NextNav Technology Rev-2 Indoor Test Report

San Francisco Bay Area

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Prepared By:

TechnoCom

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Executive Summary

NextNav commissioned TechnoCom to perform independent indoor testing of its "Technology Rev-2"wide area beacon location system in a manner as identical as possible to the tests that TechnoCom had performed for CSRIC III WG3 in the Bay Area in the fall of 2012. The Rev-2 system utilized a number of technical improvements relative to the first iteration of the system tested under CSRIC III. Indoor testing of the Rev-2 system was performed from mid-June to mid-July 2013 in the same Bay Area dense urban, urban, and suburban environments.

Leveraging the constructive relationship TechnoCom had developed with the buildings utilized during the CSRIC III-sponsored campaign, TechnoCom was successful in securing the same buildings for the purposes of this testing. The testing was performed at essentially the same 70 test points spanning the 17 buildings in the three morphologies tested. The same precisely surveyed test points were used in all but 4 test points, which had to be moved 1 to 4 meters due to changing building occupancy constraints. In all cases the ground truth accuracy was maintained to within 1 meter, which is much better than the minimum required for indoor accuracy testing.

The same test methodology as the CSRIC-sponsored testing was used. At each test point a minimum of 100 independent test calls in a "warm start" configuration were attempted. This excellent similarity to the CSRIC testing of fall 2012 allows for direct comparisons to identify the areas of "Technology Rev-2"performance improvement as well as any natural limitations.

Several clear accuracy performance improvements compared to Rev-1 were observed, with lower horizontal positioning errors, tighter positioning clusters for the test calls, and fewer outliers in a large majority of the test points. These improvements are best seen in the per-building results presented in section 7 of this report. The NextNav technology showed relatively weak performance only at a few test points that were generally deep indoors. This somewhat diluted the apparent improvement in the aggregate statistics shown in the table below.

Table ES-1. Summary Horizontal Accuracy Statistics for NextNav Technology Rev-2 and Rev-1

Location Error Statistics (meters)				
Morphology	NextNav Technology	67th Percentile	90th Percentile	95th Percentile
Dense Urban	Rev-2 (June-July 2013)	45.4	81.2	144.7
	Rev-1 (CSRIC Fall 2012)	57.1	102.4	154.0
Urban	Rev-2 (June-July 2013)	47.3	137.0	196.8
	Rev-1 (CSRIC Fall 2012)	62.8	141.1	196.1
Suburban	Rev-2 (June-July 2013)	17.5	33.0	43.8
	Rev-1 (CSRIC Fall 2012)	28.6	52.9	62.2

A better grasp of the extent of the performance improvement, however, is seen in the following three comparative CDF plots, one for each of the morphologies.

Location yield was an excellent 99% in the dense urban environment and 99.9% in the suburban environment. It was 97.3% in the urban environment impacted primarily by one particularly deep indoor test point, several meters below street level on the floor of the convention center.

The overall results of the current testing showed good consistency. For a given building, especially larger ones or ones in heavy clutter, the accuracy was generally inversely proportional to the depth of the test point inside the test building and its surrounding clutter. Consequently, very good accuracy was seen in most suburban test points.

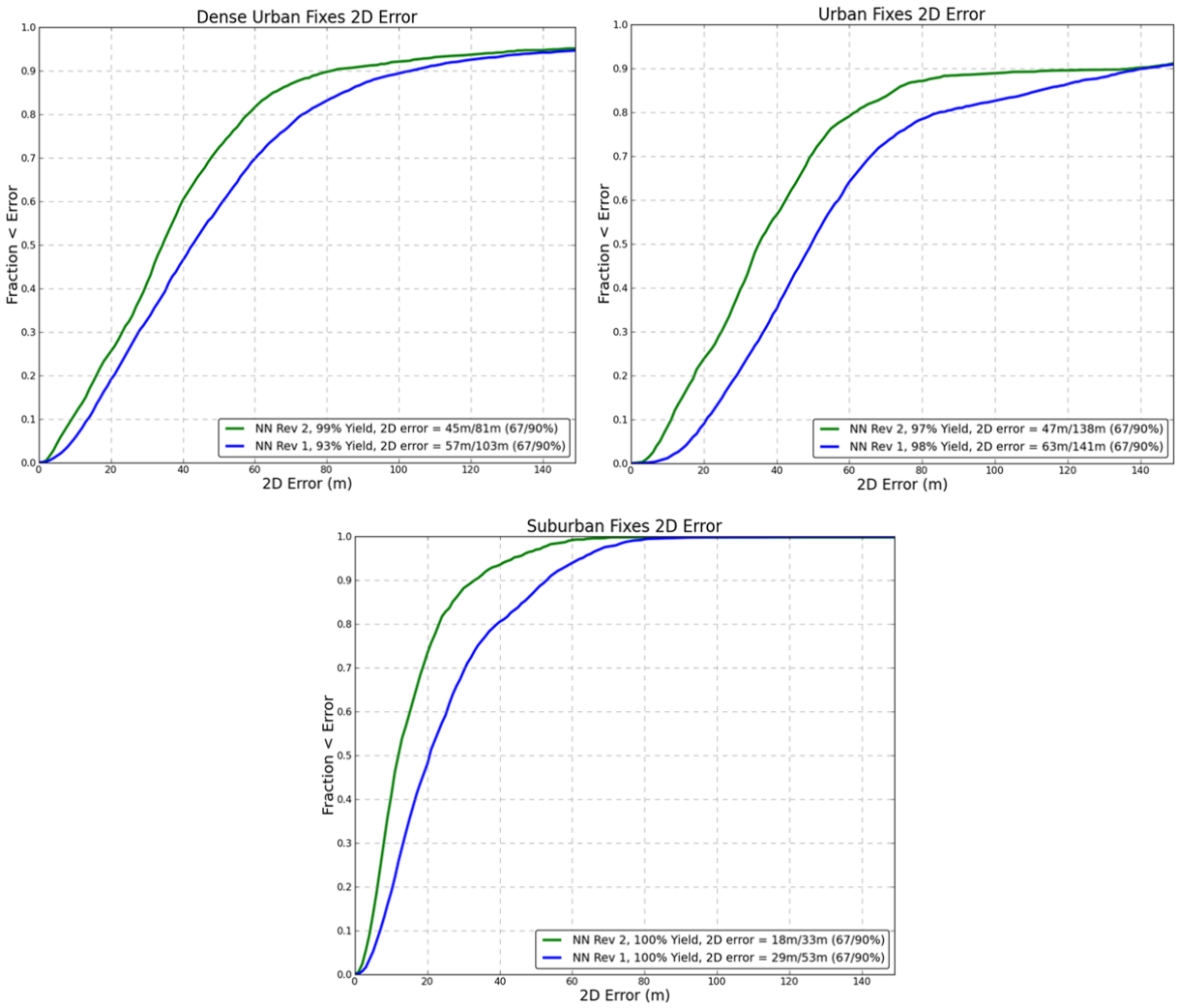


Figure ES-1. Comparative Horizontal Accuracy CDFs for NextNav Technology Rev-2 and Rev-1

Improvement in altitude accuracy performance relative to Technology Rev-1 results during the CSRIC testing was also observed across the three morphologies, with errors well within one floor most of the time.

Time to first fix results were consistent averaging between 17 and 20 seconds across the three tested morphologies. Maximum duration from location transaction initiation until location result delivery to data log was always under thirty seconds.

Overall, a multi-faceted improvement in performance was observed compared to that demonstrated during the CSRIC III-sponsored indoor campaign of the fall of 2012.

1 Introduction

1.1 Background

The FCC commissioned its third Communication, Security, Reliability and Interoperability Council (CSRIC III), specifically its Working Group 3 (WG3), to advise it on critical and timely issues related to E911. Critical among these has been the indoor performance of existing and emerging technologies applicable to E911.

The CSRIC test campaign in late 2012 and early 2013 shed excellent light on the capabilities and possible potential of three distinct location technologies. Those were the beacon-based technology from NextNav, the pattern matching based technology from Polaris Wireless, and AGPS (for both CDMA and UMTS) from Qualcomm. The CSRIC WG3 report entitled "Indoor Location Test Bed Report," and its companion, more detailed report from TechnoCom to CSRIC WG3 entitled "Indoor Test Report to CSRIC III-WG3; Bay Area Stage-1 Test Bed," are an excellent source of this plethora of information.

One of the hallmarks of the wireless industry is how fast its technology evolves and advances. Accordingly it was envisioned in CSRIC III that subsequent CSRIC commissions would tackle the expansion of the indoor testing to prominent and promising technologies that have recently emerged and were not available for testing in late 2012. Certain location technology developers, however, believe that they have achieved significant enough progress that they want to test their technologies and make that data available to the FCC in a timely manner for its consideration on indoor wireless E911.

NextNav had demonstrated very promising results with the first iteration of its system during the testing commissioned by CSRIC III. NextNav has since developed a second iteration of its technology that promised further improved performance. Wishing to provide timely and up to date input to the FCC on its most recent system implementation, NextNav commissioned TechnoCom to perform independent indoor testing of its latest technology implementation in the same environment as the CSRIC testing in the Bay Area. One exception by design has been to exclude the rural environment from the current evaluation given the level of performance already seen in that environment.

TechnoCom had performed the indoor testing for CSRIC III WG3 and thereby had the insight, contacts, and good will to enable a virtually identical indoor test campaign. Through the kind cooperation of all building owners, managers, and cognizant building staff and engineers, TechnoCom was able to use the very same buildings used in the CSRIC Bat Area Testing. Essentially the same test points were used with only a few very minor updates.

This report presents a summary of the indoor testing in the Bay Area of NextNav's second iteration of its system, to be referred to here as "NextNav Technology Rev-2," in June and July 2013.

1.2 Independent Test House

One of the key principles of the CSRIC test bed was to provide the FCC with objectively derived, independently collected test results. To obtain location performance results that are directly comparable to those obtained during the CRSIC III test bed, a very similar test process had to be followed. To insure the maximum adherence to the details of that process, the same independent test house, TechnoCom, was retained by NextNav to perform the current indoor tests.

Since its inception in 1995, TechnoCom has been providing its engineering expertise to a host of location technology companies and wireless carriers evaluating and subsequently deploying some of those technologies. Throughout its history, TechnoCom has opted to take a location technology vendor independent approach to its E911 quality of service assurance and testing business.

Since the inception of E911 TechnoCom has been a key player in the development and adoption of industry standard E911 testing methodologies. Notably, TechnoCom was a lead contributor in the development of the indoor testing methodology within ATIS's ESIF, which is the methodology that was adopted by CSRIC WG3 as the basis for indoor testing within its Bay Area test bed.

TechnoCom brought to the current indoor tests its recent, highly detailed experience performing that indoor testing and reporting for CSRIC and in turn to the FCC. TechnoCom also performed similar testing and reporting for TruePosition in Wilmington, DE. TechnoCom maintains its vendor independence and welcomes performing independent testing for various location technology vendors.

1.3 Scope of Report

This report contains the results of the indoor testing performed by TechnoCom on behalf of NextNav in the Bay Area in late June and early July 2013. To highlight the strong similarity with the CSRIC test bed in the San Francisco Bay Area, sections that concisely describe the methodology, scope of testing, test criteria, and test execution are provided. For the benefit of the reader, these are followed by summary descriptions of the representative environments (morphologies) in which the testing took place along with a quick recount of the buildings used in the testing. The various results are provided in summary tabular and graphic forms. The results are first aggregated by building and subsequently by morphology. In addition, qualitative description of the performance at each test point is captured in scatter diagrams overplayed on Google Earth imagery for each test building Concise observations and conclusions based on the various results are also provided to aid the reader in interpreting the results.

1.4 Contact Information

Company:	TechnoCom Corporation
Contact Person:	Dr. Khaled Dessouky
Title:	Executive Vice President
Phone:	818-523-7603
E-mail:	kdessouky@technocom-wireless.com

2 Test Approach

2.1 Representative Morphologies (Use Environments)

As mentioned in the Introduction, this testing followed the same methodology used for CSRIC in the San Francisco Bay Area. This included the same morphology to test point logical flow down as shown in Figure 2.2-1.

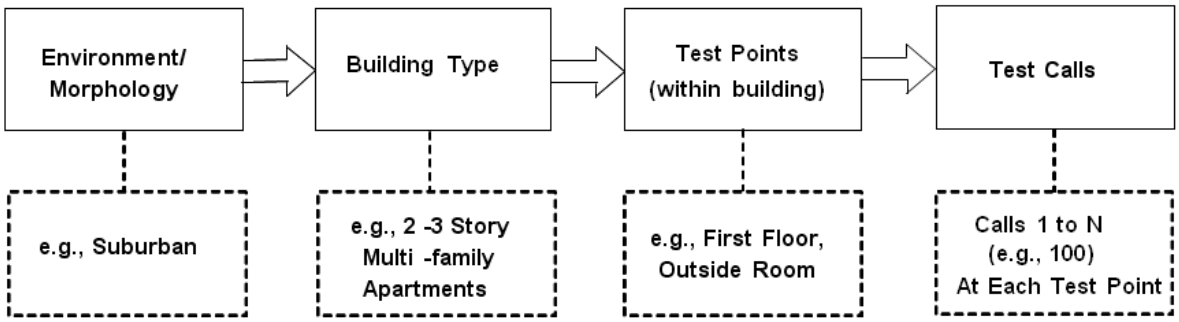


Figure 2.1-1. Morphology, Building and Test Point Flow Down

In each morphology (i.e., broad wireless use environment) a number of buildings of different sizes and types common in that morphology were identified. Within each building different test points were selected to represent the range of conditions encountered within that building.

The number of test points in each building depended on its size and complexity and ranged from 2 to 6. At each test point a statistically significant number of independent test calls (at least 100) was attempted from the device or devices under test.

In aggregate, 17 buildings spanning the three distinct morphologies (dense urban, urban, and suburban) and a good spectrum of building types, construction materials, and settings were attained. This created the broadly representative sample of indoor performance in this test region.

2.2 Test Buildings and Test Points

As mentioned above, despite the challenge envisioned at the outset of this project, TechnoCom was successful in securing the same buildings that were used in this testing. To ensure this report is a self-contained document the test buildings are described and pictured below in Section 5. They are summarized here:

Dense Urban Buildings

Bldg. 1: Marriott Marquis Hotel, SF

Bldg. 2: One Front Street, SF

Bldg. 3: 201 Spear Street, SF

Bldg. 14: The Hearst Office Building (699 Market Street), SF

Bldg. 15: The Omni Hotel, SF

Bldg. 16: One Embarcadero Plaza, SF

Urban Buildings:

Bldg. 4: AT&T Park (baseball stadium), SF

Bldg. 5: Moscone Convention Center, SF

Bldg. 17: US Federal Court of Appeals Building, SF

Bldg. 18: Super 8 Motel on O'Farrell St., SF

Bldg. 19: The 88 San Jose (condominium building), SJ

Suburban Buildings:

Bldg. 6: Westfield Valley Fair Mall, Santa Clara

Bldg. 7: Techmart Office Building, Santa Clara

Bldg. 8: 861 Shirley Avenue (house), Sunnyvale

Bldg. 9: City Library, Santa Clara

Bldg. 10: Senior Center, Santa Clara

Bldg. 11: 1405 Civic Center, Santa Clara

The distribution of the test points among the environments is as shown in the table. Identical to the CSRIC III sponsored testing, the emphasis is placed on the more challenging dense urban and urban environments.

Table 2.2-1 Summary of Test Point Distribution

Morphology	Number of test Buildings	Number of Test Points
Dense Urban	6	29
Urban	5	23
Suburban	6	18
	17	70

Of the 70 test points used, only 4 had some minor changes from the CSRIC III test campaign necessitated by building occupancy constraints.

Those minor changes were specifically:

Point BD02_TP4 was moved vertically (but not horizontally) from an open space being built on the 28th floor to a new relatively open suite just built directly above it on the 29th floor.

Point BD03_TP2 was moved horizontally about a meter to accommodate some remodeling construction in the immediate area.

Point BD14_TP2 was moved about 3 meters from inside a one room suite to just outside it in the hallway (one sheetrock wall deeper inside the building).

Point BD14_TP3 was moved about 4 meters from inside a one room suite to just outside it in the hallway (one sheetrock wall deeper inside the building).

2.3 Statistically Significant Samples

Indoor location performance can suffer from rapid changes in signal conditions and can experience significant performance variation from call to call even within a short period of time. Similar to testing for CSRIC III a minimum sample size of 100 test calls per technology per test point was required.

2.4 Accurate, Reliable Indoor Ground Truths

The general requirements for indoor ground truth accuracy were quoted in ATIS-0500013. During the CSRIC III indoor testing campaign TechnoCom very carefully documented and photographed every test point. Also during that test campaign TechnoCom hired a local certified land surveying vendor to perform precise ground truth surveys for the test points. The survey information provided by the vendor included latitude, longitude and height. The certified accuracy was +/-5 cm in the horizontal or vertical directions, which was much better than the minimum needed for indoor wireless E911 applications. 66 of the 70 test points in this current testing were unchanged. The re-test accuracy was maintained within one meter (to allow for field placement and physical dimensions of the test platform shown in Section 4). The four test points that were moved by up to 4 meters were carefully documented again and photographed and TechnoCom's senior engineers applied standard geometric tools to ensure that the accuracy of the ground truth remained within 1 meter.

2.5 Performance Attributes Analyzed

2.5.1 Location Accuracy

The error in estimating the location of the NextNav Technology Rev-2 device under test was computed by comparing its reported position (provided to TechnoCom) to the surveyed ground truth position of the test location. Each test call was assumed to be independent from prior calls and accuracy was based on the first location delivered by the NextNav system after call initiation.

This accuracy information is presented in Section 6 where the results are aggregated by building and morphology. In Section 7 more detailed results are presented for each building within the three test morphologies. The accuracy statistics include the 67th, 90th and 95th percentiles of horizontal accuracy, and vertical distance error, plus their average, standard deviation, and minimum and maximum errors, all in meters. In addition, the error CDF is also provided for each morphology in Section 6 and for each building in Section 7.

2.5.2 Latency (TTFF)

The Time to First Fix (TTFF) or the time to obtain the first computed location is reported based on the information in the NextNav Technology Rev-2 logs provided to TechnoCom. These results are aggregated by building and by morphology

2.5.3 Yield

Yield is the % of calls with delivered location to overall "call attempts" at each test point. The yield statistics for the NextNav Technology Rev-2 are based on the information received in the NextNav test logs including the number of calls attempted by the test devices. The summary yield results are reported in Sections 6 and 7 with the per test point results detailed in the appendix.

2.5.4 Reported Uncertainty

The uncertainty reported by the location system is also presented. The reported uncertainty at each test point (corresponding to a nominal 90% confidence) is compared to the fraction of calls for which the resulting (empirically measured) location falls inside the uncertainty circle. The ideal number would be 90% of the calls have an actual error that causes the reported locations to fall inside the reported

uncertainty circle. In general, the quality of the uncertainty measure reflects how well a location system is operating, with poor performance often (but not always) associated with a low proportion of computed locations falling inside the reported uncertainty circle. The uncertainty results have also been aggregated by building and by morphology.

2.5.5 Location Scatter

To provide the reader with added insight into the qualitative indoor performance of the location technology under test in the different environments, to aid in discerning possible effects of specific structural features at certain test points, and to place observed error distances in the proper indoor perspective, scatter diagrams have been prepared and provided for each building in Section 7. As with the detailed results that were provided to CSRIC WG3, the location scatter results overlaid on the building landscape, e.g., from Google Earth imagery, yields considerable insight into the potential and limitations of the attained indoor performance in each setting. The resulting clusters for all the test points in a given building are shown in the scatter diagram for that building.

3 Technology Tested

3.1 Technology Rev-2 from NextNav

The NextNav location system utilizes GPS-like spread spectrum signals transmitted by the NextNav terrestrial beacon transmitters deployed across a metropolitan area. The beacons transmit spread spectrum PRN signals in the 900MHz band and uses Time of Arrival techniques to compute the location. A variety of technical improvements were represented in the Rev-2 implementation, including improved beacon timing synchronization, faster processing allowing multiple Kalman cycle averaging, waveform modifications and assisted mode operation such that ranging and location calculation could still be done on signals that are very weak. Multi-lateration and location calculation continue to be done on the handset without use of external databases. The density of the beacon sites across the entire Bay Area increased by 10% as part of NextNav's continued efforts to improve its coverage across the area. This did not represent a metrical change in the beacon density for the focused polygons where the indoor testing was performed.

3.2 Devices Tested

The devices utilized in this stage of the test bed were standalone receivers (sleeves) similar to the units used during the CSRIC fall 2012 campaign. These sleeves received the NextNav beacons and sent the position data in real-time to a special application on the Smartphone. This NextNav software application was a key element of the NextNav test setup; it automated the capture and logging of the indoor location fixes. In addition to controlling the test, it computed the position fixes and their uncertainty based on the positioning data relayed to it by the NextNav receiver.

During the testing the Smartphone was also used in transmitting the test logs over a wireless network simultaneously to email servers at TechnoCom and at NextNav. A smartphone/NextNav receiver combo is shown in Figure 3.2-1.

Figure 3.2-1 NextNav Receiver and Smartphone

3.3 Test Configuration

The test configuration for the NextNav technology is shown in Figure 1.2

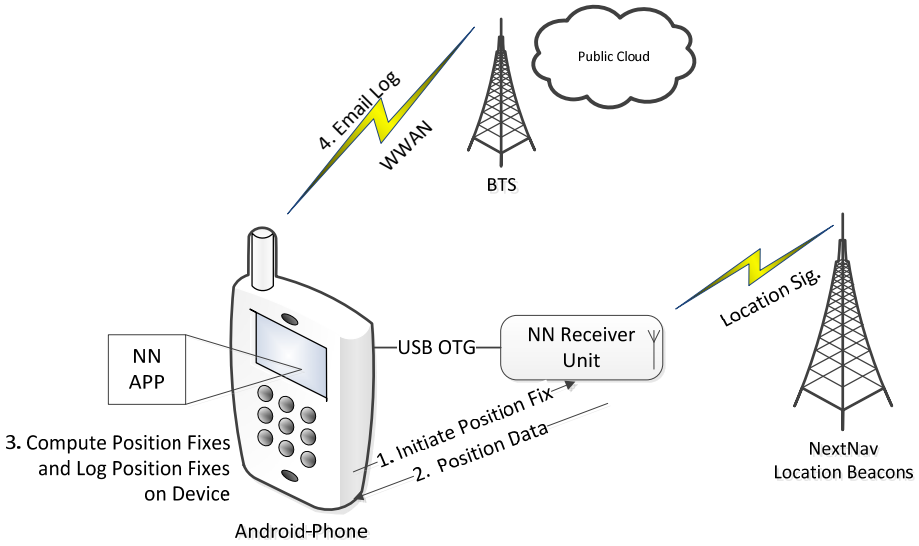


Figure 1.2 NextNav Indoor Test Configuration

In this test setup no network interfaces were invoked to trigger a test emergency type call. Instead, the App on the handset instructed the NextNav receiver to perform certain steps that emulated the events that occur during a positioning session concurrent with an emergency phone call.

To create a positioning session, the NextNav receiver was turned on and the "ON" time was recorded by looking at the time value of the RX-ON-ACK message sent out by the firmware of the receiver. The receiver then received the NextNav beacon signals and transferred the position data to the App on the Phone. Upon the App processing this data to obtain the position fix, the fix time was recorded by looking at the time value of the position message bearing a valid fix. The receiver was then turned off.

In the NextNav system the Warm-Fix mode was achieved by issuing a Receiver OFF command and then issuing a Receiver ON at the beginning of a subsequent location session, so that no state, location or other information was carried over between location attempts.

3.4 NextNav Data Logs and/or Processing

The NextNav App logged the location fixes locally in a separate file for every "Start Test" button press. The log files recorded the relative time stamps in milliseconds for turning the NextNav receiver on and off (emulating the start and end of a test call) and of the computed location fix and its uncertainty.

