



ATIS-0500038

ATIS Standard on -

Recommendations for Extensions to Indoor Test Methodology



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Recommendations for Extensions to Indoor Test Methodology

Alliance for Telecommunications Industry Solutions

Approved June 25, 2018

Abstract

This document provides recommendations specific to horizontal accuracy testing within the framework of the 9-1-1 Location Technologies Test Bed. It should be viewed as an extension to ATIS-0500031.v002, *Test Bed and Monitoring Regions Definition and Methodology*.

Foreword

The Alliance for Telecommunications Industry Solutions (ATIS) serves the public through improved understanding between carriers, customers, and manufacturers. The Emergency Service Interconnection Forum (ESIF) provides a forum to facilitate the identification and resolution of technical and/or operational issues related to the interconnection of wireline, wireless, cable, satellites, Internet, and emergency services networks.

The mandatory requirements are designated by the word *shall* and recommendations by the word *should*. Where both a mandatory requirement and a recommendation are specified for the same criterion, the recommendation represents a goal currently identifiable as having distinct compatibility or performance advantages. The word *may* denotes an optional capability that could augment the standard. The standard is fully functional without the incorporation of this optional capability.

Suggestions for improvement of this document are welcome. They should be sent to the Alliance for Telecommunications Industry Solutions, ESIF, 1200 G Street NW, Suite 500, Washington, DC 20005.

At the time of consensus on this document, ESIF, which was responsible for its development, had the following leadership:

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- R. Marshall, ESIF 1st Vice Chair (Comtech)
- J. Green, ESIF 2nd Vice Chair, ESIF ESM Co-Chair (Sprint)
- K. Springer, ESIF ESM Co-Chair (AT&T)

The **Emergency Services & Methodologies (ESM)** Subcommittee was responsible for the development of this document.

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Recommendations for Extensions to Indoor Test Methodology

1 Scope, Purpose, & Application

1.1 Scope

This document provides extensions to the indoor test methodology adopted in ATIS-0500022 (which was based on ATIS-0500013) and subsequently in ATIS-0500031, wherein indoor testing consisted of placing repeated stationary test calls at a handful of accurately surveyed test points inside each test building. The rationale, goals, and principles of the indoor test methodology extensions, as well as the tools required are presented and described with recommendations regarding the application of the methodology extensions to indoor accuracy testing. How the described methodology extensions can supplement existing indoor test methodology is also discussed.

Note that this document focuses exclusively on horizontal accuracy testing. Vertical accuracy testing is addressed in ATIS-0500030.

1.2 Purpose

The purpose of this set of guidelines and recommendations is to provide those engaged in testing the indoor performance of wireless location systems for 9-1-1 with a standardized, practical approach to mitigating some of the shortcomings of the indoor test methodology used so far. That methodology is susceptible to delivering results from samples where the consecutive collocated test calls are not independent due to various factors, including device memory. This situation is becoming more common in a range of newer handsets and technology implementations and can result in loss of statistical independence between successive test calls when testing indoors.

1.3 Application

This document is intended to be applied in future test campaigns undertaken by the 9-1-1 Indoor Location Technologies Test Bed, or independently by wireless carriers or location technology vendors. This applies particularly to test campaigns that focus on latitude, longitude, and possibly altitude, in which the handsets under test are expected to exhibit inter-dependence between consecutive collocated test calls – e.g., devices that implement a flavor of Device Based Hybrid (DBH). DBH refers to a class of User Equipment (UE)-based techniques where a location fix is generated using any combination of available location methods including Global Positioning System (GPS)/Assisted Global Positioning System (AGPS), positioning based on the presence of Wi-Fi and other beacons, and sensor-assisted positioning. This extended methodology is not intended to replace the existing indoor test methodology but rather supplement it.

2 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

[REF 1] ATIS-0500013, *Approaches to Wireless E911 Indoor Location Performance Testing*, February 2010¹

[REF 2] ATIS-0500022, *Test Plan Input for a Location Technology Test Bed*, October 2012²

[REF 3] ATIS-0500030, *Guidelines for Testing Barometric Pressure-Based Z-Axis Solutions*, May 2016³

[REF 4] ATIS-0500031.v002, *Test Bed and Monitoring Regions Definition and Methodology*, February 2017⁴

3 Definitions, Acronyms, & Abbreviations

For a list of common communications terms and definitions, please visit the *ATIS Telecom Glossary*, which is located at < <http://www.atis.org/glossary> >.

3.1 Definitions

Anchor Point: A professionally surveyed position within a test building which can be used to determine ground truth for other test points within the same structure.

Approach #1: An approach defined in this document for substantially increasing test call positional and orientation diversity. This approach calls for substantially increasing the number of specific static locations within each indoor venue where test calls are placed, and fixes are produced, while taking steps to also randomize device orientation and provide motion between test calls.

Approach #2: An approach defined in this document for substantially increasing test call positional and orientation diversity. This approach calls for testing in full pedestrian motion.

Drawing: A drawing or sketch showing the test points that form a set or route which are collected as part of a single session, illustrating information helpful in finding the points and executing the test, implemented electronically using test tooling.

Ground Truth: Knowledge of the true position of a point in space at a specific point in time, expressed as a geodetic latitude/longitude/height relative to geoid (e.g., Geoid 12B) and above ellipsoid, using the World Geodetic System (WGS)-84 datum.

Referenceable Object: A tangible object that can be physically viewed and identified by a tester in the field, used to find nearby test points.

Test Call: One mobile device call, typically to a special test number which triggers a simulated E9-1-1 call flow, which produces one or more location fixes.

Test Point: A point in space within a test building where test calls will be made for the purpose of assessing accuracy performance.

Test Point Set: A set of test points, each with known ground truth, typically on a single floor, where test calls are made as a single set as part of a single testing session.

Test Point Set File: A Test Point Set File is a means of conveying from one test tool to another the points to be tested in a given session.

Test Route: A ordered set of test points (known as waypoints or corner points), each with known ground truth, typically on a single floor, used in full-motion pedestrian testing (Approach #2).

¹ This document is available from the Alliance for Telecommunications Industry Solutions (ATIS).
< <https://www.atis.org/docstore/product.aspx?id=25009> >

² This document is available from the Alliance for Telecommunications Industry Solutions (ATIS).
< <https://www.atis.org/docstore/product.aspx?id=27856> >

³ This document is available from the Alliance for Telecommunications Industry Solutions (ATIS).
< <https://www.atis.org/docstore/product.aspx?id=28274> >

⁴ This document is available from the Alliance for Telecommunications Industry Solutions (ATIS).
< <https://www.atis.org/docstore/product.aspx?id=28279> >

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Time of Applicability: The time at which each individual location fix is deemed to be valid, as determined by the underlying positioning technology.

Tool Feature: A logical set of tooling functionality. In this document, tooling requirements are broken out by tool feature so that related requirements are grouped together.

UE-Based: Refers to positions calculated in the mobile (the 'User Equipment'), typically based on assistance information provided by a Location Server.

Waypoint: The corner positions used to form a test route.

3.2 Acronyms & Abbreviations

AGPS	Assisted Global Positioning System
ATIS	Alliance for Telecommunications Industry Solutions
CAD	Computer Aided Design
CEP68	Circular Error Probable at the 68 th percentile
CSRIC	Communications Security, Reliability and Interoperability Council
DBH	Device Based Hybrid
E9-1-1	Enhanced 9-1-1
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
OS	Operating System
PDF	Portable Document Format
UE	User Equipment
UAV	Unmanned Aerial Vehicle
UTC	Coordinated Universal Time
WGS	World Geodetic System

4 Description of the Problem

A wide range of handsets and technologies have been tested over the last two years in the 9-1-1 Location Technologies Test Bed. The Test Bed adopted the indoor test methodology developed within ATIS and described initially in ATIS-0500013, subsequently tailored to Communications Security, Reliability and Interoperability Council (CSRIC) III in ATIS-0500022, and finally described in the context of the Test Bed in ATIS-0500031. A cornerstone of this indoor test methodology has been the use of a limited number of static test points, each professionally surveyed for ground truth, where repeated, sequential test calls are placed. The cost of accurate ground truth surveys limits the practical number of precisely surveyed (e.g., +/- 5 cm) indoor test points in a building to generally between three and six, depending on building size.

The goal of this indoor testing is to emulate and accurately reflect the behavior of many callers, each placing a single call from widely dispersed points throughout a building. However, using 50 or 100 handsets, each placing a single call at a unique location, is obviously impractical. Current indoor test methodologies have been using a much smaller number of test devices, each placing numerous sequential calls from a handful of test locations. While this approach adequately captures the performance of Global Navigation Satellite System (GNSS)/GPS technologies, it has limitations when assessing performance of new technologies like DBH.

DBH refers to a class of UE-based positioning techniques, where a location fix is generated using any combination of available location methods including GPS/AGPS, positioning based on the presence of terrestrial beacons (cellular, Wi-Fi, Bluetooth, etc.), and sensor-assisted positioning. To date, the most commonly encountered beacon type in DBH positioning has been Wi-Fi. Examination of the results in the Test Bed indicated that handsets utilizing

DBH-type technologies exhibited clear interdependence between groups of collocated stationary test calls. One example is the presence of identical position fixes in groups of consecutive test calls. Another is a minor variation in positioning error of groups of calls clustered around a few discrete values. These phenomena are illustrated in Figure 4.1.

This interdependence occurs in beacon-based technologies because beacon receive conditions tend to be quite consistent at any specific static test location with a static device orientation, thus the calculated position is highly correlated to the immediate physical environment. At the same time, accuracy performance at one physical indoor location may differ greatly from the performance at a different specific location just a few meters away, or with a different device orientation. Additionally, mobile devices equipped with sensors can freeze or constrict the reported positions if no motion is detected. The result is that the same position, or only slightly changed positions, can be reported over and over until the device is moved, as seen in Figure 4.1.

