Summary of 'Report on Stage Z'

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911 Location Test Bed
on behalf of CTIA and the FCC

PROGRAM MANAGER:
Alliance for Telecommunications
Industry Standards

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Further Enterprise Solutions

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Executive Summary

This Stage Z Test Report describes the independently administered and transparent test bed process established to develop and validate a proposed Z-axis (vertical) metric for indoor wireless 911 calls, as required by the Federal Communications Commission's (FCC's) 911 Location Accuracy Fourth Report & Order. The objective of the Z-axis test campaign described in this report, known as Stage Z, was to provide a rigorous, transparent process to evaluate the accuracy and overall assessment of Z-axis technology based on standard testing methodologies.

> **Note: Since the time of this Test Bed Report, the FCC has issued a Sixth Report and Order on 911 Location Accuracy, in proceeding 07-114, requiring wireless carriers to deliver a z-axis location in the Top 25 CMAs with accuracy of 3m for 80% of calls by April 2021 and in the Top 50 CMAs by April 2023. Further, NextNav's Pinnacle technology has been adopted by AT&T for use with the FirstNet Public Safety Broadband Network, and Pinnacle technology has been deployed in 4,400 cities and towns across 105 CMAs, covering over 90% of buildings in the U.S. that exceed three stories.**

The Test Bed LLC publicly solicited technology vendors to participate in Stage Z, and two Z-axis technology vendors, NextNav and Polaris Wireless, volunteered, formally applied, and participated in Stage Z to test technologies that rely on barometric pressure sensor information from mobile wireless handsets to determine an estimated altitude of an indoor wireless 911 call.

The Stage Z testing was specifically conducted in accordance with ATIS standards and testing parameters, which account for unique factors beyond those that affect x/y (horizontal) technologies. Stage Z testing was also conducted among a wide variety of buildings types and environments, including high-rise residential and commercial buildings in dense urban, urban, suburban, and in some cases rural areas. For each selected building several test points were identified that represent different barometric pressure environments within a building, and generally span the different areas within a building from which a wireless 911 call might be initiated.

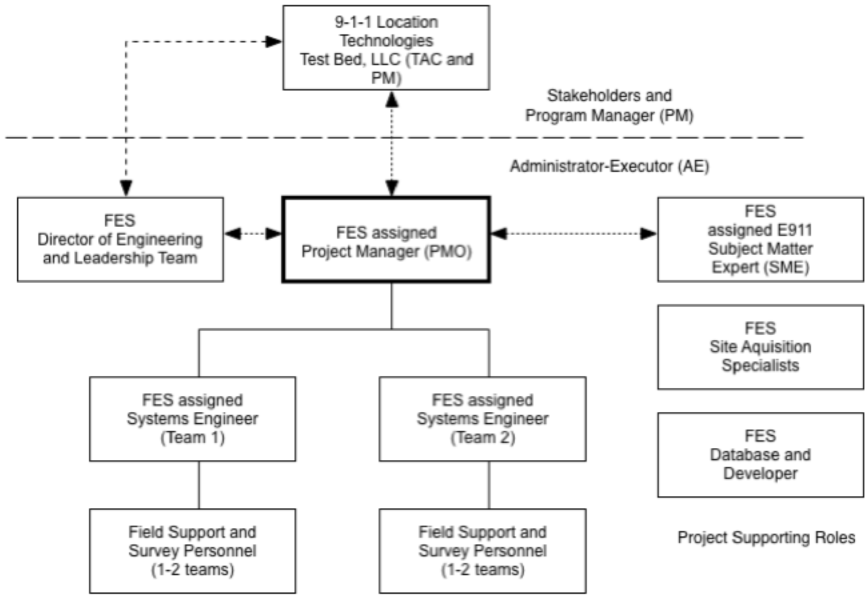
In addition to the participation of the technology vendors during the actual testing, there are stakeholders and involved parties concerned with Z-axis technologies and performance. The CTIA Z-axis Working Group is a collaboration of industry leaders from across many related disciplines, including wireless carriers, technology OEMs, sensor and handset manufacturers, service providers related to E9-1-1, and public safety representatives.

The Z-axis Working Group met on multiple occasions to provide guidance to the Test Bed, LLC on the testing and evaluation of Z-axis technologies. For example, the Z-axis Working Group held an all-day meeting on September 8th, 2015 to discuss the performance of barometric pressure sensor devices, including accuracy, trends and the state of technology. Although this document is a work product of Test Bed, LLC, the Z-axis Working Group has reviewed and provided input that has been incorporated throughout.

Z-Axis Test Organization

The Test Bed provides independent indoor performance results of deployed and emerging wireless 9-1-1 location information technologies. Test Bed, LLC has selected FES as the independent "Administrator-Executor" of the Test Bed. It also selected ATIS as the Test Bed's independent Program manager. ATIS provided guidelines on test building and test point selection and oversaw implementation of the Test Bed by the Administrator-Executor. In addition, Test Bed, LLC receives guidance from the TAC, which includes representatives of the nationwide wireless service providers, as well as the Association of Public-Safety Communications Officials International (APCO) and the National Emergency Number Association (NENA).

The organization structure of the Test Bed is described in the following diagram:



As outlined in this Figure 6.1, there were multiple stakeholders involved with the Test Bed, LLC's organization and process, consistent with the CSRIC IV recommendations. The Test Bed, LLC's Steering Committee and TAC provided guidance on operational and technical issues, respectively. Both committees included representatives of the nationwide wireless providers, as well as APCO and NENA. The Test Bed, LLC oversaw the efforts of the Administrator/Executor, ATIS, and the test service provider, FES, who performed the actual testing. ATIS' committees developed the test methodologies utilized by the test service provider.

Z-axis Location Test Procedures

"Representative testing" is the cornerstone of the test methodology that governs testing in the Test Bed. After extensive study and deliberation with ATIS ESIF ESM, consensus was achieved in adopting the San Francisco and Atlanta regions as providing sufficient test representation of the broad conditions prevailing in both the Western and Eastern United States. In both of these regions test boundaries, or polygons, that contain samples of the four distinct morphologies, dense urban, urban, suburban, and rural, which are described concisely in Section 7.3, were defined and included in ATIS-0500031.v002. (Note that these polygons are reproduced later in this report in Section 8.3 in figures that describe the buildings used in testing within those polygons.)

The following guidelines (recommended by ATIS ESIF ESM and found in ATIS-0500031.v002, ATIS-0500030) were required for executing Stage Z test scenarios and methodology:

1. Three (3) test regions: San Francisco, CA (SFO); Atlanta, GA (ATL); and Chicago, IL (CHI).[†]

2. SFO and ATL: Up to twenty (20) candidate buildings selected and surveyed per test region across all 4 morphologies, according to the requirements in ATIS-0500031.v002.

3. CHI: Up to ten (10) candidate buildings selected and surveyed across only dense urban and urban morphologies, per the guidance in ATIS-0500030 for inclusion of a colder climate in z-axis testing of barometric pressure-based technologies. (Selected within 5 miles of downtown Chicago, see Figure 8.1).

4. A range of test points in each of the test buildings, including in two high-rise buildings per region (sealed and unsealed if possible) where additional test points are selected as much as possible evenly distributed throughout the vertical axis of the building.

5. A total of approximately 120 test points in each of the San Francisco and Atlanta test regions and 75 test points in Chicago.