The log was closed at the end of a test session at a given test point. The App also sent via e-mail the individual test point logs to both NextNav and TechnoCom. At times, especially in difficult indoor settings, the NextNav test application encountered problems, which resulted in the logs not being automatically e-mailed. In those cases the TechnoCom field engineer manually e-mailed the logs to NextNav and TechnoCom between the test points. TechnoCom also encountered some situations where a manual restart of the application was necessary in order to resume test calls for a test point. These cases resulted in multiple logs that had to be handled carefully.

4 Test Execution

4.1 Test Point Visits and Verification

During the CSRIC Fall 2012 campaign TechnoCom carefully documented all the test points used. This made revisiting them and placing the platform exactly at the same surveyed test points straightforward. Further aided in that task was utilizing the same TechnoCom lead field engineer who had performed the testing during the CSRIC campaign and was intimately familiar with the scenario at each test point.

Although the test points were surveyed with exceptional accuracy and precision, a practical accuracy in test device placement relative to surveyed location was better than 1 meter. This is simply also due to the physical dimensions of the test platform (see test fixture picture in the following section). The contribution of such device placement tolerance to the overall location error is completely negligible.

As mentioned above in Section2, due to building occupancy constraints four test points had to be moved slightly (within 1-4 meters) while maintaining essentially the same type of test environment. This minor movement of those four points had no material impact on the statistical results obtained. The ground truths for those points were re-computed using the documentation gathered during the testing and also maintained to within 1 meter accuracy.

4.2 Test Platform

For ease of transportation the test devices were mounted on a two-part portable platform. As shown in Figure 4.3-1 the platform carried all the devices under test, which included in addition to the Technology Rev-2 devices subject of this report other devices such as a Technology Rev-1 prototype (as tested previously during the CSRIC Fall 2012 campaign). The two parts of the test platform were placed in close proximity to each other as shown, to ensure that the ground truth accuracy for all devices remains within 1 meter. The height of the test devices above ground was approximately 1.22 meters.

Figure 4.2-1. Test Fixture Used During the NextNav Indoor Re-Testing

4.3 Placement and Timing of Test Calls

The NextNav test application was programmed to place a “test call,”i.e., to initiate a location transaction, every 30 seconds. The duration of the positioning determination session (until delivery of position result to log) averaged typically in the 17 to 20 second range. The maximum location transaction duration across all test calls in all buildings stayed below 30 seconds. By design, the NextNav technology rev-2 device was configured to always revert back to a warm start condition regardless of the duration of the pause between “test calls,” which in some cases could be as short as a few seconds.

5 Detailed test Environments

This information can also be found in the CSRIC III WG3 report to the FCC but is provided here so that this document is a self-contained reference.

5.1 Dense Urban Morphology and Buildings

The dense urban polygon used is shown in Figure 5.1-1. It consisted primarily of the financial district of San Francisco and its immediate vicinity of high rise buildings.

Figure 5.1-1. Relative Locations of the Test Buildings Used in the Dense Urban Morphology

The dense urban buildings used for indoor testing in this stage of the test bed were:

Bldg. 1: Marriott Marquis Hotel, SF
Bldg. 2: One Front Street, SF
Bldg. 3: 201 Spear Street, SF
Bldg. 14: The Hearst Office Building (699 Market Street), SF
Bldg. 15: The Omni Hotel, SF
Bldg. 16: One Embarcadero Plaza, SF

The dense urban buildings are pictured in Figure 5-1-2.

Bldg. 1

Bldg. 2

Bldg. 3

Bldg. 14

Bldg. 15

Bldg. 16

Figure 5.1-2. Dense Urban Buildings Used in Testing

The sample of these 6 dense urban buildings provides an excellent representation of building types in the dense city environment. Distinct common building types are included. Steel buildings with glass, concrete and masonry with glass, brick veneer (in the East Coast tradition), tall buildings over 40 stories high, medium height buildings of around 15 stories high, and buildings surrounded by other tall buildings on all sides and on fewer sides are all represented.

5.2 Urban Morphology and Buildings

Identical to the testing that was done for CSRIC, two urban polygons were used, one in San Francisco and one in Downtown San Jose.

The urban polygon in San Francisco is shown in Figure 5.2-1. It contains varied building densities and construction types that range from larger commercial buildings (near the downtown dense urban polygon), to older mixed-use neighborhoods with medium and smaller sized buildings (both commercial and residential in the middle of urban clutter), as well as newer, redeveloped areas with medium height residential and commercial buildings, city government buildings, and a large stadium. The San Francisco urban polygon is typical of an "older urban" area with densely packed construction (regardless of building height), somewhat narrower streets, and similar or narrower building separation than the dense urban polygon.

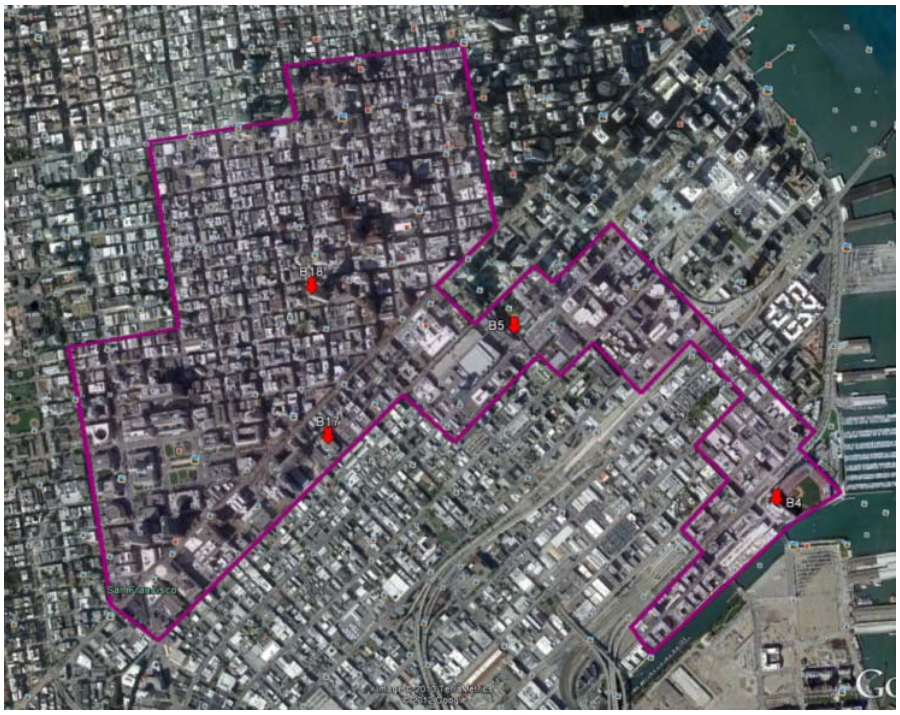


Figure 5.2-1. Urban Polygon in San Francisco and Relative Locations of the Test Buildings

The urban polygon in San Jose is representative of "newer urban" development, with a downtown typified by tall buildings of up to 30 stories, but with somewhat wider streets and somewhat greater building separation than in older urban or dense urban morphologies. It is depicted in Figure 5.2-2.

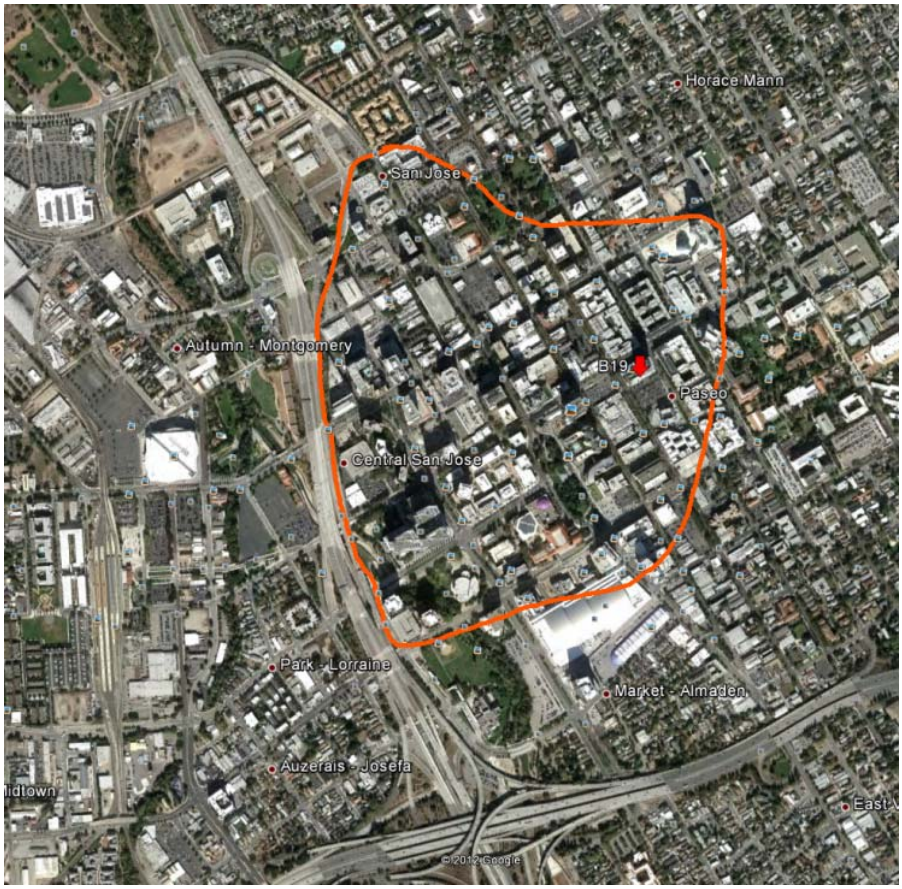


Figure 5.2-2. Urban Polygon in San Jose

The urban buildings used for indoor testing in this stage of the test bed were:

Bldg. 4: AT&T Park (baseball stadium), SF
Bldg. 5: Moscone Convention Center, SF
Bldg. 17: US Federal Court of Appeals Building, SF
Bldg. 18: Super 8 Motel on O'Farrell St., SF
Bldg. 19: The 88 San Jose (condominium building), SJ

Those buildings are shown in Figure 5.2-3.

Bldg. 4

Bldg. 5

Bldg. 17

Bldg. 18

Bldg. 19

Figure 5.2-3. Urban Buildings Used in the Indoor Testing

These five urban buildings offer a challenging environment, each in their own way. The convention center has large areas under the surface of the street, with excellent internal cellular coverage but considerable attenuation when viewed from the outside (e.g., by a beacon). The baseball stadium on the bay (BD4) has a challenging RF signal environment (although not necessarily for the NextNav system). The US Court of Appeals building (BD17) is a heavily constructed masonry structure (that survived the famous 1906 earthquake) with considerable use of tile on the inside. The motel (BD18), although not itself large or high, is sandwiched in a row of continuous side to side five story urban

buildings, with higher buildings across the street and down the corner. Finally, the high rise in urban San Jose presents its own challenges in having considerable visibility to the whole valley from its high floors and the presence of tall buildings within a few hundred yards.

The combination of buildings selected in the urban environment created a solid, challenging urban sample that represents well beyond California.

5.3 Suburban Morphology and Buildings

The suburban polygon is in Silicon Valley and includes a variety of suburban office buildings, industrial and commercial complexes, government buildings, and a range of residential buildings, including single and multi-family dwellings. Also included in the suburban polygon are shopping malls, large discount retail buildings and an airport. The boundary of the suburban polygon is shown in Figure 5.3-1.

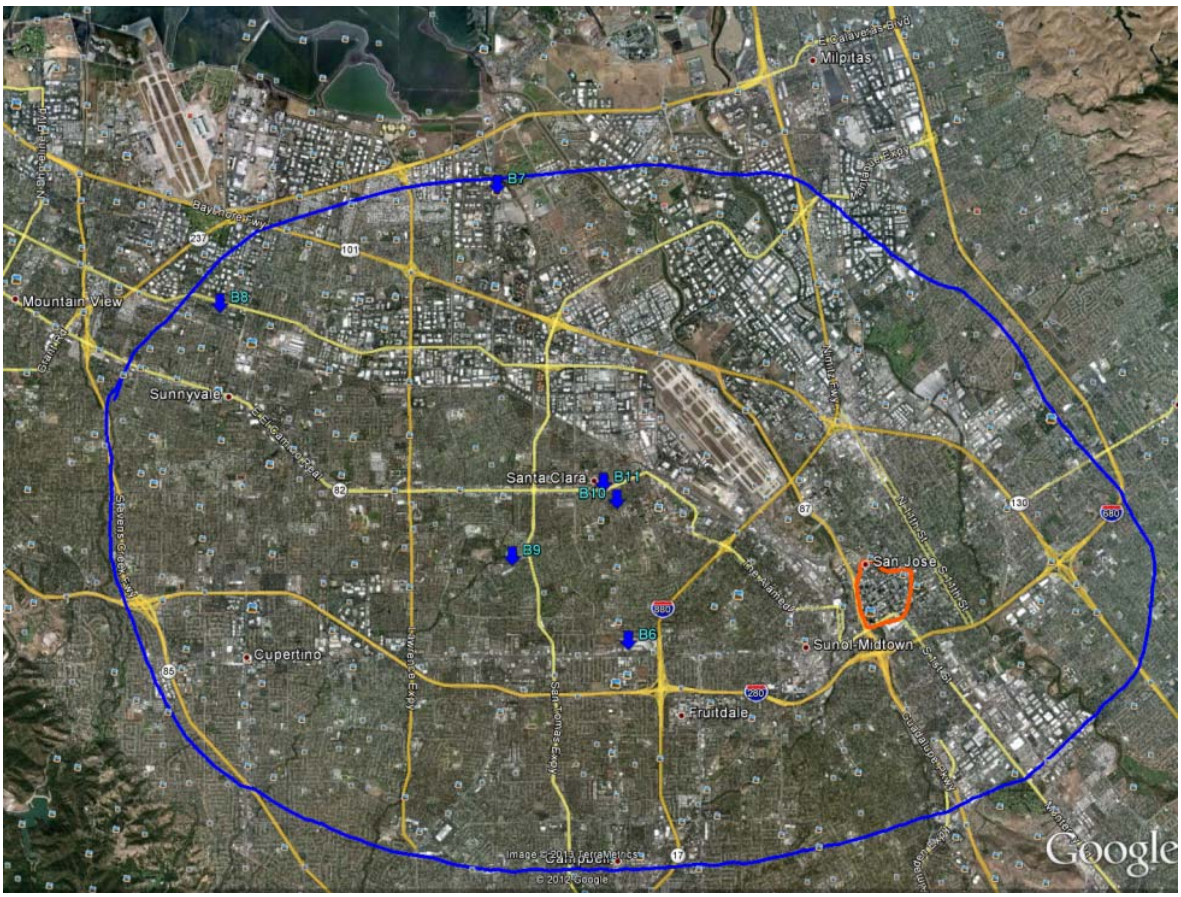


Figure 5.3-1. Suburban Polygon and Location of Buildings Used

The suburban buildings used for indoor testing in this stage of the test bed were:

Bldg. 6: Westfield Valley Fair Mall, SJ
Bldg. 7: Techmart Office Building, Santa Clara
Bldg. 8: 861 Shirley Avenue (house), Sunnyvale

Bldg. 9: City Library, Santa Clara
Bldg. 10: Senior Center, Santa Clara
Bldg. 11: 1405 Civic Center, Santa Clara

The suburban buildings are pictured in Figure 5.3-2. This suburban building sample contained smaller, lighter constructed buildings common in the Southwest as well as an office building and a major mall. The latter two larger structures could be found in virtually any part of the US. In all cases significant relative space existed between the tested structure and its neighbors, reflecting the lower density suburban setting.

Bldg. 6

Bldg. 7

Bldg. 8

Bldg. 9

Bldg. 10

Bldg. 11

Figure 5.3-2. Suburban Buildings Used in Testing

6 Summary Test Results

6.1 Number of Test Calls and Yield

The following table provides the summary yield results on a per building and per morphology basis.

Table 6.1-1. Summary Indoor Test Yield Results

Number of Test Calls and Yield				
Bldg	Technology	Total Number of Test Calls Attempted	Total Number of Test Calls with Position Fix Received	Percentage of Test Calls with Fix Received (Yield)
1	NextNav Technology Rev-2	400	370	92.5%
2	NextNav Technology Rev-2	500	500	100.0%
3	NextNav Technology Rev-2	400	400	100.0%
4	NextNav Technology Rev-2	400	400	100.0%
5	NextNav Technology Rev-2	400	338	84.5%
6	NextNav Technology Rev-2	400	400	100.0%
7	NextNav Technology Rev-2	500	500	100.0%
8	NextNav Technology Rev-2	200	200	100.0%
9	NextNav Technology Rev-2	300	298	99.3%
10	NextNav Technology Rev-2	200	200	100.0%
11	NextNav Technology Rev-2	189	189	100.0%
14	NextNav Technology Rev-2	500	500	100.0%
15	NextNav Technology Rev-2	600	600	100.0%
16	NextNav Technology Rev-2	500	500	100.0%
17	NextNav Technology Rev-2	573	573	100.0%
18	NextNav Technology Rev-2	400	399	99.8%
19	NextNav Technology Rev-2	600	600	100.0%
Dense Urban	NextNav Technology Rev-2	2900	2870	99.0%
Urban	NextNav Technology Rev-2	2373	2310	97.3%
Suburban	NextNav Technology Rev-2	1789	1787	99.9%

6.2 Accuracy Statistics

6.2.1 Horizontal Accuracy

Summary horizontal accuracy results are provided below, first in tables for each building and morphology then illustrated in bar charts and detailed cumulative distribution plots by morphology.

Table 6.2.1-1. Summary Indoor Horizontal Accuracy Statistics

Horizontal Positioning Error Statistics (m)									
Bldg	Technology	Total Number of	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
1	NextNav Technology Rev-2	370	32.4	159.0	360.3	73.6	221.6	3523.3	0.82
2	NextNav Technology Rev-2	500	53.9	63.5	68.0	46.8	13.7	86.3	12.03
3	NextNav Technology Rev-2	400	46.6	112.3	145.3	53.8	46.2	249.9	2.40
4	NextNav Technology Rev-2	400	37.2	159.2	173.1	56.7	61.0	237.5	0.86
5	NextNav Technology Rev-2	338	73.8	266.4	415.0	100.9	101.6	752.1	24.39
6	NextNav Technology Rev-2	400	18.3	27.5	31.6	15.2	8.7	41.7	0.53
7	NextNav Technology Rev-2	500	30.4	49.9	54.7	23.5	17.3	69.7	0.30
8	NextNav Technology Rev-2	200	10.9	14.0	15.9	9.7	3.8	28.5	0.83
9	NextNav Technology Rev-2	298	20.5	28.0	33.9	34.6	186.8	2853.6	2.29
10	NextNav Technology Rev-2	200	9.4	12.1	13.0	8.3	2.9	16.3	0.87
11	NextNav Technology Rev-2	189	6.7	9.8	10.5	5.9	2.6	13.2	0.34
14	NextNav Technology Rev-2	500	33.9	43.1	50.0	27.4	13.2	68.2	1.54
15	NextNav Technology Rev-2	600	46.9	219.2	309.8	71.7	97.0	644.3	4.02
16	NextNav Technology Rev-2	500	55.4	91.9	109.4	36.5	38.1	199.4	0.56
17	NextNav Technology Rev-2	573	43.0	52.1	54.9	30.8	17.0	114.1	2.47
18	NextNav Technology Rev-2	399	38.1	44.7	46.5	34.4	8.1	56.8	4.36
19	NextNav Technology Rev-2	600	47.4	199.5	241.8	66.4	99.5	906.9	2.57
Dense Urban	NextNav Technology Rev-2	2870	45.4	81.2	144.7	51.3	95.9	3523.3	0.56
Urban	NextNav Technology Rev-2	2310	47.3	137.0	196.8	55.4	73.2	906.9	0.86
Suburban	NextNav Technology Rev-2	1787	17.5	33.0	43.8	18.4	77.4	2853.6	0.30

