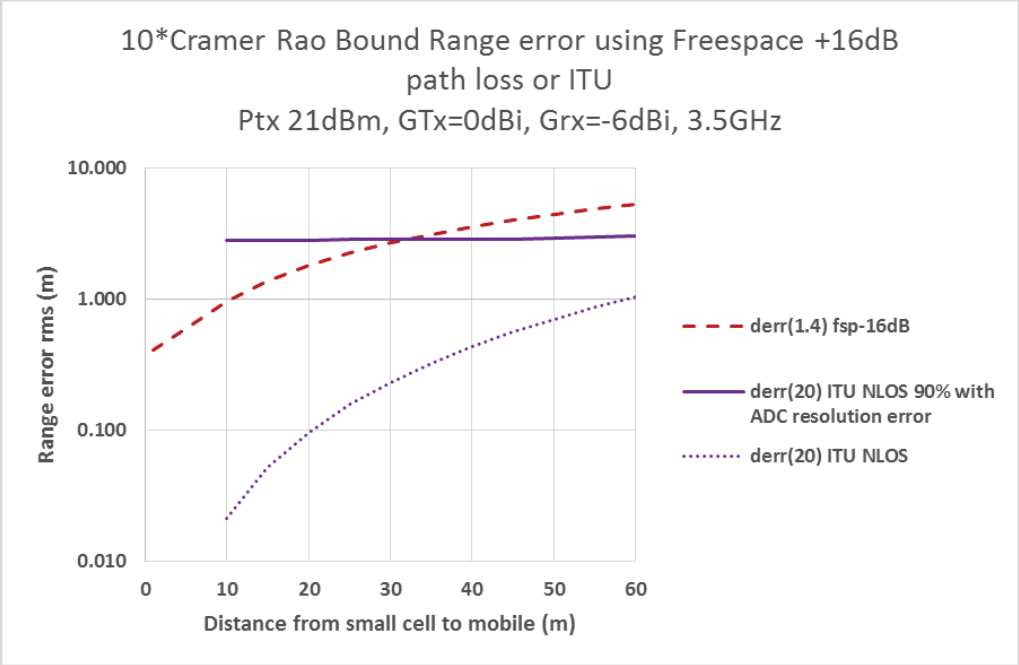

Figure 6. Total Range Error and Small Cell-to-Mobile Range

This analysis shows that for indoor and single ray attenuation with LOS or moderate blockage the LTE PRS SNR is sufficiently high to not impact the indoor range estimation for 60 meter inter cell distances. Therefore, the 2.8 meter rms range error determined from the previous analysis is taken into the Small Cell multi-lateration position calculations to estimate indoor mobile location (relative to the surrounding cells each which has a self-surveyed position).

4.3 Multi-Lateralization with LTE OTDOA

In order to compute the multi-lateralization error to location performance we need to consider all the important indoor ranging error contributors. There are three we are most concerned with:

- The PRS range estimate as function of SNR, calculated above to be 2.8m rms independent of SNR for indoor as seen in 4.2.2
- The relative time accuracy of the Small Cell array from which the ranging signals are resolved by the mobile into a mobile location fix
- The self-surveyed location accuracy of the iPosi enabled Small Cells

The relative time accuracy from Small Cell to Small Cell using iPosi time synchronization and distribution is selected at 2 levels: A 20 nsec rms relative error to the local time, and a less stringent 50 nsec rms intra-system relative timing error. iPosi has techniques consistent with reference [5] to assume in Small Cell applications that inter-node timing can be kept below 20 nsec rms. The reference to the local time means that the cells can defer to relative versus independent observation of absolute (GPS) time for indoor location determination, though managing absolute time becomes critical for other network requirements outside the scope here. A difference between two nodes with an rms error to the local time will have a difference standard deviation of local time error rms times $\sqrt{2}$. Thus a 50 nsec rms relative, local time error will result in a 70.7 nsec distribution rms time error between them.