6. Up to six (6) test devices per testing participant. Thirty (30) test calls from each of the six (6) test devices divided into five (5) groups of six (6) test calls at each visit to a test point. Total rounds of testing per building were five, executed occasionally in a round-robin manner and frequently in a more random fashion.

7. Test handsets included a variety of models and manufacturing dates. The intent was to ensure variability between on-device barometric sensor manufacturers and unit age which would more closely represent the general public handset make up. However, only relatively new handsets, released more recently than mid-2016, were tested because older devices' limitations could not support the vendors' test apps. (Accordingly, performance

[†] NextNav did not participate in the Chicago market tests in 2018 because its network was still in deployment. NextNav coverage now includes 105 FCC Cellular Market Areas (CMAs).

on older or less capable handsets cannot be inferred from the current testing.)

8. A scientific grade barometric pressure sensor unit was used alongside the test handsets for informational purpose to capture changes in ambient pressure due to activities in test surroundings and to serve as a cross check in test point ID logging. Measurements were recorded in 1-minute intervals and provided as hectopascal (i.e., millibar).

9. When possible, testing was scheduled with variability in weather conditions and randomization of atmospheric conditions. Daily atmospheric conditions were recorded from nearby weather stations using National Wireless Service standard data. Three geographically dispersed locations surrounding the test building were selected for each test region.

10. In at least one building, test devices were left with the barometric reference unit on-site to perform an extended 24-hour observation test.

11. Exterior doors and windows were normally closed at test point locations, except for certain predefined test points where testing was performed with the windows both closed and open. Room doors were closed to hallways when possible.

12. GPS was enabled on test-handsets.

13. Test handsets did not need to be power cycled at end of each 6-call test cycle and prior to moving to each subsequent test point for Stage Z. This is because the barometric pressure reading is not likely to be interdependent as was the case with x/y readings from device-based hybrid in other stages of testing.

14. No placement of pre-test configuration verification calls prior to actual testing at any of the test points was allowed. Such calls, when needed, were placed as separate as possible (horizontally and/or vertically) from the test points.

FES procured access rights from property managers and completed testing of the Z-axis location technologies in various building types in the test bed regions and morphologies specified.

Handsets and Software

The handsets used in testing were the same production-ready handsets sold by wireless carriers and available to the general public. The handsets did not contain any hardware modification that would favor these handsets over any commercially available handsets. By agreement between the Test Bed, LLC and the Z-axis technology vendors only relatively new handsets, released more recently than mid-2016, were tested. Test results, therefore, cannot be extrapolated to older, less capable handsets.

The handsets required test applications from each technology vendor participant to be installed to utilize their platforms. These applications performed, among other functions, the critical function of handset sensor bias calibration, which was mostly performed in the background using nonstandard vendor-specific methods. (More details provided in Section 8.5.)

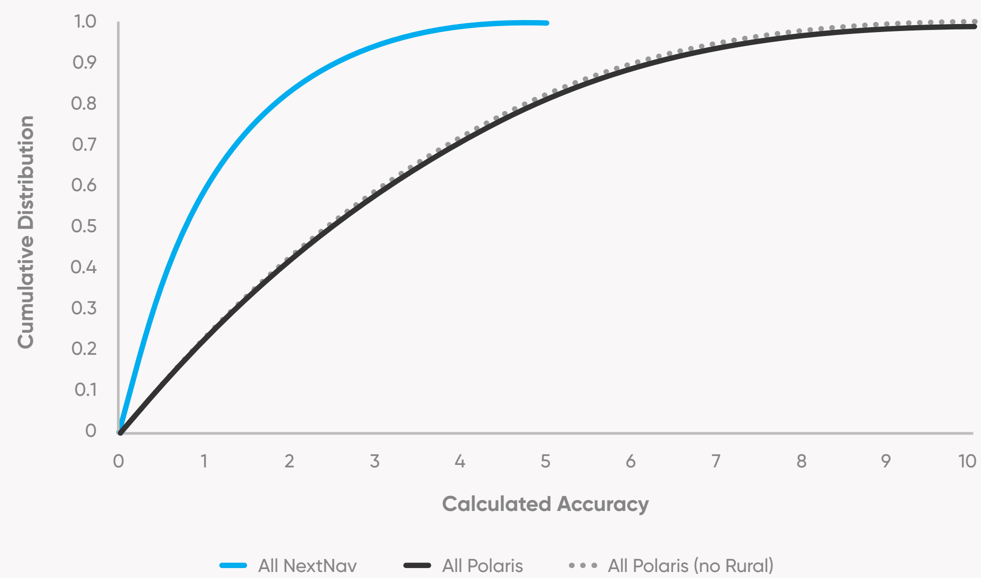
> **Note: Since this test report was published, NextNav software has been installed and used by commercial applications currently available in the market.**

Handset configurations were specified by each test participant (network preference, location accuracy settings, device timeouts and privacy controls). Test handsets were purchased from commercial sources by the test administrator and were a mix of new and somewhat older units. (More details provided in Section 8.5.) No handling of the test handset by a technology vendor was permitted.

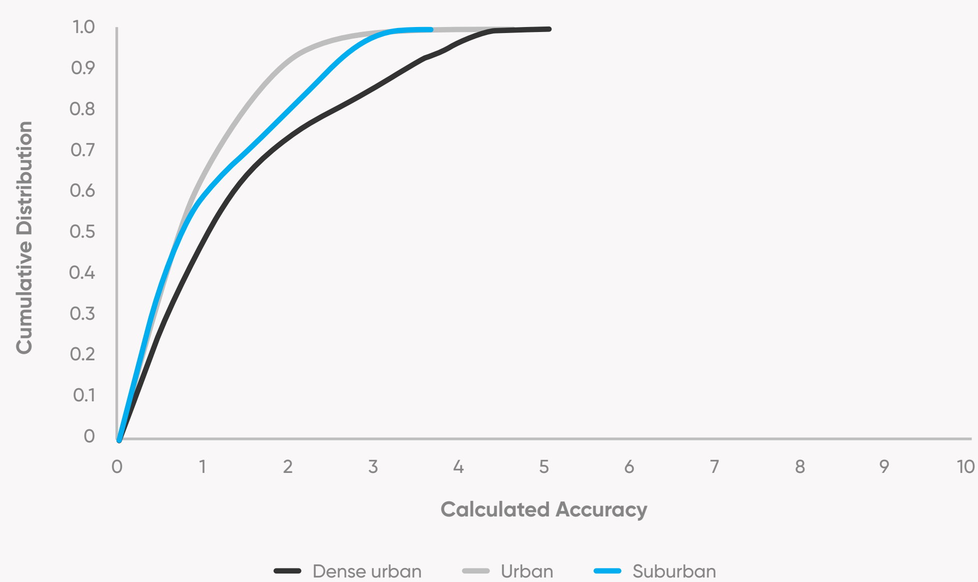
Z-axis Location Accuracy Summary

This section includes the top-level summary results for both technology vendors (NextNav and Polaris Wireless) combined and broken out by morphology.

Aggregated vertical accuracy CDF across all test data



NextNav vertical accuray CDF per morphology



NextNav Z-Axis Location Accuracy

This section includes the summary results for NextNav broken out by morphology, city and handset.

