Moving Location Indoors and Up the Stairs

How 3D Location Technology is Changing the Way We Do Business and Live our Lives

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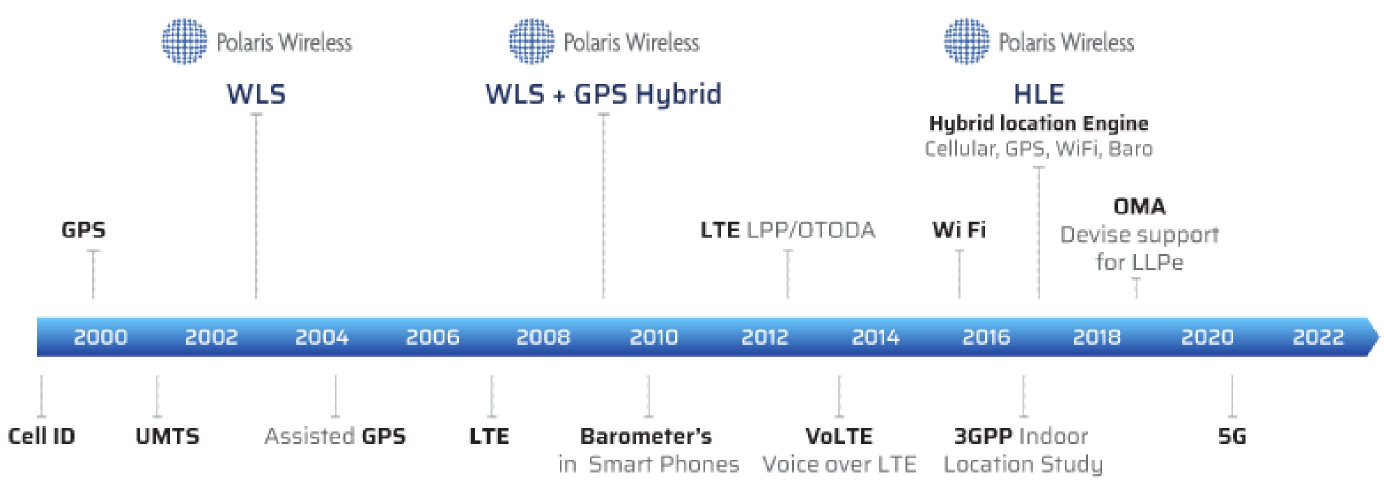
Background

In 1996 the FCC issued the first mandate that wireless network operators report the accurate location of 911 (emergency) callers to the nearest Public Safety Answering Point (PSAP). This event launched the market for wireless location, spawning a variety of solutions. Some of these relied on the Global Positioning Service (GPS) which, although ubiquitous today, was, at the time, not available on any wireless devices. Other solutions used trilateration techniques (e.g., Time Difference of Arrival) that required hardware installed in every cellular base station, which increased deployment timelines and costs.

Polaris Wireless took a more innovative approach, developing Wireless Location Signature (WLS) technology that required no change to the device and no hardware in the network. WLS relies on the fact that each location has its own unique radio fingerprint. Thus, when a device measures its radio environment and reports it to the network (these measurements are essential for seamless mobility management and supported by all air interfaces in use today), a series of sophisticated proprietary software algorithms pinpoint the device's location. This is done by comparing the device's reported measurements, or "signatures", to a set of predicted measurements. This approach requires no physical changes to the device as it must already support these measurements in order for the network to determine when it is appropriate to handoff the device from one cellular base station to another.

In the two decades since that first FCC mandate, Polaris Wireless has continued to innovate as wireless networks and devices evolve to include more enhanced capabilities. The first of these was the standardization of Assisted GPS into GSM and UMTS networks along with the introduction of the smartphone in 2007. The smartphone popularized location-aware applications, increasing the percentage of GPS-capable devices, while standardization changes made it possible to leverage this information for emergency services. This triggered Polaris Wireless to build its hybrid WLS system which leverages GPS measurements by combining them with the WLS solution, providing a robust capability able to locate devices that either don't support GPS or are in GPS-denied environments, while leveraging GPS when it is present. Polaris Wireless also developed a new product offering, Hybrid Location Engine (HLE), initially for a wireless carrier IOT location platform and now the core of an over-the-top application capability.

