LoRa Edge™
Asset Management System
Location Performance Overview
Application Note

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1 Introduction

Semtech's LoRa Edge™ Asset Management System revolutionizes how tracking devices are built and deployed. It combines the latest LoRa® long range, low power technology together with Wi-Fi and GNSS scanning capabilities into one package and, with the LoRa Basics™ Modem-E firmware, includes a full LoRaWAN® 1.0.3 stack.

Paired with this powerful silicon is a cloud-based location computation engine capable of locating devices using GNSS[1], Wi-Fi, and LoRa. Built into this system is a GNSS-aiding capability that is optimized for use over LoRaWAN networks. It is an ideal solution for numerous applications. In tracking, it is best suited for periodic updates of sensor locations in situations where the environment is changing or uncontrolled; for example, the tracker may be indoors or outdoors for any given sample.

1.1 Purpose Of This Manual

This manual describes how to customize your usage of Semtech's LoRa Edge™ Asset Management System to best suit your applications requirements, to balance location accuracy and energy consumption.

1.2 Scope Of This Manual

This manual describes the location performance of the LoRa Edge™ Asset Management System.

Reference is made to the LR1110 datasheet.

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[1] The term GNSS stands for Global Navigation Satellite System. Multiple systems are available today from different government entities. These include the Global Positioning System (GPS) from the USA, the GLObal'naya Navigationnay Sputnikovaya Sistema (GLONASS) from the Russian Federation, Galileo from the European Union and BeiDou Navigation System from China, as well as smaller regional systems from India and Japan.

2 System Overview

The LoRa Edge LR1110 has its location computed within the LoRa Cloud™. As shown in Figure 1, the flow of the data begins with a GNSS scan by the LoRa Edge™ chip. The chip then transmits the GNSS scan result over a LoRaWAN network to the LoRa Cloud™ via the customer's application logic. Subsequently, the LoRa Cloud Geolocation service processes the data into a location solution and returns the result to the customer's application logic.

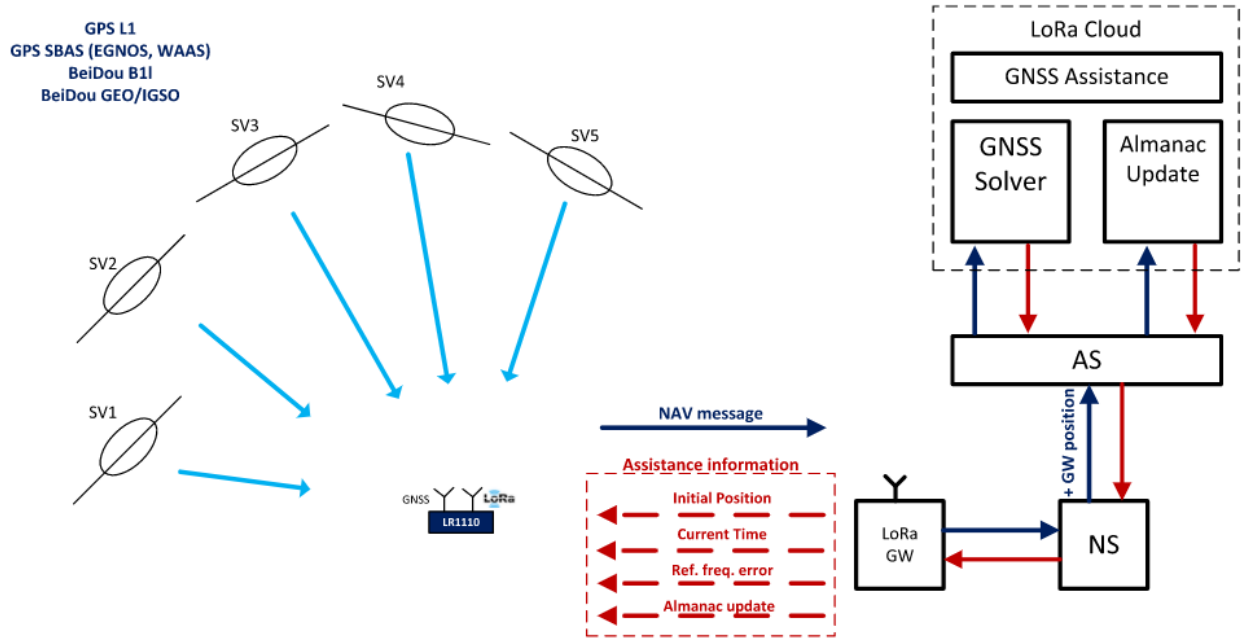


Figure 1. Overview of LoRa Edge(TM) GNSS Functionality

The LR1110 provides GNSS and Wi-Fi scan capabilities on a LoRa chip. An interesting feature of the GNSS scan is that it can be used in two ways: 1) for obtaining location information; and 2) to determine whether the device is indoors or outdoors. The second option of indoor/outdoor detection is extremely useful in saving power when a full GNSS scan might not work. This provides a quick sample locally that the MCU can use to determine if a full GNSS scan would be worthwhile or if simply performing a Wi-Fi scan would be sufficient. GNSS scans can be performed for the GPS constellation at the L1 frequency as well as for the BeiDou constellation at the B1 frequency.

Besides the option for full GNSS scanning versus scanning for indoor/outdoor detection, the LR1110 also has two distinct modes of full GNSS scanning: autonomous and aided.

- In autonomous GNSS scanning, the LR1110 performs a scan for the highest available signals. This is less power efficient and usually less effective in getting scan results than the aided scan; however, it does not require any information from the network to get results.
- The aided scan receives three different types of assistance from the network: 1) almanac data; 2) time via the Application Layer Clock Synchronization (ALCSync) process; and 3) position aiding.

Almanac data provides the orbital parameters of the satellites for up to 120 days, although it is most accurate for approximately 30 days after download.

Almanac assistance provides the LR1110 the ability to compute, given reasonably precise time, the location of the GNSS satellites.