NextNav vertical accuray results

						Horizontal					Vertical							
	Tests Initiated	Tests Completed	Successful Test Yield (%)	Avg Time to First Fix (sec)	Avg Barometric Pressure (mbar)	67th Percentile (m)	80th Percentile (m)	90th Percentile (m)	Avg Uncertainty	Within Uncertainty (%)	Avg Altitude Error (m)	Std.Dev. Altitude Error (m)	Avg Distance Error (m)	67th Percentile (m)	80th Percentile (m)	90th Percentile (m)	Avg Uncertainty	Within Uncertainty (%)
Tests Bed Regions																		
All	38485	38485	100.0%	25.0	996.9	29.2	40.4	59.1	57.1	75.7%	-0.4	1.0	1.1	1.3	1.8	2.5	3.4	96.5%
Atlanta	19419	19419	100.0%	25.0	980.0	29.9	42.3	60.5	62.9	75.8%	-0.6	1.0	1.2	1.5	2.0	2.7	3.4	95.9%
San Francisco	19066	19066	100.0%	25.0	1012.1	28.7	38.8	57.7	51.2	75.6%	-0.1	0.9	1.0	1.1	1.6	2.3	3.4	97.0%
Per Carrier																		
AT&T	18829	18829	100.0%	25.0	996.7	29.9	41.5	59.9	64.3	78.9%	-0.4	1.0	1.1	1.3	1.8	2.5	3.4	96.2%
Verizon	19656	19656	100.0%	25.0	997.1	28.6	39.5	58.5	50.2	72.6%	-0.3	0.9	1.1	1.3	1.8	2.5	3.4	96.7%
Morphology																		
Dense Urban	13413	13413	100.0%	25.0	995.8	40.5	57.4	82.7	74.8	69.3%	-1.0	1.2	1.4	1.6	2.5	3.3	3.4	90.6%
Urban	15920	15920	100.0%	25.0	995.8	25.7	34.8	48.7	51.7	79.5%	-0.2	0.7	0.9	1.1	1.5	1.9	3.4	99.5%
Suburban	9152	9152	100.0%	25.0	1002.5	21.1	28.4	39.1	40.5	78.3%	0.3	0.9	1.0	1.3	2.0	2.5	3.4	99.7%
Test Bed Regions by Morphology																		
Atlanta - Dense Urban	5753	5753	100.0%	25.0	977.0	39.2	57.2	86.9	101.5	74.7%	-1.5	1.2	1.7	2.3	3.0	3.5	3.4	87.4%
Atlanta - Urban	9913	9913	100.0%	25.0	983.5	27.7	39.2	52.1	50.6	78.0%	-0.2	0.7	0.9	1.1	1.5	1.9	3.4	99.3%
Atlanta - Suburban	3753	3753	100.0%	25.0	976.3	21.4	31.4	45.6	36.1	71.5%	-0.2	0.9	1.2	1.7	2.1	2.5	3.4	99.9%
San Francisco - Dense Urban	7660	7660	100.0%	25.0	1011.0	41.0	57.5	80.9	54.7	65.2%	-0.6	1.1	1.2	1.2	1.8	3.0	3.4	93.0%
San Francisco - Urban	6007	6007	100.0%	25.0	1014.2	22.9	29.2	38.4	53.6	82.0%	-0.2	0.7	0.9	1.0	1.4	1.8	3.4	99.9%
San Francisco - Suburban	5399	5399	100.0%	25.0	1012.0	20.5	27.1	35.0	43.5	83.1%	0.6	0.9	1.0	1.1	1.7	2.5	3.4	99.6%

NextNav vertical accuray results by handset

						Horizontal					Vertical							
	Tests Initiated	Tests Completed	Successful Test Yield (%)	Avg Time to First Fix (sec)	Avg Barometric Pressure (mbar)	67th Percentile (m)	80th Percentile (m)	90th Percentile (m)	Avg Uncertainty	Within Uncertainty (%)	Avg Altitude Error (m)	Std.Dev. Altitude Error (m)	Avg Distance Error (m)	67th Percentile (m)	80th Percentile (m)	90th Percentile (m)	Avg Uncertainty	Within Uncertainty (%)
Tests Bed Regions																		
All	38485	38485	100.0%	25.0	996.9	29.2	40.4	59.1	57.1	75.7%	-0.4	1.0	1.1	1.3	1.8	2.5	3.4	96.5%
Atlanta	19419	19419	100.0%	25.0	980.0	29.9	42.3	60.5	62.9	75.8%	-0.6	1.0	1.2	1.5	2.0	2.7	3.4	95.9%
San Francisco	19066	19066	100.0%	25.0	1012.1	28.7	38.8	57.7	51.2	75.6%	-0.1	0.9	1.0	1.1	1.6	2.3	3.4	97.0%
Handset **Each individual handset model**																		
Samsung Galaxy S8	5986	5986	100.0%	25.0	996.2	22.4	32.7	49.0	27.0	60.6%	-0.2	1.0	1.1	1.3	1.9	2.7	3.4	95.7%
Samsung Galaxy S8 plus	6536	6536	100.0%	25.0	997.1	24.8	36.3	55.2	24.7	53.6%	-0.3	1.0	1.0	1.1	1.7	2.4	3.4	96.2%
Iphone 7	6562	6562	100.0%	25.0	997.1	29.8	39.8	61.1	62.1	82.0%	-0.4	0.9	1.1	1.3	1.8	2.5	3.4	97.1%
Iphone 7 plus	6299	6299	100.0%	25.0	996.9	32.3	43.8	62.8	93.7	89.6%	-0.3	1.0	1.1	1.2	1.8	2.5	3.4	96.1%
Iphone 8	6544	6544	100.0%	25.0	997.1	33.2	44.3	64.5	70.0	85.4%	-0.5	0.9	1.1	1.3	1.8	2.5	3.4	96.8%
Iphone 8 plus	6558	6558	100.0%	25.0	997.1	30.2	41.9	59.8	63.7	82.0%	-0.4	1.0	1.2	1.4	1.9	2.6	3.4	96.8%
Atlanta individual handsets																		
Samsung Galaxy S8	3088	3088	100.0%	25.0	980.2	21.4	30.9	50.0	32.9	66.1%	-0.6	1.0	1.2	1.5	2.0	2.7	3.4	94.5%
Samsung Galaxy S8 plus	3248	3248	100.0%	25.0	980.1	25.9	40.5	59.5	28.2	53.5%	-0.5	1.0	1.2	1.4	1.9	2.7	3.4	94.7%
Iphone 7	3274	3274	100.0%	25.0	980.0	30.0	40.7	58.3	64.9	80.4%	-0.4	1.0	1.2	1.5	2.0	2.7	3.4	97.1%
Iphone 7 plus	3265	3265	100.0%	25.0	980.0	32.0	43.2	59.0	111.4	91.5%	-0.6	1.0	1.2	1.5	2.0	2.7	3.4	95.6%
Iphone 8	3270	3270	100.0%	25.0	980.0	35.3	48.9	70.0	70.5	82.3%	-0.6	1.0	1.2	1.5	2.0	2.7	3.4	96.9%
Iphone 8 plus	3274	3274	100.0%	25.0	980.0	32.1	45.4	61.7	67.8	80.2%	-0.7	1.0	1.2	1.5	2.1	2.7	3.4	96.4%
San Francisco individual handsets																		
Samsung Galaxy S8	2898	2898	100.0%	25.0	1011.7	24.6	35.2	48.7	20.8	54.7%	0.2	1.0	1.1	1.2	1.8	2.7	3.4	96.9%
Samsung Galaxy S8 plus	3288	3288	100.0%	25.0	1012.2	23.4	33.1	50.4	21.2	53.7%	-0.1	0.9	0.9	0.9	1.3	2.1	3.4	97.7%
Iphone 7	3288	3288	100.0%	25.0	1012.2	29.2	39.3	65.5	59.4	83.5%	-0.4	0.9	1.0	1.1	1.5	2.3	3.4	97.0%
Iphone 7 plus	3034	3034	100.0%	25.0	1012.3	32.7	45.2	67.4	74.7	87.6%	0.0	0.9	1.0	1.0	1.5	2.3	3.4	96.7%
Iphone 8	3274	3274	100.0%	25.0	1012.2	31.0	40.9	57.4	69.6	88.6%	-0.4	0.9	1.0	1.2	1.7	2.2	3.4	96.7%
Iphone 8 plus	3284	3284	100.0%	25.0	1012.2	28.8	37.9	56.7	59.6	83.8%	-0.1	0.9	1.1	1.3	1.7	2.4	3.4	97.2%