The location accuracy of an iPosi located node is set at two levels according to section 5.2. Based on in-building test results, we use 5 m and 20 m radial accuracy from the true Small Cell location. This means we set the standard deviation of error to 5 or 20 m respectively.

Table 3. Indoor Small Cell LTE OTDOA Range Error Statistics

Parameter	**Mean Value of Error**	**Error Distribution**
PRS range error	2.8 m rms	Uniform +/- 4.9m
Time error of each node relative to local time	20,50 ns rms (implying 6.3, 16.7 meters rms respectively)	Gaussian
iPosi GNSS/GPS horizontal error (Case I: Typical building site and loss case)	5 m (one standard deviation)	Rayleigh along radial vector
iPosi GNSS/GPS horizontal error (Case II maximum with strong multipath/ diffraction and high signal loss)	20 m (one standard deviation)	Rayleigh along radial vector

The figures below plot the total probability density function (PDF) and a cumulative distribution function (CDF) curve using values taken from the table above. The resulting estimate is the sum of the three random variables of PRS range, differential time error, and horizontal error. Observe that these can be assumed to be Gaussian as the central limit theory would predict for the sum of many variables. Therefore, a single range uncertainly standard deviation can be used in a Gaussian Monte Carlo statistical analysis to predict the ultimate bounds of indoor horizontal location performance, which is generated and results shown below.

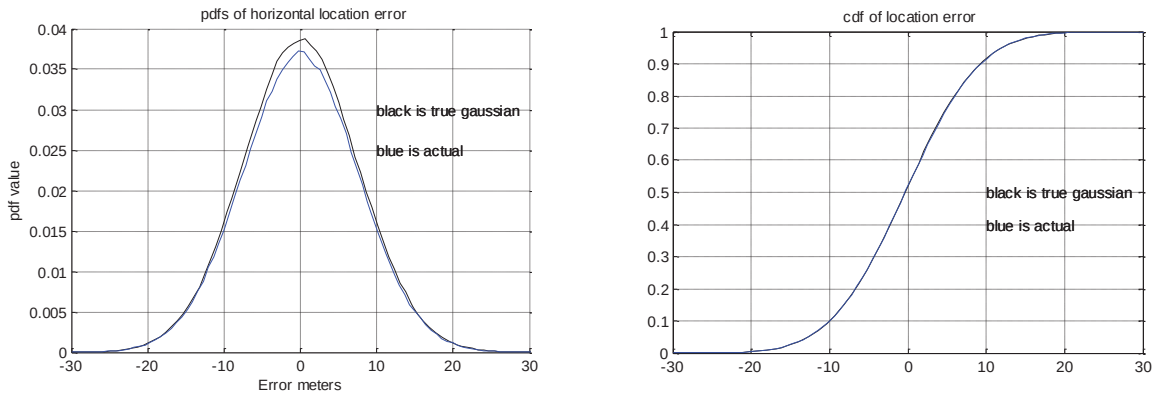

Figure 7. Magnitude of the Case I horizontal location error[11]