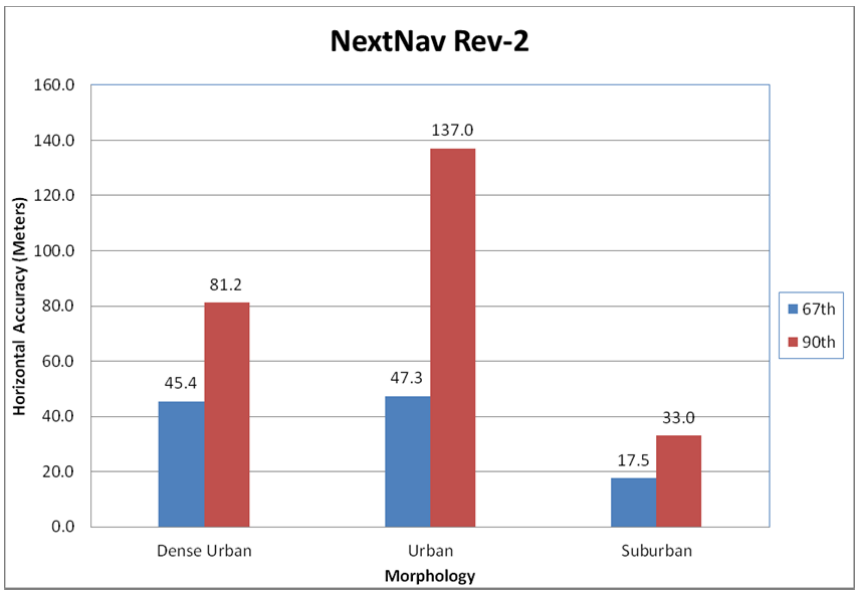


Figure 6.2.1-1 Summary 67th and 90th Percentile Errors by Morphology

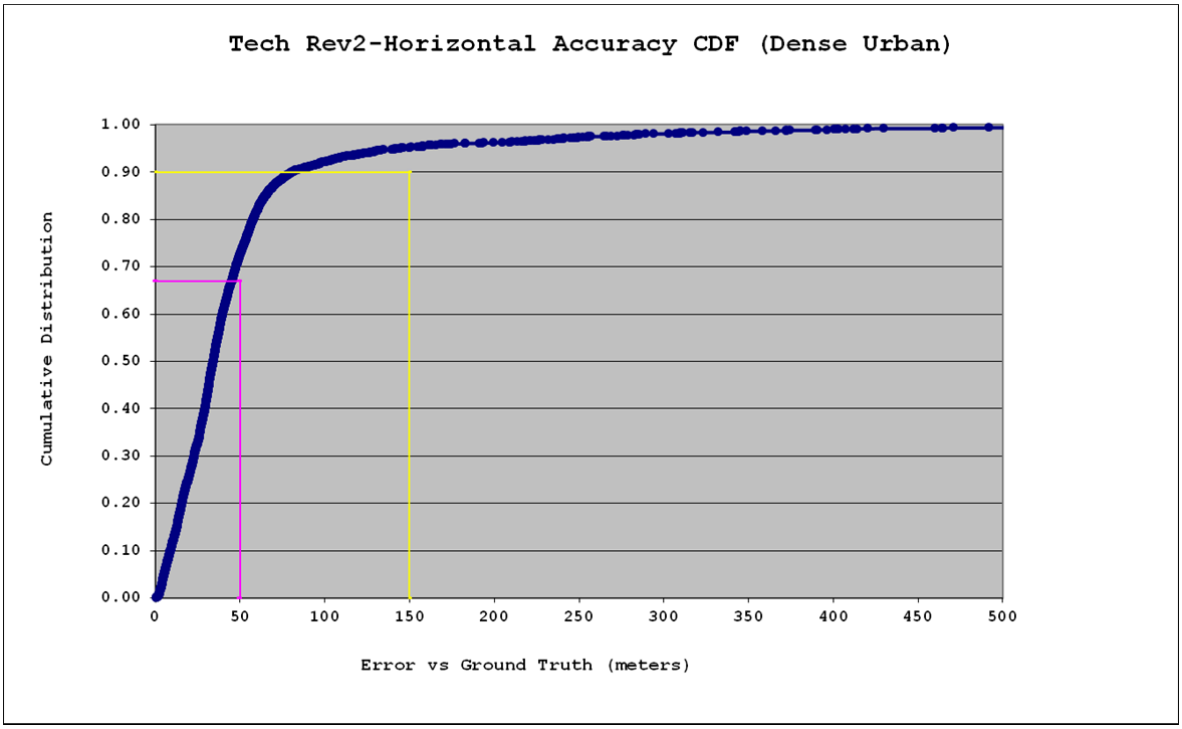


Figure 6.2.1-2 Indoor Accuracy CDF in the Dense Urban Environment

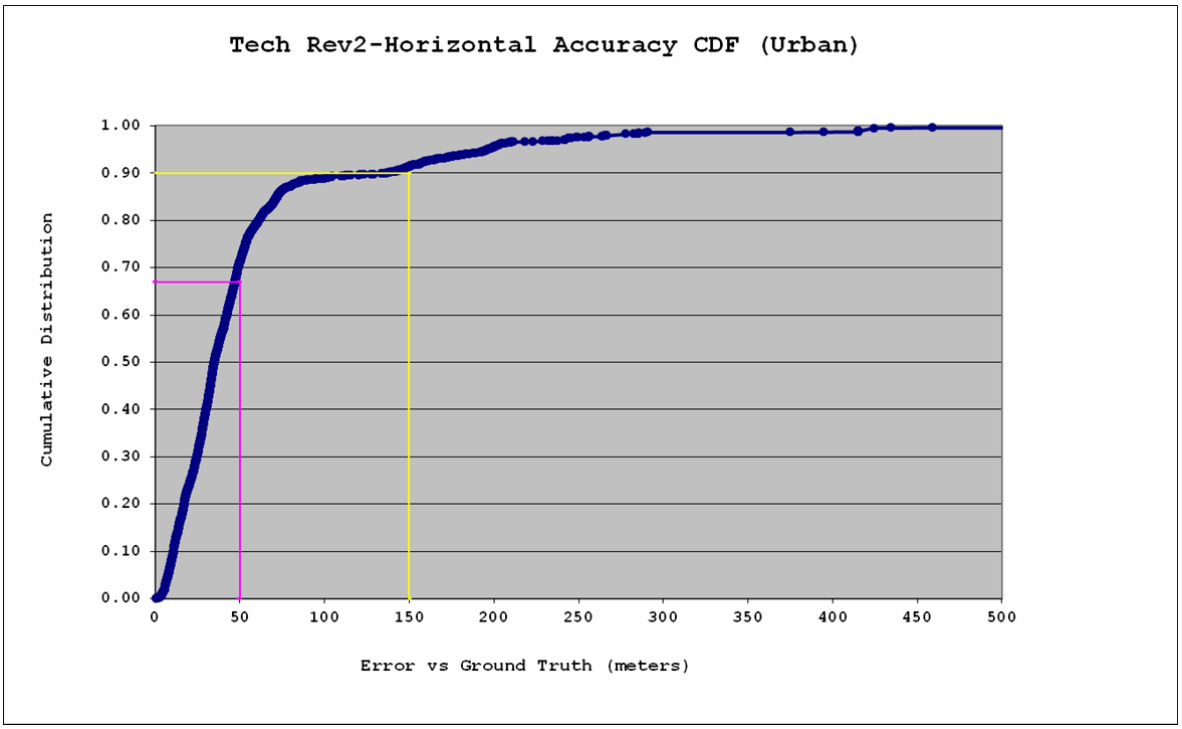


Figure 6.2.1-3 Indoor Accuracy CDF in the Urban Environment

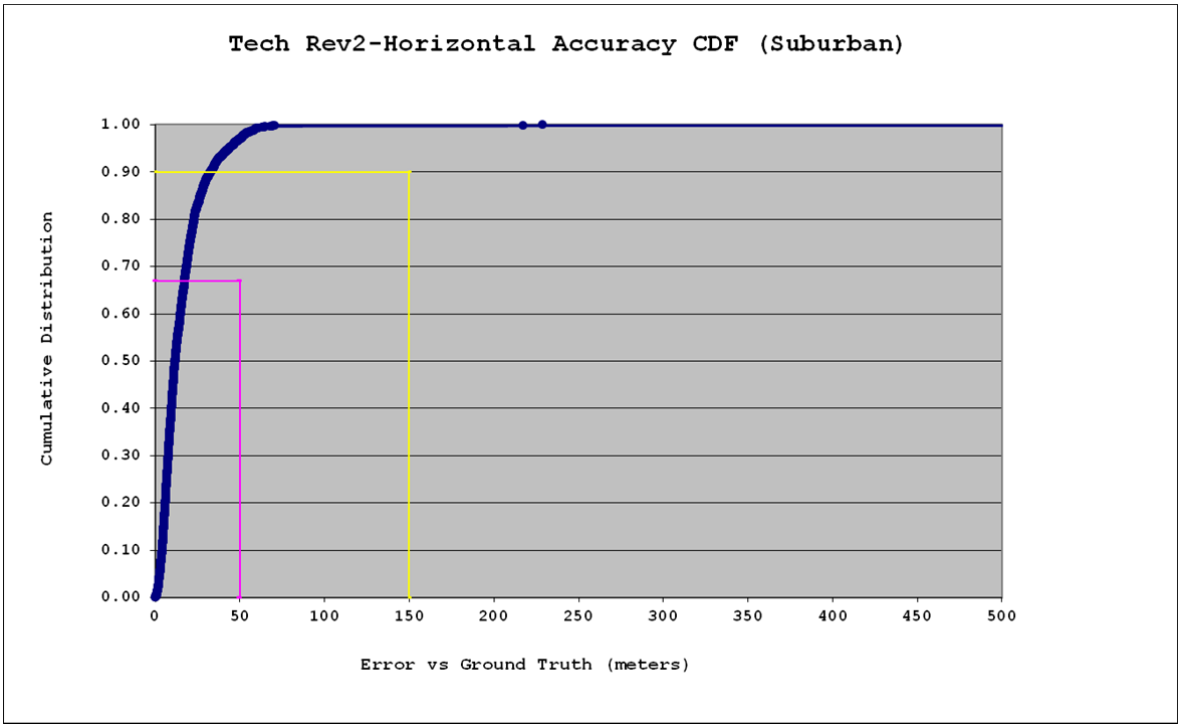


Figure 6.2.1-3 Indoor Accuracy CDF in the Suburban Environment

6.2.2 Vertical Accuracy

Summary vertical distance error results are provided below, first in tables for each building and aggregated by morphology then as a composite of cumulative distribution plots by morphology.

Table 6.2.2-1. Summary Vertical Accuracy Statistics

Vertical Distance Error Statistics (m)									
Bldg	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
1*	NextNav Technology Rev-2	370	0.8	1.4	1.6	0.6	0.5	1.9	0.00
2	NextNav Technology Rev-2	500	4.2	7.5	7.9	3.5	2.3	9.2	0.38
3	NextNav Technology Rev-2	400	3.0	4.7	5.1	2.2	1.7	6.5	0.01
4	NextNav Technology Rev-2	400	2.0	3.1	3.9	1.8	0.9	4.5	0.05
5	NextNav Technology Rev-2	338	1.6	2.2	2.6	1.4	1.6	12.7	0.02
6	NextNav Technology Rev-2	400	0.9	1.3	1.5	0.8	0.4	2.1	0.04
7	NextNav Technology Rev-2	500	3.0	3.6	3.8	2.6	0.7	4.5	0.37
8	NextNav Technology Rev-2	200	1.1	1.4	1.5	0.9	0.4	2.0	0.07
9	NextNav Technology Rev-2	298	1.4	2.1	2.4	1.1	0.7	3.1	0.02
10	NextNav Technology Rev-2	200	0.4	0.7	0.8	0.3	0.3	1.2	0.02
11	NextNav Technology Rev-2	189	0.7	1.1	1.2	0.6	0.4	1.7	0.06
14	NextNav Technology Rev-2	500	1.9	2.4	2.6	1.5	0.7	3.6	0.03
15	NextNav Technology Rev-2	600	1.2	1.8	2.3	1.0	0.7	4.8	0.06
16	NextNav Technology Rev-2	500	4.0	4.8	5.0	3.2	1.3	5.6	0.10
17	NextNav Technology Rev-2	573	1.8	2.5	2.6	1.4	0.8	3.3	0.03
18	NextNav Technology Rev-2	399	1.5	1.9	2.1	1.2	0.6	3.1	0.10
19	NextNav Technology Rev-2	600	2.4	3.2	3.6	2.0	0.8	4.5	0.07
Dense Urban	NextNav Technology Rev-2	2870	2.3	4.5	5.1	2.0	1.7	9.2	0.00
Urban	NextNav Technology Rev-2	2310	1.8	2.7	3.2	1.6	1.0	12.7	0.02
Suburban	NextNav Technology Rev-2	1787	1.5	2.9	3.4	1.3	1.0	4.5	0.02

* Computed test pt. elevation values for Bldg 1 were re-processed by NextNav due to a bug that had affected the elevation values originally obtained in that bldg.

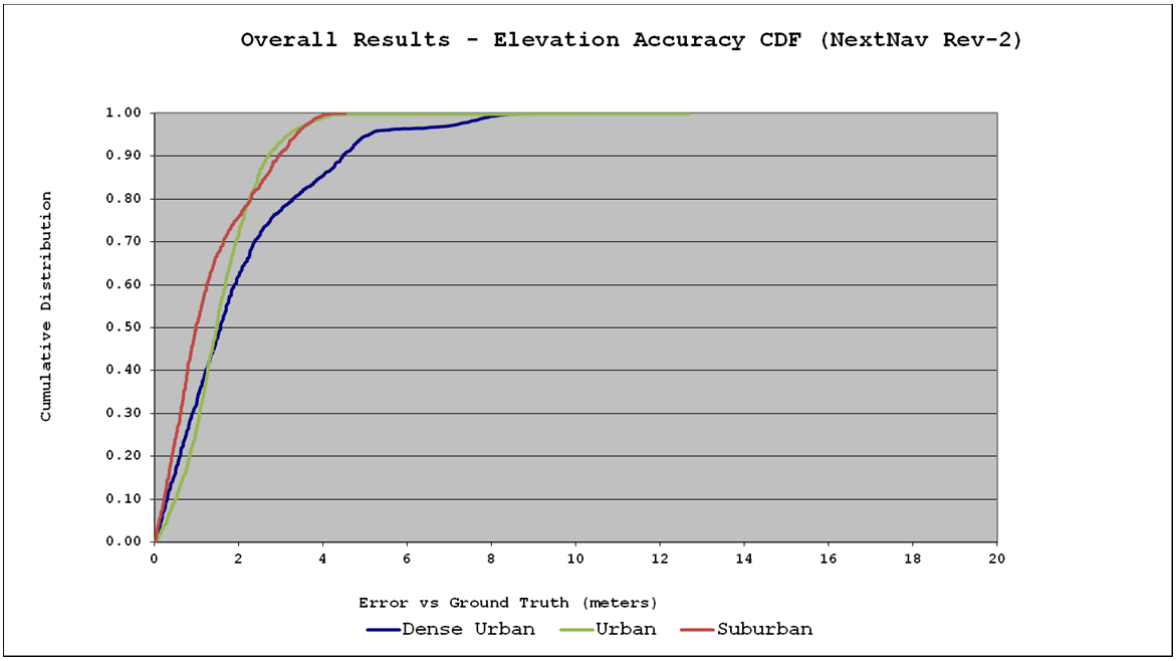


Figure 6.2.2-1 Vertical Distance Error CDF in the three Test Environments

6.3 TTFF

The TTFFs reported in the NextNav Logs are summarized below, aggregated for each building and morphology.

Table 6.3-1. TTFF Summary for NextNav Technology Rev-2

TTFF (sec)					
Bldg	Technology	Average Duration	Standard Deviation	Max Duration	Min Duration
1	NextNav Technology Rev-2	25.47	1.07	28.65	20.44
2	NextNav Technology Rev-2	16.21	1.46	26.14	14.60
3	NextNav Technology Rev-2	17.97	2.35	26.76	14.19
4	NextNav Technology Rev-2	16.83	1.69	23.07	12.72
5	NextNav Technology Rev-2	18.16	3.76	27.63	13.70
6	NextNav Technology Rev-2	20.16	2.77	25.97	14.56
7	NextNav Technology Rev-2	21.98	3.37	26.05	14.52
8	NextNav Technology Rev-2	18.13	2.31	25.54	14.55
9	NextNav Technology Rev-2	19.34	3.49	27.34	14.69
10	NextNav Technology Rev-2	15.61	0.78	18.85	13.95
11	NextNav Technology Rev-2	15.80	0.92	19.62	14.49
14	NextNav Technology Rev-2	15.79	0.82	18.92	13.55
15	NextNav Technology Rev-2	16.56	2.45	26.07	13.63
16	NextNav Technology Rev-2	16.23	1.22	21.74	14.56
17	NextNav Technology Rev-2	15.74	0.91	19.63	13.70
18	NextNav Technology Rev-2	15.79	1.00	19.91	12.73
19	NextNav Technology Rev-2	19.84	4.00	26.09	12.67
Dense Urban	NextNav Technology Rev-2	17.60	3.47	28.65	13.55
Urban	NextNav Technology Rev-2	17.36	3.15	27.63	12.67
Suburban	NextNav Technology Rev-2	19.34	3.58	27.34	13.95

6.4 Reported Uncertainty

The reported uncertainty at 90% confidence versus the actual measured empirical error for the NextNav Technology Rev-2 is summarized below. Ideally, the percentage of test calls with measured error less than the reported uncertainty (i.e., within the uncertainty circle) would be 90%.

Table 6.4-1. Reported Uncertainty for NextNav Technology Rev-2

Uncertainty				
Bldg	Technology	Total Test Calls	Number of Calls with Error < Uncertainty	Percentage of Calls with Error < Uncertainty
1	NextNav Technology Rev-2	370	351	94.86%
2	NextNav Technology Rev-2	500	304	60.80%
3	NextNav Technology Rev-2	400	371	92.75%
4	NextNav Technology Rev-2	400	300	75.00%
5	NextNav Technology Rev-2	338	208	61.54%
6	NextNav Technology Rev-2	400	381	95.25%
7	NextNav Technology Rev-2	500	469	93.80%
8	NextNav Technology Rev-2	200	200	100.00%
9	NextNav Technology Rev-2	298	284	95.30%
10	NextNav Technology Rev-2	200	200	100.00%
11	NextNav Technology Rev-2	189	189	100.00%
14	NextNav Technology Rev-2	500	379	75.80%
15	NextNav Technology Rev-2	600	555	92.50%
16	NextNav Technology Rev-2	500	457	91.40%
17	NextNav Technology Rev-2	573	493	86.04%
18	NextNav Technology Rev-2	399	279	69.92%
19	NextNav Technology Rev-2	600	563	93.83%
Dense Urban	NextNav Technology Rev-2	2870	2417	84.22%
Urban	NextNav Technology Rev-2	2310	1843	79.78%
Suburban	NextNav Technology Rev-2	1787	1723	96.42%

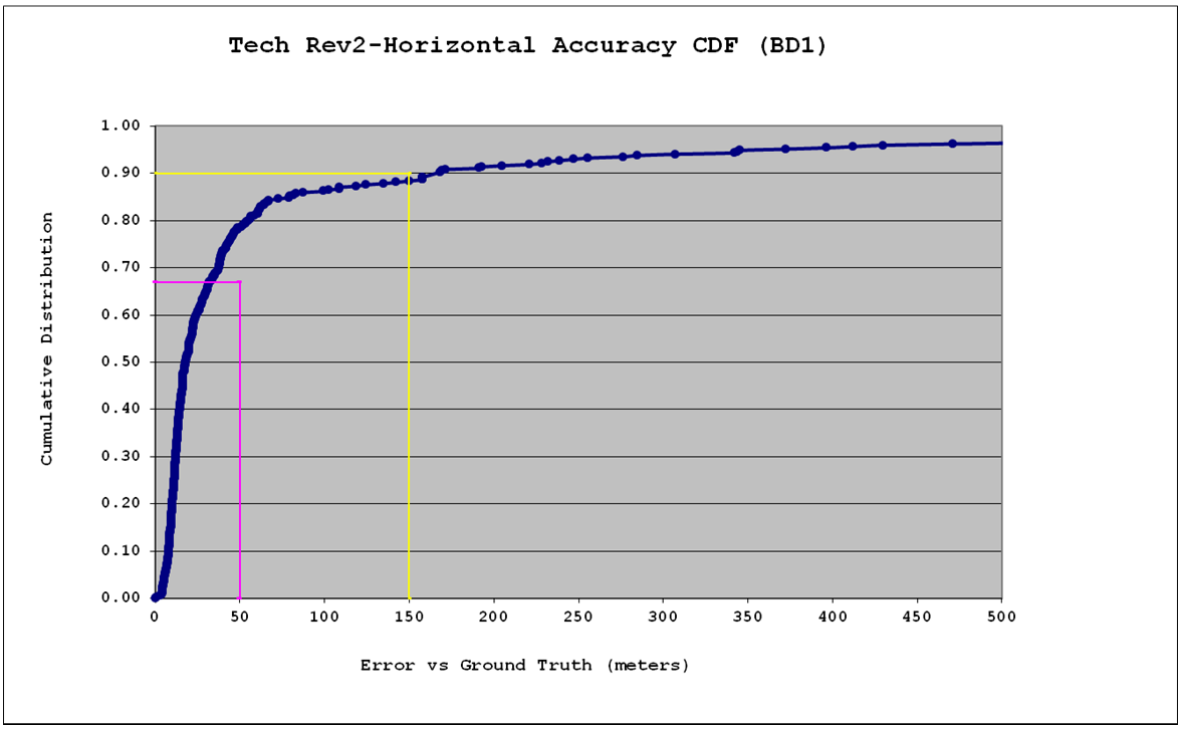
7 Performance per Building

The results in this section provide further insight into the performance of the location system. At times, aggregate summary statistics can obfuscate individual (i.e., per point) performance and levels of improvement achieved relative to prior iterations of the technology. A comparison of the scatter plots presented in this Section with those in the CSRIC WG3 report would clearly demonstrate the attained performance improvements as well as the isolated instances of degradation.

7.1 Dense Urban Buildings

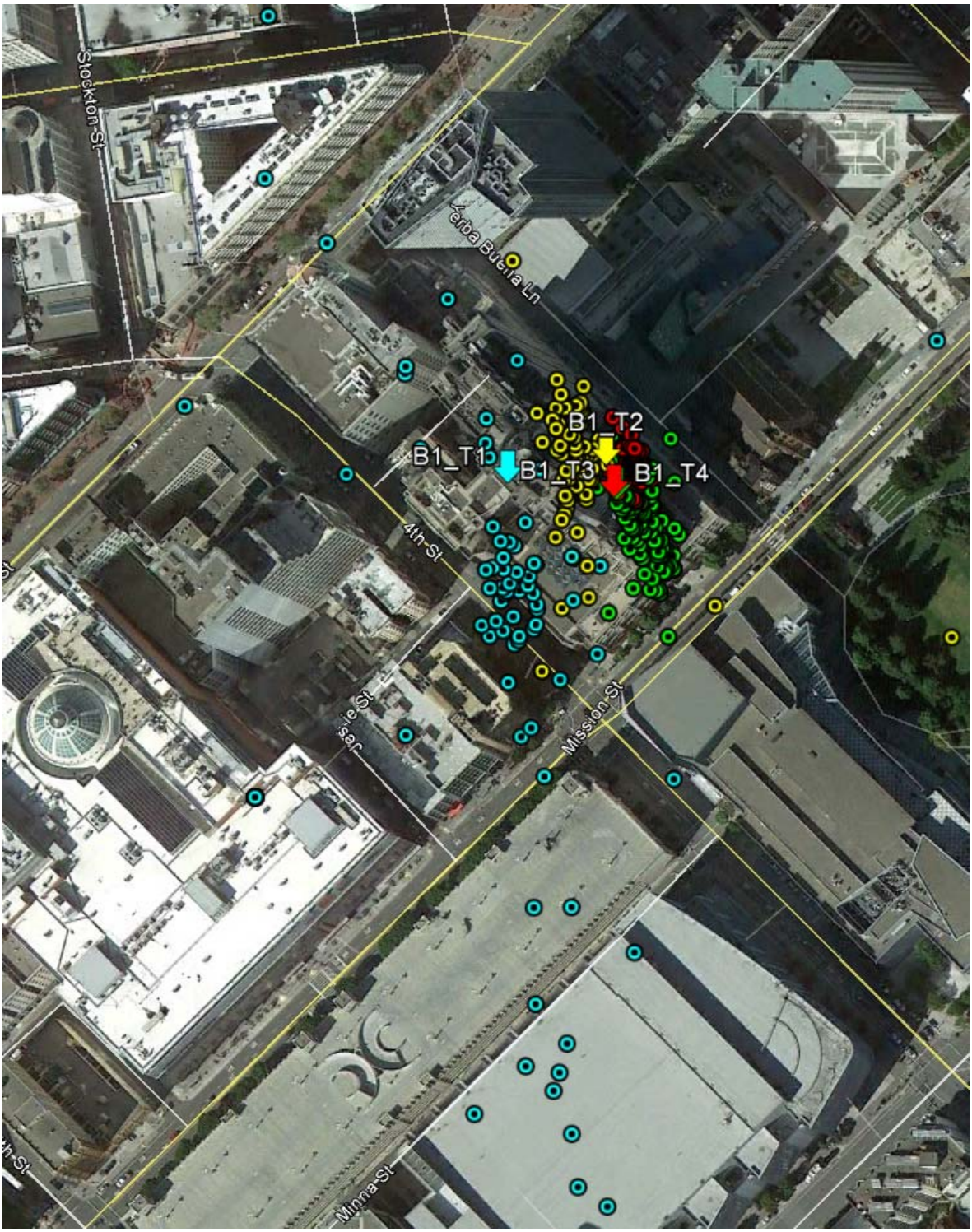
7.1.1 Bldg. 1: Marriott Marquis, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
1	1	NextNav Technology Rev-2	95	158.0	496.0	598.3	169.8	183.7	716.7	7.76
	2	NextNav Technology Rev-2	79	22.5	64.4	169.3	49.0	126.8	913.4	4.53
	3	NextNav Technology Rev-2	100	12.0	15.1	16.5	10.9	3.6	24.4	2.90
	4	NextNav Technology Rev-2	96	27.8	39.2	43.6	64.1	360.8	3523.3	0.82
	Aggregate	NextNav Technology Rev-2	370	32.4	159.0	360.3	73.6	221.6	3523.3	0.82



The aggregate performance in Building 1 is affected by the relatively poor performance at TP_1, which is depicted by the light blue dots in the scatter plot. This test point is deep inside the lobby level of this large hotel building. The extreme penetration losses affect the achieved location accuracy at that point. The resulting shape of the CDF with its somewhat low crossing at the 150 meter mark and subsequent saturation level reflect the impact of this test point. The observed performance in this

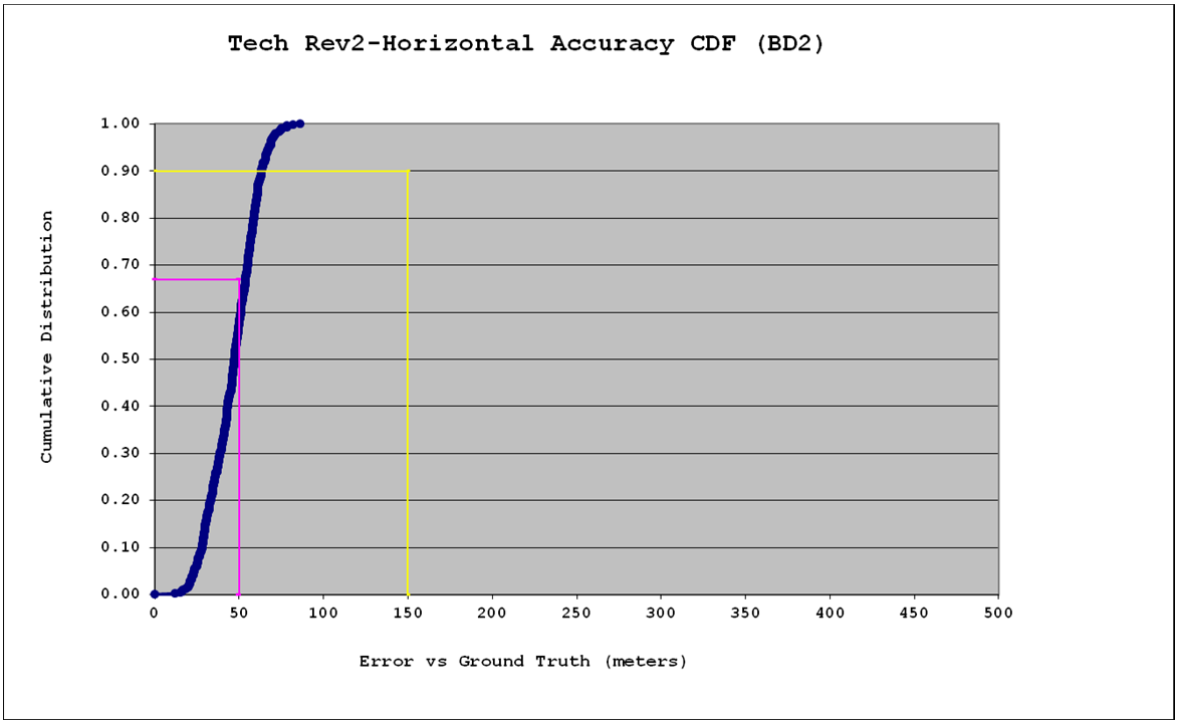
building is “classical,” for a metropolitan beacon system, being inversely proportional to the depth of the test point inside the building and its surrounding clutter.