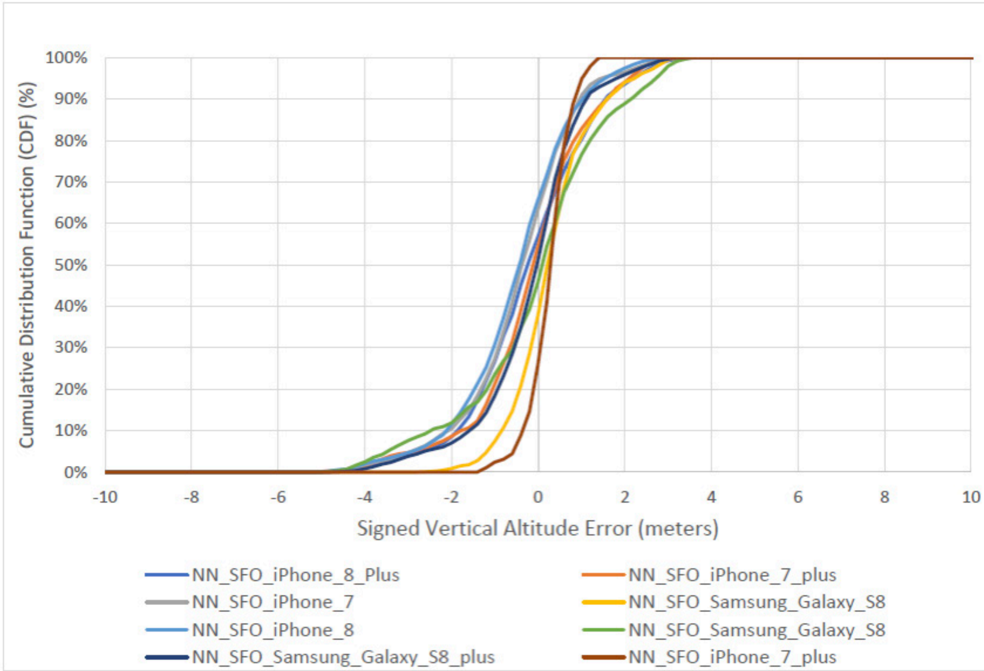


Figure 9.31 – Signed Vertical Error CDF for NextNav San Francisco Test Devices

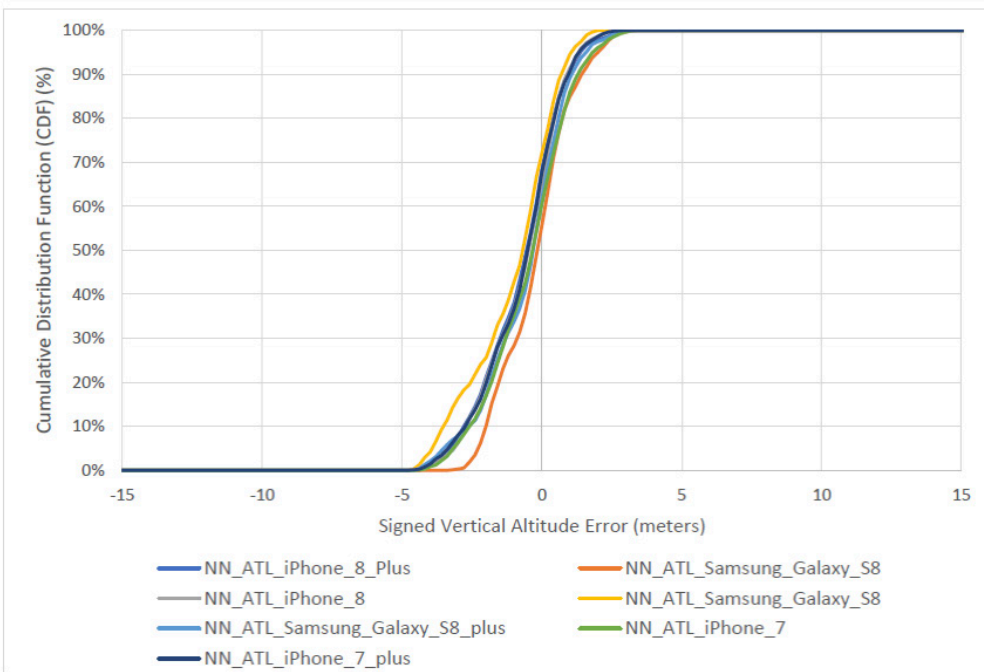


Figure 9.33 – Signed Vertical Error CDF for NextNav Atlanta Test Devices

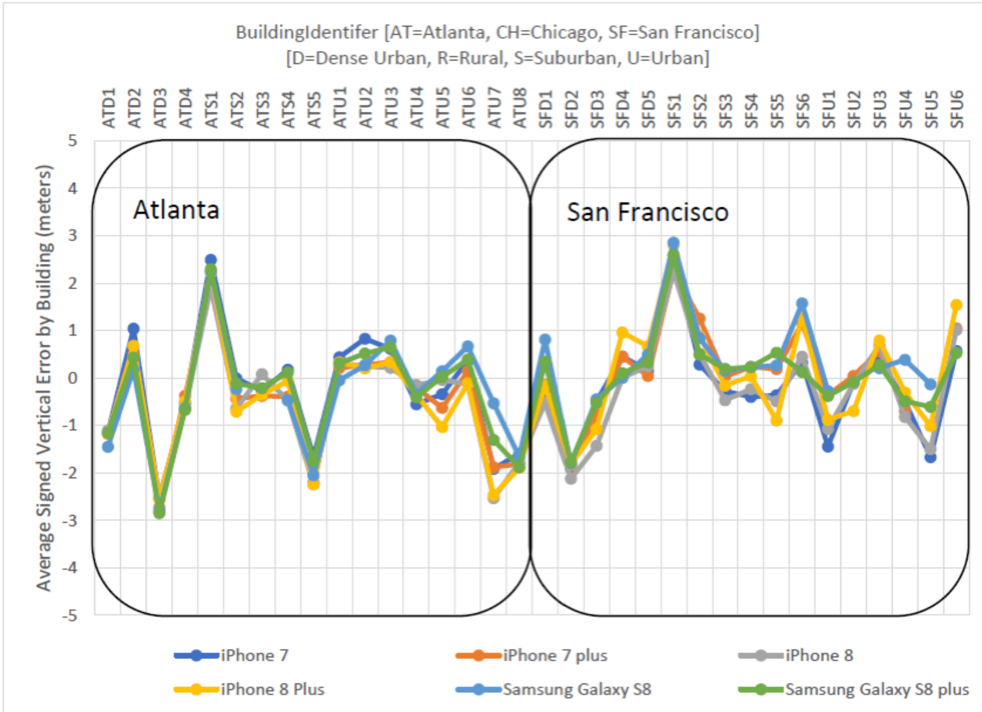
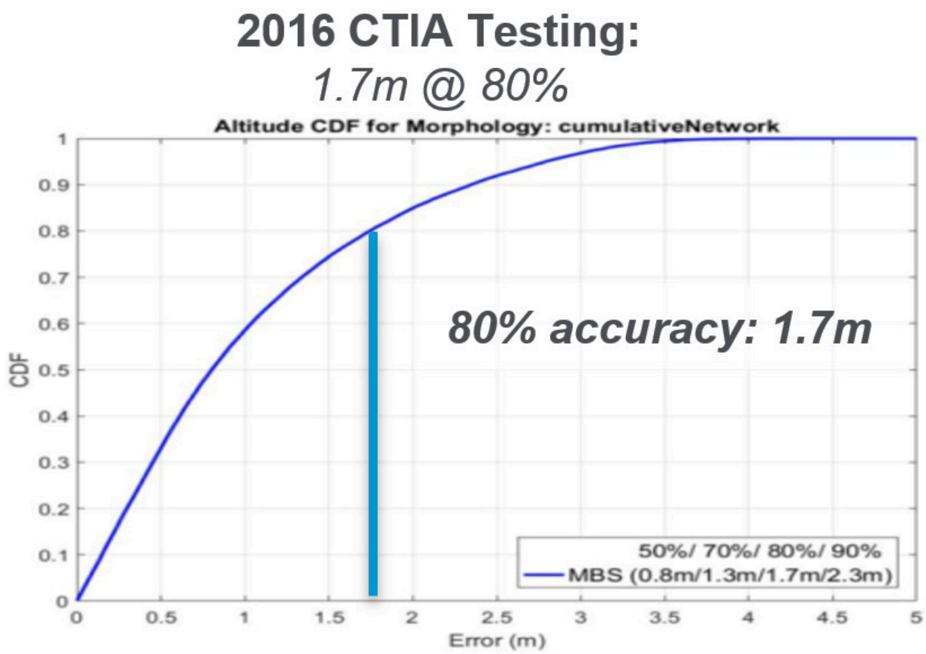
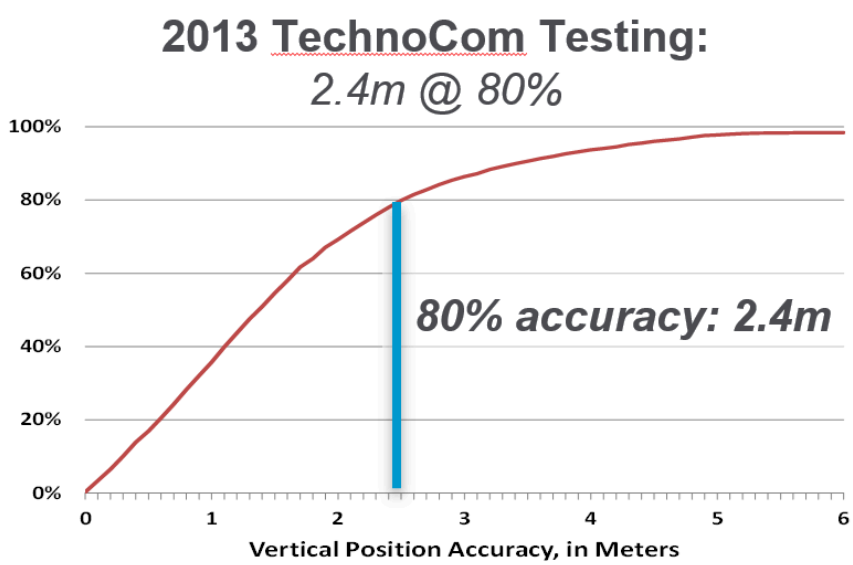


Figure 9.35 – Average Signed Vertical Error by Building – NextNav Devices

Appendix I: NextNav historical accuracy results

In addition to the CTIA testbed results summarized above, NextNav has demonstrated high accuracy of its Pinnacle vertical location solution for many years prior. Below are the results of two previous test results from reports produced in 2016 and 2013, with indicators of how those results compare against FCC accuracy requirements.





Appendix II: Polaris Wireless and Google

In addition to the NextNav Pinnacle service, the CTIA test bed also tested an OS-based vertical location from Google and a multi-source vertical location from Polaris Wireless as part of its “Stage Z” regimen.

The results for Polaris Wireless were publicly released. Following direct intervention by Google with CTIA and the FCC, only a summary of the results were released for public scrutiny. Some data from the Google tests were later included in third-party FCC filings, however, providing insight into performance quality against competing solutions and FCC requirements.

For context, below is a brief summary and a selection of data from both Google and Polaris Wireless. The data from Polaris wireless is drawn directly from the CTIA report; the data for Google is drawn from a T-Mobile filing with the FCC.

Google

Google’s testing in Stage Za was conducted in a commercially deployed configuration, but at the time of testing it was not able to demonstrate full compliance with the FCC’s vertical location accuracy benchmark.