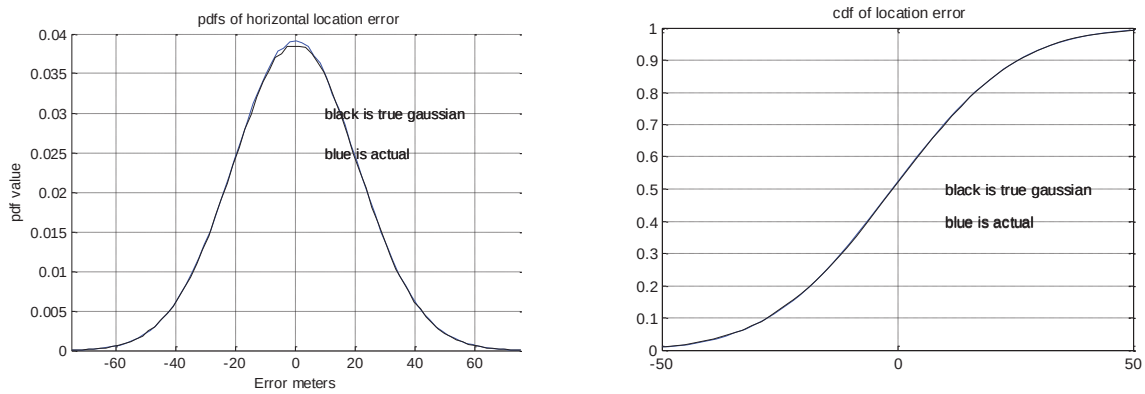

Figure 8. Magnitude of the Case II Horizontal Location Error[12]

5 iPosi GNSS/GPS Location Performance

5.1 Simulation results at threshold receiver sensitivity

iPosi attains its extremely high sensitivity as a result of its novel assistance solution that enables long term integration to promote efficient extraction and detection of very weak signals from

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[11] Mathematically, (5/1.4) m standard deviation in one direction, 20nsec rms time error, total range error 7.5 m rms, 80% +/- 5.3m.

[12] Mathematically, (20/1.4) m standard deviation in one direction, 50nsec rms time error, total range error 20.8 m rms, 80% +/-19.m

either noise or interference. The iPosi system also employs advanced algorithm techniques that provide improved location accuracy by integrating diverse satellite observations over long time intervals thus taking advantage of the fixed positions of iPosi enabled cells. The same solution is also available for many applications ranging from VOIP, WiFi access points, and Small Cells. These all have access to iPosi network resources and servers through a common IP connection. Using the specified iPosi threshold sensitivity of -175 dBm, below are the curves for 3D location accuracy performance over time from the time of initial Small Cell device installation.

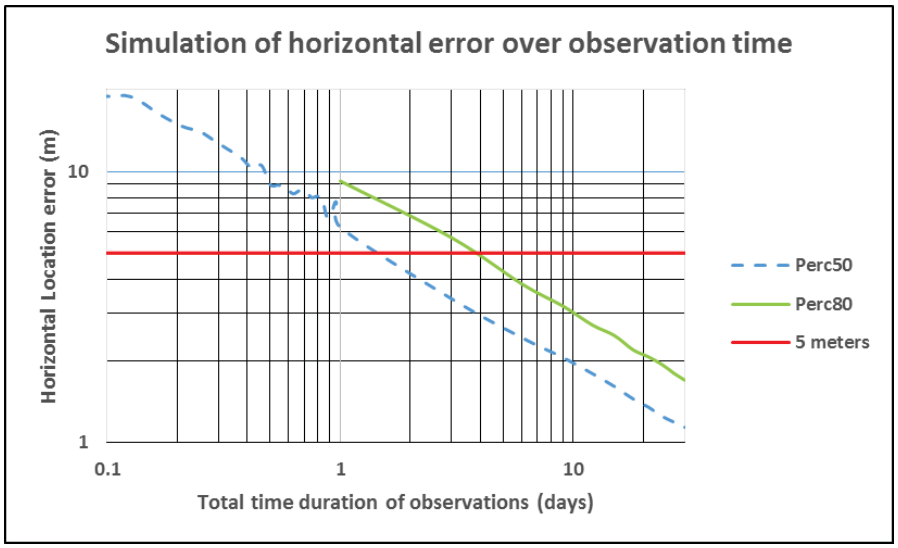

Figure 9. Simulated Horizontal Error at Threshold -175dBm Sensitivity
AWGN Channel

The simulation indicates that the horizontal error is less than 10 meters at the 80% confidence level before the end of the first day of measurements which are conducted in the background of an operating Small Cell. Based on the 80%-tile curve the self-surveyed error will be within 30 meters by 0.2 days (5 hours) observation and processing time. There is a discontinuity in the 50%-tile curve at 1 m for both the horizontal and vertical curves, this is due to a slight difference in the way processing is set for observation intervals less than one 24 hour period. The log-log plot shows that the accuracy improves with increasing time, but this simulation does not take into account other path distortion factors such as atmospheric effects (though these effects sharply diminish at night) and localized diffraction effects (most multipath impacts stabilize and reduce

with time). Nevertheless, long-term processing shows the potential to obtain high in-building Small Cell and mobile location accuracies by extending in the background host processing of the GPS/GNSS signals, long term coherent and non-coherent integration times, receiver correlation assistance, and network intelligence algorithms to provide extraordinary indoor mobile location results.