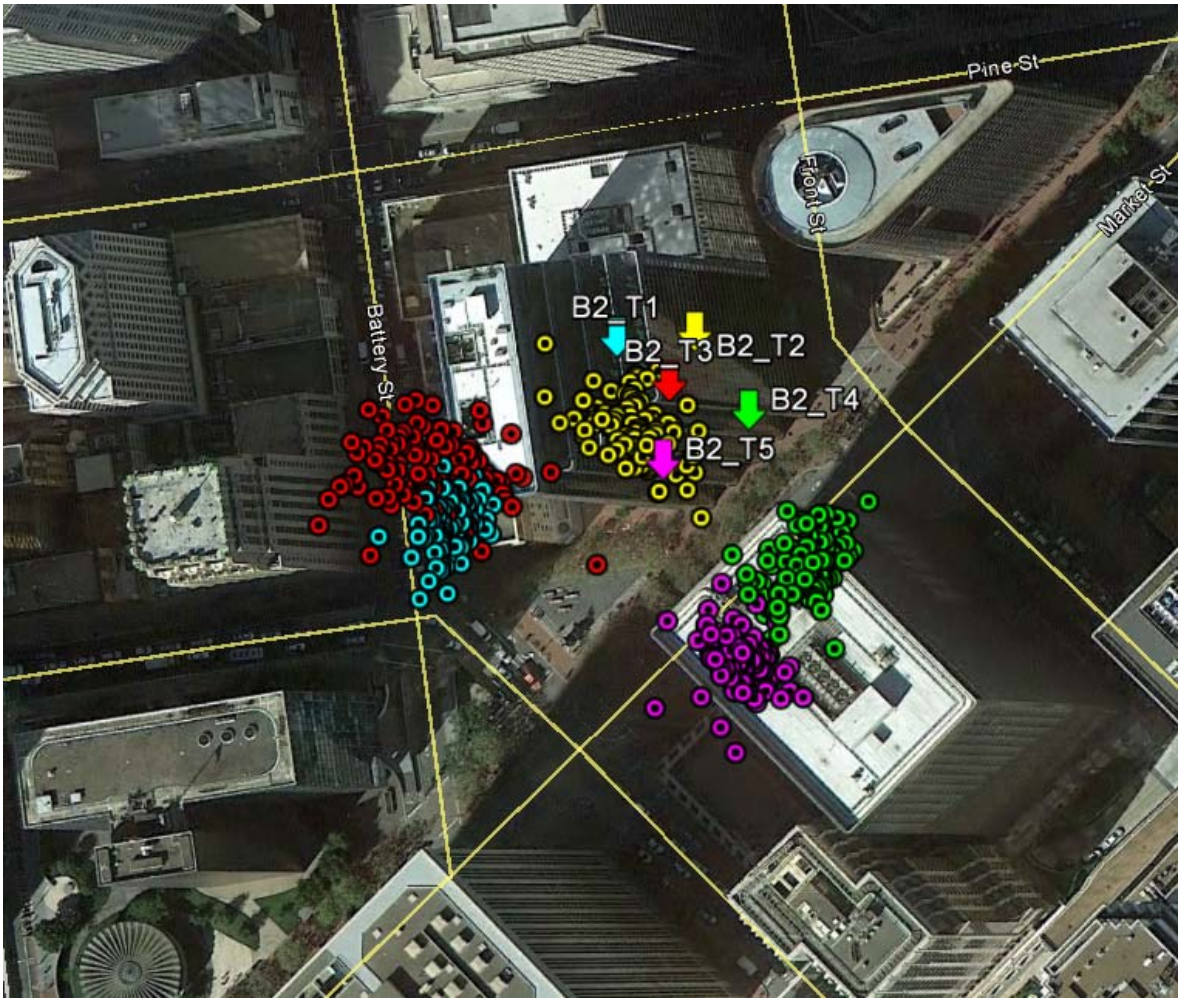
Bldg. 1 Scatter Plot

7.1.2 Bldg. 2: One Front Street, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
2	1	NextNav Technology Rev-2	100	60.5	64.8	67.3	57.8	6.0	75.1	45.78
	2	NextNav Technology Rev-2	100	30.6	34.6	37.1	27.9	5.7	43.6	12.03
	3	NextNav Technology Rev-2	100	63.5	71.9	75.7	59.2	10.2	86.3	34.14
	4	NextNav Technology Rev-2	100	42.5	46.2	48.1	39.6	6.0	58.5	25.21
	5	NextNav Technology Rev-2	100	51.4	56.7	59.8	49.4	6.3	69.1	31.81
	Aggregate	NextNav Technology Rev-2	500	53.9	63.5	68.0	46.8	13.7	86.3	12.03



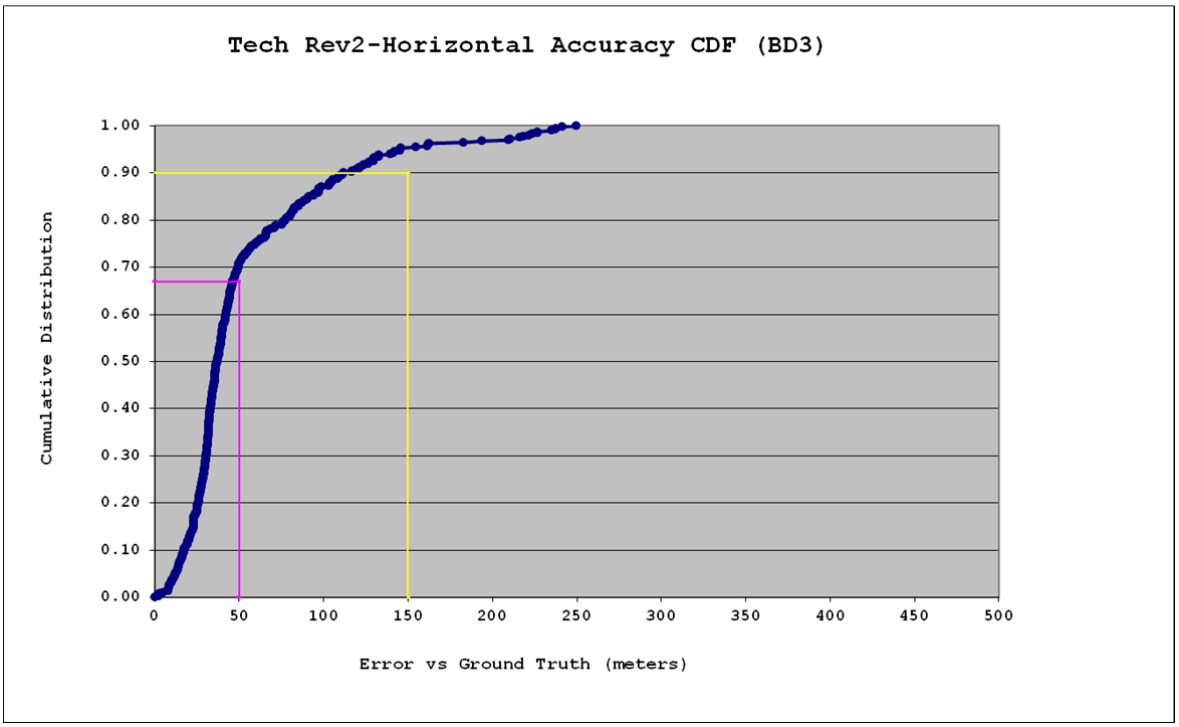
The position fixes reflect good clustering and absence of outliers but with the phenomenon common in certain denser urban settings where the location is at times offset to the neighboring building. This is caused by the inescapable multipath pattern at certain indoor test points (the signal to/from the handset can only propagate to/from the outside world through the window and bounces off the neighboring building creating a false position at that nearby building.) This is reflected in the moderate shift to the right (by a few tens of meters) of an otherwise very good cumulative CDF function.



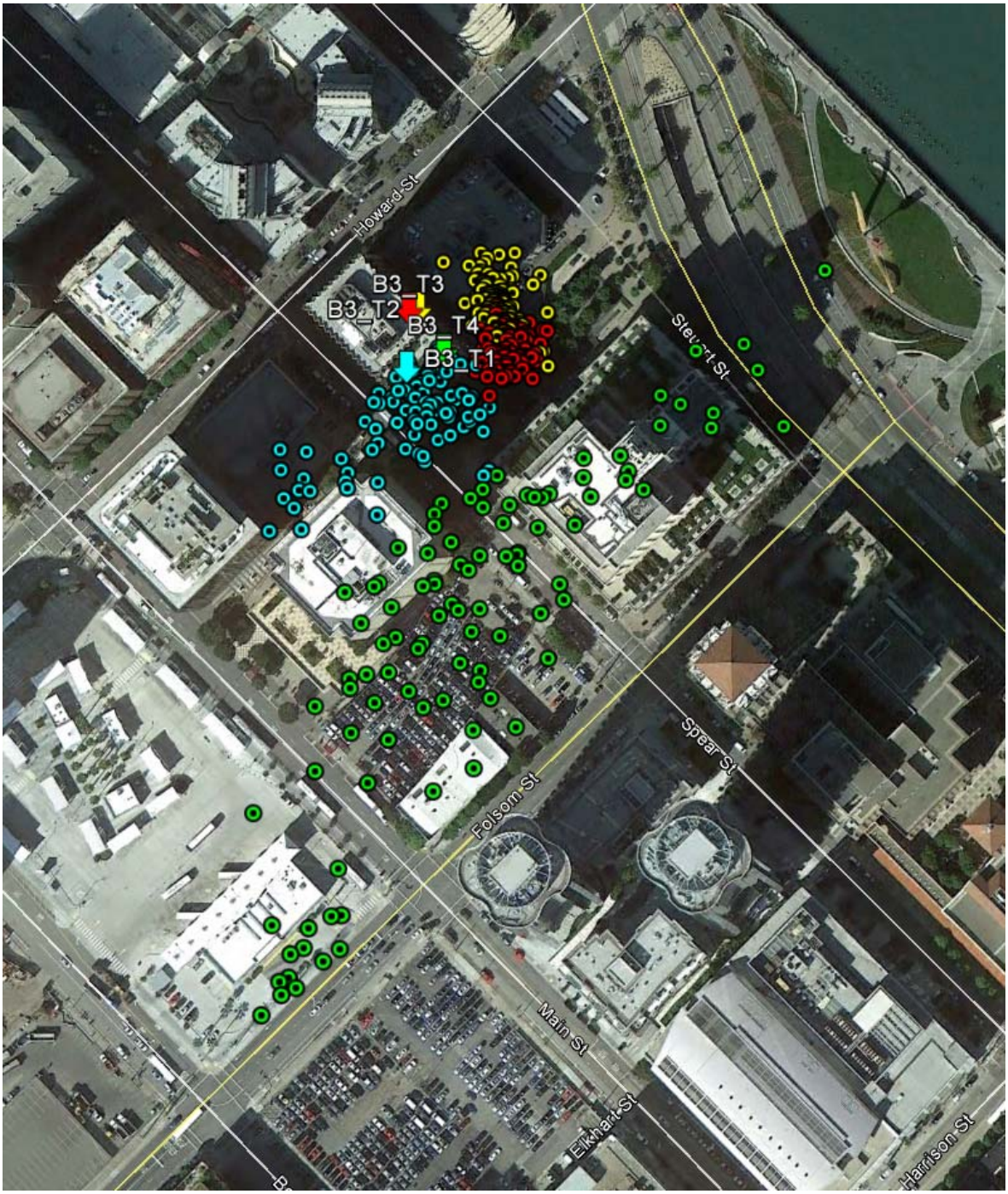
Bldg. 2 Scatter Plot

7.1.3 Bldg. 3: 201 Spear Street, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
3	1	NextNav Technology Rev-2	100	27.7	50.2	59.5	25.6	16.6	78.5	2.40
	2	NextNav Technology Rev-2	100	32.4	38.6	44.5	31.5	6.3	53.5	18.07
	3	NextNav Technology Rev-2	100	42.9	47.1	50.3	40.3	5.6	53.4	27.99
	4	NextNav Technology Rev-2	100	124.7	216.6	227.2	117.7	51.6	249.9	51.16
	Aggregate	NextNav Technology Rev-2	400	46.6	112.3	145.3	53.8	46.2	249.9	2.40



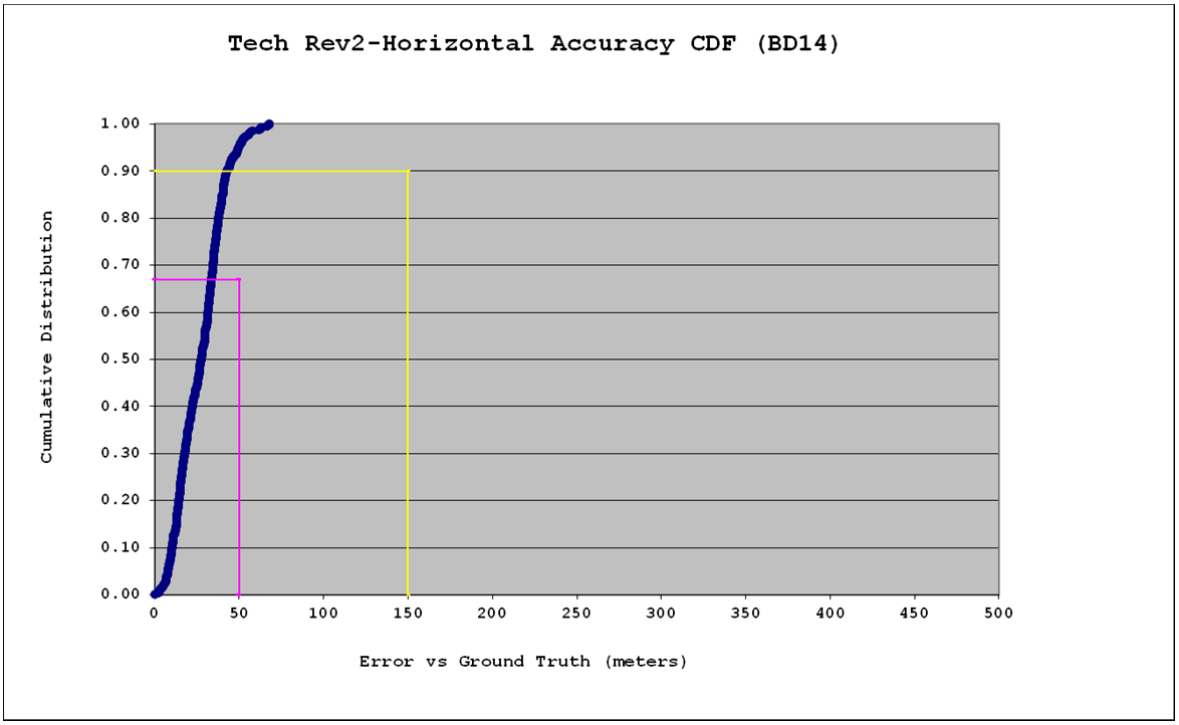
The results in the table above and the scatter plot show generally good performance except for PT_4 (shown in green), which is located in the garage one floor below the lobby, thereby presenting a particularly harsh environment with severe penetration losses. Despite that, the aggregate performance for the building is relatively good as seen in the cumulative CDF.



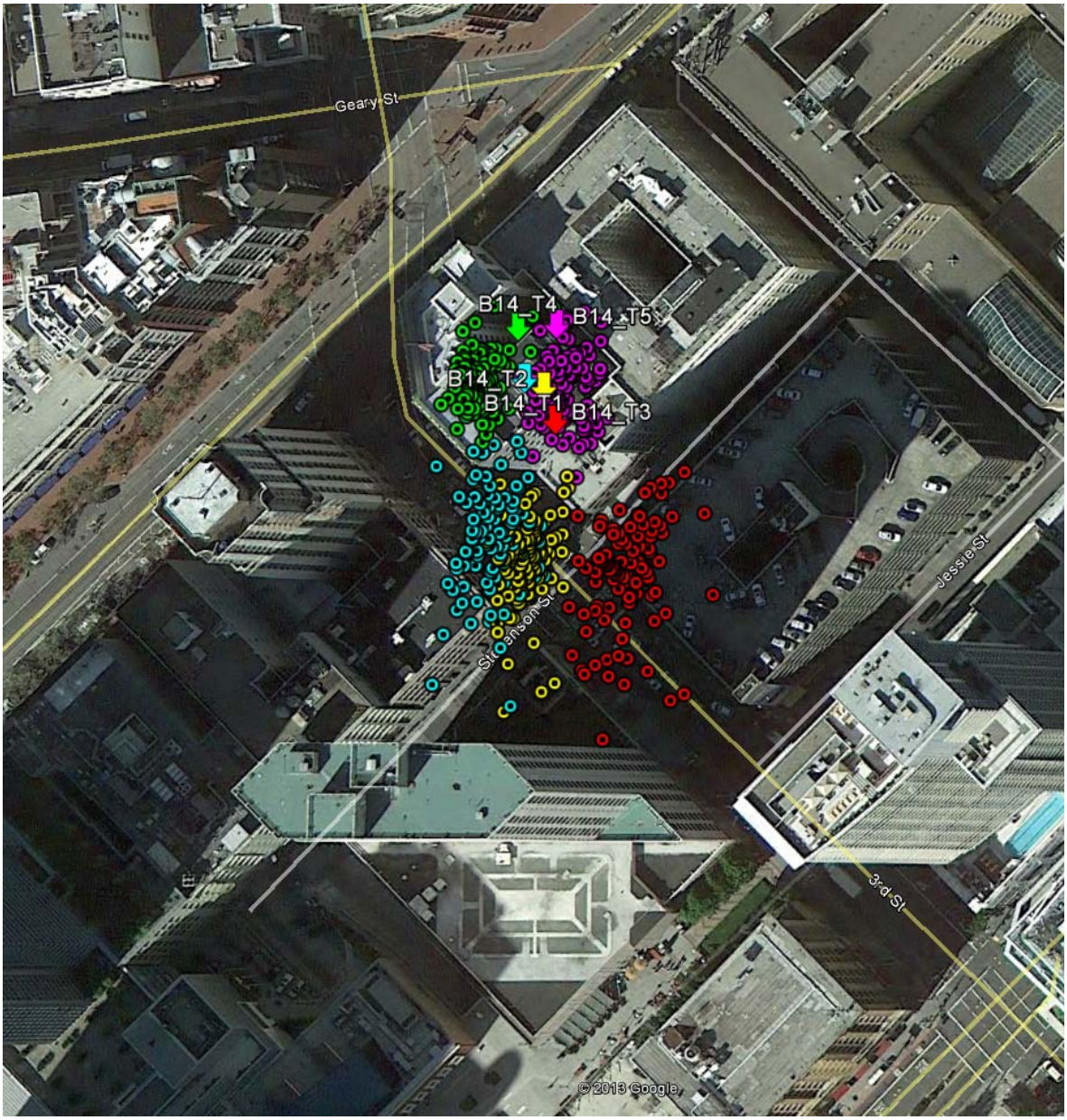
Bldg. 3 Scatter Plot

7.1.4 Bldg. 14: Hearst Building, 699 Market Street, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
14	1	NextNav Technology Rev-2	100	37.8	47.6	51.2	34.6	10.2	68.2	13.10
	2	NextNav Technology Rev-2	100	39.0	45.4	52.1	36.6	8.5	68.1	19.39
	3	NextNav Technology Rev-2	100	38.2	51.1	54.6	36.6	9.5	67.1	20.53
	4	NextNav Technology Rev-2	100	16.7	20.4	21.6	14.7	4.6	25.3	4.07
	5	NextNav Technology Rev-2	100	17.6	22.9	25.3	14.6	6.4	32.5	1.54
	Aggregate	NextNav Technology Rev-2	500	33.9	43.1	50.0	27.4	13.2	68.2	1.54



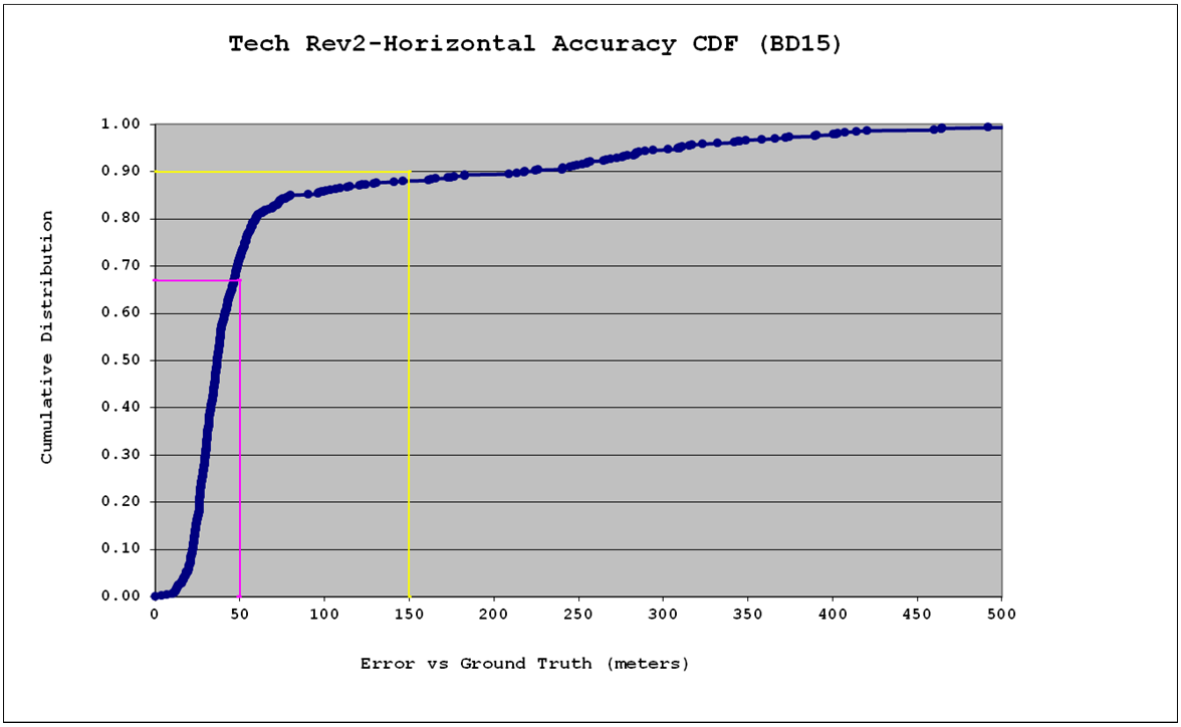
A range of good performance is seen in this building with significant performance improvement when compared to that observed with the first iteration of the technology during the CSRIC testing in Fall 2012. This is manifested visually in significantly tighter clusters that are closer to the test points.