FIGURE 1: EVOLUTION OF POLARIS WIRELESS INNOVATION



Further technology innovation followed in 2015 when the FCC issued the Fourth Report and Order on E-911. In this report the FCC recognized that mobile devices were rapidly replacing traditional land lines and that mobile device usage patterns made the need to locate devices indoors critically important.

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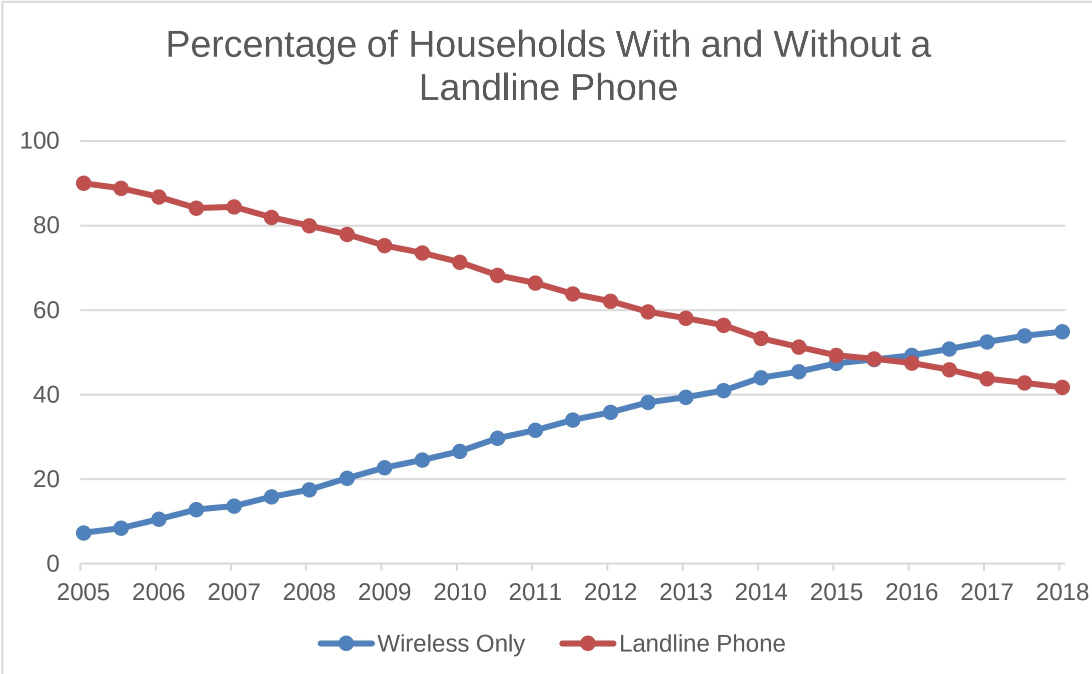
FIGURE 2: PERCENTAGE OF HOUSEHOLDS WITH AND WITHOUT LANDLINE PHONES



From CDC's biannual National Health Interview Survey

The original FCC rules had different accuracy requirements for network-based and handset-based location methodologies: 100m for 67% of calls and 300m for 95% of calls for network-based solutions and 50m for 67% of calls and 150m for 95% of calls for handset-based solutions. There was no requirement for indoor testing nor a specified geographic area for aggregated performance. The rules were later changed to be on a PSAP or county basis with the 95% requirement reduced to 90%. To verify, compliance operators would test their system by placing pseudo 911 calls in a variety of outdoor locations throughout the geographic area under test. Actual tested location accuracy was weighted proportionally with historical 911 call volume statistics. Needless to say, there was considerable flexibility for carriers to statistically demonstrate compliance.