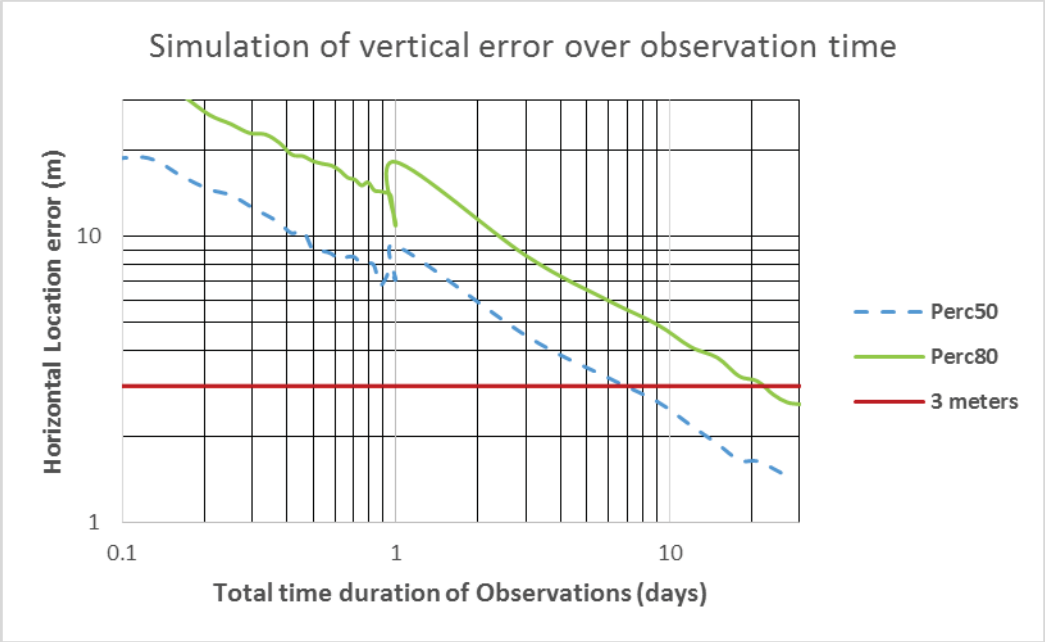

Figure 10. Simulated vertical error at Threshold -175dBm
AWGN Channel

Similarly the vertical high loss simulation shows the iPosi located node can provide < 3 meters of accuracy to 80% confidence at 15 days of observations and post processing assuming all incoming signals are at worst case threshold level. If all or some signals are higher than the threshold -175 dBm vertical and horizontal accuracy improves.

5.2 iPosi GPS Field Measurements

iPosi has conducted extensive measurements in the field and in its lab sites at the University of Colorado (CU). Along with numerous measurements across the country which shows ample margin compared to the company's lab sites at CU. Thus the CU interior sites offers a set of locations representative of those in the field including sites that reach threshold where it is

unlikely mobiles are small cells will be placed since they are in a basement under multiple heavy load floors, and floors of research equipment.

The proprietary joint processing analysis method used in the simulation data of section 5.1 shows consistently increasing location accuracy with increased observation time. This is due to the bounded impact of AWGN channel noise at the -175 dBm threshold. Many environments can be more complicated including highly non-uniform signals levels plus multipath, scattering and diffraction propagation components. Thus we can expect some variation between any given indoor Small Cell site and prediction, but based on the data obtained across a significant set of indoor environments the impact of longer term fixed device processing correlates well with the AWGN simulations.