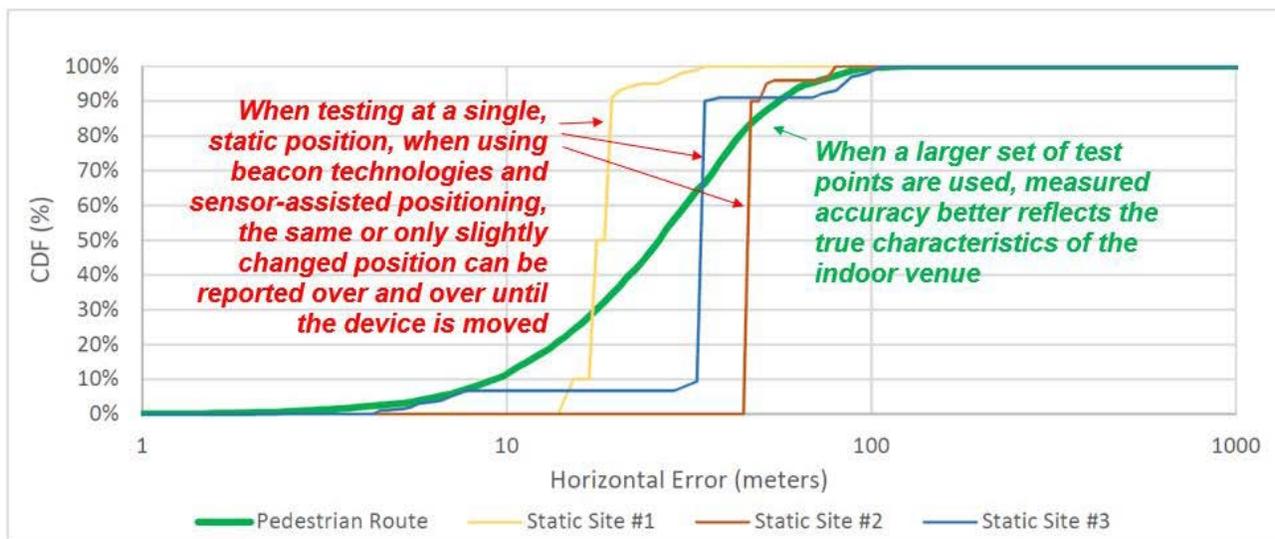


Figure 4.1 – Example Showing Benefit of a Larger Number of Indoor Test Points

In an attempt to mitigate this phenomenon, a modification to the test methodology was adopted wherein the test calls at each test point are segmented into groups of 10 calls. At the end of each call group, the test devices are power cycled then moved to a subsequent test point in the building. The testers eventually return to the original test point to gather another group of 10 test calls, and the cycle is repeated until all required test calls in the building are gathered. As part of a logistical simplification for this method, it was deemed acceptable to reduce the total number of test calls from each device to 50 at each test point. This change from 100 to 50 test calls was justifiable given the relative statistical stability of the majority of the test results observed and the use of multiple test devices per test participant.

However, even with this methodology modification, devices using DBH-type technologies are exhibiting positioning result repetition and interdependence within each group of 10 test calls. This was often observed after only two or three calls in each 10-test call group. Alternative ways to efficiently gather data from many more points within a structure are therefore needed.

5 Goals of the Methodology Extensions

As can be gleaned from the discussion in Clause 4 above, the indoor test methodology represents a tradeoff between cost and logistical complexity on one hand and reliability of the indoor accuracy results on the other. The goal here is to define and recommend practical testing solutions that represent a good balance between those competing constraints.

Real world constraints of indoor testing in buildings of opportunity must also be taken into consideration. It cannot be assumed that the testers have ownership rights to the test buildings. Testing is often performed using a cart with

over 10 active test handsets, backup batteries, a laptop, and possibly other instrumentation. Test operation that interferes with the normal function of the building or its occupants must be avoided. For example, marking the interior of a building, to note the positions of test points along select hallways, is generally not allowed. Likewise, a lengthy presence of testing and survey crews, causing any kind of commotion, or any kind of high-profile presence also needs to be avoided.

Additionally, any recommended methodology must not be so overly complex that it cannot be followed faithfully and repeated without error by field technicians under limited supervision from an experienced wireless engineer. Furthermore, any tools required to follow the steps of the methodology must be attainable without large cost or major acquisition challenges.

The goals of the test methodology extensions described in the following clauses are to achieve the desired statistical reliability while taking into account these real-world constraints and to create a practical indoor testing approach that can be used in conjunction with the existing test methodology in upcoming test campaigns in the Test Bed and by others who need to perform such testing.

6 Approaches

For the reasons explained above, an indoor testing methodology that produces more independent fixes is desired, so that testing better emulates and measures the behavior of many callers making individual 9-1-1 calls from diverse locations throughout each indoor venue. This must be achieved efficiently and in a logistically feasible way that provides the largest quantity of valid field test data with the least amount of effort and cost. This clause summarizes two basic approaches that can achieve these goals, analyzes the pros and cons of each approach, and defines the requirements for each approach.

6.1 Approaches to Achieve Increased Positional Diversity, Orientation Diversity, & Motion

Fundamentally needed are more test call positional and orientation diversity and motion between the test calls. Two basic test enhancement approaches are possible:

1. Substantially increase the number of specific static locations within each indoor venue where test calls are placed, and fixes are produced, while taking steps to also randomize device orientation and provide motion between test calls.
2. Test in full motion (at indoor pedestrian speed), where the devices are in constant motion as test calls are placed and location fixes are produced.

Both approaches achieve motion, positional diversity, and orientation diversity, but there are a number of advantages and disadvantages to each approach, as summarized in Table 6.1.

Table 6.1 – Advantages & Disadvantages of Each Test Enhancement Approach

	Advantages	Disadvantages
1. Substantially Increased Number of Static Test Locations	<ul style="list-style-type: none"> • Provides improved positional and orientation diversity, without greatly changing current testing processes or practices. • Existing static and highly accurate approaches for comparing position fix results to ground truth can still be used. • Easier to implement with a larger number of test devices, using existing cart-based field testing methods. 	<ul style="list-style-type: none"> • Not as much positional and orientation diversity as a pedestrian motion approach. • Not as much complex motion (to ensure a high degree of test call independence).

	Advantages	Disadvantages
	<ul style="list-style-type: none"> • Fewer tooling changes needed. 	
2. Test in Full Motion (at indoor pedestrian speed)	<ul style="list-style-type: none"> • Maximum amount of positional and orientation diversity. • More motion and more complex motion as fixes are generated to ensure a high level of representative diversity and independence of test calls. 	<ul style="list-style-type: none"> • Requires sophisticated new tooling to determine ground truth position while in motion. Ground truth must remain highly accurate to maintain trust in established performance results. • Precise 'time of applicability' – the exact time when the fix is considered valid – must be available, in order to accurately determine ground truth. This time is not currently available in the logs of some devices and some location technologies. • Difficult to implement full pedestrian motion with a fairly large number of test devices using existing cart-based field testing methods. • May pose logistical challenges during test execution (e.g., may restrict testing to after business hours or may limit suitable business locations).

The second approach achieves greater positional and orientation diversity and more complex motion, thus the samples are more independent, but it requires more changes to current testing practices and more tooling development to implement. While a full pedestrian-type motion approach may be a longer-term goal, it is clear that increasing the number of test sites is a more achievable approach in the short-term.

6.2 Approach #1: Substantially Increased Number of Static Test Locations

Described here is an enhancement to the current indoor testing approach, which significantly increases the number of static test locations, enables orientation diversity, and provides for motion between test fixes with the goal of producing more independent fixes. The essential elements of this test methodology enhancement are summarized as follows:

- Substantially more test points are used within each indoor venue, with many fewer test calls made from each point.
- Test points are positioned at regular intervals along enclosed 'routes'. This serves two purposes:
 - Ground truth for the test points is less expensive to obtain, for the reasons defined in Clause 6.2.6.
 - Field test personnel can rapidly move from test point to test point, lessening time and cost of test execution.
- To increase the amount of motion between fixes, the tester does not move to the next test point, but rather skips one or more test points with each move, then repeats the loop additional times picking up the missed test points.
- Orientation is also randomized as the tester moves from to test point to test point.

This approach is illustrated in Figure 6.1. One or a small number of test calls are placed from each device at each test point before moving on to the next point. The tester then skips forward one or more test points with each move, in order to increase the amount of motion and displacement between test calls. Once the loop (or semi-loop or branch) is completed, the route is then repeated as many times as is necessary to gather data at each test point. Criteria for determining the number of test calls to place from each point are provided in Clause 6.2.4.

While the loops may have diversions to facilitate site diversity and better characterize the wireless environment within each building, the tester can move rapidly from point to point by organizing the points in a loop, when possible, thus reducing the time needed to collect the data. If an incomplete loop or a branch is the feasible “route” on a

certain floor, then the tester may have to double back or move from near one end of the route to near its beginning on the floor to capture the test points that have been missed. Testing consecutively at adjacent test points should be avoided.

Arranging a subset of the test points in a loop also facilitates less expensive ground truth determination, as further explained in Clause 6.2.6. It is possible to add some branches to the loop illustrated in Figure 6.1 to include exterior (e.g., window office) test points in the overall mix of test points. It is also possible to include branches that cross the deep interior of the floor for a good overall representation of the wireless environment. The selected path should be feasible, practical, and representative.