Bldg. 14 Scatter Plot

7.1.5 Bldg. 15: Omni Hotel, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
15	1	NextNav Technology Rev-2	100	45.9	53.4	56.7	39.4	11.4	59.8	4.02
	2	NextNav Technology Rev-2	100	31.3	37.2	38.9	27.0	8.1	47.7	10.01
	3	NextNav Technology Rev-2	100	41.3	51.1	57.6	37.3	11.7	72.6	11.23
	4	NextNav Technology Rev-2	100	31.9	37.3	40.0	29.4	6.1	47.2	11.95
	5	NextNav Technology Rev-2	100	297.0	408.0	466.3	250.0	132.2	644.3	23.39
	6	NextNav Technology Rev-2	100	54.0	72.5	75.7	47.1	16.8	96.3	20.97
	Aggregate	NextNav Technology Rev-2	600	46.9	219.2	309.8	71.7	97.0	644.3	4.02

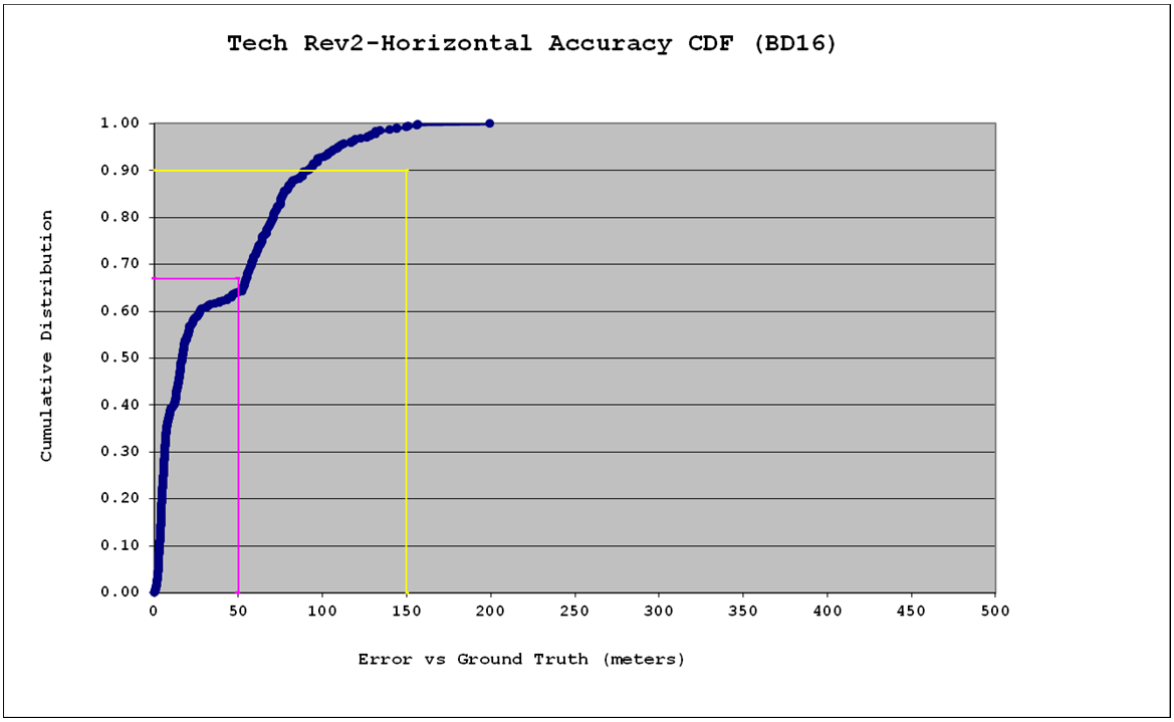


The performance in this sizeable hotel building is again adversely affected by PT_05, which is one level below the lobby creating a severe attenuation scenario. The scatter for that point is shown in purple. Some offset of the other location fix clusters towards the buildings across the streets is observed.

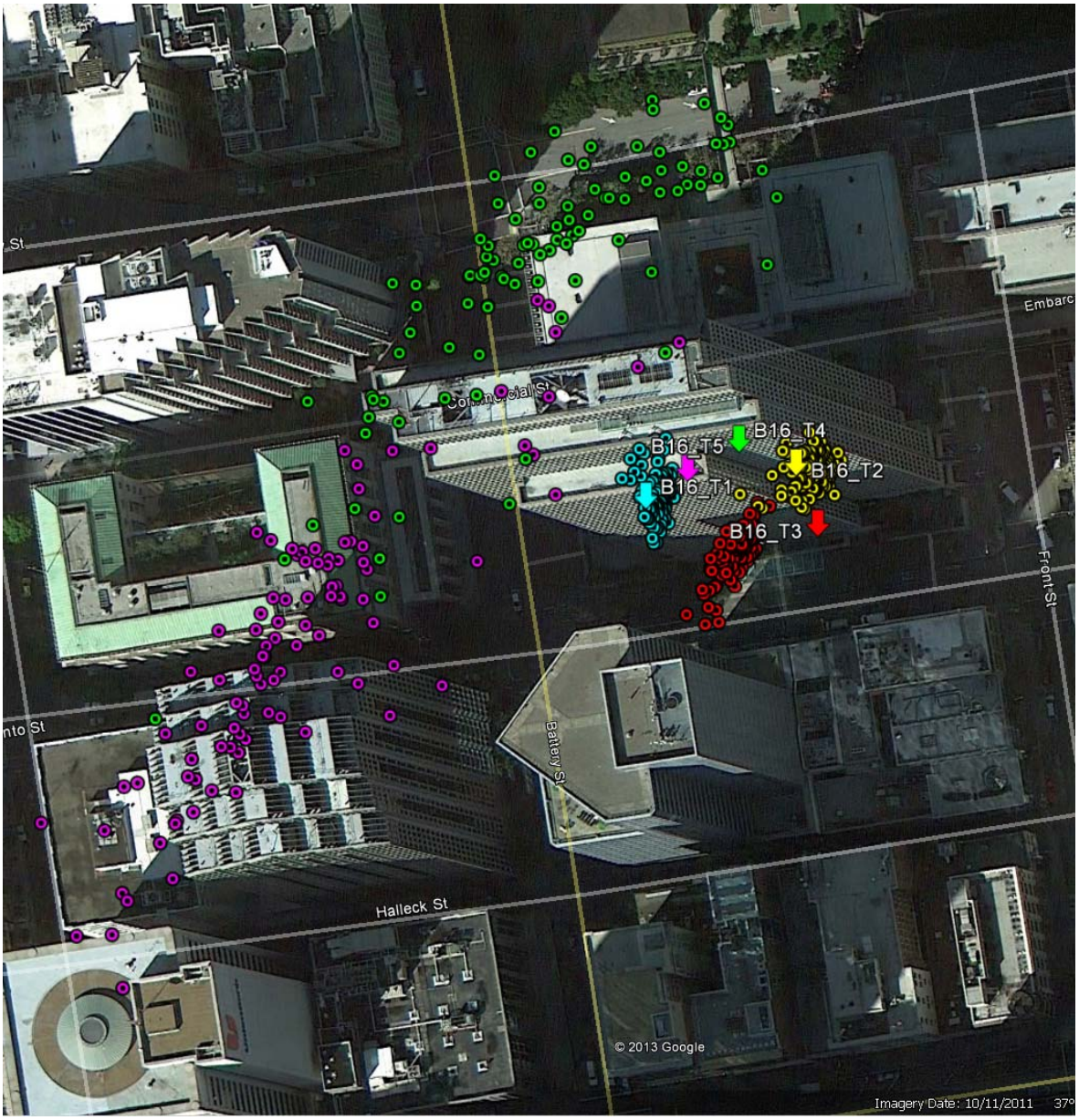
Bldg. 15 Scatter Plot

7.1.6 Bldg. 16: One Embarcadero Center, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
16	1	NextNav Technology Rev-2	100	5.3	7.8	9.0	4.7	2.2	12.7	0.95
	2	NextNav Technology Rev-2	100	6.5	7.9	9.4	5.5	2.3	12.9	0.56
	3	NextNav Technology Rev-2	100	18.6	24.2	27.1	17.9	4.4	32.4	10.36
	4	NextNav Technology Rev-2	100	66.0	77.2	89.0	64.9	20.2	199.4	23.27
	5	NextNav Technology Rev-2	100	99.6	129.4	144.1	89.4	29.9	156.8	23.19
	Aggregate	NextNav Technology Rev-2	500	55.4	91.9	109.4	36.5	38.1	199.4	0.56



Good to very good performance is seen here in the points on higher floors (PT_01 and PT_02 on the 42nd floor and PT_03 on the 29th floor). Relatively weaker performance is observed at the test points on lower floors and deeper in the clutter, as seen in the green dots of PT_04 (deep inside the 3rd floor) and purple for PT_05 at the plaza level. Both of these points have high levels of signal attenuation and scattering compared to the points on high floors.

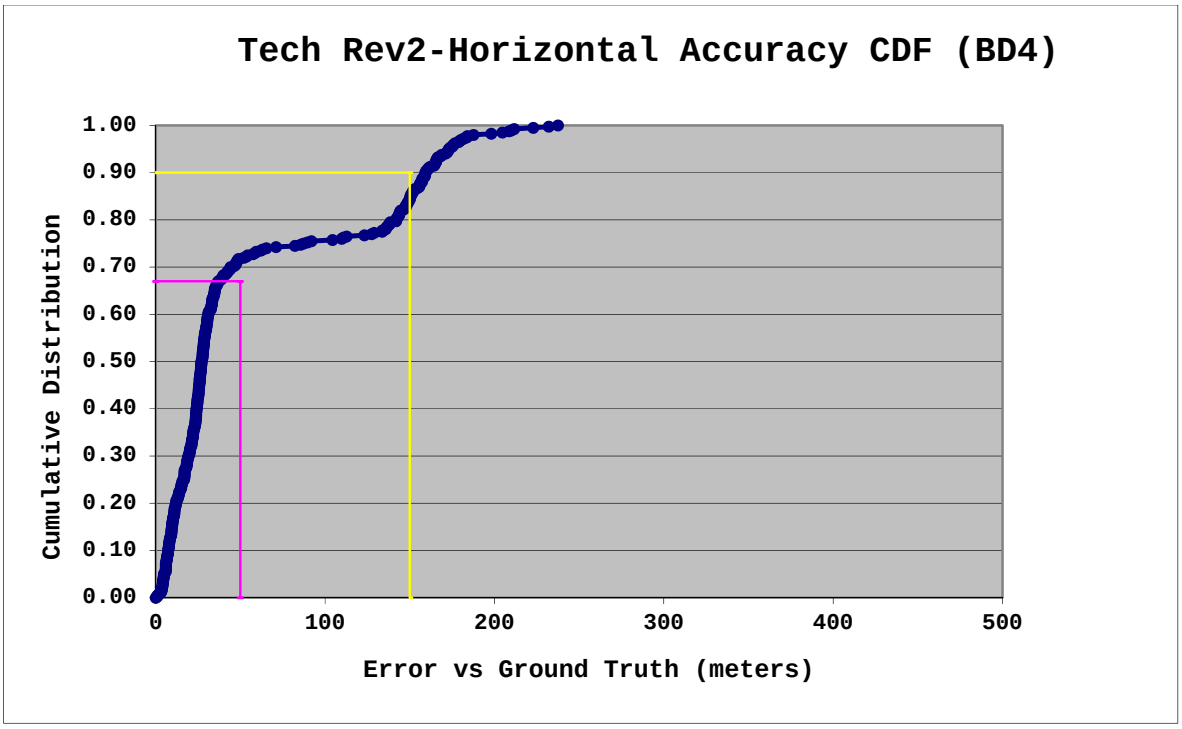


Bldg. 16 Scatter Plot

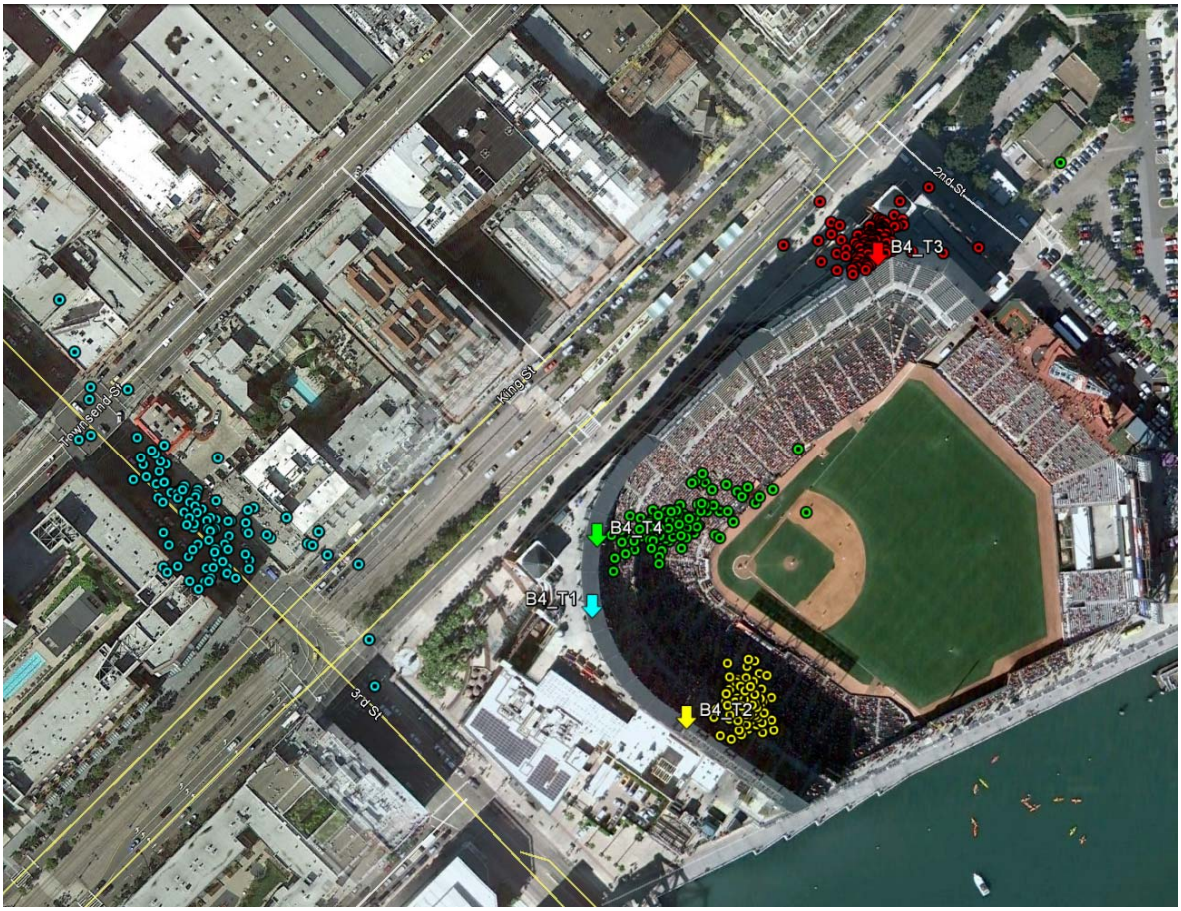
7.2 Urban Buildings

7.2.1 Bldg. 4: AT&T Park (Baseball Stadium), SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
4	1	NextNav Technology Rev-2	100	164.5	182.2	204.9	156.1	25.4	237.5	87.27
	2	NextNav Technology Rev-2	100	27.4	30.5	33.3	25.0	4.9	35.6	10.89
	3	NextNav Technology Rev-2	100	10.8	18.7	23.6	10.4	7.2	39.8	0.86
	4	NextNav Technology Rev-2	100	36.3	54.6	63.3	35.4	25.0	232.1	5.93
	Aggregate	NextNav Technology Rev-2	400	37.2	159.2	173.1	56.7	61.0	237.5	0.86



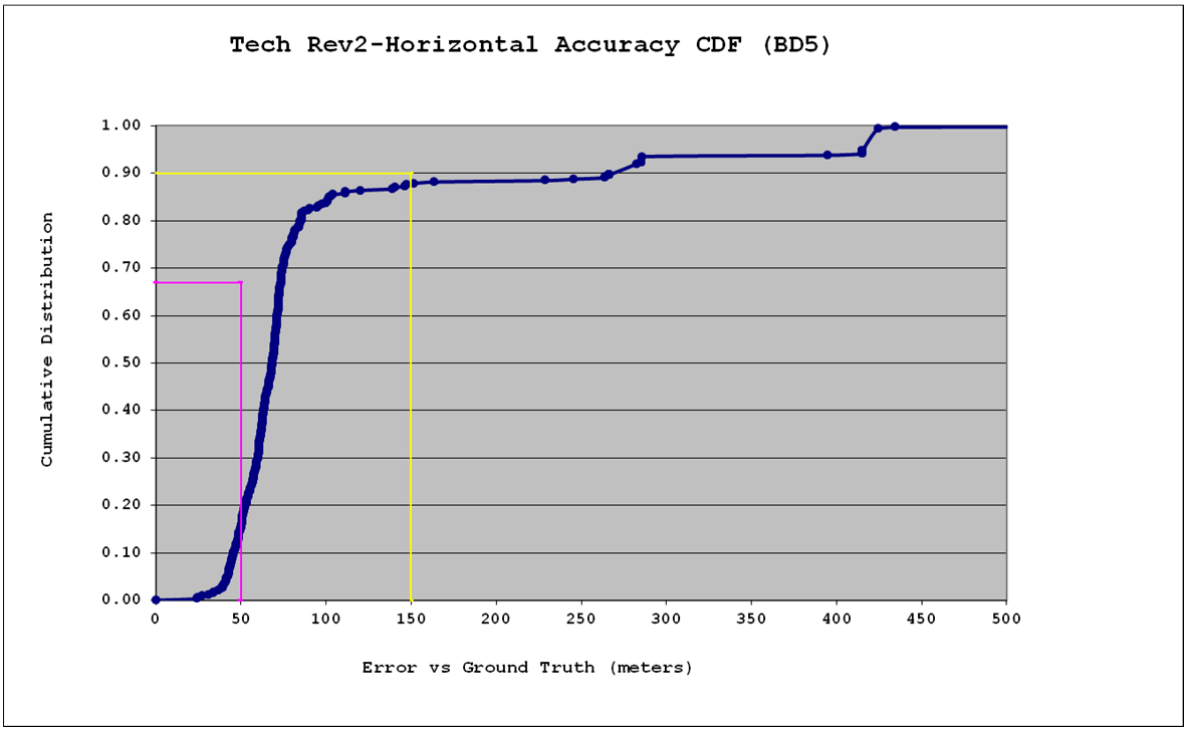
Although the performance at PT_02 and PT_03, and to a lesser extent PT_04, exhibit relatively good performance with significant improvement over prior testing during the Fall 2012 CSRIC campaign, the aggregate performance for the building is adversely affected by the poorer performance for PT_01. As in previously described buildings, PT_01 is deep inside the main building of the stadium on the first floor, with relatively high levels of signal attenuation and scattering. The relatively large offset in the indicated position of PT_01 results in the odd shape of the cumulative CDF above.



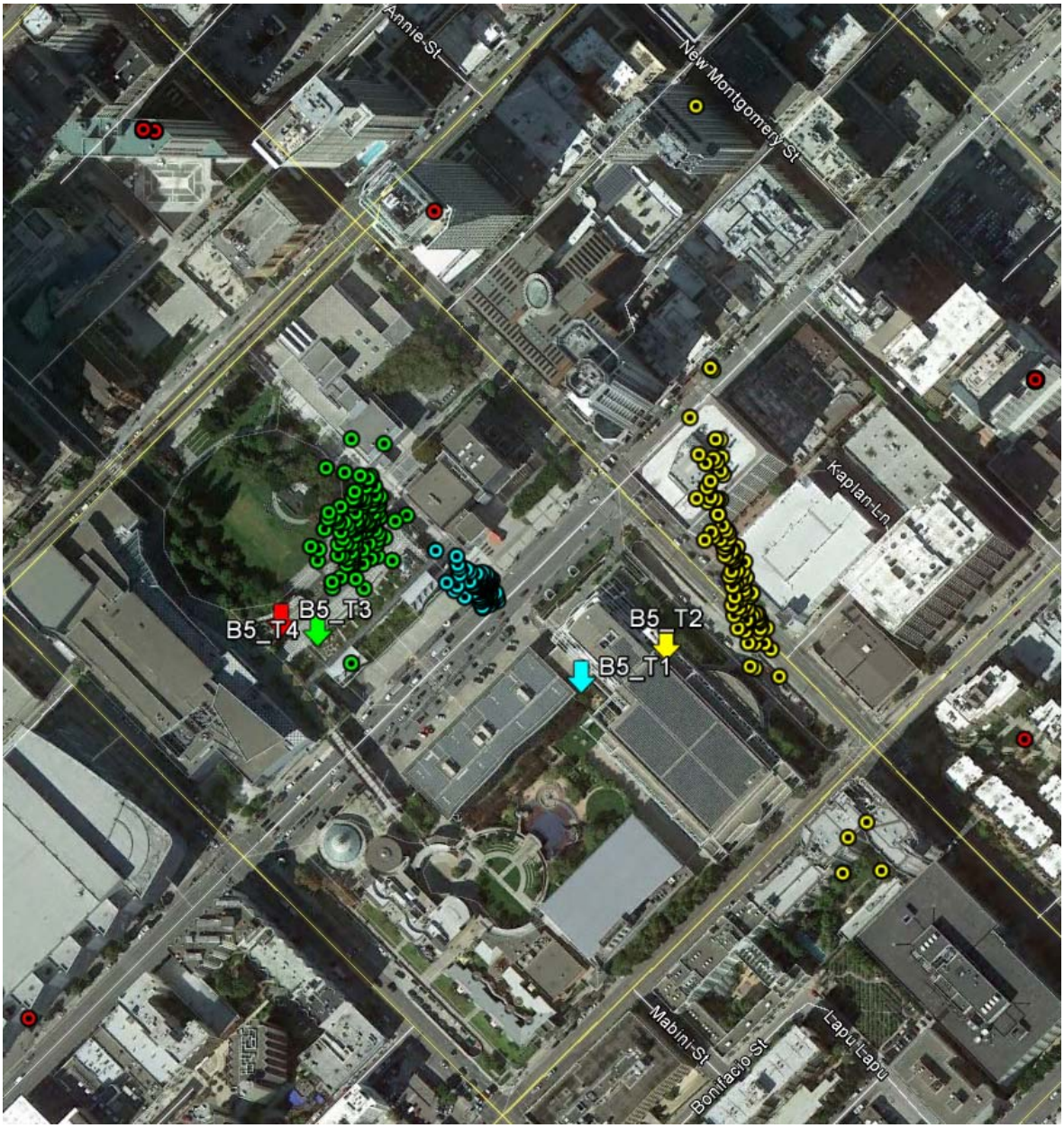
Bldg. 4 Scatter Plot

7.2.2 Bldg. 5: Moscone Convention Center, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
5	1	NextNav Technology Rev-2	100	72.6	77.2	83.3	71.3	6.5	100.7	59.27
	2	NextNav Technology Rev-2	100	64.7	111.3	146.5	73.0	50.4	434.3	39.20
	3	NextNav Technology Rev-2	38	415.0	415.0	416.4	358.0	98.6	752.1	229.02
	4	NextNav Technology Rev-2	100	67.9	80.1	84.6	60.7	15.8	104.3	24.39
	Aggregate	NextNav Technology Rev-2	338	73.8	266.4	415.0	100.9	101.6	752.1	24.39



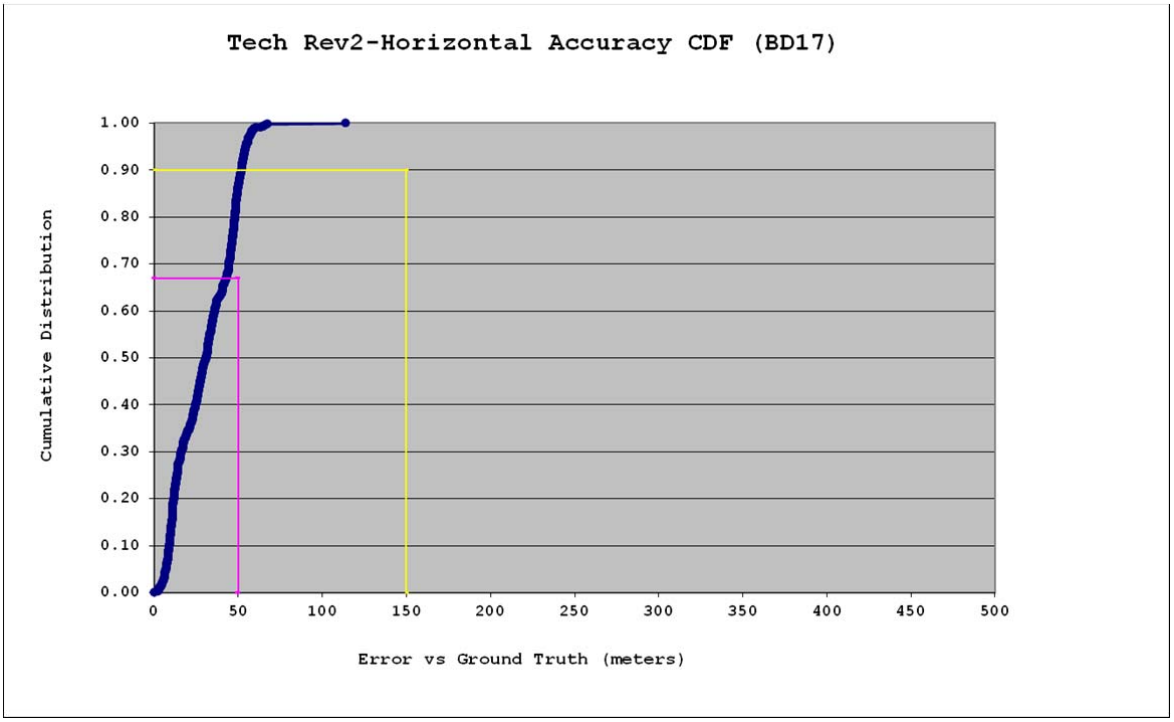
The observed performance in the Convention Center demonstrates cases of very high signal attenuation at PT_02, on the mezzanine level of conference rooms 3 meters below street lobby level, and PT_03 on the floor of the exhibit hall 10 meters below the lobby. The linearly arranged yellow fixes shown below indicate reception of a reduced number of beacon signals, whereas the red fixes indicate that received signal levels were not adequate for meaningful location determination. The aggregate results for this building shown in the table and its composite CDF should be interpreted in light of these harsh test conditions.