To obtain an accurate position estimate iPosi has developed proprietary techniques to optimize the location calculation using individual, running and aggregated satellite signal observables. The final step is called “post processing” and is collected and calculated in the iPosi network assistance/position determination engine (PDE) server.

Figure 11 provides a picture of the basement location with a mobile patch antenna. The ceiling of the basement and thus the antenna site shown below is underground thus signals essentially arrive through several floors of overhead building structure.

Figure 11. Lab Below-Grade Basement Test Site

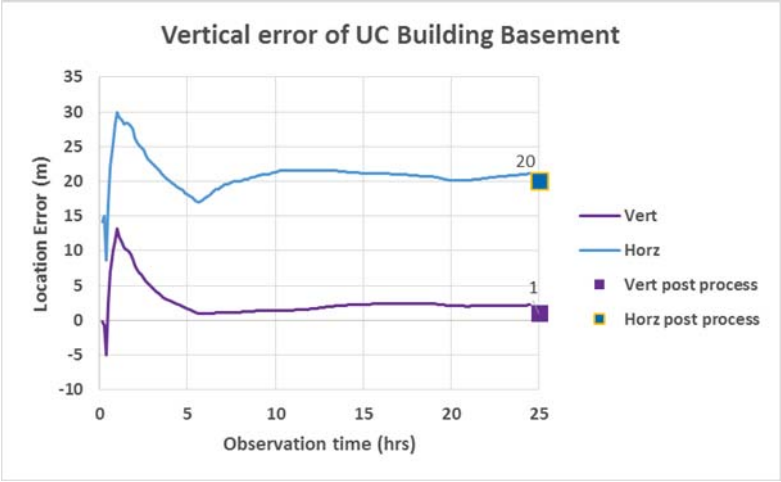

Figure 12. CU Basement GPS Location Error

Figure 13 is a picture of a window-less lecture room (does not obtain mobile A-GPS) on the second and top floor of the test building again with the original test antenna.

Figure 13. CU Windowless Lecture Room Site
(Ground Truth X,Y seen on floor)