In the 2015 mandate, the FCC established a new location accuracy metric that includes indoor locations and added a new requirement for carriers to locate callers in the vertical dimension. The new rules stipulated an improved accuracy metric phased in over time, culminating in a requirement that 80 percent of calls must be located within 50 meters. Further, compliance testing can no longer rely on just outdoor environments and must now include a mix of both indoor and outdoor calls. Because of the prevalence of indoor wireless callers and the fact that indoor locations tend to be vertical, location on the horizontal (X,Y) axis alone is no longer sufficient. The new mandate requires that carriers provide a Dispatchable Location (e.g., civic address) or a vertical height, or Z-axis, estimation of the emergency caller and requires that industry propose a Z-axis accuracy metric by August of 2018 based on independent testing of available technology. In early 2019, the FCC issued a Notice of Proposed Rulemaking (NPRM) establishing 3m for 80% of calls as the Z-axis requirement. The NPRM is in a period of industry comment before the FCC considers a final decision. Regardless, wireless carriers must comply with the eventual location requirements in the Top 25 cities by 2021 and in the Top 50 cities by 2023.

The FCC order created a flurry of activity within the industry. The 3rd Generation Partnership Project (3GPP) launched an indoor location study that yielded new standards that provide support for delivery of Wi-Fi, Bluetooth, and barometric pressure – all significant measurements for locating devices indoors. Standards support is of course important, but it only becomes useful when devices and networks actually implement these standards. Devices are now appearing in the marketplace that support these updated protocols.

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Polaris Wireless

Polaris Wireless has continued to enhance its technology by developing its Hybrid Location Engine (HLE) and participating in multiple independent testbeds conducted on behalf of the FCC by the CTIA industry group. These tests have been separated into various stages, each focusing on different technologies. In 2016, Polaris Wireless demonstrated a horizontal accuracy of 41.4 meters better than 80 percent of the time. This achievement satisfies the most stringent FCC requirement which network operators must comply with by the year 2021. In 2018, Polaris Wireless participated in the Stage Z testbed which focused on the ability to provide a vertical, or Z axis, coordinate estimate of a device's position. As indicated in the addendum to the formal report submitted to the FCC, Polaris Wireless achieved floor level accuracy of 2.8 meters better than 80 percent of the time. Further, although not the focus of the testing, but still critical to accurate vertical location, Polaris Wireless improved its overall horizontal accuracy to less than 23.6 meters 80 percent of the time.

Polaris Wireless provides two commercially-available and highly innovative location solutions to the market today: WLS and HLE. WLS is the best in class when dealing with minimal information or cooperation from the device; such as simple signal strength measurements and timing measurements. HLE is designed for scenarios where there is a richer set of measurements available and cooperation from devices; such as indoor location in urban environments where Wi-Fi and barometric pressure can be leveraged, or in more suburban and rural settings where only GPS and cellular information is available. The focus of this paper is on the HLE.

The Polaris Wireless Hybrid Location Engine

The Polaris Wireless Hybrid Location Engine (HLE) is a robust hybrid location system that combines measurements from multiple sources, such as GNSS, LTE-OTDOA, LTE-ECID, Wi-Fi, Bluetooth, and Barometric pressure to produce a 3-axis location estimate. HLE is different from traditional hybrid systems that rely on fallback mechanisms, whereby if the first location attempt fails (e.g. using GPS) a second location is attempted using a different approach (e.g., OTDOA). Rather, HLE combines all of these measurements into a single framework and leverages techniques in advanced statistical signal processing to combine them in a way that minimizes unreliable measurements in favor of measurements that are more reliable.

HLE offers several advantages:

1. HLE allows for use of partial measurements in a way that other systems do not. For example, using the OTDOA positioning method on its own would require a minimum of two measurements to solve for an X,Y location. However, it is quite common to only obtain a single OTDOA measurement from the device, providing a poor location yield when using OTDOA by itself. The HLE is able to leverage this single measurement in a meaningful way and combine it with other information to provide an accurate location estimate. This is illustrated in Figure 3, where the different colored lines represent how a measurement contributes to the overall location estimate - the thinner the line the more reliable the measurement and hence its contribution to the final solution is greater.