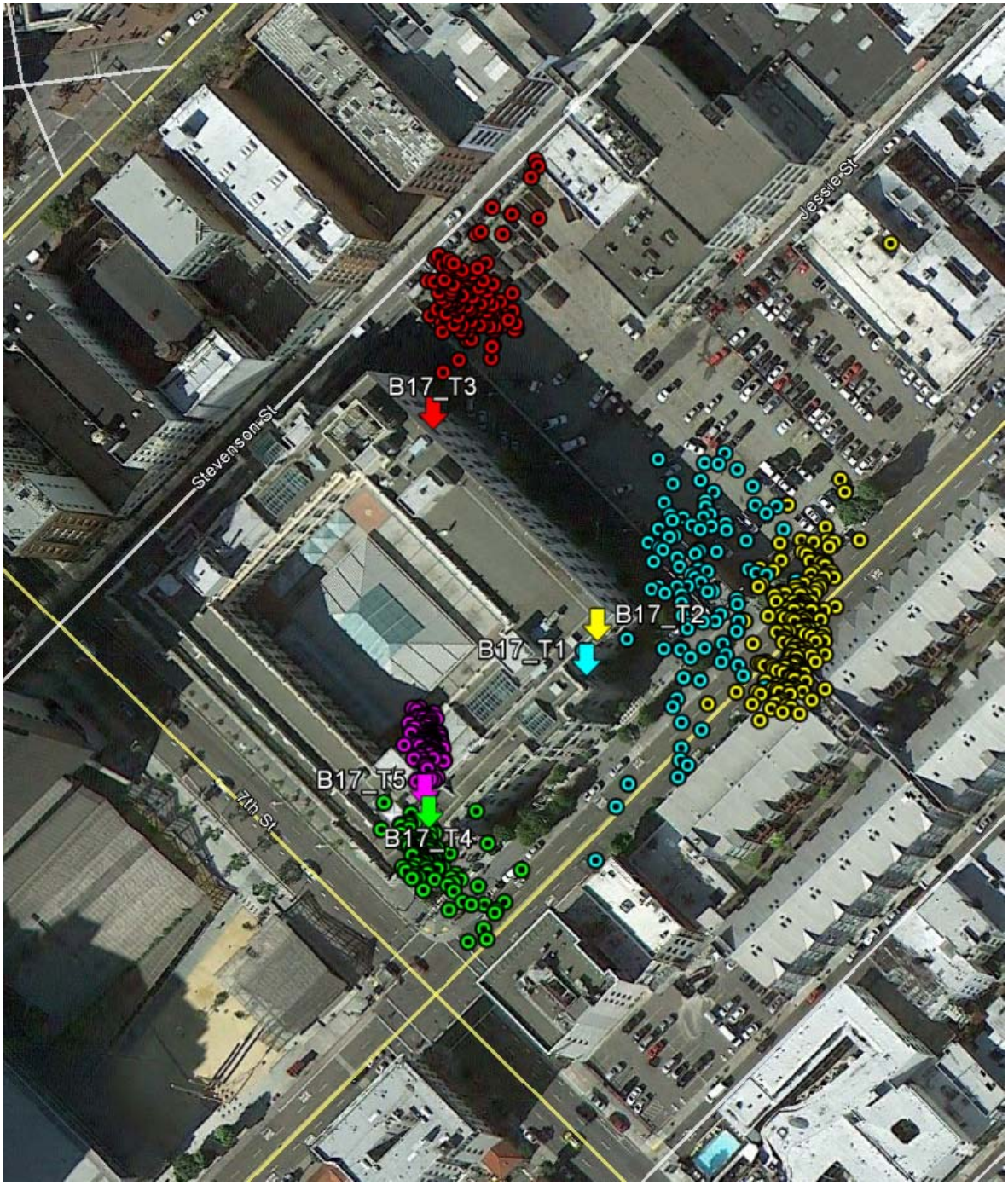
Bldg. 5 Scatter Plot

7.2.3 Bldg. 17: US Court of Appeals Building, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
17	1	NextNav Technology Rev-2	100	40.1	52.4	56.3	36.7	10.6	59.2	2.47
	2	NextNav Technology Rev-2	173	50.2	55.1	57.2	49.2	7.2	114.1	32.17
	3	NextNav Technology Rev-2	100	31.9	37.5	50.8	30.3	9.1	64.7	10.26
	4	NextNav Technology Rev-2	100	12.8	22.6	27.8	12.3	6.5	32.9	3.61
	5	NextNav Technology Rev-2	100	13.6	17.5	17.9	12.2	3.7	19.9	2.91
	Aggregate	NextNav Technology Rev-2	573	43.0	52.1	54.9	30.8	17.0	114.1	2.47



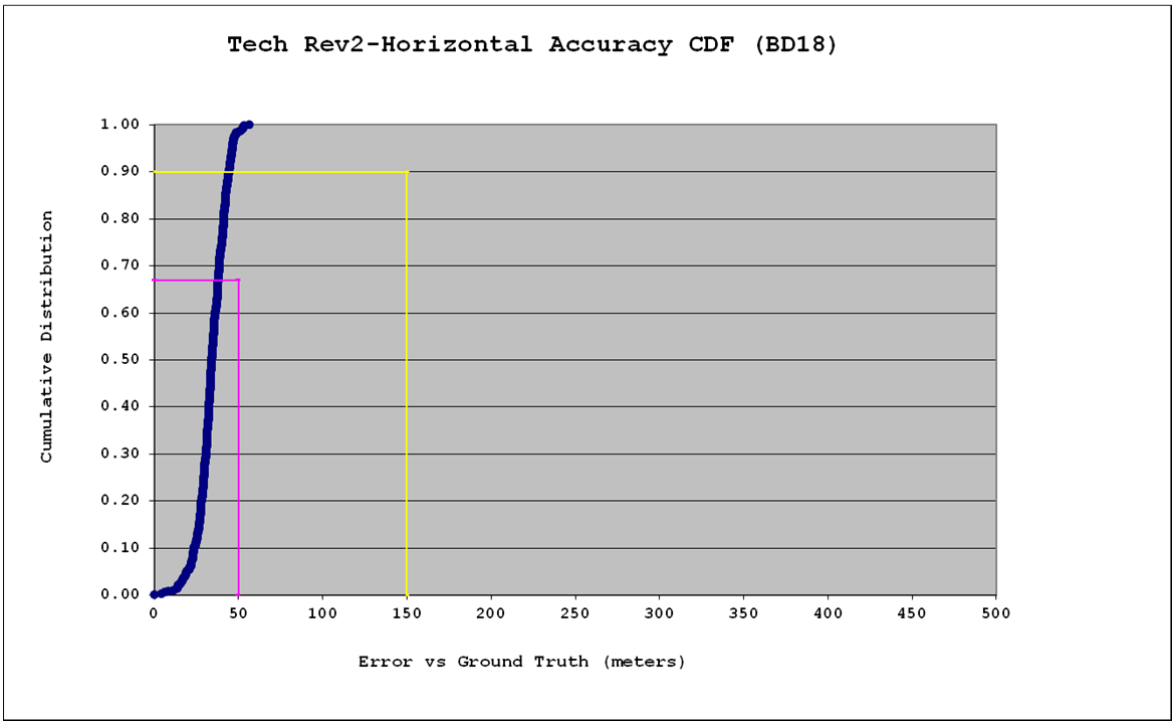
Tighter fix clusters that are also closer to the test points relative to prior testing reflect improved performance of the Rev-2 system. Some offsets in the location fixes due to the indoor environment and reflection off neighboring structures, which are 40-50 m away, is still observed but overall performance is distinctly improved.



Bldg. 17 Scatter Plot

7.2.4 Bldg. 18: Super 8 Motel—O'Farrell Street, SF

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
18	1	NextNav Technology Rev-2	99	38.7	43.4	44.9	35.0	7.5	53.4	14.19
	2	NextNav Technology Rev-2	100	35.9	41.4	44.3	31.9	9.4	53.0	4.36
	3	NextNav Technology Rev-2	100	32.8	38.2	40.5	30.9	5.8	53.1	19.25
	4	NextNav Technology Rev-2	100	43.1	46.9	47.6	39.9	6.1	56.8	27.94
	Aggregate	NextNav Technology Rev-2	399	38.1	44.7	46.5	34.4	8.1	56.8	4.36

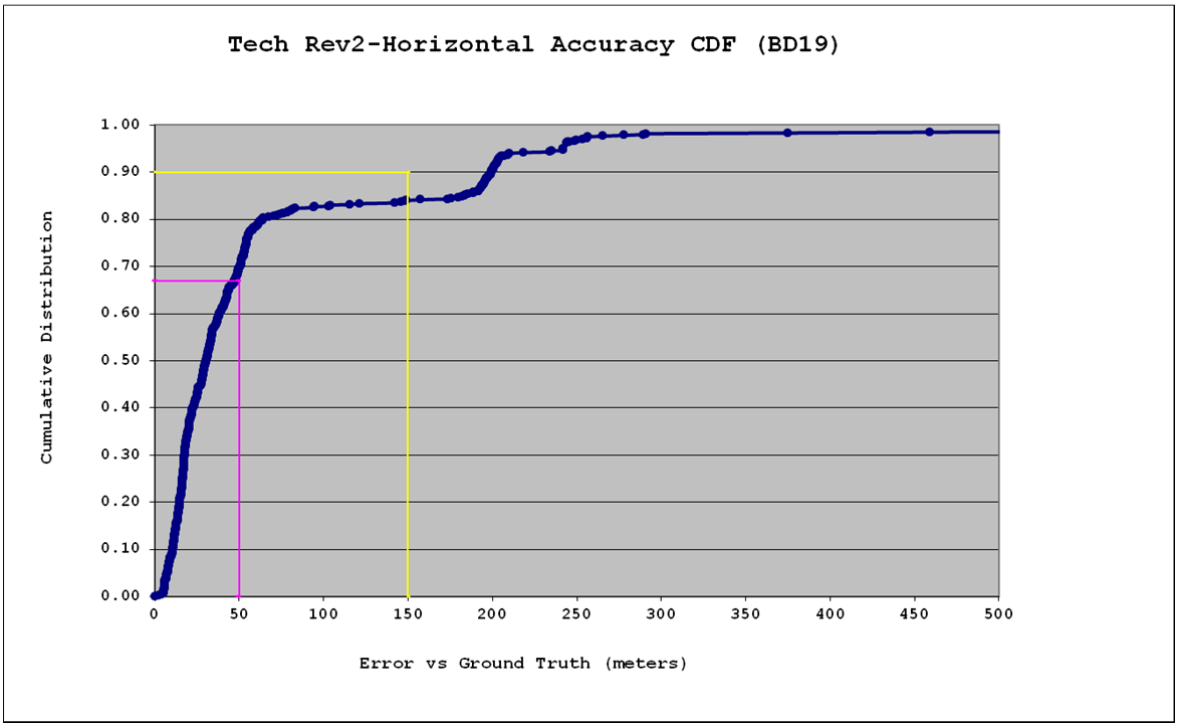


Similar to Bldg 17 above, tighter location fix clusters are observed relative to prior testing during the CSRIC Fall 2012 campaign. Overall performance as seen from the statistics per test point and the composite CDF is improved. However, some test points show similar offset behavior with fixes clustered at or closer to the building across the street (about 35 meters away).

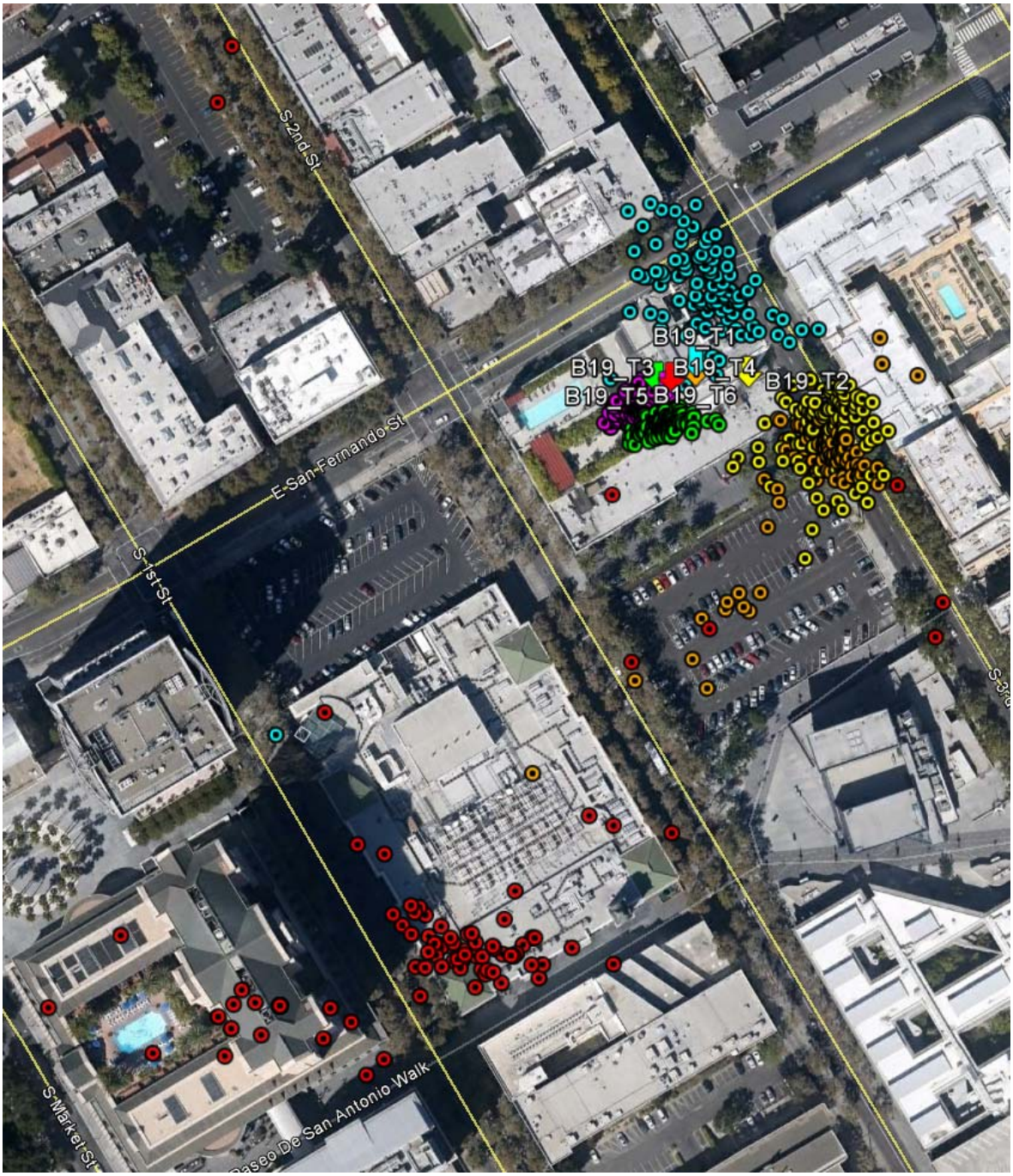
Bldg. 18 Scatter Plot

7.2.5 Bldg. 19: The 88 San Jose, San Jose

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
19	1	NextNav Technology Rev-2	100	31.9	42.2	49.5	29.4	18.9	183.5	4.69
	2	NextNav Technology Rev-2	100	37.1	50.9	53.2	34.5	10.2	63.8	14.17
	3	NextNav Technology Rev-2	100	209.6	266.6	545.5	227.0	100.3	631.4	42.78
	4	NextNav Technology Rev-2	100	17.6	20.3	21.7	16.8	2.8	25.9	10.80
	5	NextNav Technology Rev-2	100	12.0	17.0	18.6	10.8	4.4	23.0	2.57
	6	NextNav Technology Rev-2	100	57.1	79.2	106.0	79.9	122.9	906.9	31.56
	Aggregate	NextNav Technology Rev-2	600	47.4	199.5	241.8	66.4	99.5	906.9	2.57



The position determination performance of the NextNav Technology Rev-2 in this building consisted of a mix of four performance levels. These can be discerned from the accuracy statistics table as well as a close look at the shape of the composite CDF. Very good performance is observed at test points 4 and 5, which are close to windows on the 5th and 22nd floor respectively, moderately good performance (given the environment) is seen at test points 1 and 2 in inside the lobby and in the 2nd floor garage, with errors between 30 and 50 meters, less accurate performance is experienced at point 6 near the middle of the 10th floor, and poor performance exists at point 3 inside the staircase on the 5th floor. This last point is surrounded by masonry walls and is therefore subject to high external signal attenuation levels. As such, the performance in this challenging urban high rise building is again, "classical" for this beacon location system, being inversely proportional to the depth of the point inside the building, and more importantly to the overall beacon signal attenuation levels experienced at each test point.

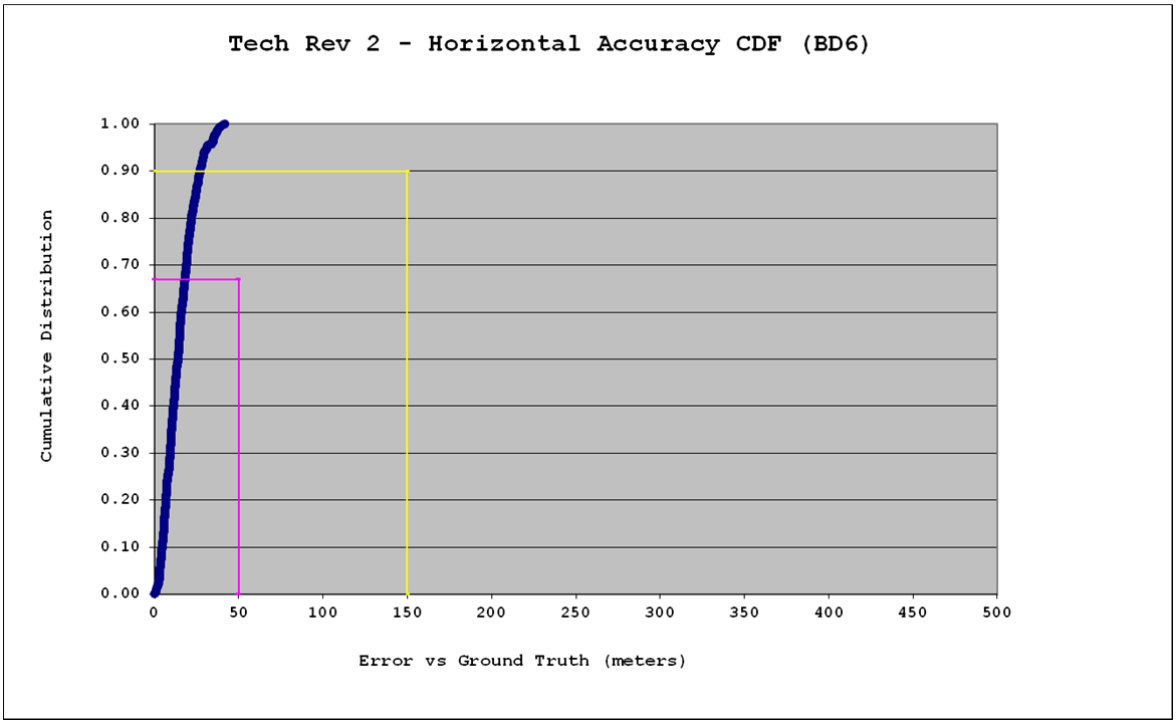


Bldg. 19 Scatter Plot

7.3 Suburban Buildings

7.3.1 Bldg. 6: Westfield Valley Fair Mall, Santa Clara

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
6	1	NextNav Technology Rev-2	100	12.4	15.8	17.7	10.4	4.5	23.2	2.74
	2	NextNav Technology Rev-2	100	28.5	35.6	38.1	25.4	7.5	41.7	6.21
	3	NextNav Technology Rev-2	100	18.6	23.9	25.3	16.8	4.8	28.6	3.45
	4	NextNav Technology Rev-2	100	9.1	15.9	20.1	8.2	5.3	23.9	0.53
	Aggregate	NextNav Technology Rev-2	400	18.3	27.5	31.6	15.2	8.7	41.7	0.53

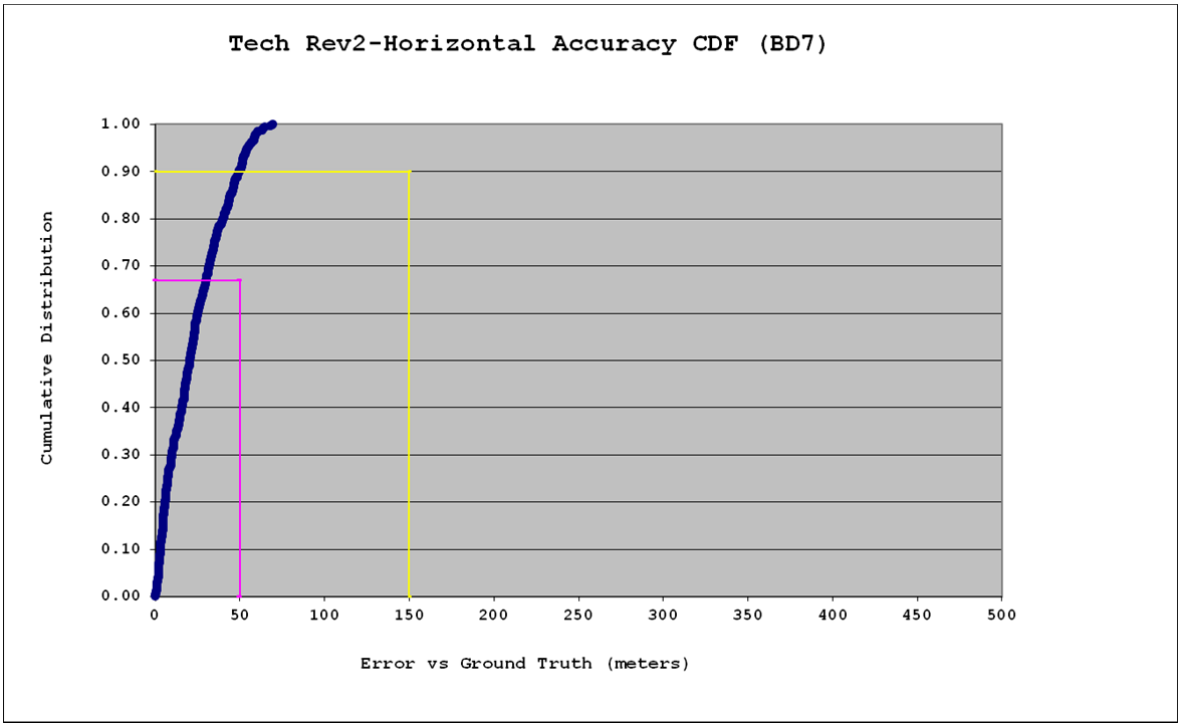


A range of excellent to relatively good performance is seen in this large suburban commercial building, even for points relatively deep inside the hallways of that mall structure. Notable also is the excellent performance seen at point 4 which is in the lower level of a 3-level concrete garage structure.