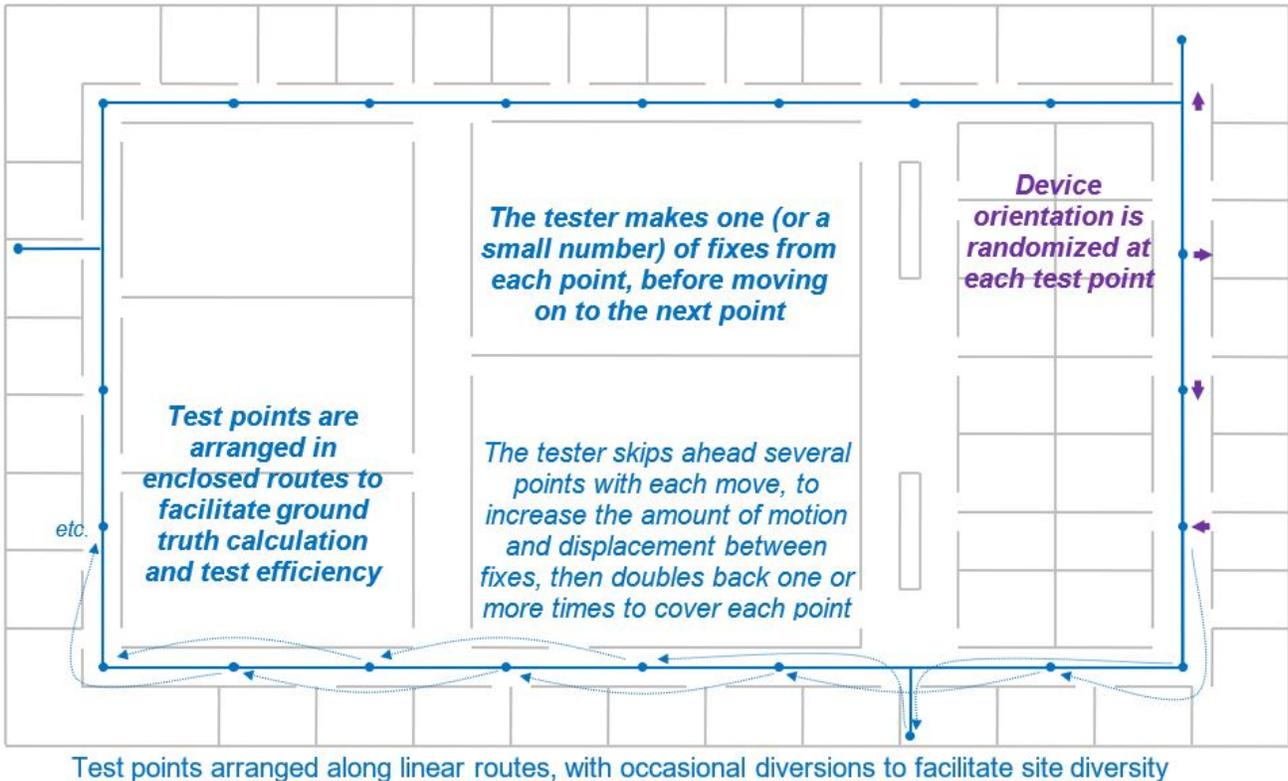


Figure 6.1 – Illustration of Approach #1: Increased Number of Static Test Locations

6.2.1 Test Point Spacing

The test points should be spaced no closer than three meters apart to reduce position fix correlation caused by physical proximity when beacon-based indoor location technologies are used.

6.2.2 Orientation Randomization

Randomizing the orientation of the test mobile devices at each test point further reduces fix correlation caused by physical proximity. Thus, the physical orientation of the test devices should be changed with each site move, as illustrated in Figure 6.1.

6.2.3 Desired Number of Test Points

The number of test points along a route will be driven largely by the physical characteristics of each building used in testing, and thus cannot (and need not) be concretely prescribed. As a general rule, buildings should be chosen to allow for sufficient routes so that their overall placement and the test points along them provide a good overall representation of the building under test and the environments within it. The overall number of routes and test points

will necessarily vary by the size, height, and type of building. For a large, commercial high rise, e.g., in an urban or dense urban setting, it is desirable to choose points on five or six different floors at different zones along the height of the building, e.g., bottom floor, mid-lower floor, middle of building height, mid-upper floor, and among the upper floors. Each such test floor could possibly have eight to ten test points for a total number of 50 test points in the building. For a medium-sized building, the number of floors could be three or four, with seven to ten or even 12 test points each, depending on the footprint and the space available for access in each floor inside the building. (A commercial mid-rise is likely to have a different footprint from a four-story apartment building.) The desired number of test points would be in the 25 to 40 range. For small buildings, testing may be on two to three floors and as few as four test points maybe feasible in a small floor plan, resulting in as few as eight to 12 test points in a particularly small, suburban, or rural building – e.g., a single-family home or a two-story standalone small business.

6.2.4 Number of Test Calls

With the traditional indoor test methodology, between 100 and 300 calls per test device are placed from a few stationary, precisely surveyed test points in each building, depending on the size of the building. The performance from those test calls is then aggregated per morphology. From a statistical standpoint, if the individual test call attempts in a building are largely independent and the sample of calls is sufficiently large, then as discussed in Annex B, via Normal approximations, a sample of 68 test calls would conservatively determine the proportion of positioning error (in the building) relative to a 50 m threshold, estimated to within ten percent at a 90% confidence⁵.

This sample size applies in the most conservative scenario where, as in a big urban or dense urban building, the probability of the positioning error is not known beforehand and could either be within or beyond 50 m with more or less equal likelihood. This is the case where the sample size is determined with the least a priori knowledge about positioning performance and results in the largest minimum number of test calls required in the test sample.

In the case of a smaller, less challenging suburban building, it is more likely that the probability that the positioning error is within 50 meters is closer to 80%. In that case, per the analysis in Annex B, the minimum required test sample is 44 calls. The analysis could be similarly applied to derive the sample size for any likelihood between 50/50 and 80/20. However, due to limitations in applying the normal distribution (also explained in Annex B), smaller samples would not be reliable and cannot be relied upon with confidence in extreme cases, e.g., when we are 90 or 95% sure that the positioning error is within 50 m.

Accordingly, as a rule of thumb, minimum test call sample sizes would be between 68 and 44 per building, with more conservative samples ranging between 50 to 150 test calls. The larger the sample the smaller the confidence interval or the higher the precision (better than ten percent) in estimating p , the proportion of calls with location errors within 50m. (Note that a 1:3 range in sample sizes is similar to the mix used across buildings in the traditional, repeated test call per point methodology.)

Since for each test participant multiple handsets are almost always used in a test campaign, typically three or four test handsets and one cycle through the approximately 50 test points in a large building would be adequate to collect the required sample using one call per handset per test point. This approach also ensures a high degree of test call independence. The same applies for a mid-sized building with say 25 test points. One cycle with four test handsets and one call per handset per test point would suffice. For smaller and less challenging buildings, one or two cycles through the roughly eight to 12 test points would suffice with three to four test handsets and one test call from each handset per visit to a test point.

6.2.5 Motion Between Test Points

To reduce fix correlation caused by sensor-assisted positioning, the motion between test points should not be perfectly smooth, as to better simulate real user behavior. Changes in acceleration and orientation, as would naturally occur as test devices are physically repositioned, are encouraged.

Frequent movement between test points can result in ambiguity during post processing of the data collected in the field unless an effective, automated mechanism exists to track where the test calls have been placed. Such a mechanism ensures that the correct ground truth is correlated with the test calls placed at each specific test point.

⁵ From confidence intervals for proportions, see Annex B.

Primary reliance on test technician logs is not recommended and is not reliable in situations where movement is involved between many test points, as is the case in a typical test building.

Test instrumentation to provide this mechanism is specified and further described in Clause 7.1.1.

6.2.6 Determining Ground Truth for Test Points Along Test Routes

Currently, indoor static test points are professionally surveyed with high accuracy, at a significant cost. With a substantially increased number of static test locations, this will no longer be viable due to the high cost. Thus new, less expensive methods to determine ground truth for the test points along the routes must be developed.

Figure 6.2 illustrates a way to produce less expensive ground truth for points along linear routes. Since distance can be measured quite accurately along an indoor route, and since building orientation (and from it hallway orientation) can be determined accurately using overhead imagery, it is possible to leverage a small number of very high quality professionally surveyed “anchor points” to determine ground truth for all other test points along a route.

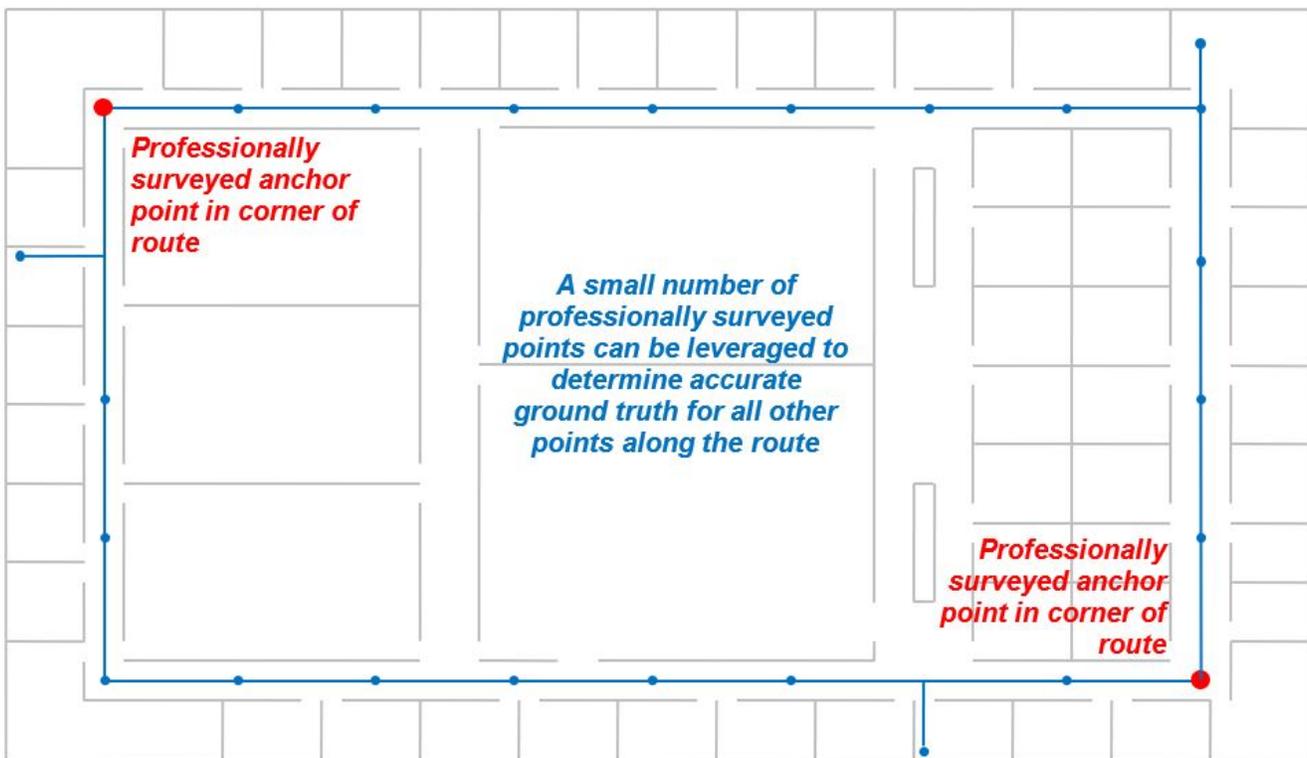


Figure 6.2 – Approach to Ground Truth Determination for Points Along Route

The professionally surveyed anchor position(s) should be chosen to facilitate the creation of the additional points. As shown in Figure 6.2, surveying two opposite corners of a rectangular route enable optimal utilization of the surveyed positions to produce all other positions.