2. The HLE framework provides a great deal of extensibility. Should new measurements become available it is straightforward to incorporate them into the HLE and improve the overall performance. For example, Angle of Arrival (AOA) is currently a standardized measurement but remains unsupported by infrastructure. Should this change, the HLE doesn't need a complete re-write, rather some straightforward extensions can be added to quickly support its inclusion. This is significant. As the industry prepares to launch 5G, there will be a corresponding need for location systems. HLE is well positioned to leverage existing measurements and any new measurements that become available through the 5G standardization process.

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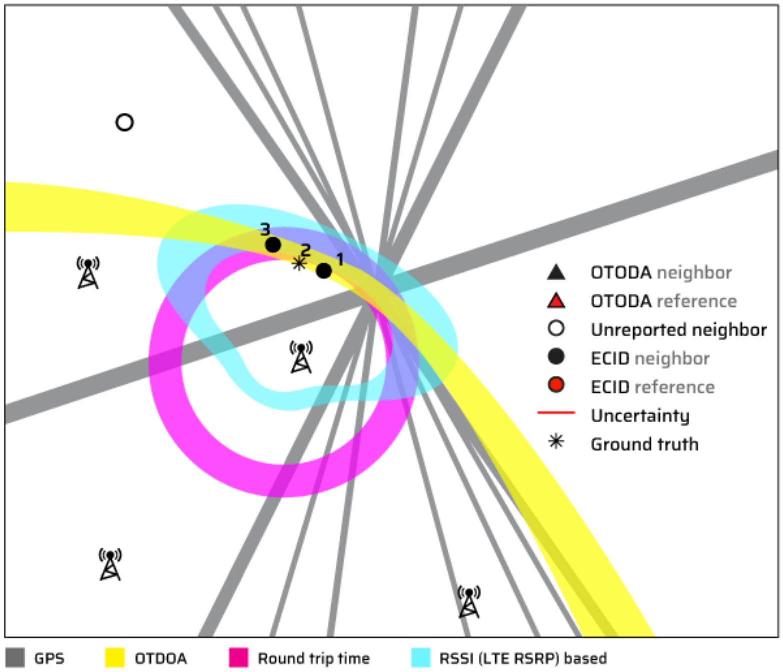
FIGURE 3: DEPICTION OF HLE MEASUREMENT



3. It is also worth highlighting the support within the HLE for the Z-axis. As eluded to earlier, the Z-axis has become important as devices are increasingly used indoors, presenting challenges in urban areas where there is a significant vertical component to the morphology. The two most significant pieces of information the device can provide to facilitate the estimation of the Z-axis is the barometric pressure reading and Wi-Fi access point information. The barometric pressure is the weight of the air-column overhead and hence the higher one is, the lower the air-pressure. However, the barometric pressure does come with some impairments that must be corrected. These include weather effects, sensor biases, and building effects, which are outlined below.

Impacts of External Factors on Barometric-based Vertical Location Technology

Weather conditions impact the barometric pressure readings causing variations over time and location as high and low-pressure weather systems move in and out of an area. Figures 4 and 5 show this geographic variation across the USA and the temporal variation in the San Francisco Bay Area. One can see pressure changes that are equivalent to a change in height of over 80 meters during a 70-hour window. Polaris Wireless leverages an extensive network of weather stations to understand the weather conditions at any point in space and time. This network includes highly calibrated publicly available data supplemented where needed with Polaris Wireless managed off the shelf weather stations. This allows the “uncompensated” barometric pressure reading made by the device to be “compensated” for local weather conditions.