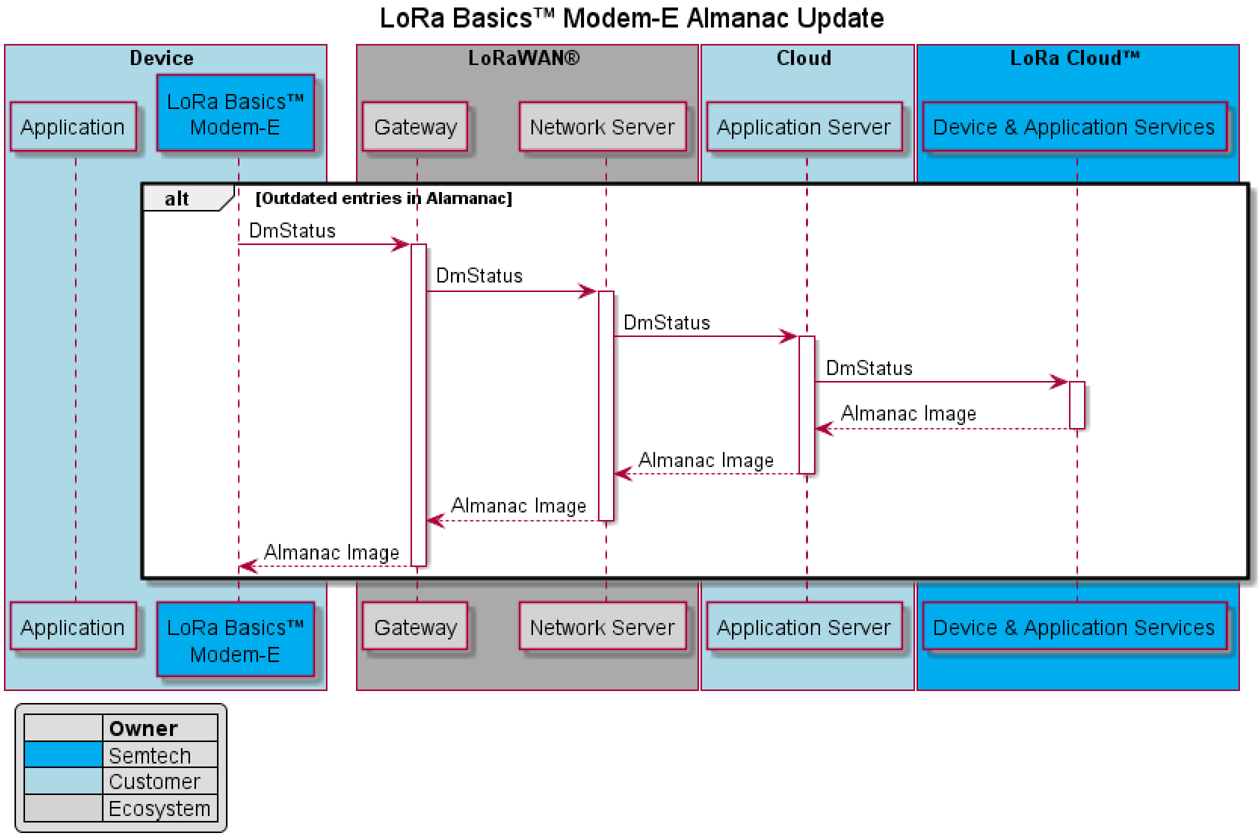


Figure 2. Almanac Aiding Flow

The second type of assistance, the Application Layer Synchronization, or “ALCSync”, process allows time-transfer to the LR1110. A completely unsynchronized device can start an overt query to the LoRa Cloud Geolocation service. After the initial synchronization, the timing sync can be automated on a regular basis as part of the standard uplinks that include scans of GNSS. The LoRa Cloud™ Device & Application Services will monitor the variation of the device clock from the server reference clock. The Device & Application Services will return the ALCSync message to be directed by the Application Server to the device keeping its clock up to date.

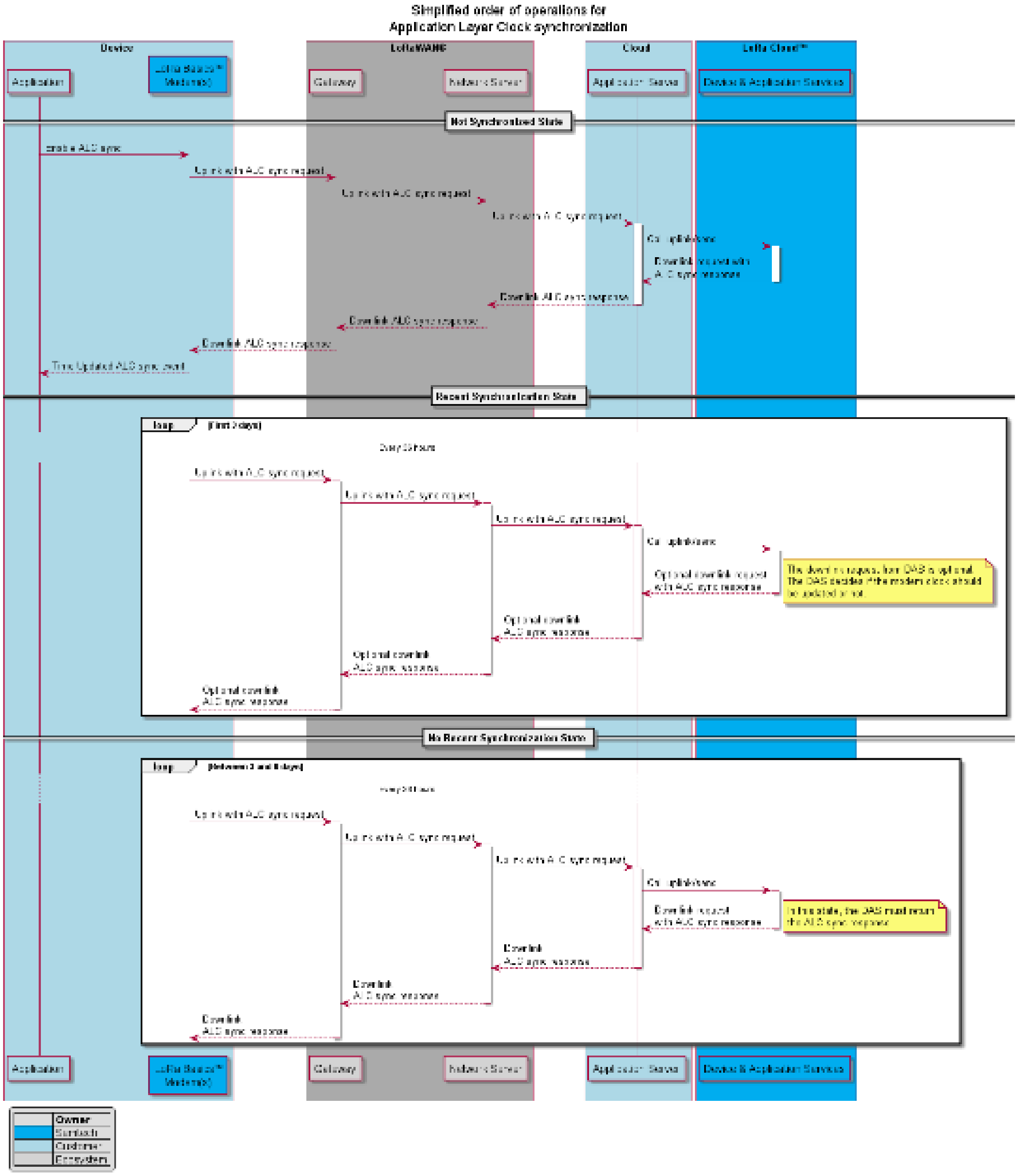


Figure 3. Application Layer Clock Synchronization (ALCSync) Flow

The final type of assistance is an approximate location. While it might seem a bit ironic to improve the GNSS scan used to find a position by already having a rough idea of your location; it is for a good reason. The combination of a rough estimate of location of the end-device, almanac, and time can be used to predict which satellites should be visible and approximate their Doppler frequency offset necessary for signal tracking. Table 1 below provides the approximate values for Best, Good, and Minimum Assistance values for aided GNSS scans.

Table 1. Assistance Criteria

	Best Assistance	**Good Assistance**	**Minimum Assistance**
Almanac Age	< 4 weeks	< 8 weeks	< 15 weeks
Time Accuracy	< +/- 10s	< +/- 30s	< +/- 120s
Initial Assistance Position	< 50km	< 100km	< 150km

Once the scan is complete, the scan data of the autonomous or aided GNSS scan is sent to the LoRa Cloud Device & Application Services, which computes a position.