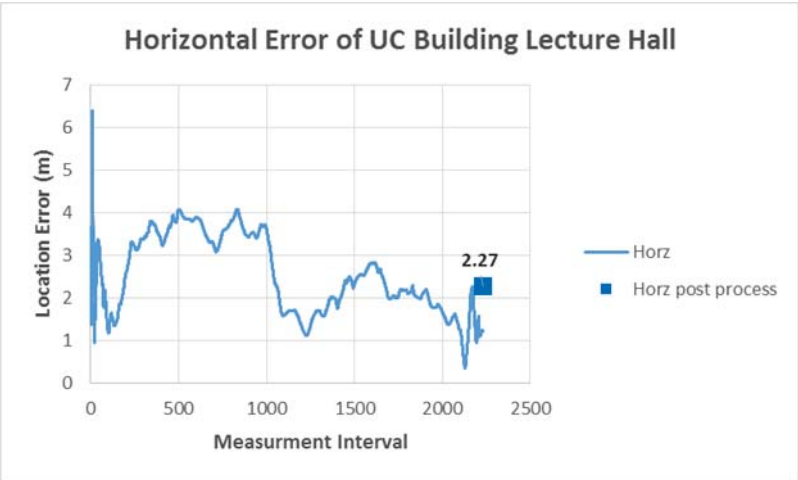

Figure 14. CU Lecture Room Site
GPS Horizontal Location Error

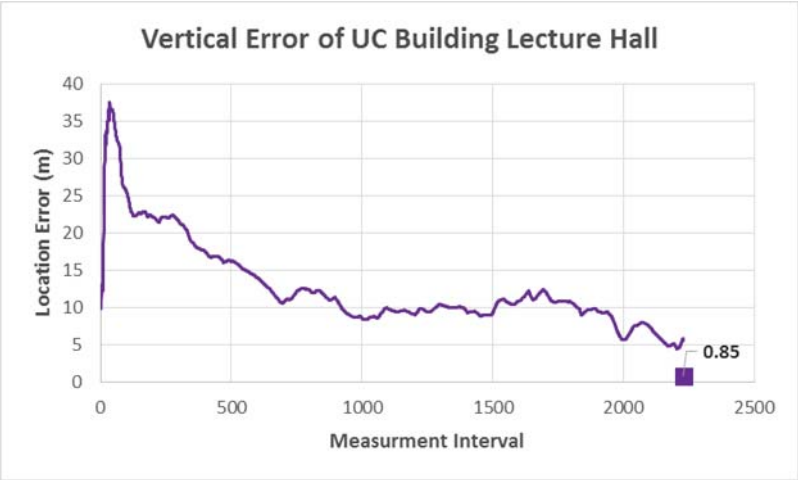

Figure 15. CU Lecture Room GPS Vertical Location Error

In both locations the error tends to decrease over time with the actual value reported and used in the iPosi located small cell as the post-processed value. Notice that the post-process result is not necessarily a one-dimensional result of the continuously processed or averaged data time-series, as in Figure 12 and is based on an iPosi proprietary technique.

This measurement campaign shows two extreme in-building environments create not unexpectedly two different horizontal location errors, but still produce indoor accuracy within the Commission's proposed 50 m horizontal accuracy error criterion. In heavily attenuated locations with some likely diffraction and multipath the standard deviation result in a 20 m rms, seen in Figure 12. While less aligned to the AWGN bounded channel case, the location performance is still quite good for a broad range of in-building environments. In less attenuated parts of the building environment the 5 m horizontal error rms model value is consistent or conservative with environments such as those tested and shown in Figure 14. The horizontal graph axis in Figures 14 and 15 are a concatenation of distinct time series to provide a longer term result.

6 Location by Proximity/Association to an iPosi Enabled Small Cell

Using the results of section 4 we are prepared to estimate the accuracy of a mobile device associated with a self-surveyed iPosi enabled Cell.

As earlier, the first case is where the inter-cell distance is 35 m. In this case the worst range error that can occur in a cluster of 3 nodes is when a mobile is 5 meters from a node, but to assess worst case conditions where the mobile is served by a more distant node than the physically closest Cell. In this example we assume the farthest practical case where the mobile is served by a cell 30 m away. Next we assume an iPosi located node uncertainty of 20 m rms for a strong multipath environment. The one sided probability that the associated node is further away at the 80% level or 30% on the further side yields distance value of $.841(20)$=16.8 m. Adding this to the 30 m yields an 80% factor for the worst case of 47 m. Clearly the overall probability will be better than 80 % considering all locations.

Next we consider the case where the nodes are, following the ITU standard case above, separated by 60 m. First consider that the mobile is at the farthest point from any Cell, thus is close to the center of a triangle of three Cells, or at the star in the middle of Figure 16.

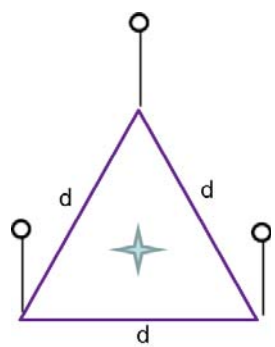

Figure 16. Mobile at Farthest Position, at Center of Triangle formed by 3 Surrounding Small Cells

In this case, the maximum range is 34.6 m from any Small Cell to the center of the triangle. Using the self-surveyed position error of 20m rms for all Cells, and the 80%-tile the total error reaches 34.6+16.8 m, or 51.4m worst case at the worse, center-triangle point location.

Using the self-surveyed position error of 20m rms for all Cells, and the 80%-tile of uniform mobile device placements over the entire indoor coverage area, the total error reaches 34.6+12 m, or 46.6m.