For the small distances present within structures, simple “flat earth” approximations are sufficiently accurate to determine an unknown position. Several simple ground truth calculation methods based on “flat earth” approximations are illustrated in Annex A.

At a minimum, two anchor point surveys are required for any building. However, the larger the building and the more test point sets or routes contained within it, the more surveys would typically be needed. For example, a minimum of four to six anchor point surveys would be expected for a large building.

Ground truth can also be propagated vertically by leveraging physical features within the structure that are known to be truly vertical, such as elevator shafts, stairwells, and load-bearing columns. In this way, ground truth calculated

on one floor can be propagated to other floors if there is an accurate means of measuring the vertical displacement between floors. A careful measurement using a tape measure in a stairwell may be sufficient for this purpose.

When using the same survey to establish ground truth on multiple floors, the test engineer and his/her surveyors have some flexibility when deciding on which floor to perform the survey. Typically, to reduce effort and cost, the floor most technically feasible for the surveyor (with simpler logistical requirements) is the desired choice.

6.3 Approach #2: Testing with Pedestrian Motion along Predefined Routes

A more comprehensive approach is to place test calls continuously while walking predefined routes. Unlike Approach #1, the location fixes occurring with each test call are made from random locations along the route, with random orientations. Successive fixes are less correlated, thus aggregated results are a better assessment of the overall performance within each building and better reflect real-user behavior.

The challenge with this approach is establishing ground truth at every 'time of applicability' of each individual fix. Time of applicability is produced by the underlying positioning system with each fix and refers to the time at which the fix is deemed to be valid. How time of applicability is determined varies by positioning technology; for example, for Wi-Fi-beacon-based positioning, time of applicability is typically the time when the Wi-Fi scan occurs. Since time of applicability can occur at any point during the execution of the test, a way to produce ground truth at any arbitrary time along the route is needed.

The solution is to create tooling that allows a tester to walk predefined trajectories, as shown in Figure 6.3, capturing the times when the mobile devices depart from and arrive at predetermined, fixed points along the route. These predefined trajectories consist of a series of line segments, separated by fixed, known positions. Ground truth for these fixed positions are first determined using the same methods described in Clause 6.2.6. Using the captured times of arrival and departure and the known positions of the route points, the tool can linearly interpolate between the points to produce a truth position for any arbitrary time during the test, including when paused at one of the route points. Such a tool would need to be implemented on a mobile device, such as a smart phone or tablet, so that the tester can hold the device in his/her hand while walking a predefined route, clicking a button as he/she arrives at, or departs from, each point along the route. Requirements for this tooling are described in Clause 7.1.2.



Figure 6.3 – Test in Pedestrian Motion Along Fixed Routes

6.3.1 Route Length, Duration, & Number of Test Calls

Similar to Approach #1, the number of test points along a route are driven largely by the physical characteristics of each building used in testing, and thus cannot, and need not, be concretely prescribed. But unlike Approach #1, Approach #2 does not have a fixed set of test points, as location fixes can happen at any point along the route.

Never the less, a similar number of test calls as defined in Clause 6.2.4 is still required, and the conditions of these test calls need to be sufficiently diverse. The way to achieve sufficient diversity is for the routes in any building to reflect the conditions present in that building and for the total length of the routes to be sufficient.

One approach to determining the needed total length of the routes in any specific building is to allocate a fixed amount of distance for each needed test point as defined in Clause 6.2.4. Clause 6.2.4 states approximately 50 test points in a large building, 25 test points in a medium building, and eight to 12 test points in a less challenging building (such as a small residential structure) are deemed adequate to collect the required sample, when multiple test devices are used. As a rule of thumb, three meters or more of route can be allocated for each test call to achieve sufficient diversity. Thus, target route lengths should total at least approximately 150 meters in a large building, 75 meters in a medium building, and 24 to 36 meters in a less challenging smaller building consistent with the desired call separation and number of test points.

Like the test points defined in Clause 6.2.4, the routes need to reflect the diverse conditions present in the venue. For example, in multistory buildings, routes should be present on several floors and should encompass both interior and exterior conditions, etc. Note that separate routes for different conditions are not necessarily required. It is perfectly acceptable for a single route to encompass a diverse set of conditions. Note, however, that in a multistory building, a single route would probably not be sufficient, as routes are typically confined to a single floor and it is desirable to perform test calls from a diversity of floors, as discussed in Clause 6.2.3. In an urban or dense urban setting, routes in the different zones along the height of the building are required.

The number of test calls needed for each type of building by each test mobile is defined in Clause 6.2.4. With Approach #2, the tester continuously walks each route as many times as is needed for all mobiles to make at least this many calls. The total time needed for each route is the time required by the slowest mobile device to place and complete a single test call times this target number of calls.

Note that every venue has a different layout and no single route selection strategy will be generally applicable to all buildings. Like static test points, the routes selected must also be logistically viable and not inconvenience the building occupants. Thus, route selection must consider the diversity of conditions present in the structure as well as logistical considerations. Flexibility will be required.

6.3.2 Time of Applicability

When using Approach #2, “Time of applicability” – the exact time when the position fix is considered valid – must be produced by the location technology utilized by the test device in order to accurately associate each location fix with a ground truth position. To avoid becoming a dominant ground truth error source, time of applicability precision should be within about ±0.5 seconds, as discussed in Clause 6.3.3. Also, time of applicability must be present in a log available to the testers, in a form referenceable to Coordinated Universal Time (UTC), and with sufficient resolution to achieve the above stated precision.

6.3.3 Accuracy of Ground Truth in Approach #2

Table 6.2 summarizes the error sources believed to contribute to overall ground truth inaccuracy while using Approach #2 and provides an approximate value for each error source. The experiments summarized in Annex C were performed to determine these values. See Annex C for additional explanation of the error sources, for a description of the experiments performed, and for additional detail about real-world conditions affecting ground truth error while using this approach.

Table 6.2 – Sources of Ground Truth Error in Approach #2

Error Source	Description/ Approximate Value	Error Source Approximate Value
$E_{time_capture}$	This error source quantifies inaccuracies introduced when the tester captures the time of arrival at or departure from a point along a route (e.g., by pressing a button on a mobile device) slightly before or slightly after the true time of arrival or departure. See Annex C for additional detail.	1 meter

Error Source	Description/ Approximate Value	Error Source Approximate Value
$E_{nonlinearity}$	This error source quantifies axial inaccuracies introduced when the tester moves slightly faster during one portion of a line segment, and slightly slower during another portion of the same line segment. Since Approach #2 relies on linear interpolation to produce ground truth, changes or “non-linearity” in speed along the axis of travel translates into position error. See Annex C for additional detail.	1.25 meters
$E_{path_deviation}$	This error source quantifies transversal inaccuracies introduced when the tester deviates from the linear path. Unlike $E_{nonlinearity}$, this error source focuses on the transversal error caused when the tester has to travel slightly to the left or right off the true direct path, typically to avoid an obstruction. See Annex C for additional detail.	1 meter
E_{point_error}	This error source quantifies inaccuracies caused by ground truth errors of the pre-defined points used to form the route. Except for professionally surveyed points, this can easily become the dominant source of error. As explained below, this error source needs to be kept to about one meter to achieve the ground truth accuracy target defined in Clause 6.4.	1 meter
$E_{time_of_applicability}$	This error source quantifies ground truth error caused by inaccurate time of applicability of the device under test (see Clause 6.3.2). If the device under test is not able to precisely indicate at what point in time any given fix is valid, or if the precision with which this time is delivered is insufficient, time error translates directly into position error, as a function of the speed of travel. A typical pedestrian walks at about 1.4 meters/second. (Speed is likely to be less when a cart is used, thus this is effectively a maximum.) Thus, the maximum time of applicability error defined in Clause 6.3.2 translates to up to 0.7 meters of error of ground truth.	0.7 meters

Assuming the error sources listed in Table 6.2 are not correlated to each other, they can be summed in quadrature, as follows:

$$E_{overall} = \sqrt{E_{time_capture}^2 + E_{nonlinearity}^2 + E_{path_deviation}^2 + E_{point_error}^2 + E_{time_of_applicability}^2}$$

Assuming the approximate error source values listed in Table 6.2, approximate overall error is calculated as follows:

$$E_{overall} = \sqrt{1^2 + 1.25^2 + 1^2 + 1^2 + 0.7^2} = \sim 2.25 \text{ meters}$$

As point position errors increase, they quickly come to dominate overall error. Thus, the key to keeping overall ground truth error down while using Approach #2 is keeping route point position errors to about one meter.

6.4 Required Ground Truth Accuracy

Ground truth is the key to any positioning technology testing, thus it is important to define its target accuracy in the context of each testing scenario. As a rule of thumb, ground truth accuracy should be kept to no more than 10% to 20% of the expected error at the 68th percentile Circular Error Probable (CEP68) value, so that ground truth inaccuracies do not have a major effect on the accuracy results produced. As indoor location technologies become more accurate, and CEP68 accuracies are becoming plausible in the low 10's of meters, this argues for a target ground truth accuracy of two to two and a half meters.

6.5 Test Point Selection & Documentation Strategies

For Approach #1, a set of test points must be selected, and for Approach #2, points that serve as the corners of the routes must be selected, within every building. These points are typically selected by the test engineer during an

initial survey of the building. These points must be chosen, and their positions documented in a way that allows a tester who has never visited the venue to accurately and consistently find the points. This necessitates that sites be chosen near referenceable objects, and it necessitates careful documentation of the test points and the referenceable objects.