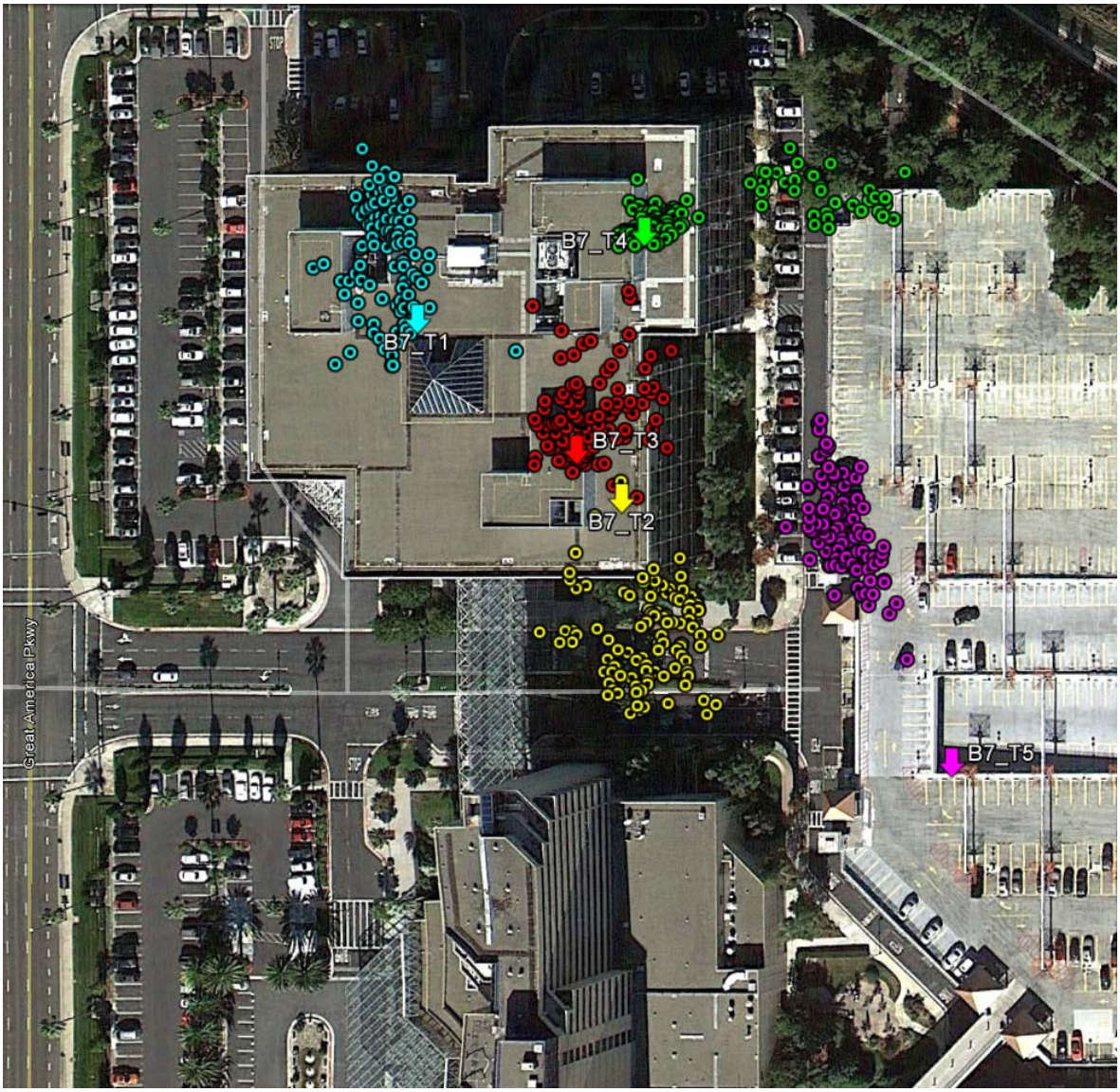
Bldg. 6 Scatter Plot

7.3.2 Bldg. 7: Techmart Office Building, Santa Clara

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
7	1	NextNav Technology Rev-2	100	20.3	24.0	27.2	15.8	7.5	34.1	2.37
	2	NextNav Technology Rev-2	100	31.6	36.7	39.6	27.3	7.9	43.8	3.40
	3	NextNav Technology Rev-2	100	12.0	20.4	23.1	10.4	6.9	31.9	0.69
	4	NextNav Technology Rev-2	100	22.6	40.2	44.8	14.7	15.7	50.9	0.30
	5	NextNav Technology Rev-2	100	53.1	60.0	64.0	49.5	8.9	69.7	21.41
	Aggregate	NextNav Technology Rev-2	500	30.4	49.9	54.7	23.5	17.3	69.7	0.30



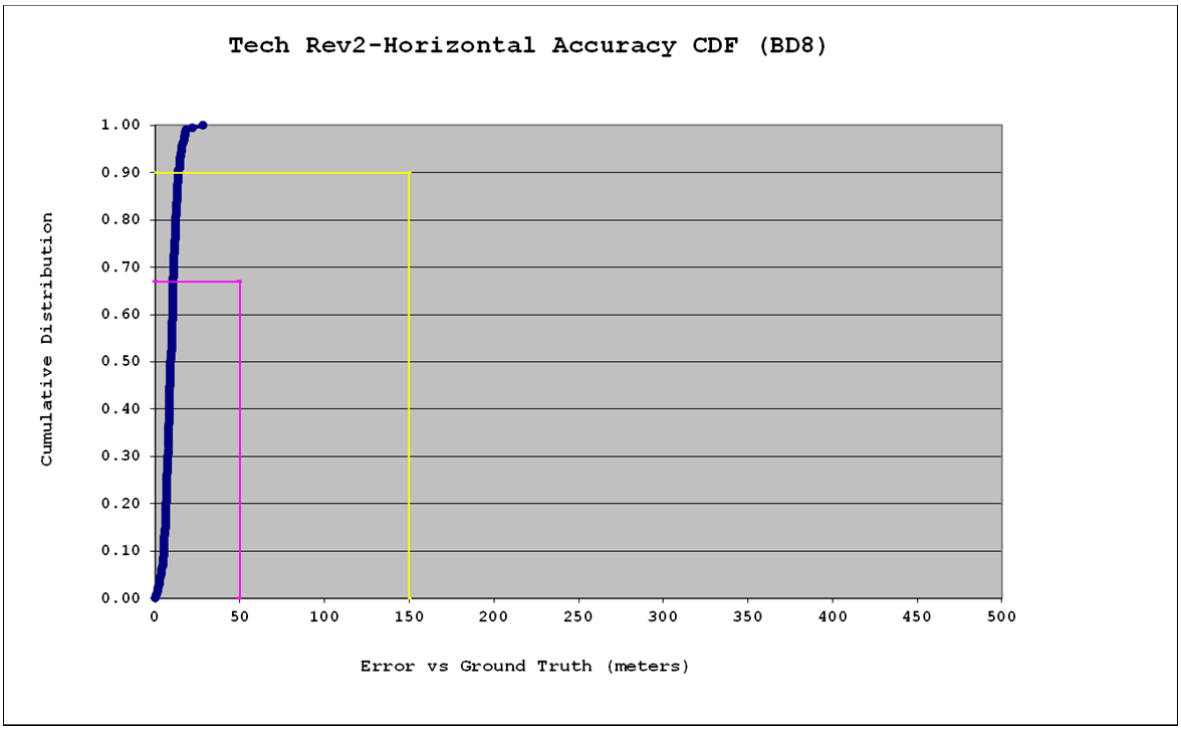
Tighter location fix clusters that are generally closer to the actual test points are observed relative to prior testing in this building as well. Some test points still show some offset behavior due to reflection from nearby large structures, although with position fix clusters that are now closer to the actual test points.



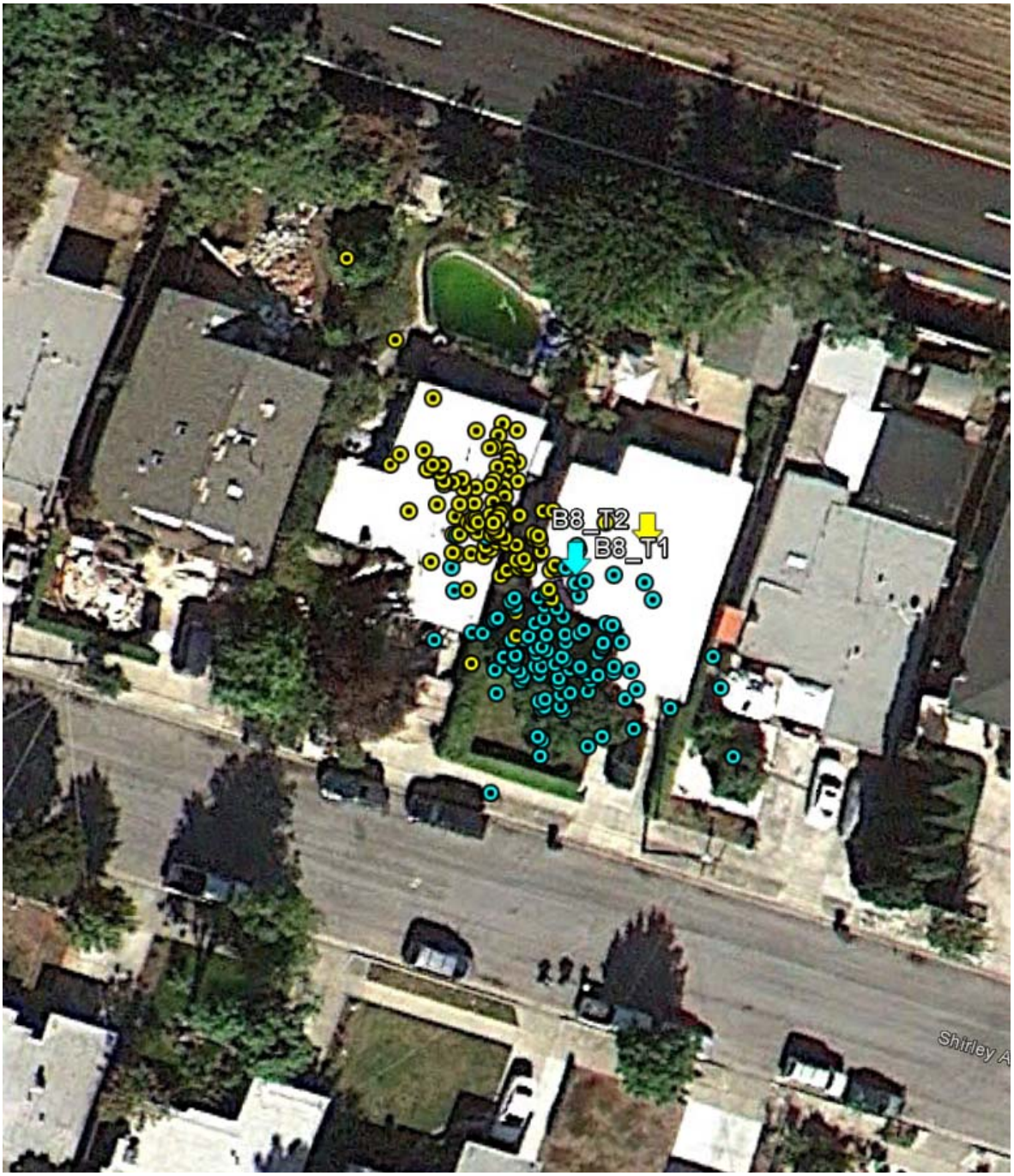
Bldg. 7 Scatter Plot

7.3.3 Bldg. 8: Single Family Home, Sunnyvale

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
8	1	NextNav Technology Rev-2	100	8.6	11.9	12.9	7.8	3.1	17.8	0.83
	2	NextNav Technology Rev-2	100	12.4	15.5	16.8	11.6	3.5	28.5	2.92
	Aggregate	NextNav Technology Rev-2	200	10.9	14.0	15.9	9.7	3.8	28.5	0.83



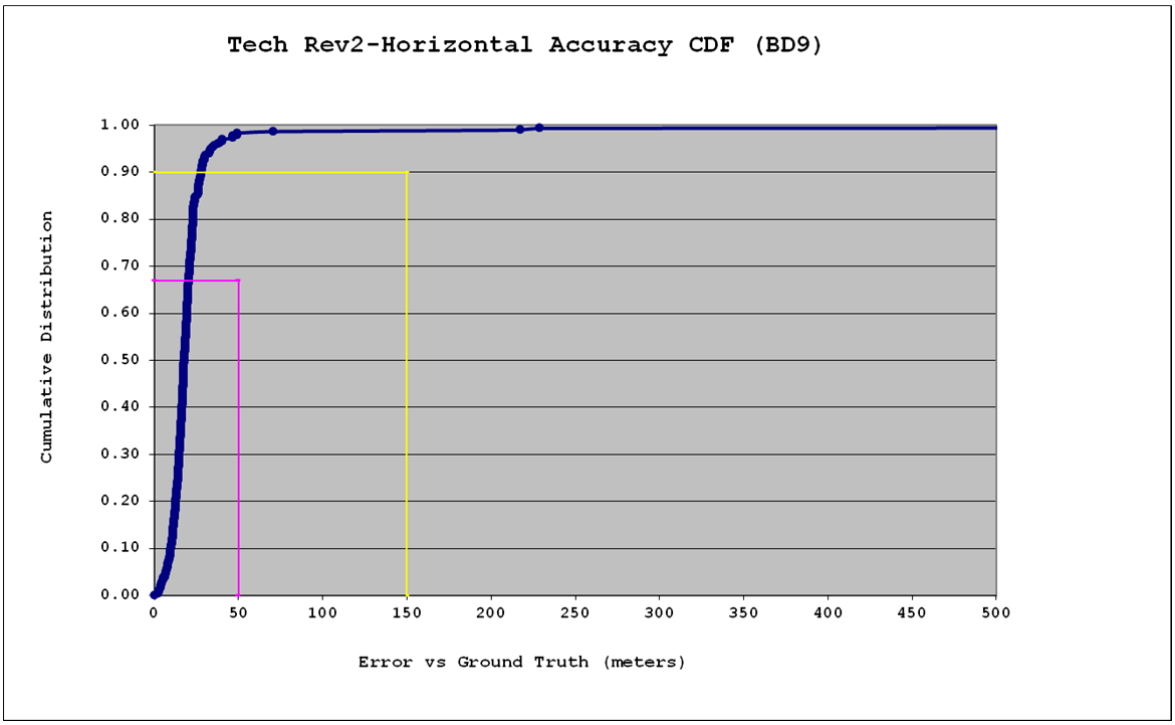
Very good error distance performance is observed in this small suburban house. Unfortunately, due to the small size of the house and its lot, some indicated position fixes fall in the house next door even though they are only 15 – 20 meters from the actual location.



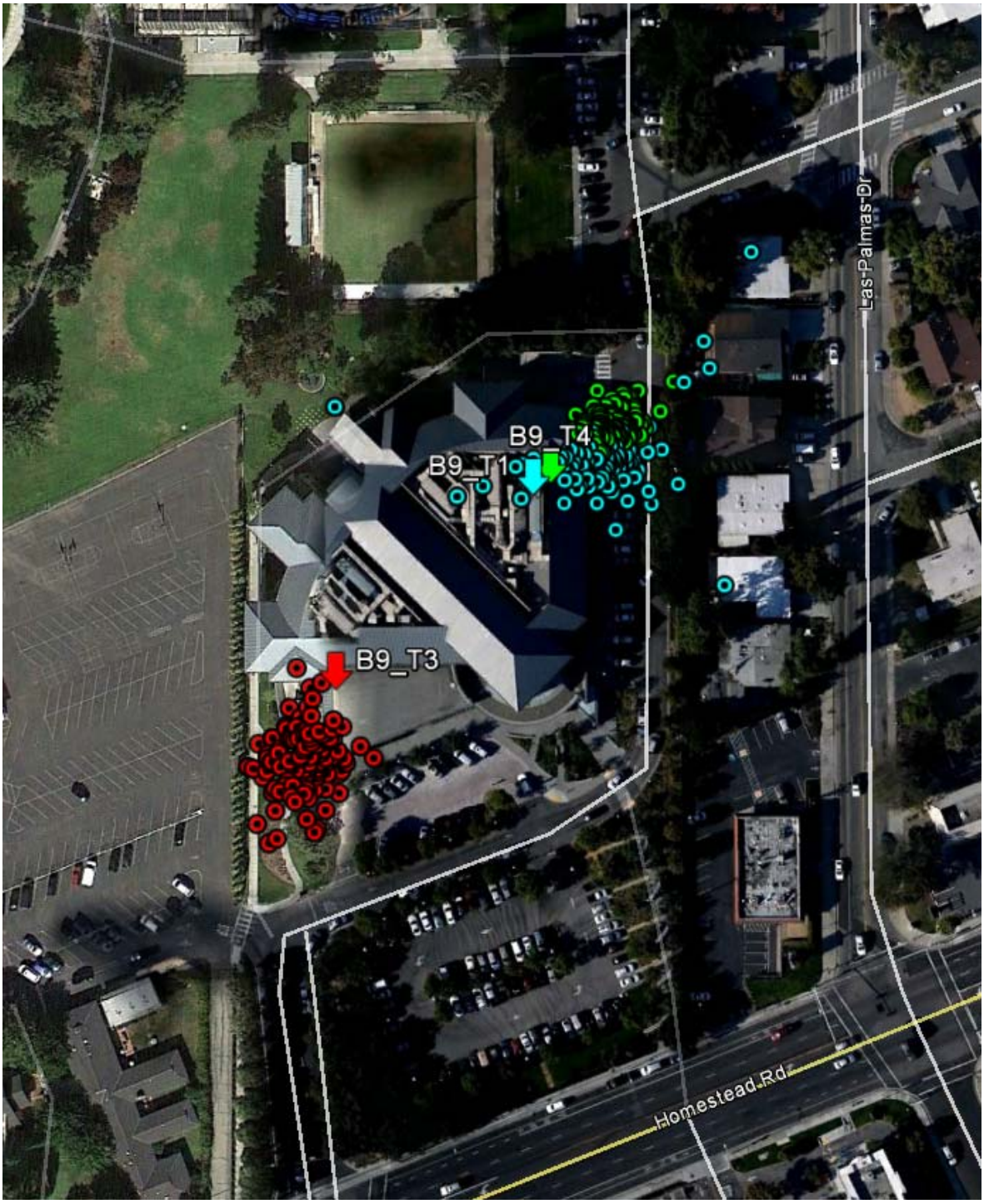
Bldg. 8 Scatter Plot

7.3.4 Bldg. 9: City Library, Santa Clara

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
9	1	NextNav Technology Rev-2	98	19.8	35.0	52.5	66.2	324.5	2853.6	2.29
	3	NextNav Technology Rev-2	100	23.3	29.2	33.4	21.1	7.0	40.5	3.67
	4	NextNav Technology Rev-2	100	19.0	22.6	23.2	17.0	4.5	33.7	6.84
	Aggregate	NextNav Technology Rev-2	298	20.5	28.0	33.9	34.6	186.8	2853.6	2.29



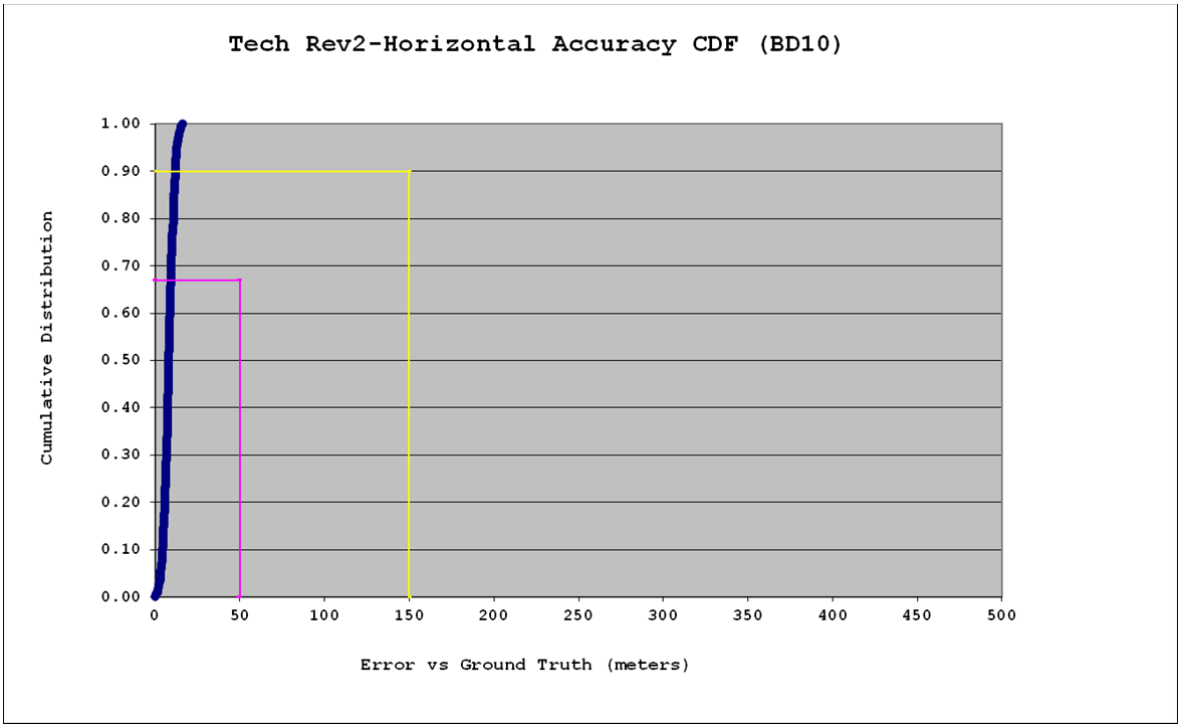
Good positioning performance, which is also significantly improved relative to prior testing during CSRIC Fall 2012 testing, is observed in this larger suburban library building.