The cases of concern are where the mobile is between a closest node and the center of the constellation indicated by the star in Figure 17 .

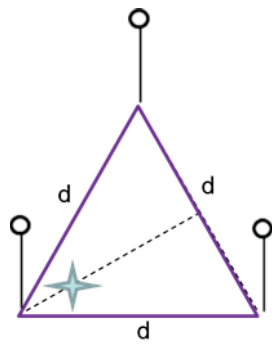

Figure 17. Mobile Operating Close to a Small Cell

Here the location error changes due to the true distance from the node and probability of being associated with the wrong node. From Figure 3 we see that closest node will very likely have a LOS view to the closest node and a blocked view from the others within 18m from the closest node which means it should have significantly higher power than the others and be selected as the closest node. This indicates that the range of concern is between 18 and the center 34.64 meters where the actual associated cell that arises will not change the accuracy result.

7 Simulated iPosi GPS + LTE OTDOA Location Performance

More accurate mobile locations can be provided when LTE OTDOA ranging techniques are combined with the iPosi located Small Cell. In the simulations conducted here we used the 5 and 20 m rms range error and Small Cells spaced 60 m apart on a triangular grid. We also placed a fixed mobile at several locations within the constellation of the three Small Cells as seen in Figure 18 below.

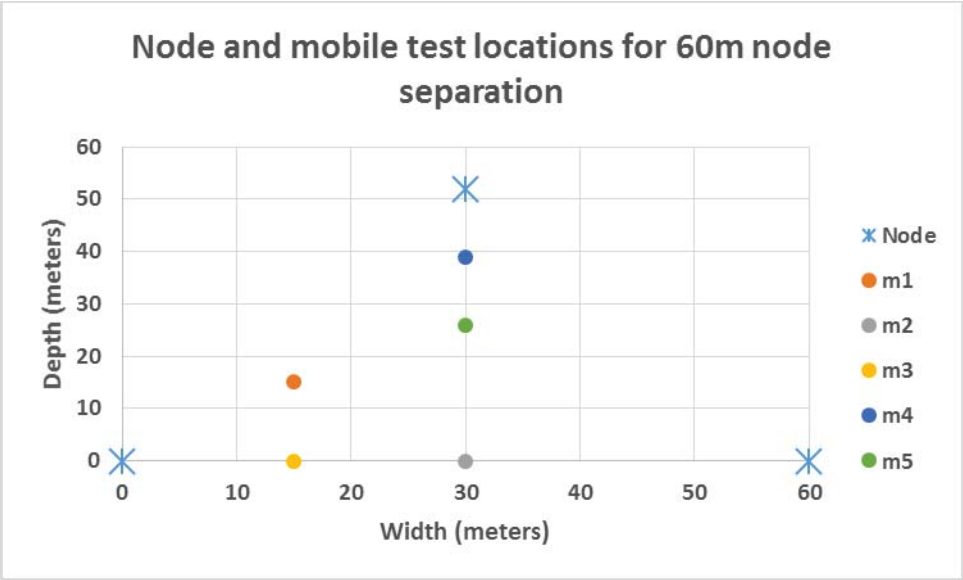

Figure 18. Small Cells and mobiles placed in a 60 m Inter Cell constellation

Next we computed the mobile position errors using an iterative least squares trilateration method in 2D with a starting position of in the center [1.1] and working outward. There were 100,000 runs performed during which the PRS correlation error was modelled in meters as a uniform in [-5,5] which results in a 2.8 m rms value.