Although the current state of the art barometric sensor is very sensitive, it also has an intrinsic bias. Experience shows that this bias varies from sensor to sensor from the same manufacturer and can be significant enough to add over +/-20 meters of error. This bias may also slowly change over time as the sensor ages. Polaris Wireless has developed a set of compensation algorithms to opportunistically correct for this bias so that, when the location and height is well determined by other means (e.g., GPS, device is located in a geographic region on earth with little terrain variation, Wi-Fi access point) the bias of the device is estimated.

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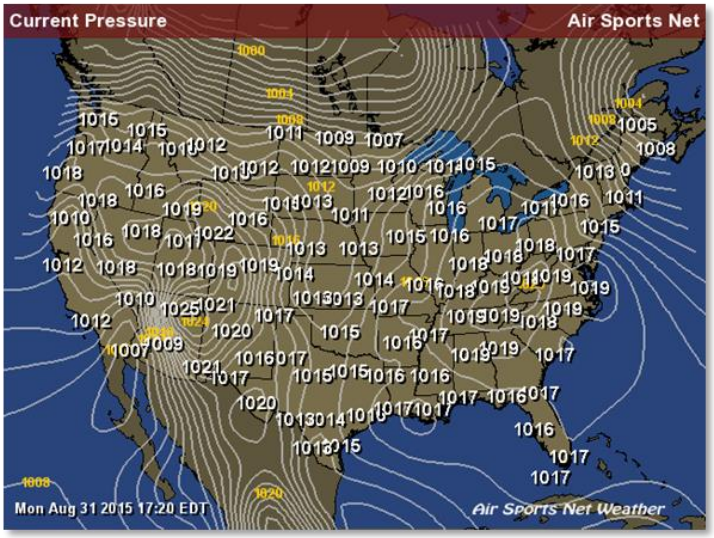
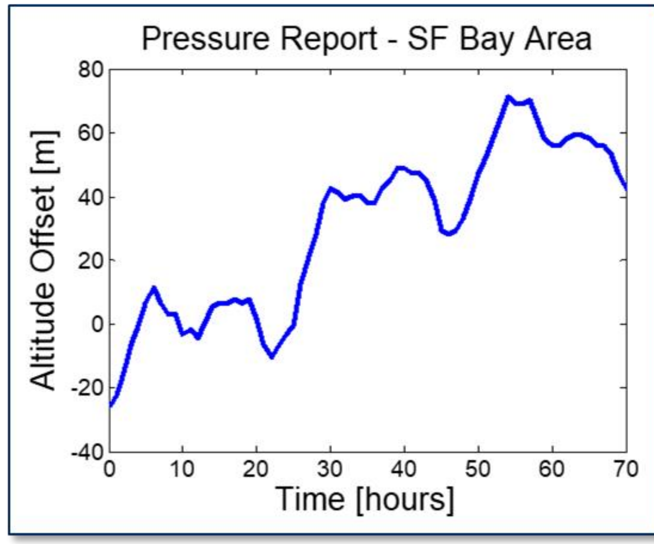
FIGURE 4: WEATHER VARIATIONS IN THE UNITED STATES

FIGURE 5: TEMPORAL VARIATION IN THE SAN FRANCISCO BAY AREA





Lastly, there are well known building effects that can have an impact on the estimation of the vertical dimension. Because indoor spaces are often heated or cooled, the indoor temperature is different than the outdoor ambient temperature. As the weight of the air mass is a function of temperature, this leads a different pressure gradient as a function of height between the indoor and outdoor environment. This is the well-known “Stack Effect” and is more pronounced in larger buildings and when there is a significant difference between the indoor and outdoor temperatures. HVAC effects, especially in well-sealed buildings, further contribute to the overall impact by controlling the positive or negative pressurization of the building. HLE addresses this issue in two ways. First, it uses building models to estimate the in-building effects on pressure. Second, the HLE is a “hybrid” algorithm and leverages Wi-Fi measurements for both the X,Y and Z estimate.