T-Mobile estimates that vertical location obtained through Google’s ELS and Apple’s HELO systems produce vertical locations of ±3 meters for about 55% of 911 calls, which falls short of the FCC requirement of ±3m 80% of the time.

Yet even this estimate is speculative. T-Mobile created that number based on Google’s testing in Stage Za (in which more than half of calls achieved a vertical location estimate within ±3 meters), combined with an estimate that 50% of calls from iOS devices can meet the vertical location benchmark—although iOS performance has not yet been verified in the test bed—and weighted by the relative percentages of Android and iOS devices on T-Mobile’s network.

Polaris Wireless

The Polaris Wireless Hybrid Location Engine (HLE) Z-axis hybrid is a software-based solution that utilizes data from the handset including handset GPS, raw GPS, Barometer, ECID, and WiFi. These measurements are collected in the Polaris Wireless location Server where these sources are combined, and proprietary algorithms are applied to generate a hybrid Z-location estimate.

Polaris Wireless originally proposed that its complete hybrid solution be put under test. It also intended to collect test and calibration data within test buildings in each Test Region in advance of the Z-axis test bed campaign. The TAC asked Polaris Wireless not to enter potential test buildings in advance of the test since doing so would not be representative of the process that can be scaled to the remainder of the country and therefore would not render a fair assessment of the technology. Given this restriction, Polaris Wireless opted not to include the 3D WiFi component of their hybrid location solution and tested only the barometric component.