The standard transmission technique from the device to the Application Server uses a streaming protocol called ROSE. This streaming protocol increases the reliability and lowers the impact of message loss from the device to the LoRaWAN network. Any missed messages can be recovered from later uplinks. It also handles long packets, breaking them up into multiple uplinks based on data rate.

The first step in processing the stream is to recover the original scan result from the device. That scan result received from the Device & Application Services is then passed back to the Device & Application Services for location processing. The location is returned to the Application Server, along with any almanac or timing that the Device & Application Services determine is necessary for the proper operation of future assisted GNSS scans.

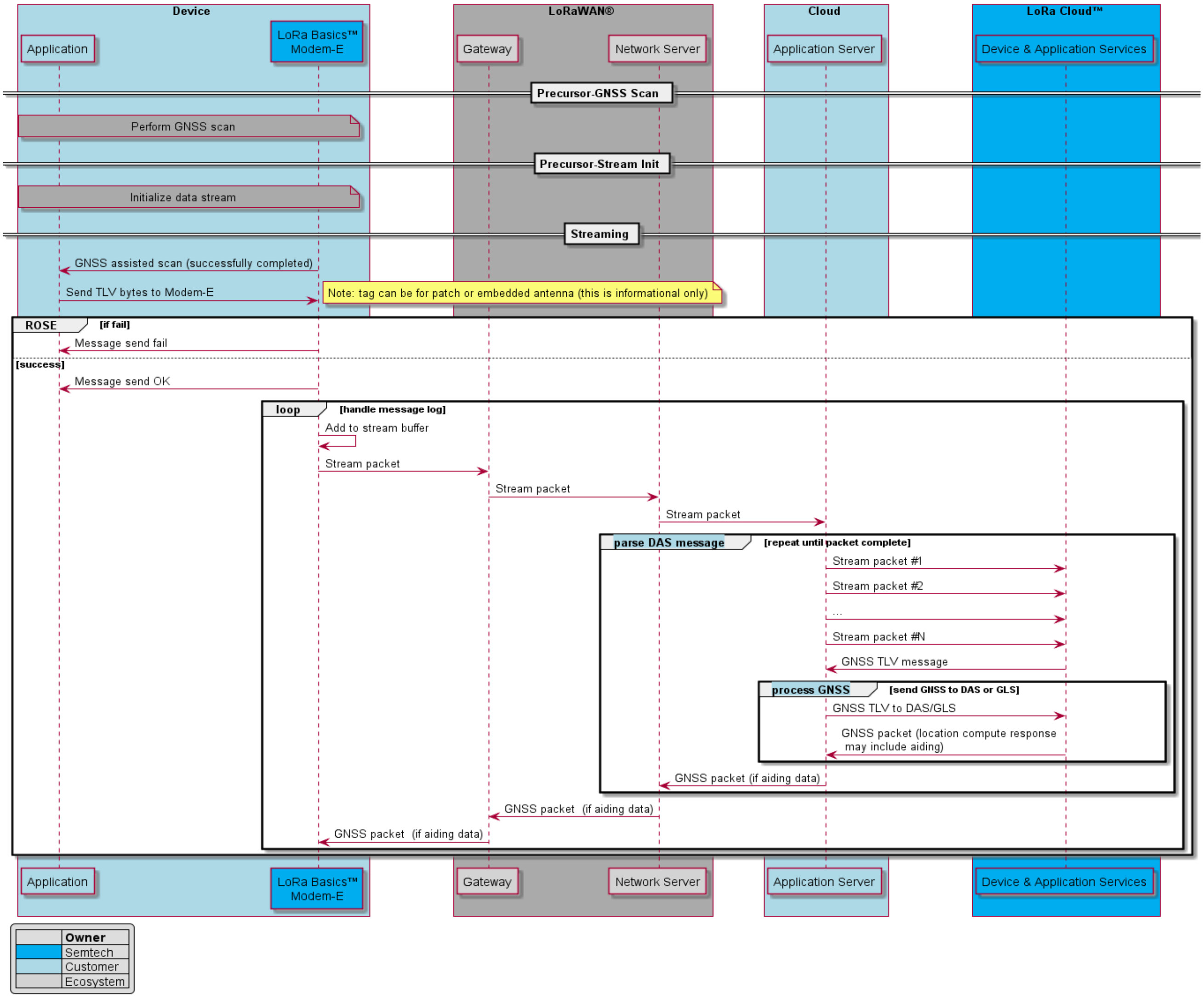


Figure 4. GNSS Scan Processing with ROSE

2.1 LoRa Cloud Geolocation Service

The LoRa Cloud Geolocation Service takes scans from GNSS, Wi-Fi, or LoRa signals and produces location estimates.

The LoRa Cloud Geolocation Service can be accessed through an API directly to the Geolocation Service, or through the Device and Application Services; the input and output are the same both interfaces. The API is stateless, meaning that no history is collected about a device; nor does the API collect past observations to contribute to the current estimate.

The scan is processed by the Geolocation Service and returned via the API as a JSON record with the following information:

- For a Wi-Fi or LoRa scan:
    - computed latitude, longitude, and altitude
    - computed accuracy (Geolocation Service -only)
    - solution type (e.g., “RSSI”)
    - timestamp.
- For an uploaded scan of GNSS data:
    - position in ECEF coordinates (Earth-Centered Earth-Fixed Cartesian coordinates, discussed later)
    - latitude, longitude, and height (WGS84 LLH coordinate frame); GDOP (Geometric Dilution of Precision)
    - computed accuracy
    - timestamp.

The GNSS-based location estimation of the LoRa Cloud Geolocation service uses GNSS scans of LR1110 transceivers to compute location estimates for end nodes. In the single-capture case, the service requires at least a single on-device GNSS scan and an associated capture timestamp to make an estimate. Additional parameters may be specified to improve the result. These are described in the API v3 GNSS section.

To carry out the HTTP JSON request, the LoRa Cloud Geolocation service also requires the following:

- an HTTP POST request with content type ‘application/json’
- an HTTP header field ‘Ocp-Apim-Subscription-Key’ with a valid API token
- a payload in valid JSON format, according to the API specification

Wi-Fi data is scanned and processed in a similar fashion to GNSS.

3 Test-setup, Device Configuration, and Field-testing Scenarios

An extensive set of tests were run to evaluate the performance in a variety of real-world conditions. For some tests the Evaluation Kit version of the LR1110 implementation was used (Figure 5); that kit has two available GNSS antenna options, but only the active patch antenna (the black antenna in the foreground) was used. The second test device used was the Tracker form-factor Evaluation Kit reference design of the LR1110, shown in Figure 6. This device employs two embedded antennas: one an active patch form-factor, and one embedded in the substrate of the PCB. Tests were conducted separately on those two GNSS antennas and the results are shown independently.

Figure 5. Evaluation Kit for LR1110

Figure 6. LR1110 Tracker Form Factor Evaluation

3.1 Test Summaries

A series of tests were run to evaluate the location capabilities of the LoRa Edge Asset Management System with the LR1110. The summary of the conditions is in Table 2. The tests focused primarily on the evaluation of GNSS performance, because the Wi-Fi results are highly correlated to the database solution utilized.