Wi-Fi has been leveraged for positioning solutions for several years and provides accurate X-Y location when the Wi-Fi access database has been properly constructed through crowd-sourcing or other mechanisms. The Wi-Fi database typically describes the estimated latitude, longitude and some measure of uncertainty for each detected Wi-Fi access point. What is missing from commercially available databases is the height of the access point. For this reason, Polaris Wireless has developed its own crowd-sourcing mechanisms to estimate the Z coordinate.

The Polaris Wireless Location Server

In order to realize the novel algorithms contained with the HLE, Polaris Wireless has developed a Location Server illustrated in Figure 7. This Location Server contains all the HLE algorithms and manages the collection of the needed measurements from the device and network. This process is done either through Control Plane mechanisms as defined by the 3GPP standardization body, through Secure User Plane (SUPL) mechanisms defined by the Open Mobile Alliance (OMA), or through the Polaris Wireless defined user plane API.

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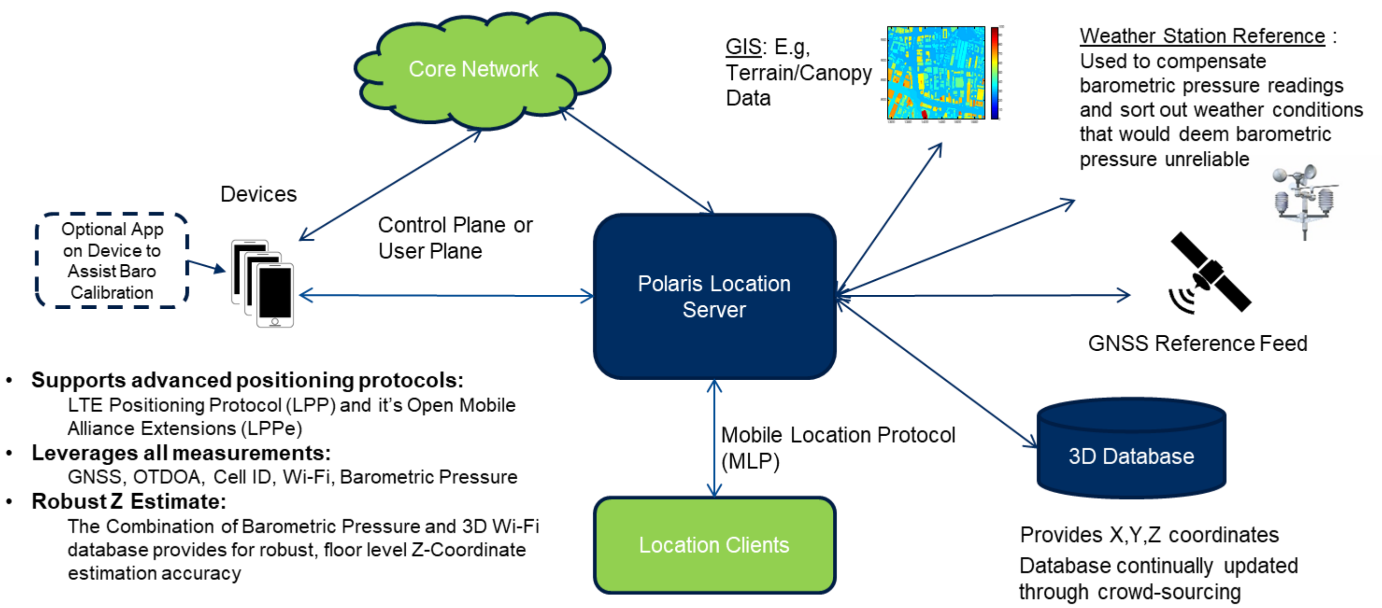
Aside from the measurements defined by the system, there are other pieces of information required for the overall solution to work to its fullest capacity. This includes items like a 3-D Wi-Fi (and Bluetooth) database, a weather compensation network, terrain information, and GNSS information.

The result is a state-of-the-art location platform able to provide location estimates in the horizontal and vertical direction for a variety of applications. These include public safety, healthcare, hospitality, enterprise security, and other IOT applications.