Polaris Wireless asserts that its barometric-based Z-axis capability was initially commercially available in the market through an over-the-top application for iOS and Android devices and was demonstrated to the FCC in 2014. Nevertheless, the Polaris Wireless solution under Stage Z testing currently is not available on consumer handsets and therefore required a software application, which was installed on the test handsets by FES field technicians and configured for testing using Polaris Wireless specifications.

The Polaris Wireless z-axis solution includes the ability for an application to run in the background of the device with the purpose of measuring device and barometric sensor bias over time – continuous opportunistic (background) calibration. Device and sensor bias are key sources of location error, and the Polaris Wireless software includes proprietary algorithms to calibrate and compensate for these sensor biases, which may improve accuracy performance. Polaris Wireless chose to disable this feature for Stage Z testing based on their interpretation of available procedures and guidance from the Test Bed's TAC and Program Manager. (The Test Bed provided the same procedure to both NextNav and Polaris). As such, Polaris Wireless results in the current test campaign may underestimate the performance results that might be achieved using an effective continuous (background) calibration algorithm for each individual mobile device.

Table 9.3 Polaris Vertical Accuracy Results

						Horizontal					Vertical							
	Tests Initiated	Tests Completed	Successful Test Yield (%)	Average Time to First Fix (sec)	Average Barometric Pressure (mBar)	67th Percen-tile (m)	80th Percen-tile (m)	90th Percen-tile (m)	Average Uncertainty	Within uncertainty (%)	Average Altitude Error (m)	Std. Dev. Altitude Error (m)	Average Distance Error (m)	67th Percen-tile (m)	80th Percen-tile (m)	90th Percen-tile (m)	Average Uncertainty	Within uncertainty (%)
Test Bed Regions																		
All	55592	55592	100.0%	25.5	993.4	16.7	23.6	39.0	84.6	91.0%	-1.1	3.8	3.0	3.7	4.8	6.2	8.5	79.3%
Atlanta	21029	21029	100.0%	25.5	980.4	16.5	22.6	31.7	59.5	92.9%	-0.1	4.9	2.0	2.3	3.1	4.0	5.0	93.6%
San Francisco	21115	21115	100.0%	25.5	1005.4	15.5	21.6	30.9	44.8	93.0%	-1.6	2.7	3.6	4.4	5.6	7.0	9.7	73.9%
Chicago	13448	13448	100.0%	25.5	992.6	19.6	40.4	137.5	186.2	84.9%	-2.2	2.8	3.7	4.9	5.8	6.8	11.9	65.6%
Per Carrier																		
AT&T	27826	27826	100.0%	25.5	993.4	16.8	23.9	39.3	87.5	91.1%	-1.3	4.8	2.7	2.8	4.7	6.6	11.7	81.4%
Verizon	27766	27766	100.0%	25.5	993.4	16.5	23.4	38.8	81.6	90.9%	-1.0	2.3	3.4	4.1	4.9	5.9	5.2	77.2%
Morphology																		
Dense Urban	20716	20716	100.0%	25.5	994.5	22.7	36.8	115.3	149.2	85.5%	-1.5	2.6	3.1	3.8	4.7	6.2	9.3	79.0%
Urban	22662	22662	100.0%	25.5	995.1	13.8	19.2	27.7	54.5	95.1%	-1.2	2.3	2.9	3.8	5.0	6.1	4.6	75.7%
Suburban	9336	9336	100.0%	25.5	1001.7	11.5	15.8	20.2	30.4	96.5%	-1.5	7.1	2.7	3.1	4.1	5.5	15.5	86.8%
Rural	2878	2878	100.0%	25.4	953.8	24.4	28.9	36.9	31.8	80.5%	2.5	4.2	4.9	5.6	8.6	11.4	10.6	86.4%
Test Bed Regions by Morphology																		
Atlanta - Dense Urban	5735	5735	100.0%	25.5	977.0	20.9	28.8	40.6	80.7	93.6%	-0.5	2.0	2.2	2.6	3.5	4.2	4.5	91.9%
Atlanta - Urban	9917	9917	100.0%	25.5	983.5	15.3	21.1	32.4	62.8	92.5%	0.6	1.6	1.8	2.2	2.9	4.0	4.5	92.1%
Atlanta - Suburban	3944	3944	100.0%	25.5	976.5	12.0	16.5	21.5	30.1	94.1%	-0.5	10.6	2.0	2.0	2.5	3.3	5.3	98.2%
Atlanta - Rural	1433	1433	100.0%	25.4	985.7	20.9	24.5	28.5	32.6	89.3%	-1.7	1.6	2.4	3.0	3.8	4.5	10.1	98.5%
San Francisco - Dense Urban	7638	7638	100.0%	25.5	1011.0	20.3	27.1	48.1	50.0	89.9%	-2.1	2.3	3.4	4.1	5.3	6.8	4.5	73.6%
San Francisco - Urban	6640	6640	100.0%	25.5	1014.2	11.5	16.3	23.5	53.4	96.8%	-2.3	2.2	3.4	4.4	5.4	6.6	4.7	70.3%
San Francisco - Suburban	5392	5392	100.0%	25.5	1012.0	11.1	15.5	19.2	30.7	98.2%	-2.2	2.3	3.2	4.0	5.1	6.4	22.9	78.5%
San Francisco - Rural	1445	1445	100.0%	25.5	935.8	28.2	33.9	42.0	31.0	71.8%	6.7	4.5	7.3	9.6	11.4	13.7	11.0	74.4%
Chicago - Dense Urban	7343	7343	100.0%	25.6	992.6	40.5	133.9	141.6	305.8	74.5%	-1.6	3.1	3.5	4.2	5.4	6.7	18.0	74.6%
Chicago - Urban	6105	6105	100.0%	25.5	992.5	14.0	19.2	24.9	42.3	97.4%	-2.9	2.5	4.0	5.4	6.1	6.9	4.7	54.9%