6.5.1 Referenceable Objects Defined

The purpose of a 'referenceable object' is to help the tester find a test point. Referenceable objects are 'things' that can be physically viewed by a tester in the field. Such objects are leveraged by the tester to find nearby test points. To avoid confusion and to preserve the ability to find test points in to the future, more 'permanent' things are typically chosen, such as:

- windows and window frames
- support posts
- doors and door frames
- vents
- fire extinguisher enclosures
- drinking fountains
- electrical outlets and panels
- structural corners
- elevator shafts and framing
- permanent building infrastructural components.

In other words, *things that do not easily move* are chosen as referenceable objects.

6.5.2 Associating Test Points and Referenceable Objects

Each test point must be associated with at least one referenceable object in concrete, physical terms. This means that the position of the test point is described in a way that ties it physically to the referenceable object(s), so that the test point position is unambiguous and clear. This is typically achieved by taking distance and angle measurements from the reference object(s) to the point. Figure 6.4 shows some examples of how one or more referenceable objects are associated with a test point.

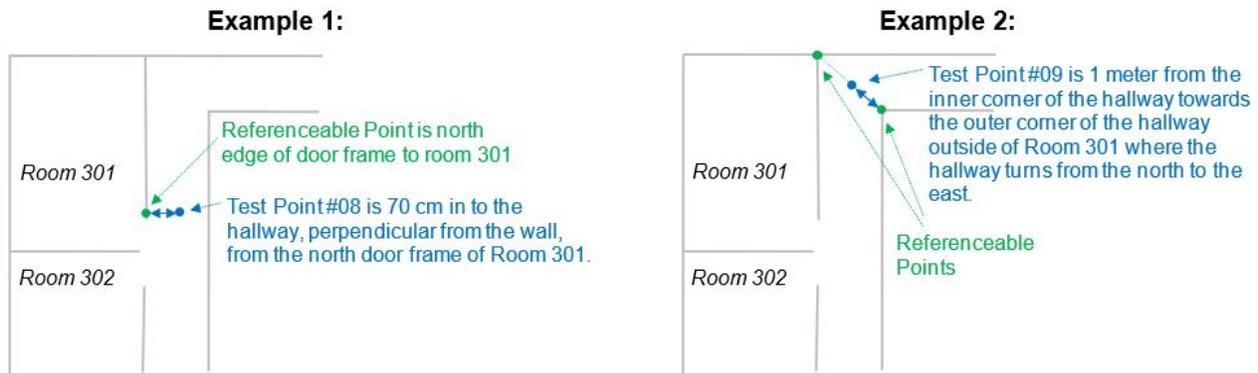


Figure 6.4 – Examples of How Referenceable Objects Are Associated with Test Points

Note that the purpose of the referenceable objects is *only* to locate the test points. Thus, ground truth for these objects themselves need not be calculated. Ground truth is only needed for the test points and route waypoints.

6.5.3 Documenting Test Points and Referenceable Objects

A tester who has never been to a test building before and has never observed its test points must be able to find all reference objects, and from them, find every test point. Documentation is the key to making this happen. The following documentation is needed:

- **A drawing or sketch of each floor containing the test points or route:** This is needed to see all the points in context. Full building details are not required (though they are helpful), nor does the drawing need to be to scale, but it must be clear from this drawing where to start searching for every point. Each point must have a unique identifier noted on this drawing, and in the case of routes, the ordering of the waypoints must be illustrated.
- **Photos of each point:** For each point, photos are needed that illustrate the referenceable object(s) and the test point relative to each other, taken from several angles. It should be clear from which angle each photo was taken. In the photos, it is helpful to place an object in the test position and show measurements to the referenceable object(s).
- **A full description of each point:** Additionally, a textual description of each referenceable object is needed, along with distance and angle measurements, and other descriptions, that tie the referenceable object(s) to the test point, were necessary. The point's unique identifier, building name, building address, floor number, suite or room number, date of survey, and any other helpful reference information should also be captured.

Any convenient format for this documentation is acceptable, though having a copy in a common electronic format, such as Portable Document Format (PDF), would be helpful for loading on to and viewing from an electronic device.

6.5.4 The Point Selection Process

The methodology defined in this document calls for points to be selected initially, as part of a site survey following gaining access to a building, then reused over and over in testing. In other words, test points and routes are *predefined*. Points would not typically be created or changed on the fly during testing, though it may be necessary due to access or logistical reasons to add, delete, or move points from time to time. Such changes would typically be done by the test engineer. Given that it is not anticipated that the tester will be creating or changing test points or routes on the fly in the field, the test tooling should allow for subsets of points or routes to be executed in case a point becomes unavailable, as described in Clause 7.

Where available, in-building maps can be helpful in the test site and test route planning process, even before the test engineer travels to the building to perform the survey and select the points. Interior building layout maps can help identify possible routes and test point sets, but a site visit is *always* needed to assess conditions on the ground.

6.5.5 Leveraging the Same Point on Multiple Floors

Note that in some cases the layout of several floors of a multi-story structure are sufficiently similar that the same position in the X and Y axis can be reused for several floors, as described in Clause 6.2.6. Such situations can be leveraged to provide additional sets of test points or routes with minimal effort.

7 Required Tools

Efficient, capable, and convenient tools are the key to good processes that are likely to be followed, and good processes are the key to efficient, cost-effective test execution. In this clause, the tooling features needed to implement the methodologies presented in this document are described and their requirements are summarized.

7.1 Tool Features

Figure 7.1 shows the 'tool features' – the logical sets of tooling functionality – needed to implement the concepts described in this document. Also shown in the figure are the data flows between the tool features, a summary of the types of data transmitted in each data flow, and an indication of where the tooling is likely to be implemented – in the office, in the field, or in wireless network elements. Next, Table 7.1 lists each tooling feature and provides a brief textual introduction.

The following clauses describe these tooling features and summarize the requirements for each. Note that neither of these requirements, Figure 7.1, nor Table 7.1, prescribe a specific tool or set of tools or a specific tooling architecture, but capture the basic functionality needed. These requirements define 'what' capabilities are needed in these tools, not 'how' tools will be constructed, or which tools will be purchased. Alternate tooling architectures are possible and acceptable.

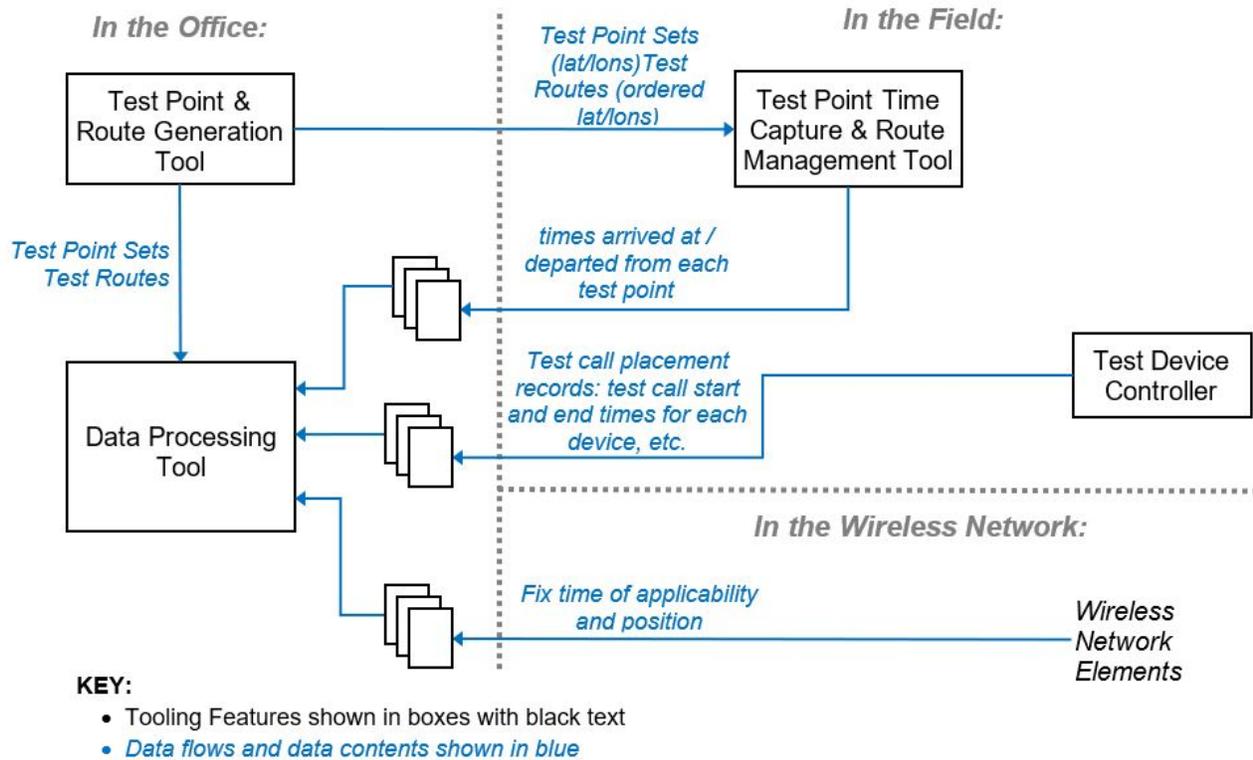


Figure 7.1 – Tool Features & Flow of Data Between Tool Features

Table 7.1 – Tool Features

Tool Feature	Description
<i>Test Point Time Capture & Route Management Tool</i>	Efficiently capturing true position while testing is underway is critically important for both approaches defined in this document. In Approach #1, needed is a feature that allows the tester to quickly and accurately indicate when the test devices are present at each predefined test point. In Approach #2, needed is a feature to calculate a ground truth position for any arbitrary time of applicability during the traversal of a route. To accommodate these needs, tool features are needed to capture when test points are arrived at and departed from, and to manage routes. Since these functions will be needed over and over again, a high degree of automation is desired, to be as easy as possible to execute, and to maximize the integrity of the data captured. This tool feature would be implemented on a mobile device.