Table 2. Test Summaries

Tests	Hardware	Antenna	Sky Visibility	Satellites/Wi-Fi	Location
1	EVK	Active	Open	GPS+BeiDou	Grenoble France
2	Tracker	Patch	Open	GPS+BeiDou	Grenoble France
3	Tracker	PCB	Open	GPS+BeiDou	Grenoble France
4	EVK	Active	Half-Sky	BeiDou-only	Shanghai China
5a	Tracker	PCB	Multi	GPS+Beidou	Grenoble France
5b	Tracker	Patch	Multi	GPS+Beidou	Grenoble France
6a	Tracker	Patch	Semi-Urban	GPS+Beidou	San Jose CA USA
6b	Tracker	PCB	Semi-Urban	GPS+Beidou	San Jose CA USA
7a	Tracker	Patch	Urban-Canyon	GPS+Beidou	San Francisco CA USA
7b	Tracker	PCB	Urban-Canyon	GPS+Beidou	San Francisco CA USA
8	Tracker	PCB	Urban-Canyon	Wi-Fi	San Francisco CA USA

For tests 1-3, the test condition was Open-Sky: from the top of a building with very few obstructions and with a clear view of the sky except for one tall building obstructing the view to the north at an angle of about 15° above the horizon and a wall on the roof to the south, also with an obstruction angle about 15°. This represents a real-world test case and both types of hardware were used. In the case of the Tracker EVK, the on-board PCB antenna was tested, as was the patch antenna, with the patch oriented toward the zenith (i.e., patch facing upwards). These tests also evaluated the use of multiple-scans for stationary objects. This is when multiple GNSS scans are combined over time and processed by the LoRa Edge Asset Management System.

Test #4 was conducted in Shanghai. It was the only single-constellation test using only the BeiDou constellation. It used the EVK hardware with the active patch antenna but was in a challenging environment.

Tests 5a and 5b tested how the orientation of the Tracker EVK impacts performance for the two different antennas.

Tests 6a and 6b provides combined GNSS performance information at street-level in a semi-urban environment for the two antennas in the Tracker EVK.

Tests 7a and 7b show performance of the Tracker EVK in combined GNSS performance in an urban-canyon environment.

Test 8 shows performance of Wi-Fi location performance vs GNSS performance in an urban-canyon environment while moving.

3.2 Parameters

The following paragraphs explain a number of parameters that designers will be interested in for their systems employing LoRa Edge LR1110 and LoRa Cloud processing. Additional discussion of these parameters can be found in the upcoming sections on test results.

3.2.1 Coordinate Systems

Each GNSS solution from the LoRa Cloud Geolocation Service returns two equivalent coordinate types.

- Latitude, Longitude, and Height in the WGS84 coordinate frame (latitude and longitude in decimal degrees, height in meters).
- Earth-Centered Earth-Fixed (ECEF) x,y,z coordinates. The center of this reference frame is taken at the center of mass of the Earth. The x axis corresponds to a point along the equator of the Earth that intersects the prime meridian in Greenwich (i.e., 0° latitude and 0° longitude). The z-axis extends through true north from the center mass of the Earth. However, the z-axis does not correspond perfectly to the center of rotation of the Earth. Therefore, there is a slight “wobble” about the rotational axis. Since the x-axis and y-axis spin as the Earth rotates, the coordinate frame stays fixed as it turns, thus the term “Earth Fixed”.

3.2.2 GNSS and Wi-Fi Scan times

The GNSS scan time depends on a number of factors. The most significant impact on scan time is whether you choose to scan for both GPS and BeiDou satellites. Since the time of each individual scan is not precisely known, there is a gap inserted between the first and second scans that can be as long as four seconds (there is a four-second offset from the start of the first scan until the start of the second scan). A scan on GPS or BeiDou alone can be completed in two seconds or less.

The next most important factor in GNSS scan times is recent and accurate aiding information. This additional data can reduce scan times and improve the ability to track low-power signals appreciably. It can reduce GPS scan times from 2 to 1.25 seconds. Choices about the maximum number of satellite measurements to track can limit the data processing for small signals (after the requisite number of higher power signals were found). In short, the GNSS scan times can be as low as 1.25 seconds for GPS-only, as low as 1.81 seconds for BeiDou-only, and as much as 6.10 seconds for GPS+BeiDou scans.

For Wi-Fi scanning, there are a few more options available that can impact scan times. The available settings are:

1) Channels to scan (channel mask of 1-14);
2) Type of 802.11 signals (b, g ,n, or b then g+n options);
3) Acquisition mode (beacon-only or beacon+packet search);
4) Maximum number of MAC addresses to return;
5) Maximum number of passive scans per channel to be executed (1-255);
6) The timeout in Preamble Search mode in milliseconds (ms). For example, for a beacon period of 102.4 ms a 105-ms timeout value can be set to ensure the scan covers the entire beacon period;
7) Abort on timeout: if set to 1, when a preamble timeout occurs the scanning on this channel is aborted

The preamble search duration depends on the traffic in the channel. For busy channels, a preamble is detected quickly. For channels with only an AP signal and little traffic, the preamble search can be as long as the beacon interval set for that specific AP (nominally set to 102.4 ms).

Consider an example for the following conditions: a busy channel; a maximum MAC setting of 6; three channels at 1,6 and 11; 802.11b only; beacon only.

These conditions would result in a scan time of less than 75 ms. However, this is a best-case scenario. A more typical scan time for a busy channel in a dense urban environment would be about 100 ms. For a standard urban environment, the scan time might be 250 ms, and for a less busy channel the typical scan time might be 500 ms.

3.2.3 End-to-End Latency

Scan time is only the first step in delivering data to where it needs to be. The steps to produce a location solution are:

1) Performing a scan
2) Transmitting the scan via LoRaWAN to the LoRa Cloud
3) Processing the scan into a location
4) Returning the location estimate to the application processor

The end-to-end latency first depends on the scan times discussed in the previous section. The transmit time depends on the current channel settings, including spreading factor and bandwidth. However, this is usually bounded by approximately 200 hundred milliseconds. Similarly there is the transmission over a backhaul from the Network Server to the LoRa Cloud processing engine, which can take a few hundred milliseconds more.

If the LoRa Cloud processing is bounded by about one second, the total latency from transmit to solution is on the order of 200 ms+300 ms+1000 ms or 1.5 seconds. This means that, for best-case scenarios, the latency for GNSS scans is less than 2.75 seconds. Latency for Wi-Fi scans is approximately 1.58 seconds from start of scan to it being available to the Application Server for storage, display, or further processing. Of course, these are the best-case scenarios. Latencies in the network connectivity or additional loads on interfaces may drive this up appreciably.