Table 9.4 Polaris Vertical Accuracy Results by Handset

						Horizontal					Vertical							
	Tests Initiated	Tests Completed	Successful Test Yield (%)	Average Time to First Fix (sec)	Average Barometric Pressure (mBar)	67th Percen-tile (m)	80th Percen-tile (m)	90th Percen-tile (m)	Average Uncertainty	Within uncertainty (%)	Average Altitude Error (m)	Std. Dev. Altitude Error (m)	Average Distance Error (m)	67th Percen-tile (m)	80th Percen-tile (m)	90th Percen-tile (m)	Average Uncertainty	Within uncertainty (%)
Test Bed Regions																		
All	55592	55592	100.0%	25.5	993.4	16.7	23.6	39.0	84.6	91.0%	-1.1	3.8	3.0	3.7	4.8	6.2	8.5	79.3%
Atlanta	21029	21029	100.0%	25.5	980.4	16.5	22.6	31.7	59.5	92.9%	-0.1	4.9	2.0	2.3	3.1	4.0	5.0	93.6%
San Francisco	21115	21115	100.0%	25.5	1005.4	15.5	21.6	30.9	44.8	93.0%	-1.6	2.7	3.6	4.4	5.6	7.0	9.7	73.9%
Chicago	13448	13448	100.0%	25.5	992.6	19.6	40.4	137.5	186.2	84.9%	-2.2	2.8	3.7	4.9	5.8	6.8	11.9	65.6%
Handset																		
Each individual handset models																		
Sony Xperia XZ1	9273	9273	100.0%	25.5	993.4	17.6	25.2	44.5	96.4	91.0%	-1.3	2.4	2.2	2.3	3.3	4.7	19.7	91.3%
Huawei Mate 9	9272	9272	100.0%	25.5	993.4	16.3	23.2	38.2	69.2	91.5%	-3.2	6.9	4.2	5.8	6.8	7.8	5.5	58.7%
Samsung Galaxy Note 8	9264	9264	100.0%	25.5	993.4	17.2	24.1	41.1	85.7	90.2%	-3.0	2.0	3.4	4.4	5.1	5.8	5.2	76.1%
Samsung Galaxy S8	9259	9259	100.0%	25.5	993.5	16.2	22.9	37.4	76.9	91.2%	-2.9	2.2	3.4	3.9	5.0	6.1	5.3	78.3%
Motorola Z2 Force	9281	9281	100.0%	25.5	993.4	16.8	23.4	35.7	96.9	90.7%	0.6	3.4	1.8	1.7	2.3	3.6	10.1	94.3%
Essential	9243	9243	100.0%	25.5	993.4	16.0	23.0	37.3	82.3	91.2%	2.9	2.6	3.3	3.9	4.6	5.6	5.2	77.2%
Atlanta individual handset																		
Sony Xperia XZ1	3509	3509	100.0%	25.5	980.3	17.0	22.8	33.7	60.7	93.0%	-0.2	1.0	1.1	1.4	1.9	2.3	4.6	99.1%
Huawei Mate 9	3515	3515	100.0%	25.5	980.3	16.1	21.7	29.3	55.0	94.6%	-0.1	10.4	1.8	1.8	2.5	3.1	4.9	98.4%
Samsung Galaxy Note 8	3506	3506	100.0%	25.5	980.4	17.0	22.7	31.2	58.4	92.2%	-1.8	1.3	2.0	2.3	3.0	3.9	4.8	98.6%
Samsung Galaxy S8	3495	3495	100.0%	25.5	980.4	15.8	21.6	30.6	57.2	93.5%	-2.0	1.2	2.1	2.5	3.0	3.8	5.7	99.0%
Motorola Z2 Force	3512	3512	100.0%	25.5	980.4	16.9	23.5	33.3	63.8	92.1%	0.2	4.5	1.4	1.6	2.0	2.5	5.1	99.7%
Essential	3492	3492	100.0%	25.5	980.4	16.4	23.3	32.6	61.8	91.9%	3.5	2.4	3.6	4.4	4.9	5.4	5.0	66.7%
San Francisco individual handset																		
Sony Xperia XZ1	3522	3522	100.0%	25.5	1005.2	14.9	21.0	29.0	41.6	93.5%	-1.0	1.9	2.0	2.2	2.8	3.7	17.1	96.9%
Huawei Mate 9	3515	3515	100.0%	25.5	1005.4	15.9	23.3	33.4	47.9	92.2%	-6.2	1.7	6.6	7.3	7.9	8.6	6.4	16.0%
Samsung Galaxy Note 8	3514	3514	100.0%	25.5	1005.4	16.1	22.3	33.2	47.6	92.6%	-3.7	1.5	4.5	4.9	5.5	6.1	5.8	62.5%
Samsung Galaxy S8	3529	3529	100.0%	25.5	1005.4	15.1	20.9	29.7	43.8	93.1%	-2.8	1.7	3.7	4.1	4.7	5.3	5.3	81.9%
Motorola Z2 Force	3520	3520	100.0%	25.5	1005.4	16.7	22.4	32.2	45.1	91.8%	0.9	2.5	1.7	1.5	2.0	3.3	18.2	97.9%
Essential	3515	3515	100.0%	25.5	1005.4	14.6	20.1	27.3	42.8	94.4%	3.3	2.9	3.3	3.5	4.2	5.2	5.6	87.7%
Chicago individual handset																		
Sony Xperia XZ1	2242	2242	100.0%	25.6	992.6	26.7	74.3	140.5	238.1	84.1%	-3.4	3.4	4.0	4.7	5.4	6.3	47.3	70.4%
Huawei Mate 9	2242	2242	100.0%	25.5	992.6	17.7	38.0	136.2	124.9	85.7%	-3.6	2.4	4.1	5.0	5.6	6.6	5.0	63.4%
Samsung Galaxy Note 8	2244	2244	100.0%	25.6	992.6	20.4	44.8	137.2	187.9	83.4%	-3.6	2.4	4.1	5.1	5.8	6.6	4.8	62.2%
Samsung Galaxy S8	2235	2235	100.0%	25.5	992.6	19.3	40.4	134.3	160.0	84.4%	-4.7	2.8	4.9	6.1	6.8	7.6	4.8	40.4%
Motorola Z2 Force	2249	2249	100.0%	25.6	992.6	16.7	26.5	121.3	229.6	86.8%	0.6	2.5	2.4	2.5	4.1	6.1	5.1	80.1%
Essential	2236	2236	100.0%	25.6	992.6	19.2	32.9	137.7	176.3	85.0%	1.7	2.5	2.8	3.0	4.7	7.2	4.7	77.2%