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Tool Feature	Description
<i>Test Device Controller</i>	A tool feature is needed to control mobile devices to initiate test calls. Tooling exists today to initiate a sequence of test calls, from numerous devices, at each existing site. For Approach #1, this tooling will need to be improved to reduce the set-up and tear-down time of each sequence of calls, to enable efficient use of a much larger number of test points.
<i>Data Processing Tool</i>	Tooling exists today to process the data coming back from the field and from wireless network elements to create accuracy performance metrics based on the results of a series of location fix test calls, and knowledge of ground truth. These fundamental calculation methods remain unchanged. The modification needed is the ability to associate each individual test call with a distinct ground truth position.
<i>Anchor Position Creation</i>	A few high-accuracy positions are needed in each structure, from which many test points and test routes can be created, as described in Clauses 6.2.6, 6.3, and Annex A. Such points have been and will continue to be created using professional surveying. The tooling needed for professional surveying is beyond the scope of this document.
<i>Test Point & Route Generation Tool</i>	A tool feature is needed to create test point sets, and in the case of Approach #2 test routes, leveraging anchor positions. Annex A describes some simple methods to translate a small number of high-accuracy positions into numerous nearby test points. These methods can and are being implemented manually today, but tooling to automate these methods, perhaps in a graphical context leveraging georeferenced indoor images, would reduce the time needed to prepare a test building. Since test points (and test routes formed from a set of test points) are typically created once, then used over and over, there is less imperative to heavily automate this function. Nevertheless, there is value in pursuing such a tooling feature.

7.1.1 Test Point Time Capture & Route Management Tool Feature for Approach #1

For Approach #1, tooling is needed to capture when the tester (and test devices) arrive at and depart from each test point so that location fix test calls occurring between these times can be associated with the ground truth of the test point. The following list summarizes the requirements for this tooling feature:

1. Provide the tester with the ability to visualize a set of test points within a given structure on a given floor, superimposed over an indoor georeferenced background image, where available. Background images provide additional context to the tester, which has the effect of improving the correctness of the test point selected. It should be possible to zoom and pan between test points, showing any background visual content, in real time during testing.
2. Automatically leverage widely available indoor georeferenced images, such as Google Maps™, to provide a background image for the test points, where available. Also accept other sources of georeferenced background images from third party vendors. Note that Google Maps™ accuracy may or may not be sufficiently accurate to be the source of ground truth itself. Nevertheless, while not essential, background indoor images can be very helpful in the testing process to provide context to the tester, which helps to avoid errors.
3. Provide the tester with a mechanism to select the set of test points of a given floor of a given building. This is discussed in Clause 6 but can be as simple as loading a ‘test point set file’ containing the necessary information.
4. Have the ability to remove (or hide) the map background visual (in the event it is not helpful).
5. Implement the tool on a mobile platform, so that the computing device used to run this tool can be held in the user's hand while performing testing. Also, implement the tool in a desktop environment, so it could be used in the back office in test pre-planning activities.
6. During testing, enable the user to capture the time at which he/she arrives at and/or departs from each test point, using button presses on the mobile device.
7. Provide large, easy-to-see textual feedback, as well as graphical feedback, to indicate which test point is currently selected, for how long the current test point has been selected, or that no test point is currently selected.
8. Optionally provide audio or tactile feedback to the user indicating arrival at and departure from a test point.

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9. Provide graphical feedback to the user indicating the sequence of previously selected test points within a set. Indicate the amount of time spent at each test point, the number of test points already visited, as well as the total time for the current set of points.
10. Provide a mechanism to archive all arrival and departure times for all test points tested in any given session. This archival information should be sufficient to reconstruct ground truth and the sequence the test points were traversed. This capability would be of great value during post processing to avoid potential errors in associating test calls with test points.
11. Transmit arrival and departure time information automatically and electronically at the conclusion of a session (as opposed to a manual process involving file downloads or any other slow processes) to wherever the Data Processing Tool Feature is implemented. Also archive this information on the test device in case the data is lost in transmission. This data is sent when the user manually invokes file transfer.
12. Provide a mechanism for the mobile device on which this tool is run to synchronize time to within 50 milliseconds of UTC time. (In most cases, this is easily achieved by slaving the mobile device to the time of a wireless network.)
13. Provide the capability to indicate that a previously visited site is suspect and allow the user to indicate the reason for this designation.
14. Provide a mechanism to view a document describing the test points, as described in Clause 6.5.3, including both text and photos. This may be implemented using a separate document viewing tool.

7.1.2 Test Point Time Capture & Route Management Tool Feature for Approach #2

For Approach #2, tooling is needed to produce ground truth in pedestrian walking situations by capturing the times when a tester departs and arrives at predetermined, fixed points (waypoints) along a fixed route. Using these captured times, and the known positions of the points, the Data Processing Tool feature can linearly interpolate between the points to produce a truth position for any time of applicability during the route. Such a tool must be implemented on a mobile device, so that a tester can hold the device in his/her hand while walking a predefined route, clicking a button as he/she arrives at and departs from each point along the route. The following list summarizes the requirements for this tooling feature:

1. Provide the tester with the ability to view the line segments and waypoint positions (waypoints) that form a test route, superimposed over an indoor georeferenced background image, where available. It should be possible to zoom and pan the route, and any background map visual content, in real time during a route execution.
2. Automatically leverage widely available indoor georeferenced images, such as Google Maps™, to provide a background image for the route to provide additional context, where available. Also accept other kinds of georeferenced background images from third party vendors.
3. Provide the tester with a mechanism to select a pre-defined route. How this is achieved is not prescribed but can be as simple as loading a 'Test Route File' containing the necessary information.
4. Have the ability to remove (or hide) the map background visual (in the event it is not helpful).
5. Implement the tool on a mobile platform, so that the computing device used to run this tool can be held in the user's hand while he/she walks a pedestrian route.
6. During route execution, enable the user to capture the time at which he/she arrives at and/or depart from each point, using button presses on the mobile device.
7. Provide a mechanism to 'pause' on any point along the route. When paused, the ground truth reported can be the position of the pause point. Pausing on a point allows the tester to wait momentarily while obstacles move out of the way of the next line segment.
8. Provide large, easy-to-see textual feedback, as well as graphical feedback, to provide the user with the status of the current route execution. It should be possible to know whether or not the data collection has started or been paused, and if so, on which point, the leg currently being walked, and whether or not the route has ended.

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9. Optionally provide audio and tactile feedback to the user during route execution to indicate when the user arrives at and/or departs each waypoint. Provide audio feedback whenever a user arrives and/or departs from a point, so it is clear without looking at the screen that the button-press was successful.
10. Display the name of the route being followed during route execution.
11. Provide a mechanism to archive the results of the route, including the positions of the points that define the route, their order, and the known times at which the tester arrived at and departed each point. This archival information should be sufficient to reconstruct ground truth for any positioning time of applicability occurring during the route.
12. Transmit route arrival and departure time information automatically and electronically at the conclusion of the route (as opposed to a manual process involving file downloads or any other slow processes) to wherever the Data Processing Tool Feature is implemented. Also archive this information on the test device in case the data is lost in transmission. This data is sent when the user manually invokes file transfer.
13. Provide a mechanism for the mobile device on which this tool is run to synchronize time to within 50 milliseconds of UTC time. (In most cases, this is easily achieved by slaving the mobile device to the time of a wireless network.)
14. Provide a mechanism to select a subset of points and reorder the waypoints in a route. This is intended to adapt to unforeseen circumstances in the field that prevent testing along the entirety of a pre-defined route. Providing the capability to arbitrarily edit a route during field testing is not recommended.
15. Provide a mechanism to execute a subset of a route, in case a portion of the route is inaccessible.
16. Provide a mechanism to view a document describing the route and waypoints, as described in Clause 6.5.3, including both text and photos. This may be implemented using a separate document viewing tool.

7.1.3 Test Device Controller Tool Feature

Tooling exists today to initiate a sequence of test calls on each test device at each test point. The main new feature needed is that the time it takes to set up to place one or a small number of test calls needs to be significantly shortened to accommodate the much larger number of test points. Similarly, the time it takes to complete any needed processing after the call(s) at any one test point or route have completed must be minimal. The following list summarizes the requirements for this tooling feature:

1. Maintain the existing capability to automatically initiate a series of test calls from a large number of test devices, on command.
2. The setup time needed to setup to place the first test call from each device, following arrival at a test site, should not exceed 30 seconds.
3. The time needed to complete any processing and be ready to move following the last test call at a test point should not exceed 30 seconds.
4. Automatically generate logs noting the times when test calls were initiated.

7.1.4 Data Processing Tool Feature

Tooling exists today to calculate horizontal error for each fix and from these distances generate accuracy performance statistics. This tooling needs to be expanded to accommodate the dynamically determined ground truth inherent in the methodologies defined in this document.

When using Approach #1, this tooling needs to be expanded to receive from the Test Point Time Capture & Route Management Tool Feature in the field the time windows when the test devices were physically present at each test point. Using this information, along with a database of the positions of each test point provided by the Test Point & Route Generation Tool Feature, this tool feature must associate the point ground truth position with the fixes performed while at each test point, and exclude any fixes performed while in transit between points. Then, horizontal error and performance metric calculations can proceed in the usual way, based on this dynamically associated ground truth based on time.

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When using Approach #2, this tooling needs to be expanded to receive from the Test Point Time Capture & Route Management Tool Feature in the field the times when the tester arrived at and departed from each waypoint in the execution of each route. Using this information, along with a database of each test route's waypoint positions provided by the Test Point & Route Generation Tool Feature, this tooling must determine a unique ground truth position for each individual test call fix in one of the following ways:

- If the time of applicability of the fix does not fall within the start time and end time of any route execution, the fix is excluded from further consideration.
- If the time of applicability of the fix falls between the departure from one point and the arrival at another point, linear interpolation is applied, using the positions of the arriving and departing points, the time of departure, the time of arrival, and the fix's time of applicability.
- If the time of applicability of the fix occurs while paused at a route waypoint, the position of this waypoint is used as ground truth for this fix.

Once ground truth is determined for each individual fix, horizontal error and performance metric calculations can proceed in the usual way, based on this dynamically determined ground truth.

This tooling must maintain a database of test points and/or route waypoints. A mechanism for inputting this information must also be provided.