When we look at combined GNSS scans of GPS+BeiDou, the latency from scan to application server solution is 6.10+1.50=7.6 seconds and for Wi-Fi on non-busy channels it is 0.5+1.5=2.0 seconds. It is illustrative to compare these latencies to heritage GNSS approaches. In a heritage system, location is computed on the device directly; this means that the position information is sent directly from the device to the cloud application service. However, the processing of the location on the receiver takes substantially more power than just performing the scan. When no aiding is available to a heritage receiver, the cold start initialization is about 30 seconds, compare this to the 6.1 seconds for an autonomous scan from the LoRa Edge device. With warm start assistance, including predicted ephemeris (usually about 30 bytes per satellite valid for 2 hours), approximate time and approximate location, this can find a solution within 3 seconds for devices that can use predicted ephemeris (note that for devices that do not use predicted ephemeris, the warm-star acquisition time is still about 30 seconds). Note that the transmission of the location can proceed directly from the device to the application server and there is no processing of the scan result on the cloud since it was already computed in the device. Also, the transmit time over the air is about 75% less to send the relatively smaller location information for the GNSS scan. With this information, the following summary can be made:

Table 3. Latency Comparison

	Best Case Latency to Application Server	**Worst Case Latency to Application Server**
Heritage GNSS	3.35 sec	30.35 sec
LoRa Edge™ GNSS	2.75 sec	7.60 sec
Heritage/LoRa Edge™ Wi-Fi	1.58 sec	2.00 sec

Note that the heritage Wi-Fi latency is the same as that of LoRa Edge. This is due to the presumption that the scan timing parameters would be adjusted to be optimal in both cases for the application, and that the same data over the same channel setting would need to be sent for the same duration, so they would be equivalent by comparison.

3.2.4 Satellite Measurements

The choice of the number of satellite measurements that are sent produces either better accuracy or power saving. The data in Figure 7 shows collected accuracy data vs number of GNSS satellite measurements returned from a scan. For each of the CDF levels, increasing the number of satellites tracked decreases the error rate in locating a given device. However, increasing the number of satellites tracked also decreases localization accuracy. As Figure 7 indicates, the fewer satellite measurements, the higher the error rate.

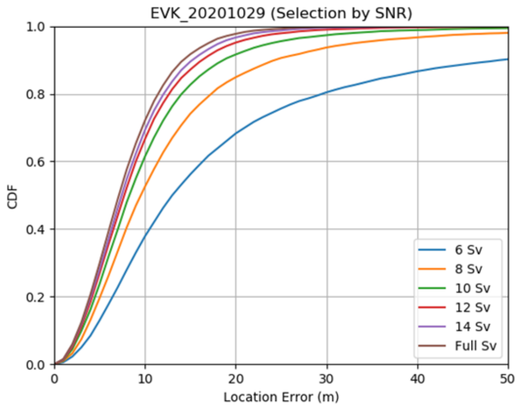


Figure 7. Example Position Accuracy vs Number of Satellites

This analysis is shown in Table 2. From this, you can see that limiting the number of satellite measurements to 12 only sacrifices 11% accuracy. Since all measurements need to be sent from the device, expending transmit energy, there could be savings in power consumption for processing fewer satellites in the LR1110 engine, and also for fewer bytes being sent over the air.

To interpret the data in the table, let's say you had 10 m of accuracy with 14 space vehicles (SVs), then the corresponding accuracy with 12 SVs would be 11% higher (11.1 m) and 29% higher for 10 SVs (12.9 m), etc. It is application dependent whether the trade-off in accuracy versus power savings is beneficial.

Table 4. Accuracy Degradation vs Number SVs Processed

SV Measurements	Relative Accuracy Decrease Compared vs 14 SV
14	0%
12	11%
10	29%
8	51%
6	97%

3.2.5 Indoor/Outdoor Detection

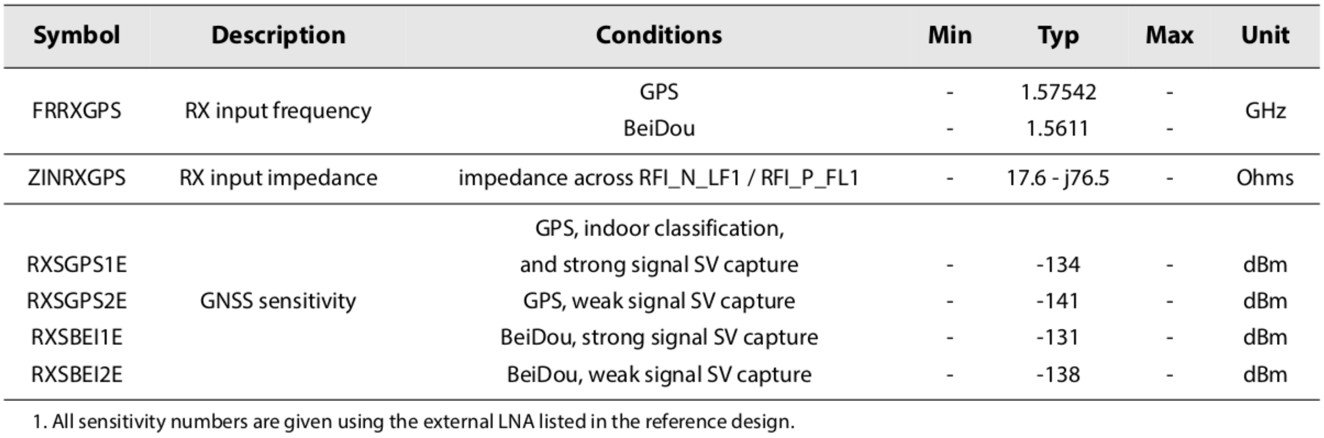
As mentioned previously, the LoRa Edge™ LR1110 has the ability to quickly and efficiently determine whether the receiver is located indoors or out. This is determined by scanning for high-powered satellites. If none are found, that is usually due to some environmental condition that is attenuating the satellite signal. Regardless of whether the device is truly indoors or not, by using this relatively quick and power-efficient scan, if it is determined there are no high-powered signals available, it would be a waste of power to try to perform a full scan for all satellites because the end result will likely be a marginal GNSS solution at best.

The way this works is that a brief GPS-only scan is conducted. This scan takes approximately 0.70 seconds if the aiding data is up-to-date, and as much as 1.25 seconds if the device needs to perform an un-aided scan. The core power consumption on the LR1110 chip is as little as 15.8 mJ of energy which, when combined with a reference LNA and TCXO (as on the LR1110 Tracker EVK), consumes a total of 20.4 mJ when precise aiding is available.

To provide a bit of context, a small battery at 100 mAh holds approximately $1.3x10^6$ mJ, which is enough energy to perform this scan more than 65 thousand times. The local device can consume this result without sending it over the network. If the device determines that there is a significant chance of getting a GNSS fix, it can decide to proceed with a full GNSS scan. Alternatively, it could decide to conduct a Wi-Fi scan, which may be more efficient and more likely to obtain a successful location.