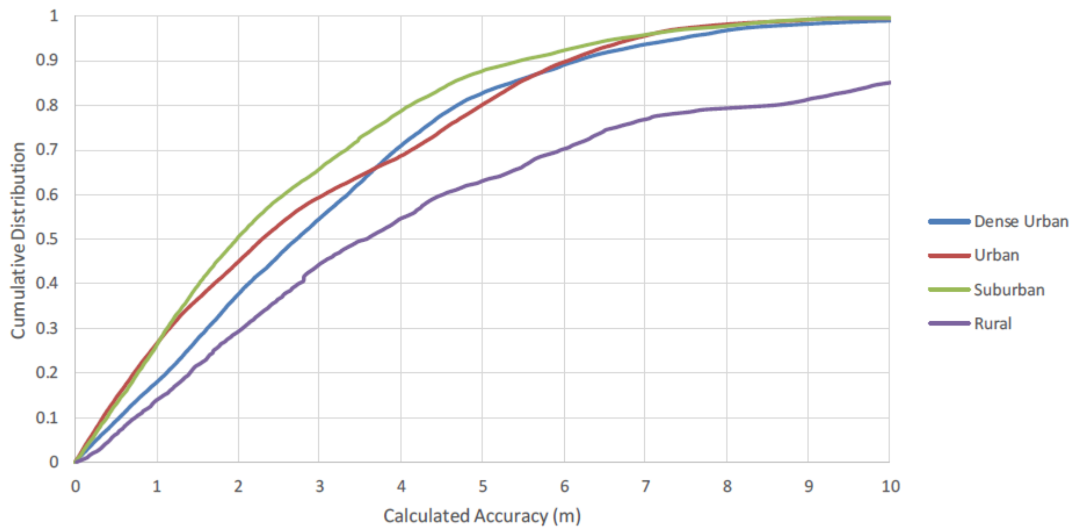


Figure 9.3 Polaris Wireless Vertical Accuracy CDF per Morphology

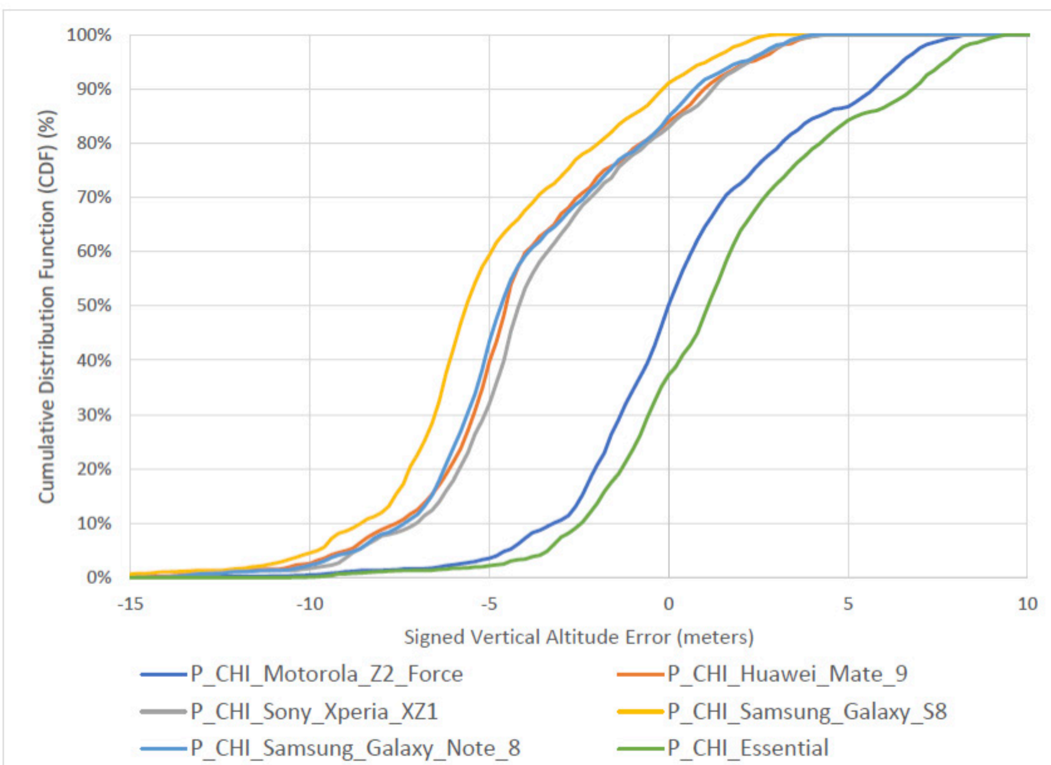


Figure 9.29 – Signed Vertical Error CDF for Polaris Wireless Chicago Test Devices

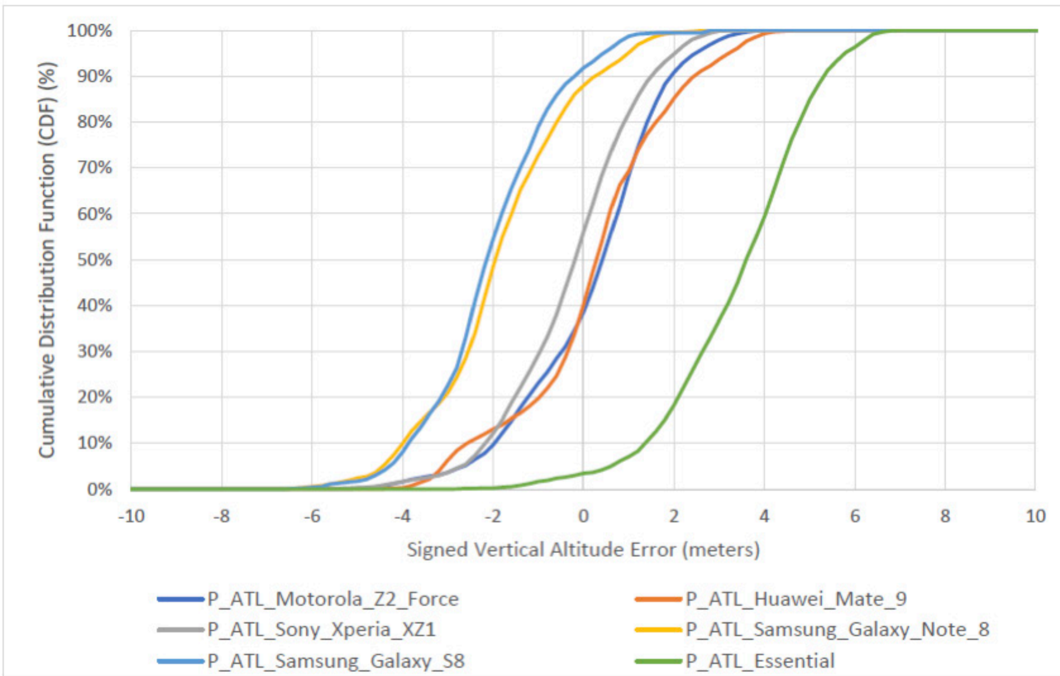


Figure 9.27– Signed Vertical Error CDF for Polaris Wireless Atlanta Test Devices

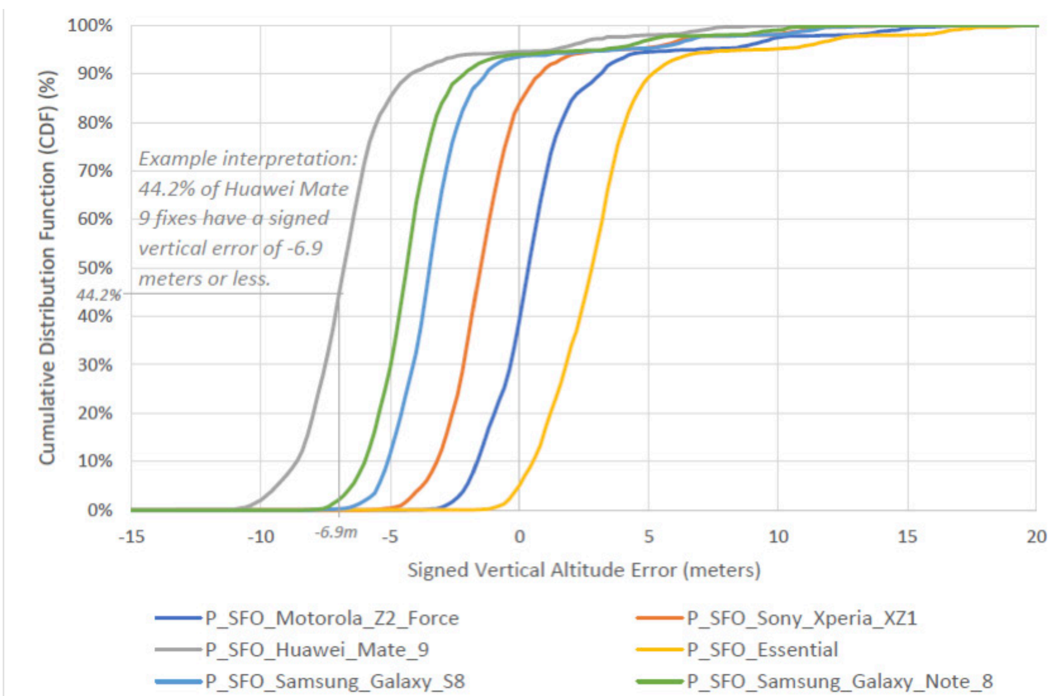


Figure 9.25 – Signed Vertical Error CDF for Polaris Wireless San Francisco Test Devices