7.1.5 Test Point & Route Generation Tool Feature

For both Approach #1 and Approach #2, ground truth for a large number of test points must be determined and formed in to 'test point sets' or 'test routes'. While this could be done manually, there are advantages and efficiencies to be achieved by automating these functions.

Clause 6.2.6 introduced the concept of leveraging a small number of highly-accurate, surveyed anchor positions to create ground truth for nearby test points, with simple 'flat earth' geometric calculations as discussed in Annex A used to perform the calculations. This approach to ground truth creation is the initial basis for this tooling feature. Additionally, and more significantly, features to automate data entry and editing, document creation, and test point set / test route file creation are critical features for improving efficiency and reducing error, and are thus also part of this tooling feature.

The following list summarizes the requirements for this tooling feature:

1. Provide simple tools to perform the calculations described in Annex A to determine position coordinates for test points and waypoints based on anchor positions, distance measurements, and angle measurements.
2. Provide the test engineer user with a graphical environment in which to visualize test point sets or test routes (ordered test point sets) on a 'drawing'. There will be one drawing for each specific test point set or test route. Typically, a drawing would capture all the test points on a single floor of a single building.
3. Provide a mechanism for the user to place test points, waypoints, anchor points, and referenceable objects at arbitrary positions on the 'drawing'.
4. Provide a mechanism for the user to manually enter test point, anchor point, and waypoint position coordinates.
5. Provide a mechanism to import existing indoor floor plan georeferenced or non-georeferenced images to provide background context, where available, and display it behind the drawing. See Annex D for more information regarding floor plan generation techniques.
6. Optionally provide a georeferencing mechanism to translate a simple, 'flat' building layout image of any given floor in to a georeferenced image.
7. Provide a way for the user to give a set or route a unique name, and to add background textual information, including:
 - a. The building name, building address, floor number, suite or room number, or any other useful textual information associated with the set or points or route.
 - b. The date of survey.

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8. Provide a way for the user to import and associate one or more images with the set or route.
9. Display the points in a test point set or test route together on the drawing, along with anchor points and referenceable object positions on a background image, if available and desired. Allow the user to zoom and pan within the drawing, showing any background visual content.
10. For test routes, show lines between the points, in order to convey the ordering of the route.
11. Provide a mechanism for the user to change the order of the points in a route.
12. Provide a way for the test engineer to arbitrarily assign a unique identifier to each point within a set or route and display this identifier on the drawing.
13. Provide a way for the user to create new test points, delete test points, graphically move the position of a test point, and edit details about a test point including:
 - a. The point's unique identifier.
 - b. A textual description of the test point.
 - c. A textual description of each referenceable object used to find the test point, along with distance and angle measurements.
 - d. Other descriptions that tie the referenceable object(s) to the test point.
14. Provide a way for the user to import and associate one or more images with any test point.
15. Provide a way for the user to attach textual background information to an anchor position or reference object.
16. Provide a way for the user to attach one or more photos to an anchor position or reference object.
17. Provide a way for the user to click on any test point, waypoint, anchor point, or referenceable object and view the text and image(s) associated with this point.
18. Provide a way for the user to copy one or more test points, waypoints, anchor points, or referenceable objects from one set to a different set (for example to propagate a point to a different floor.)
19. Upon user command, export a documentation file, for example, in.pdf format, containing the drawing showing the test points, waypoints, anchor points and reference in context, set or route textual and visual information, and textual and visual information for each of the test points, waypoints, anchor points, and referenceable objects.
20. Upon user command, export the 'test point set' or 'test route' file, containing the ground truth positions of the points. In the case of a test route, these points are ordered. This file is used by both the Test Point Time Capture & Route Management Tool Feature and the Data Processing Tool Feature.

It is preferable that this tool feature be implemented in a way that is device independent, allows for backups of source data, and allows for transferability between devices, etc.

7.1.5.1 Use of Georeferenced Images for Ground Truth

In the future, it may be possible to use georeferenced images directly to determine ground truth, perhaps with assistance and calibration from professionally surveying anchor positions, thus eliminating or reducing the need to make distance and angle measurements. Annex D provides a synopsis of different methods to collect indoor floor map data. However, at this time it is unclear if such approaches will meet the ground truth targets outlined in Clause 6.4. Some error sources that need further investigation include:

- The accuracy of floor layouts.
- Error introduced in the georeferencing process.
- Accuracy of existing georeferenced image sources.

Once these error sources are better understood, it may be possible to expand the Test Point & Route Generation Tool Feature to leverage georeferenced images directly to produce ground truth.

8 Recommendations

It is recommended to introduce and evaluate “Approach #1” in the upcoming 9-1-1 Location Technologies Test Bed campaign. The implementation should be a phased approach with a side-by-side evaluation including one to two different building types per morphology, per test region, using dense urban, urban, and suburban morphologies. Examples for test case buildings include commercial high rises, large urban buildings, and multi-floor suburban apartment buildings.

A phased approach will allow the ability to assess the reliability in the location accuracy measurement process, differences in observed location performance, time to execute the testing, and cost, compared to the traditional indoor test methodology. It is likely that the enhanced methodology described in this document will yield a more accurate representation of indoor location performance; however, this improved accuracy needs to be assessed in the context of overall cost and complexity of execution.

It is recommended that development of a mobile platform-based tool, specifically the “Test Point Time Capture & Route Management Tool Feature for Approach #1” described in Clause 7.1.1, be undertaken under the direction of the 911 Location Technologies Test Bed.

This evaluation exercise should be leveraged for:

- Providing feedback to enhance the testing process including tool functionality, and provide feedback based on real world testing experience.
- In-depth comparative analysis of horizontal error and cdf plot analysis, on a per route and a per building basis.
- Temporal analysis of the results produced from a set of test points or a route versus obtained from one test point along the path.

Analysis results from the phased “Approach #1 Methodology” introduction should be used to help guide future test campaigns.

A Simple Referential Ground Truth Calculation Methods

Simple 'flat earth' referential ground truth position calculation methods can be used to populate one or more high-quality ground truth points to nearby points. The term 'flat earth' refers to assuming that the surface of the earth approximates a flat surface over short distances, so that very simple geometric and trigonometric calculations can be applied.

Figure A.1 illustrates a simple approach for determining position coordinates for any unknown point between two known positions, using linear interpolation. Note that for points on the same floor, the Height Above Ellipsoid can typically be assumed to be the same.

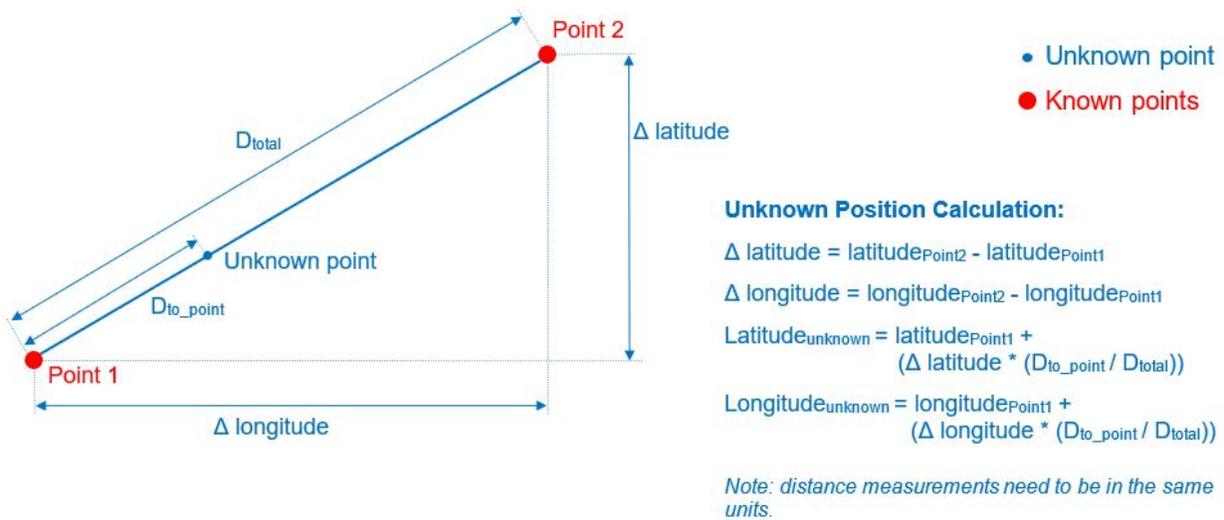
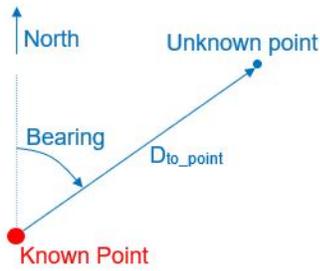


Figure A.1 – Determining Unknown Position Using Two Known Positions and Relative Distances

Figure A.2 illustrates a simple approach for determining position coordinates for any unknown point based on the position of a single known point and the bearing and distance from the known point to the unknown point. As before, for points on the same floor, the Height Above Ellipsoid can typically be assumed to be the same.



- Unknown point
- Known point

Intermediate Calculations:

Meters_per_degree_of_latitude = 110,946.26 meters

Meters_per_degree_of_longitude_at_ref_latitude = $\text{COS}(\text{latitude}_{\text{known}} * \text{Pi}/180) * 111,319.49$ meters

$\text{Bias}_{\text{North}} = D_{\text{to_point}} * \text{COS}(\text{Bearing} * \text{Pi}/180)$

$\text{Bias}_{\text{East}} = D_{\text{to_point}} * \text{SIN}(\text{Bearing} * \text{Pi}/180)$

Unknown Position Calculation:

$\text{Latitude}_{\text{unknown}} = \text{Latitude}_{\text{known}} + (\text{Bias}_{\text{North}} / \text{Meters_per_degree_of_latitude})$

$\text{Longitude}_{\text{unknown}} = \text{Longitude}_{\text{known}} + (\text{Bias}_{\text{East}} / \text{Meters_per_degree_of_longitude_at_ref_latitude})$

NOTES:

- Bearing measured clockwise from North, in degrees.
- All distances in meters.
- All angles in degrees.
- Meters/degree coefficients based on the WGS-84 reference ellipsoid.