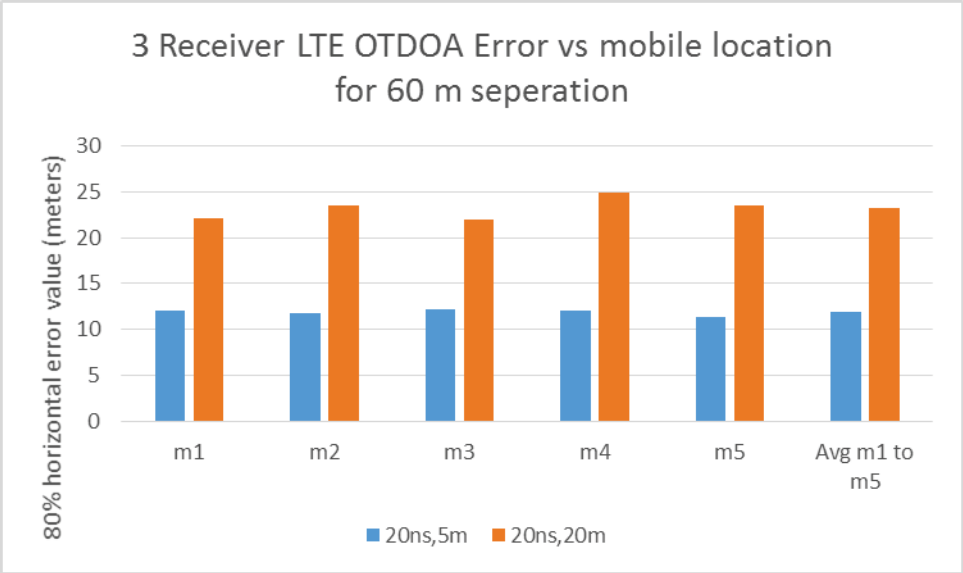

Figure 19. 80%-tile 60 m Inter-Cell Distance Using iPosi & OTDOA

We also generated a multipath model where one ray was assumed to be elongated by 10m due to multipath or diffraction and was the only ray available from the Small Cell. For sake of robustness, the simulations added a high 10 m multipath induced error to one Small Cell per trial in a round robin fashion across the 100,000 simulated trials.

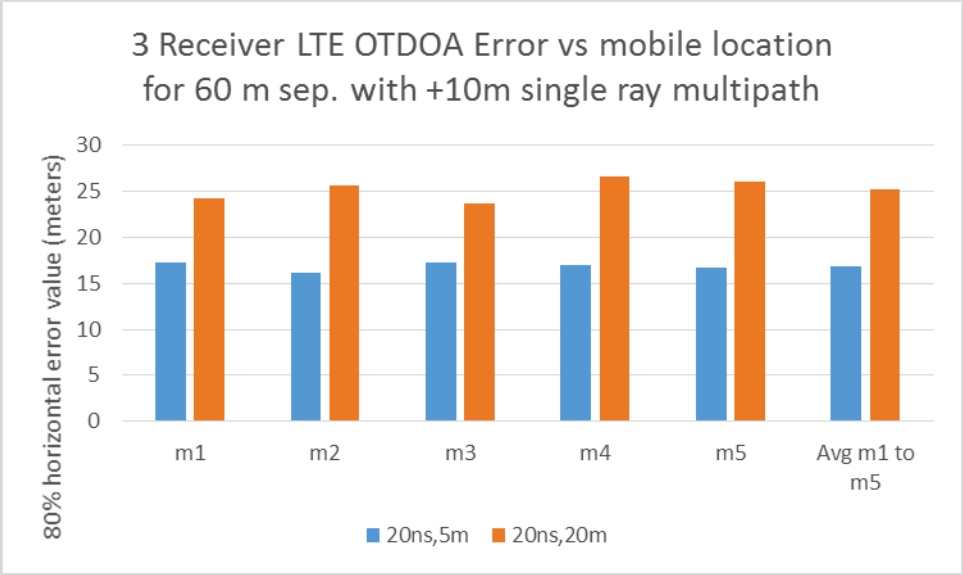

Figure 20. 80%tile 60 m Inter Cell separation iPosi +OTDOA position error with 10m multipath error

In all of the position calculated the results are satisfying and show well under 50 meters error at the 80%-tile of indoor position attempts, and typical < 20-25 meters with between 20 and 50 nsec inter-cell timing errors.

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