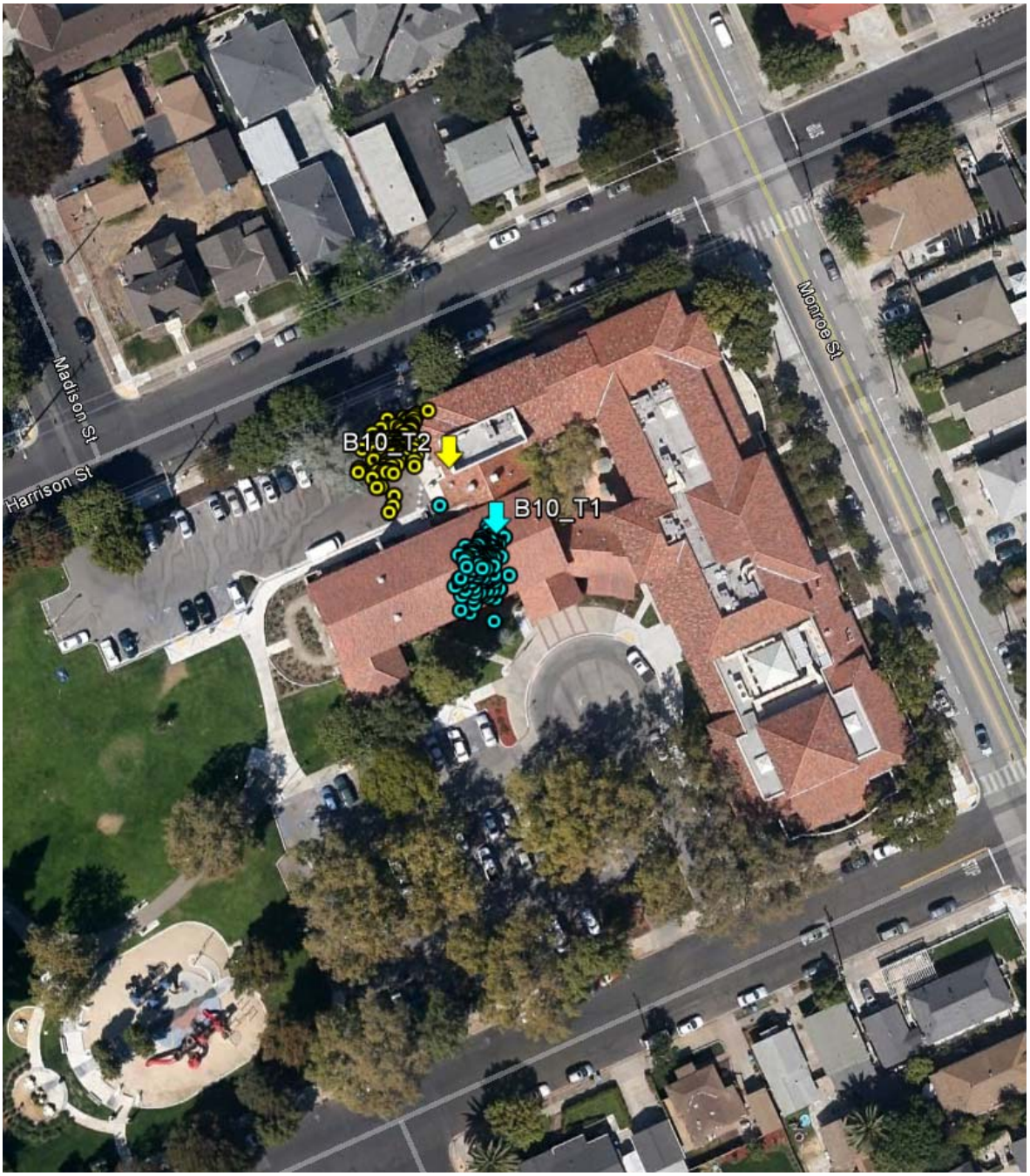
Bldg. 9 Scatter Plot

7.3.5 Bldg. 10: Senior Center, Santa Clara

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
10	1	NextNav Technology Rev-2	100	9.3	12.1	13.0	7.7	3.4	16.3	0.87
	2	NextNav Technology Rev-2	100	9.5	12.0	12.7	9.0	2.2	14.7	4.70
	Aggregate	NextNav Technology Rev-2	200	9.4	12.1	13.0	8.3	2.9	16.3	0.87



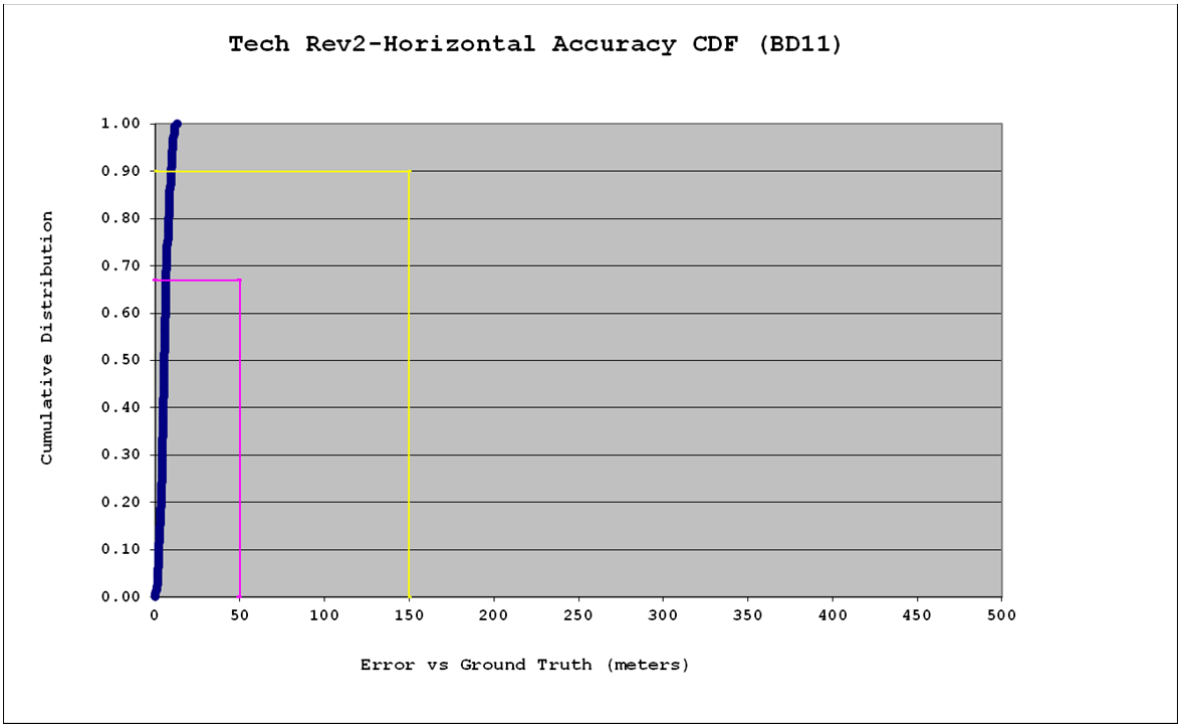
Excellent location performance is seen in this mixed stucco and masonry structure housing the senior center of the City of Santa Clara.



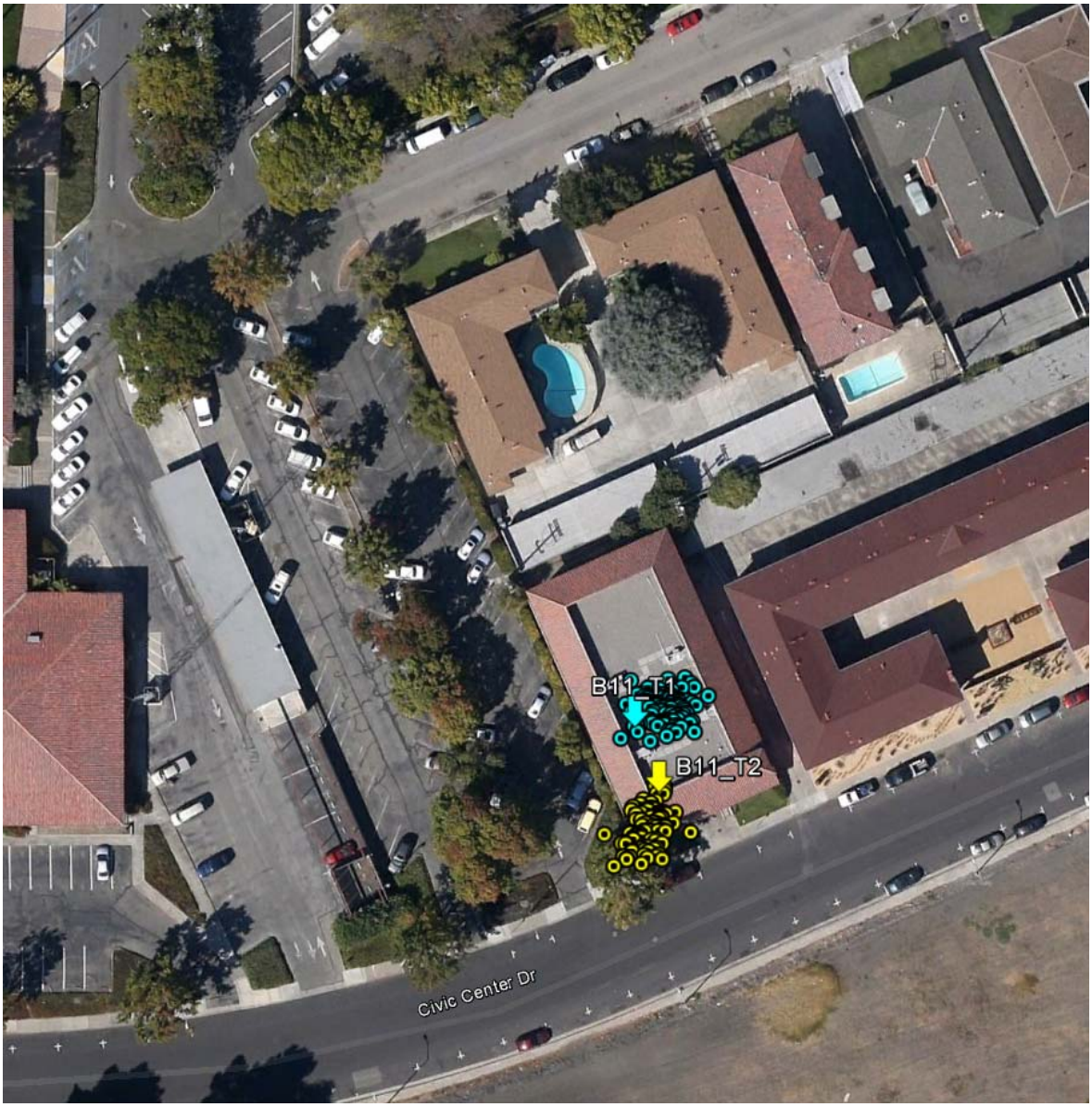
Bldg. 10 Scatter Plot

7.3.6 Bldg. 11: 2-Story Converted Apartment Building, Santa Clara

Horizontal Positioning Error Statistics (m)										
Bldg	Test Point	Technology	Total Number of Calls	67th Percentile	90th Percentile	95th Percentile	Average Error	Standard Deviation	Max Error	Min Error
11	1	NextNav Technology Rev-2	100	5.8	7.2	8.3	4.8	2.0	10.2	0.34
	2	NextNav Technology Rev-2	89	8.4	10.5	11.4	7.2	2.7	13.2	1.13
	Aggregate	NextNav Technology Rev-2	189	6.7	9.8	10.5	5.9	2.6	13.2	0.34



Excellent positioning performance is also seen in this smaller, lightly constructed, 2-story stucco apartment building converted to administration use for the City of Santa Clara.



Bldg. 11 Scatter Plot

8 Summary Observations and Conclusions

Detailed analytical observations on the performance of the NextNav Technology Rev-2 system have been provided with each test building above in Section 7. This section only provides a broad summary of the findings taking into consideration all of the results.

TechnoCom tested NextNav technology Rev-2 at the same test points it tested NextNav's Technology Rev-1 and two other vendor technologies during the CSRIC indoor test campaign in the fall of 2012. The success in securing the same test points enables a very good comparison that reveals the extent and nature of performance improvements achieved with Rev-2 and the isolated occasions of performance degradation. The wide sample of buildings across the dense urban, urban, and suburban environments yields consistent results that shed clear light on how the NextNav Rev-2 system performs, including its strengths and natural limitations.

Clear accuracy performance improvement compared to Rev-1, with lower horizontal positioning errors, tighter positioning clusters for the test calls, and fewer outliers are experienced in a large majority of the test points. Only few test points show relatively weak performance, and unfortunately dilute the apparent improvement in the aggregate statistics. Overall performance improvement is still seen across all three morphologies as seen in Table 8-1 and illustrated in Figures 8-1, 8-2 and 8-3 providing the comparative CDFs for each morphology.

Table 8-1. Summary Horizontal Accuracy Statistics for NextNav Technology Rev-2 and Rev-1

Location Error Statistics (meters)				
Morphology	NextNav Technology	67th Percentile	90th Percentile	95th Percentile
Dense Urban	Rev-2 (June-July 2013)	45.4	81.2	144.7
	Rev-1 (CSRIC Fall 2012)	57.1	102.4	154.0
Urban	Rev-2 (June-July 2013)	47.3	137.0	196.8
	Rev-1 (CSRIC Fall 2012)	62.8	141.1	196.1
Suburban	Rev-2 (June-July 2013)	17.5	33.0	43.8
	Rev-1 (CSRIC Fall 2012)	28.6	52.9	62.2

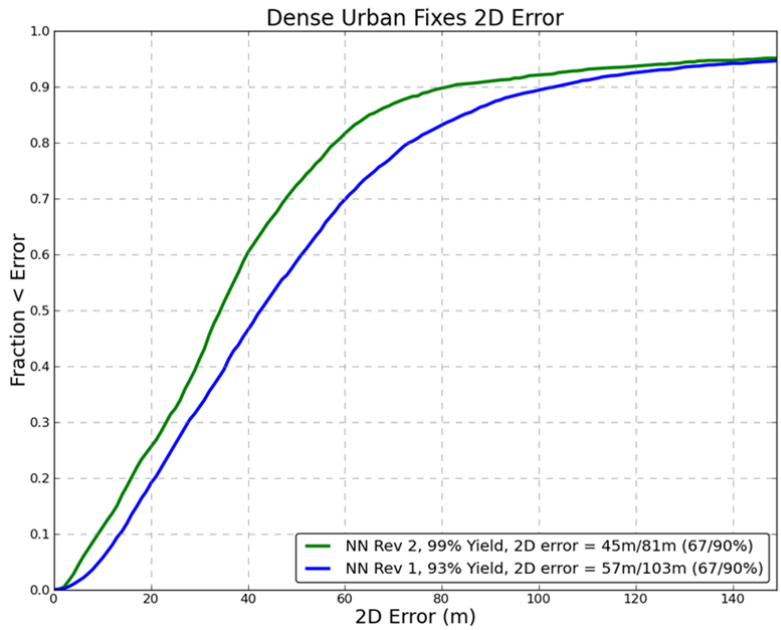


Figure 8-1. NextNav Technology Rev-2 and Rev-1 CDFs for Dense Urban Morphology

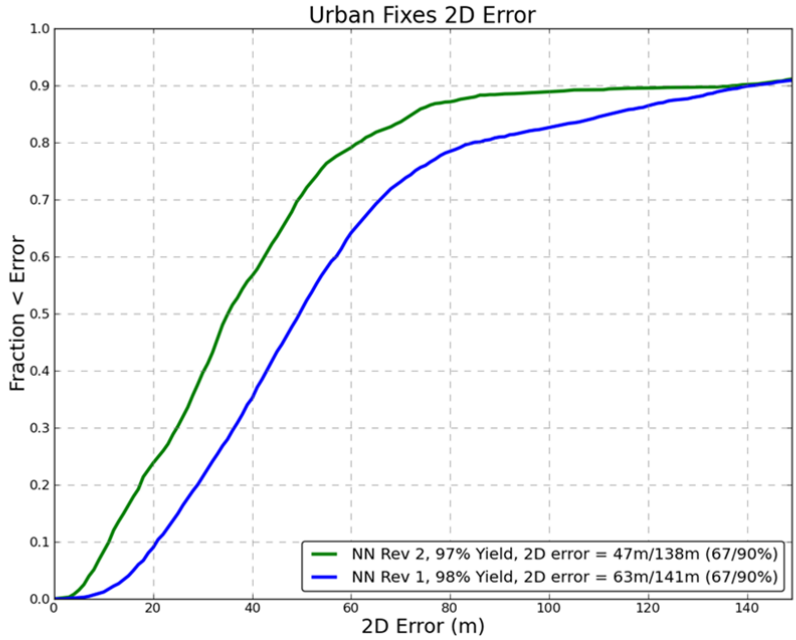


Figure 8-2. NextNav Technology Rev-2 and Rev-1 CDFs for Urban Morphology

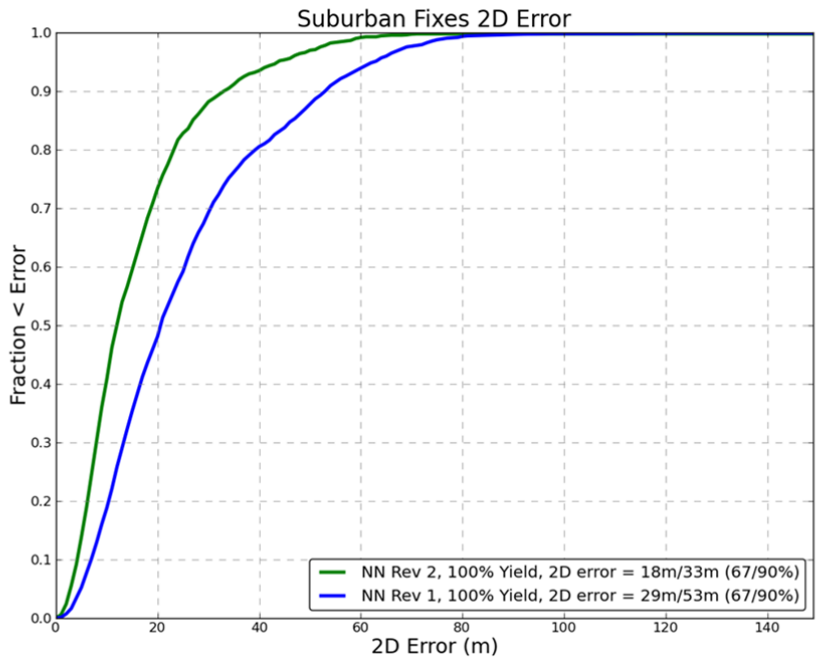


Figure 8-3. NextNav Technology Rev-2 and Rev-1 CDFs for Suburban Morphology

The overall results of the current testing show a reassuring consistency. One can term the general observed performance as "classical" for a wide area beacon location system. For a given building, especially larger ones or ones in heavy clutter, the accuracy is inversely proportional to the depth of the test point inside the test building and its surrounding clutter. Observed performance is consistently better in outside rooms compared to inside rooms, higher floors than lower floors, and is weakest in floors below street level, as one would expect. Deep indoor points in large structures in urban and dense urban environments create high levels of signal attenuation from the outside world together with

the usual signal scattering. These scenarios with challenging signal penetration are the ones where the natural limitations of the NextNav Technology Rev-2 system are manifested.

Location yield was an excellent 99% in the dense urban environment and 99.9% in the suburban environment. It was 97.3% in the urban environment impacted primarily by one particularly deep indoor test point, several meters below street level on the convention floor of the Moscone Center. A comparison of the yield achieved with Technology Rev-2 and Rev-1 (during the CSRIC testing in Fall 2012) is shown in Table 8-2.

Table 8-2. Summary Yield Statistics for NextNav Technology Rev-2 and Rev-1

Yield Statistics (in %)		
Morphology	**NextNav Technology**	**Yield**
Dense Urban	Rev2 (June-July 2013)	99%
	Rev1 (CSRIC Fall 2012)	93.90%
Urban	Rev2 (June-July 2013)	97.30%
	Rev1 (CSRIC Fall 2012)	95.40%
Suburban	Rev2 (June-July 2013)	99.90%
	Rev1 (CSRIC Fall 2012)	100%

One of the phenomena identified during the CSRIC testing in the fall of 2012 was the offset of some of the location fixes to a building across the street or across an open space. This is a manifestation of inescapable indoor multipath scenarios in big buildings where signals can only travel through a window and bounce off a building surface across a street or space. This phenomenon continued to be observed in the current testing but was clearly less severe with Rev-2.

Improvement in altitude accuracy performance relative to Technology Rev-1 results during the CSRIC testing was also observed, with errors well within one floor most of the time. A comparison of the vertical accuracy achieved with NextNav's Technology Rev-2 and Rev-1 (during the CSRIC testing) is shown in Table 8-3.

Table 8-3. Vertical Accuracy Statistics for NextNav Technology Rev-2 and Rev-1

Vertical Accuracy Statistics (in m)				
Morphology	**NextNav Technology**	**67%**	**90%**	**95%**
		Percentile	**Percentile**	**Percentile**
Dense Urban	Rev2 (June-July 2013)	2.3	4.5	5.1
	Rev1 (CSRIC Fall 2012)	2.9	4	5.6
Urban	Rev2 (June-July 2013)	1.8	2.7	3.2
	Rev1 (CSRIC Fall 2012)	1.9	2.8	3.2
Suburban	Rev2 (June-July 2013)	1.5	2.9	3.4
	Rev1 (CSRIC Fall 2012)	4.6	5.5	5.8

Time to first fix results were consistent averaging between 17 and 20 seconds across the three tested morphologies. Maximum duration from location transaction initiation until location result delivery to data log was always under thirty seconds. The TTFF statistics are summarized for Technology Rev-2 and Rev-1 in Table 8.4. (It should be noted however that during the CSRIC testing the "call duration" was set by design to be around 27 seconds.)

Table 8-4. TTFF Statistics for NextNav Technology Rev-2 and Rev-1

TTFF Statistics (in secs)					
Morphology	NextNav Technology	Average Duration	Standard Deviation	Max Duration	Min Duration
Dense Urban	Rev2 (June-July 2013)	17.6	3.47	28.65	13.55
	Rev1 (CSRIC Fall 2012)	27.36	0.61	32.98	8.35
Urban	Rev2 (June-July 2013)	17.36	3.15	27.63	12.67
	Rev1 (CSRIC Fall 2012)	27.4	0.48	32.59	14.61
Suburban	Rev2 (June-July 2013)	19.34	3.58	27.34	13.95
	Rev1 (CSRIC Fall 2012)	27.39	0.52	32.67	12.35

Reported uncertainty values by the location systems were often well behaved given the difficult indoor environment, being close to the target 90% or higher (for measured error < uncertainty) in 12 of the 17 buildings. Least reliability in the reported uncertainty was observed in the urban environment, where the most challenged accuracy performance was also encountered.

The results of this independent testing and analysis provide valuable information for the FCC in its assessment of indoor location for E911. This testing represents a significant milestone along the challenging path towards attaining the best and most practical indoor location. It is hoped that the FCC will continue to stimulate this path of development to achieve the highest public safety in the twenty first century leveraging the now ubiquitous mobile technologies.