Figure A.2 – Determining Unknown Position Using Known Position, Known Angle, and Distance

B Confidence Intervals for Proportions in the Context of Test Calls

Placing a sample of wireless location test calls in the environment of a given building can be considered as a probabilistic experiment of repeated trials (Bernoulli Trials), where one of two outcomes of each trial is of interest, either the positioning error of the test call is within 50m, or it is not. We are interested in the proportion p of the sample of n calls for which the positioning error is within 50 m. We can estimate this proportion with a certain level of confidence and a certain level of “precision”, which is more commonly called the confidence interval.

Note that if we do not know much about p , then $p= 0.5$ provides the most conservative analysis for sample size. This basically means that any given test call is equally likely to have a positioning error either less or more than 50 m.

For a sufficiently large sample of independent test calls n (at least 20) and when np and $n(1-p)$ are not too small, Normal approximations for the estimation error can be used and the estimate for the proportion p is given by

$$p \pm z \text{ Sqrt} [p (1-p) / n]$$

where z is a number derived from the area under the unit Normal density function and corresponds to the desired level of confidence in the estimate. For 90% confidence $z = 1.645$ and for 95% confidence $z = 1.96$.

If it is acceptable to estimate the proportion p to within, for example, ten percent, then we can readily solve for n for different nominal values of p , including a most conservative case with $p =0.5$ and a less conservative case of $p = 0.8$. This latter case is still quite practical in the context of indoor wireless location testing. Whereas in a large urban or dense urban building a 50/50 chance of the positioning error being within 50 m is a good starting assumption, in a smaller, less challenging suburban building, the likely probability of the positioning error being within 50 m is much closer to 80%. This will result in a somewhat smaller minimum sample size.

The most conservative sample size corresponds to $p = 0.5$. For estimating p within 10% the minimum sample size is 68 test calls. For $p = 0.8$ the minimum sample is 44 calls. The Normal approximation conditions commonly break for higher values of p (closer to one) or conversely for very small values of p close to zero, since np or $n(1-p)$ becomes a small number, e.g., less than five. Hence smaller samples would not be reliable. It is also critical that the test calls be independent.

C Summary of Experiments Used to Estimate Error Sources for Pedestrian Motion Ground Truth

In 2014, experiments were performed to establish the viability of using simple linear interpolation between a series of points with known position to determine ground truth while in pedestrian motion between the points. As part of this assessment, the error sources inherent in this method were identified, and using simple experiments, each error source value was approximated. This Annex summarizes how these experiments were performed, defines the error sources, provides the approximate error source value calculated, and describes how each error source value was approximated.

This experimentation consisted of two phases:

1. Two outdoor routes in open sky conditions were constructed. These routes were then walked while generating interpolation-based truth using a prototype interpolation-based ground truth handset-based tool. A high-quality GNSS device, in some cases with an inertial measurement unit, was also positioned with the tester while repeatedly walking the routes. The results from the interpolation-based ground truth tool were compared against the GNSS results to approximate error sources.
2. Routes were then constructed in numerous public indoor venues, and a tester was carefully observed while walking routes to witness how real-world conditions affected the ground truth error produced. From these observations, error values were confirmed, and the relationships between real-world conditions and error were better understood, leading to the definition of several usage guidelines.

Note that this error assessment focused on the error sources inherent to the execution of this pedestrian test methodology, specifically $E_{\text{time_capture}}$, $E_{\text{nonlinearity}}$, and $E_{\text{path_deviation}}$, as defined below. Inaccuracies caused by ground truth errors of the points used (pre-defined) to form the route were not assessed in this experiment, as this error source is driven by entirely different processes. Likewise, the inaccuracy caused by device time of applicability problems was not assessed. Also note that this was a relatively simple series of experiments, thus it is not possible to confidently measure an error source below a resolution of about one meter. This was deemed sufficient to determine an approximate baseline.

Table C.1 lists each error source assessed, defines the error source, gives the approximate error from these experiments, summarizes the method used to derive the error approximation, and provides additional observations.

Table C. 1 – Pedestrian Motion Error Sources

Error Source	Error Source Description	~Error	Methodology / Observations
$E_{time_capture}$	This error source quantifies inaccuracies introduced when the tester captures the time of arrival at or departure from a point slightly before or slightly after the true time of arrival or departure. This error source focuses on the user's inaccuracies in pressing the button on the mobile platform-based tool, not on timing errors within the tool itself, which are presumed to be minimal. This human-caused timing error translates in to position error of the ground truth produced, as a function of pedestrian speed, and the geometry of the points.	One meter or less	<p>The tester used a tool running on a mobile device to capture these times by pressing a button. The accuracy of time within the mobile device is known to be within milliseconds of true time, as the device was slaved to network time, and thus negligible.</p> <p>Accurate GNSS-based and interpolation-based positions were compared at the time of arrival at and departure from the points, and found to be quite close.</p> <p>Also, while walking public routes, the prototype handset-based tool produced an audio beep when the tester departed from and arrived at each point. The tester was visually observed to arrive and depart at the same time as the beep – easily within a half a second, which translates to less than 0.7 meters at typical walking speeds, confirming the numerical calculations.</p>
$E_{nonlinearity}$	This error source quantifies axial inaccuracies introduced when the tester moves slightly faster during one portion of a line segment, and slightly slower during another portion of the same line segment. Since Approach #2 relies on linear interpolation to produce ground truth, changes or 'non-linearity' in speed along the axis of travel translates into position error, as a function of the amount of non-linearity, the geometry of the beginning and ending linear segment points, and the positions within the line segment where the non-linearity occurred.	Typically no more than about 1.25 meters	<p>An error vector between accurate GNSS and interpolation-based positions were compared at GNSS time of applicability, and the axial component was measured to determine typical worst-case error.</p> <p>Investigation into this error source suggests that tester speed while walking is surprisingly consistent, for route legs under 100 meters. This was in conditions where there was no significant pedestrian traffic in the route area. One caveat is that in crowded conditions along the route of travel, this error source can increase. Thus, it is desirable to pick data collection times when the venue is not crowded to minimize error. Also, it is important to account for known obstacles by placing a point before the obstacle and using a pause capability in the tool when needed. Note that it is also desirable to avoid very large route leg distances. This is easily done by adding additional points to breakup long, straight legs.</p>
$E_{path_deviation}$	This error source quantifies transversal inaccuracies introduced when the tester deviates from the linear path. Unlike $E_{nonlinearity}$, this error source focuses on the transversal error caused when the tester has to travel slightly to the left or right off the true direct path, typically to avoid an obstruction.	One meter or less	<p>Error vectors between accurate GNSS and interpolation-based positions were compared at GNSS time of applicability, and the transversal component was measured to determine typical worst-case error. Also, testers were observed while walking real-world line segments, and the deviation needed to avoid obstacles was visually assessed.</p> <p>This error source was found to be minimal – under one meter – as long as the venue was not crowded. Picking data collection times when the venue is not crowded is needed to minimize this error source.</p>

D State of the Art for Indoor Maps

The presentation of accurate map data, whether printed or electronically displayed is useful as an aid for performing indoor location testing setup and execution. Integration of floor plan map data into data acquisition tools is the ultimate goal of how indoor map data can best be used.

Acquisition of Floor Plan (Map Data)

It is helpful, and often advisable, to have underlying indoor floorplan data to aid in the definition and execution of the test methodology enhancements described in this document. Map data, or “Floor Plan” information can be generated in a variety of ways, using different tools, each method having its unique level of effort and resulting precision and display.

A sampling of popular approaches to generating floor plans are listed below.

Manual Survey Techniques

Manually surveyed floor plan information requires a dimensional drawing at a minimum, which may be georegistered. For georegistration to be valid, there must be one known point anchored as a ground truth position aligned with a geographic grid or datum by either a rotation or the establishment of a second ground truth point at a certain known distance from the first known point. Other reference points within the datum can be calculated based on distance and angular rotation or simply plane geometry. Tools typically used for collecting measurements may include a tape measure, laser rangefinder, transit, etc.

Creating the floor plan map data can be demonstrated via a drawn sketch or a more carefully constructed engineering drawing. It may also be created using automated means.

There are many Computer Aided Design (CAD) software applications/tools that can create building floor plans. A sample list is as follows: < https://en.wikipedia.org/wiki/Comparison_of_computer-aided_design_editors >.

High quality CAD tools are highly specialized and typically require trained personnel to manually construct a representation of an indoor mapped space including the floor plan itself.

Automated Survey Techniques

Progression of technology has more recently introduced advanced survey techniques and software tools that seek to automate both 2D building floor plan generation, and 3D rendered graphics for indoor spaces based on a combination of advanced software and sensors built in to common off-the-shelf mobile devices, and some specialized hardware. The different approaches to capturing indoor environment data have application in many areas, including real-estate, virtual-reality gaming, construction, healthcare, security monitoring, and location-based technologies, such as emergency 9-1-1.

The following lists a few popular methods to acquire indoor location.

- Robots – devices in the form of autonomous vacuums with built in optical, radio, and acoustical sensing can now map out the indoor room or house, present the floor plan to a user’s mobile device, and use the data to provide zone control, Wi-Fi signal coverage reporting, activity reports, energy audits, and integration into other smart house technologies. Several commercial devices are available currently.
- Drones – small Unmanned Aerial Vehicles (UAVs) can fly-through an indoor space and collect spatial data to produce a 3-dimensional indoor map.
- Mobile Device Software – software applications that run on mobile devices that are fitted with specialized hardware (e.g., chipsets) and software features to collect data from a combination of user inputs, including multiple on-board cameras for static, in-motion, and depth imaging have been shown to produce 2D digital representations and 3D visualizations of indoor spaces, outputting these as either a dimensional floorplan, or a 3D photo-realistic rendered space. Several software applications are commercially available and require specific mobile platform Operating System (OS) support and built-in hardware into the devices that can utilize it. Despite the practical application of the produced diagrams, there are remaining questions regarding the dimensional accuracy of the resulting diagrams.

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Once map data is generated, it must be produced in a usable form and format for analysis, potential processing, and archiving. Several mapping service companies exist, with the ability to produce standardized high-resolution maps based on a variety of input formats. This map transformation serves to normalize the way maps look in terms of formats, colors, callouts, style, and resolution.