FIGURE 6: POLARIS WIRELESS LOCATION SERVER



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Location Test Bed Results

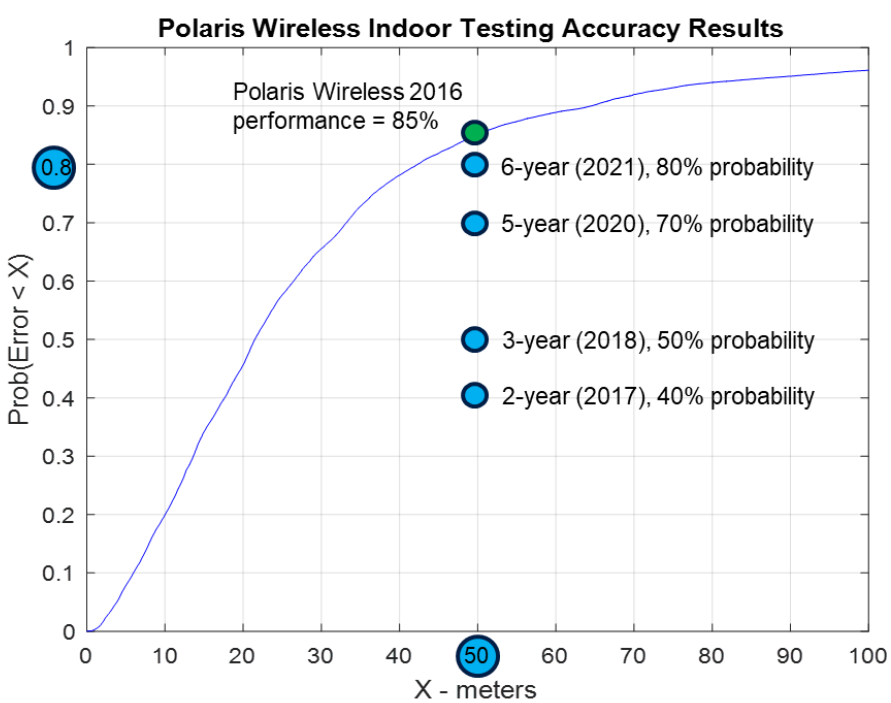
As required by the Federal Communications Commission's 9-1-1 Location Accuracy Fourth Report & Order, an independently administered test bed was established to develop and validate vendor location solutions. The independent entity administering the test bed, The Test Bed LLC, has organized the testing in a number of stages:

1. Stage 1 was conducted in mid-2016 and focused on testing the horizontal accuracy of existing carrier solutions.
2. Stage 2 completed at the end of 2016 with a focus of characterizing the horizontal accuracy of emerging technologies.
3. Stage Z was completed in June of 2018 and focused on vertical accuracy.
4. There have been subsequent tests (e.g. Stage 1a, Stage 2a, etc.) to further characterize existing solutions and to test additional emerging solutions.

Polaris Wireless participated in both Stage 2 and Stage Z testing.

Stage 2 testing focused on the indoor location performance of emerging technologies. The testing was conducted in both San Francisco and Atlanta in roughly 40 different buildings spread across dense urban, urban, suburban, and rural morphologies. The testing is perhaps the most rigorous indoor testing conducted to date with over 40,000 individual location test points. The performance is summarized in the Cumulative Distribution Function in figure 8. To interpret this figure, one can look at a specific error on the X-axis and the Y axis which will indicate the percentage of time the reported location is no greater than this value. Of particular importance is the 50-meter error rate because this is the requirement imposed by the FCC in a graduated fashion, meaning: In year 2017 operators must provide better than 50-meter accuracy for 9-1-1 calls at least 40 percent of the time. By 2021, operators must provide better than 50-meter accuracy for 9-1-1 calls at least 80 percent of the time. Significantly, Polaris Wireless already meets and exceeds the 2021 mandate providing 50-meter accuracy 85 percent of the time.