3.2.6 GNSS and Wi-Fi Sensitivity

Table 3-13 from the LR1110 datasheet, shows the GNSS sensitivity data:



Symbol	Description	Conditions	Min	Typ	Max	Unit
FRRXGPS	RX input frequency	GPS	-	1.57542	-	GHz
		BeiDou	-	1.5611	-	
ZINRXGPS	RX input impedance	impedance across RFI_N_LF1 / RFI_P_FL1	-	17.6 - j76.5	-	Ohms
RXSGPS1E	GNSS sensitivity	GPS, indoor classification, and strong signal SV capture	-	-134	-	dBm
RXSGPS2E		GPS, weak signal SV capture	-	-141	-	dBm
RXSBEI1E		BeiDou, strong signal SV capture	-	-131	-	dBm
RXSBEI2E		BeiDou, weak signal SV capture	-	-138	-	dBm

1. All sensitivity numbers are given using the external LNA listed in the reference design.

The corresponding Wi-Fi sensitivity is provided in Table 3-14 in the LR1110 datasheet:

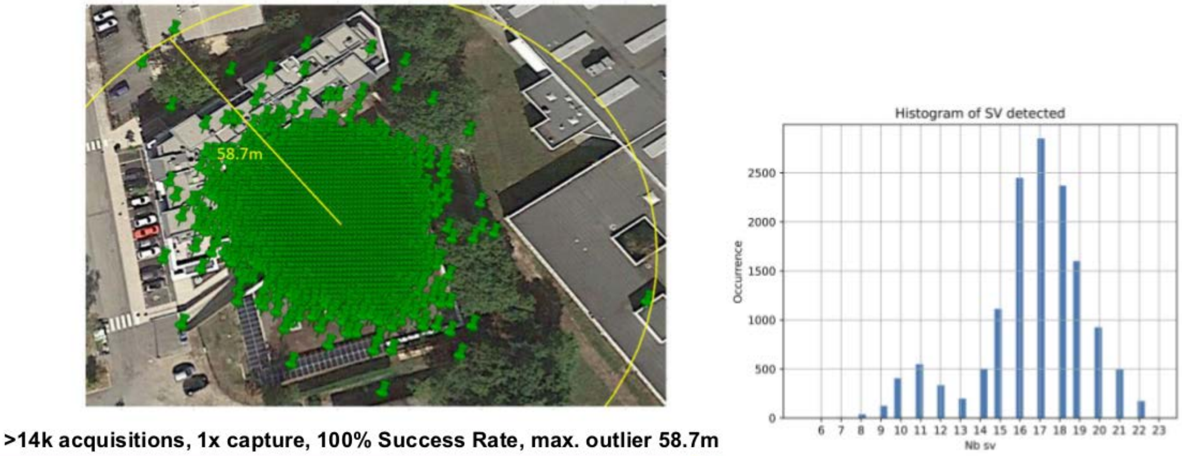
Symbol	Description	Conditions	Min	Typ	Max	Unit
FRRXWF	RX input frequency	Wi-Fi channels	2412	-	2484	MHz
RXSWFB1	Wi-Fi sensitivity for Wi-Fi 802.11 b, DSSS	DBPSK, DR = 1 Mb/s	-	-94	-	dBm
RXSWFB2		DQPSK, DR = 2 Mb/s	-	-91	-	dBm
RXSWFG1	Wi-Fi sensitivity for Wi-Fi 802.11 g, OFDM, 20MHz channel spacing	BPSK, CR = 1/2, DR = 6 Mb/s	-	-88	-	dBm
RXSWFG2		BPSK, CR = 3/4, DR = 9 Mb/s	-	-85	-	dBm
RXSWFG3		QPSK, CR = 1/2, DR = 12 Mb/s	-	-87	-	dBm
RXSWFG4		QPSK, CR = 3/4, DR = 18 Mb/s	-	-84	-	dBm
RXSWFG5		16-QAM, CR = 1/2, DR = 24 Mb/s	-	-82	-	dBm
RXSWFG6		16-QAM, CR = 3/4, DR = 36 Mb/s	-	-78	-	dBm
RXSWFG7	Wi-Fi sensitivity for Wi-Fi 802.11 n[1], OFDM, 20MHz channel spacing, long guard interval	BPSK, CR = 1/2, DR = 6.5 Mb/s	-	-87	-	dBm
RXSWFG8		QPSK, CR = 1/2, DR = 13 Mb/s	-	-85	-	dBm
RXSWFG9		QPSK, CR = 3/4, DR = 19.5 Mb/s	-	-81	-	dBm
RXSWFG10		16-QAM, CR = 1/2, DR = 26 Mb/s	-	-80	-	dBm
RXSWFG11		16-QAM, CR = 3/4, DR = 39 Mb/s	-	-75	-	dBm
RXSWFG12	Wi-Fi sensitivity for Wi-Fi 802.11 n[1], OFDM, 20MHz channel spacing, short guard interval	BPSK, CR = 1/2, DR = 7.2 Mb/s	-	-87	-	dBm
RXSWFG13		QPSK, CR = 1/2, DR = 14.4 Mb/s	-	-85	-	dBm
RXSWFG14		QPSK, CR = 3/4, DR = 21.7 Mb/s	-	-82	-	dBm
RXSWFG15		16-QAM, CR = 1/2, DR = 28.9 Mb/s	-	-80	-	dBm
RXSWFG16		16-QAM, CR = 3/4, DR = 43.3 Mb/s	-	-76	-	dBm
IIP3WF	3rd order input intercept point	unwanted tones @22 MHz and 24 MHz offsets	-	-28	-	dBm
		unwanted tones @25 MHz and 48 MHz offsets	-	-15	-	dBm
ACRWFB	Selectivity, at sensitivity + 3dB, for 50% PER	Wi-Fi b 1Mb/s, 25 MHz offset	-	51	-	dB
ACRWFG		Wi-Fi g 6 Mb/s, 25 MHz offset	-	24	-	dB

[1] 2.4 GHz Wi-Fi n only, mixed mode

4 Location Performance Measurement Data

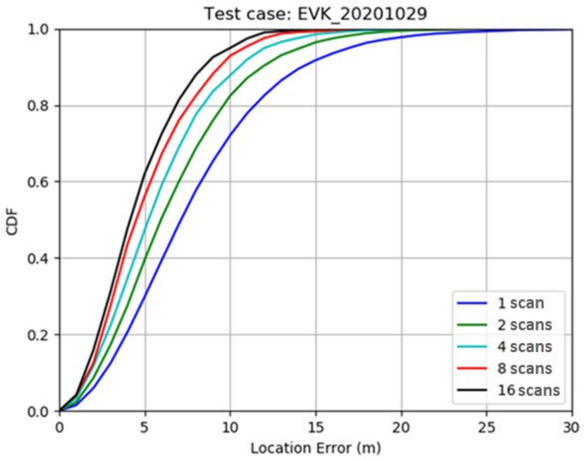
The following result summaries are from the tests conducted on the LR1110 EVK devices.

4.1 Test Cases 1, 2 and 3 (Open-Sky)



>14k acquisitions, 1x capture, 100% Success Rate, max. outlier 58.7m

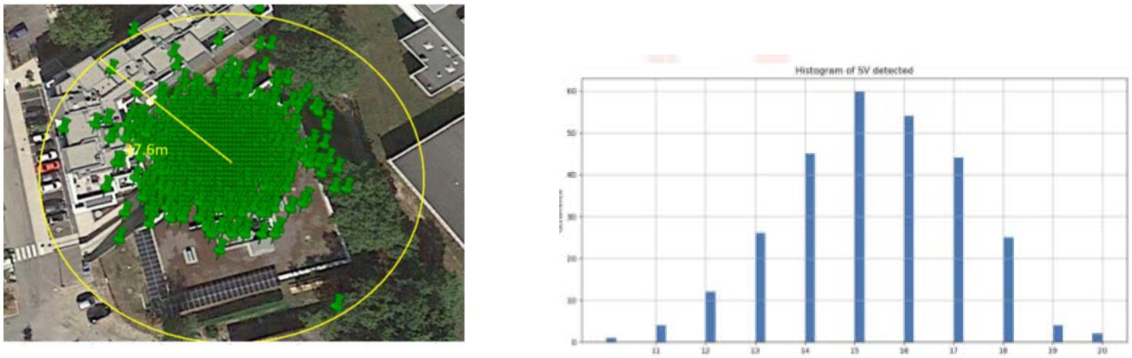
Figure 8. Test 1 Position Plot and Number of Satellites Tracked



Number of captures used to solve

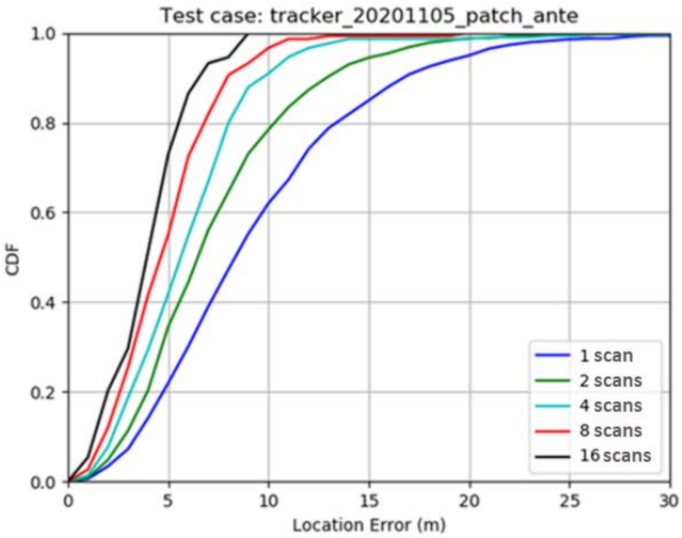
Position accuracy	1x	2x	4x	8x	16x
@50% CDF [m]	7.1	6	5.5	4.8	4
@80% CDF [m]	12	9.5	8	7.5	7

Figure 9. Test 1 Results for Single and Multiple Solutions



1.2k acquisitions, 1x capture, 100% Success Rate, max. outlier 37.6m

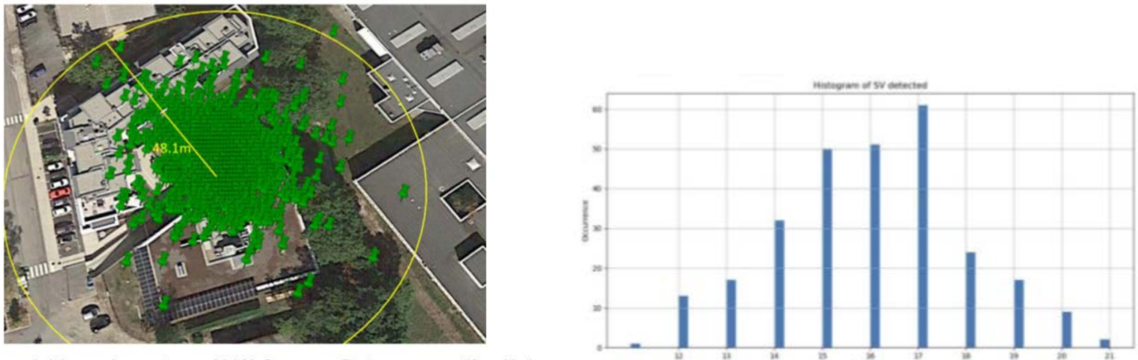
Figure 10. Test 2 Position Plot and Number of Satellites Tracked



Number of captures used to solve

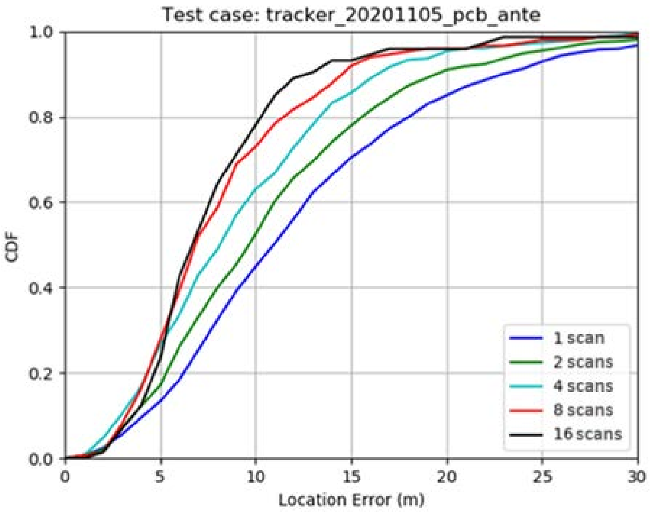
Position accuracy	1x	2x	4x	8x	16x
@50% CDF [m]	7.5	6.8	5.5	4.8	4
@80% CDF [m]	12.5	10.2	7.6	6.5	5.5

Figure 11. Test 2 Results for Single and Multiple Solutions



1.2k acquisitions, 1x capture, 100% Success Rate, max. outlier 48.1m

Figure 12. Test 3 Position Plot and Number of Satellites Tracked

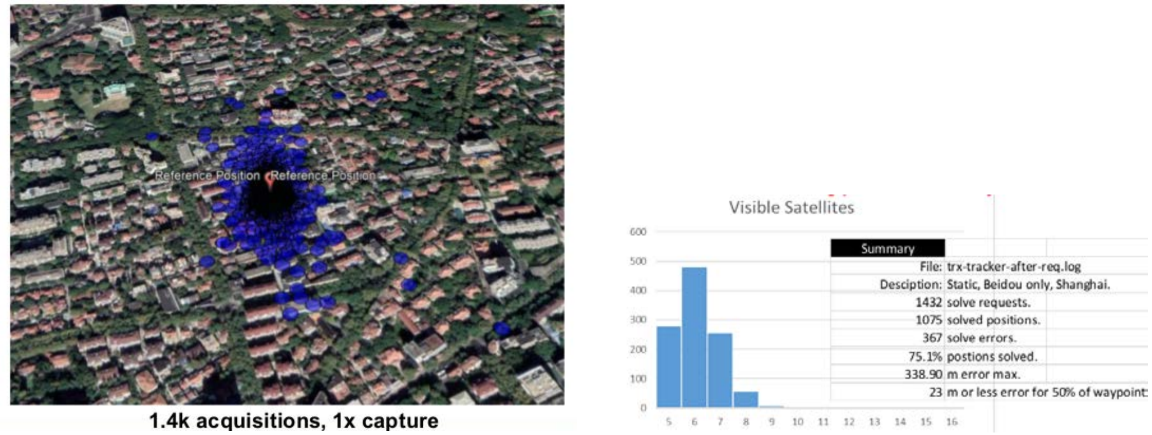


Number of captures used to solve

Position accuracy	1x	2x	4x	8x	16x
@50% CDF [m]	12	10	8	7	7
@80% CDF [m]	17.5	15.5	13	12	10.2