FIGURE 7: POLARIS WIRELESS INDOOR TESTING ACCURACY RESULTS



The Stage-Z trial testing was completed in April 2018 and the report was filed with the FCC in August 2018. Only two vendors were able to participate in this round of testing, highlighting the difficulty of developing a robust Z-axis solution.

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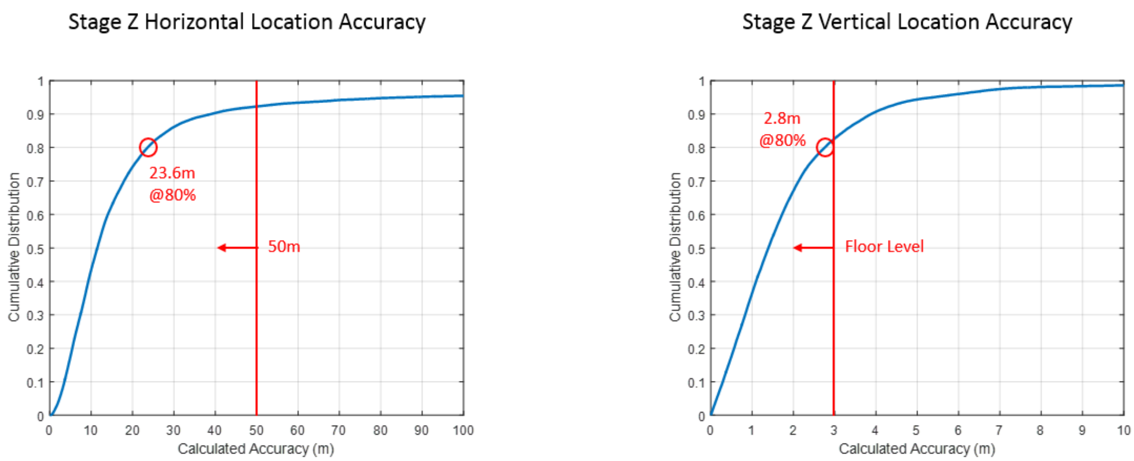
Further, in order to test in a more extreme climate, the Test Bed committee elected to add Chicago to go along with San Francisco and Atlanta as markets for testing. Polaris Wireless was the only company that was able to test both in all cities and all morphologies. The other test participant solution was not able to deploy their system for testing in Chicago or in rural areas of Atlanta and San Francisco. In order to get representative performance across different device manufacturers and, perhaps more importantly, different barometric sensor manufacturers, Polaris Wireless used six devices of various makes, models and ages. Results in these images are drawn from actual test data and show an improved indoor horizontal location from Stage 2 testing and show better than floor level vertical accuracy.

FIGURE 8: STAGE Z TEST RESULTS



What’s Next?

Building on the innovation of 3D location, in March 2019 Polaris Wireless announced the commercial availability of the industry’s first high-accuracy, carrier-independent 3D location platform for application developers. Polaris Wireless is integrating its new platform with wireless device leaders and application developers such as Orion Labs, Inc., a San Francisco-based company delivering instant and secure voice and location communication to public safety and other industries, as depicted in the figure below which is a screenshot of a live video demonstration conducted by Orion Labs and Polaris Wireless at IWCE 2019 in Las Vegas, Nevada.

By integrating the new platform in their applications, developers can provide their end users with pinpoint location, including indoors and in high-rise buildings with floor level accuracy, delivering enhanced situational awareness and improved operational efficiency. The Polaris Wireless 3D location platform is cloud-based and is available to application developers via a standard Android and iOS SDK. By operating independently, or ‘over the top’, of wireless carrier networks, the platform is truly universal, enabling applications to locate any device on any network. Only Polaris Wireless has been tested in all markets, all morphologies, and using commonly available smartphones. With two decades of experience and a successful track record of location technology innovation, Polaris Wireless is the only choice for companies who want to deploy 3D location now.

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