Figure 13. Test 3 Results for Single and Multiple Solutions

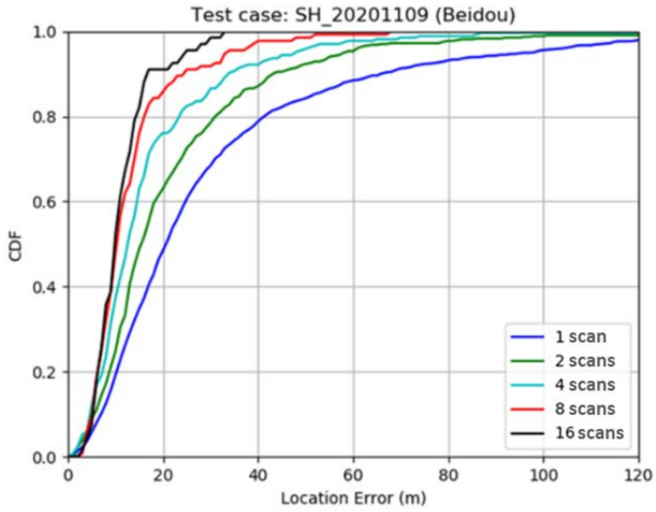
4.2 Test Case 4 (Half-Sky BeiDou-only)



1.4k acquisitions, 1x capture

Summary	
File:	trx-tracker-after-req.log
Desciption:	Static, Beidou only, Shanghai.
1432	solve requests.
1075	solved positions.
367	solve errors.
75.1%	postions solved.
338.90	m error max.
23	m or less error for 50% of waypoint:

Figure 14. Test 4 Position Plot and Number of Satellites Tracked



Number of captures used to solve

Position accuracy	1x	2x	4x	8x	16x
@50% CDF [m]	21	17	12	10	10
@80% CDF [m]	40	30	21	13	12

Figure 15. Test 4 Results for Single and Multiple Solutions

4.3 Test Cases 5a and 5b (Multi)

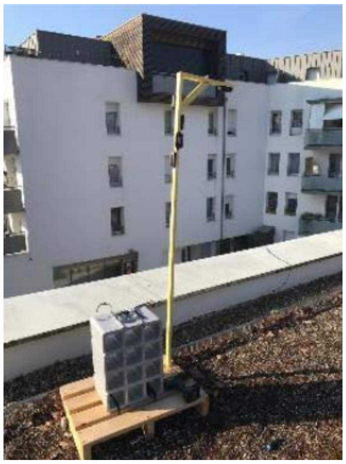
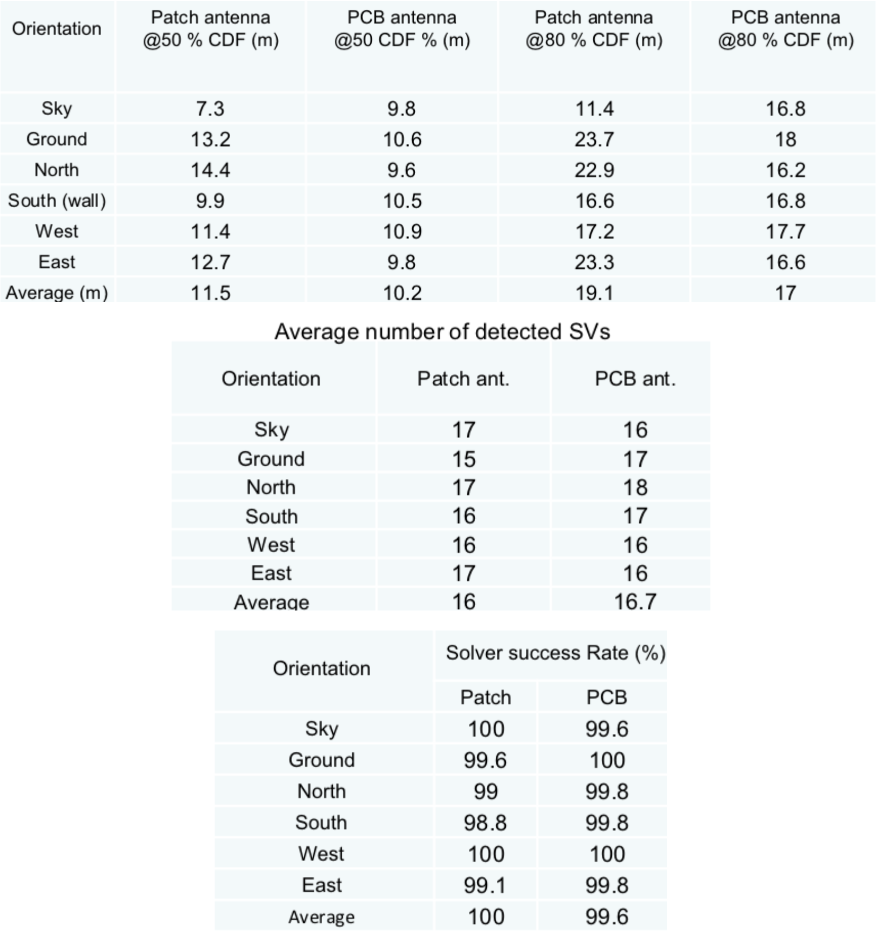


Figure 16. Test 5a Setup: Orientation in each Direction



Orientation	Patch antenna @50 % CDF (m)	PCB antenna @50 CDF % (m)	Patch antenna @80 % CDF (m)	PCB antenna @80 % CDF (m)
Sky	7.3	9.8	11.4	16.8
Ground	13.2	10.6	23.7	18
North	14.4	9.6	22.9	16.2
South (wall)	9.9	10.5	16.6	16.8
West	11.4	10.9	17.2	17.7
East	12.7	9.8	23.3	16.6
Average (m)	11.5	10.2	19.1	17

Average number of detected SVs

Orientation	Patch ant.	PCB ant.
Sky	17	16
Ground	15	17
North	17	18
South	16	17
West	16	16
East	17	16
Average	16	16.7

Orientation	Solver success Rate (%)	
	Patch	PCB
Sky	100	99.6
Ground	99.6	100
North	99	99.8
South	98.8	99.8
West	100	100
East	99.1	99.8
Average	100	99.6

Figure 17. Test 5a Results for Single Scan over Multiple Orientations vs the Sky

Figure 18. Test 5b Setup at Grenoble Site 2: Orientation in each Direction

Orientation	Patch antenna @50 % CDF (m)	PCB antenna @50 CDF % (m)	Patch antenna @80 % CDF (m)	PCB antenna @80 % CDF (m)
Sky	17.3	25.8	31.8	51.3
Ground	47	24.4	92.4	45.6
North	33.5	26.8	66.9	51.7
South (wall)	42.4	32.5	102.1	69.6
West	29.6	32.6	56.6	59.6
East	42.8	30.2	85.3	60.6
Average (m)	35.4	28.7	72.5	56.4

Average number of detected SVs

Orientation	Patch ant.	PCB ant.
Sky	11	9
Ground	7	10
North	8	9
South	6	7
West	9	8
East	5	10
Average	7.7	8.8

Orientation	Solver success Rate (%)	
	Patch	PCB
Sky	97.5	79.2
Ground	57.1	92.6
North	78.1	88.4
South	52.7	78.3
West	84.8	71.7
East	54.3	87.1
Average	70.7	82.9

Figure 19. Test 5b Results for Single Scan over Multiple Orientations vs the Sky

4.4 Test Cases 6a and 6b (Semi-Urban)

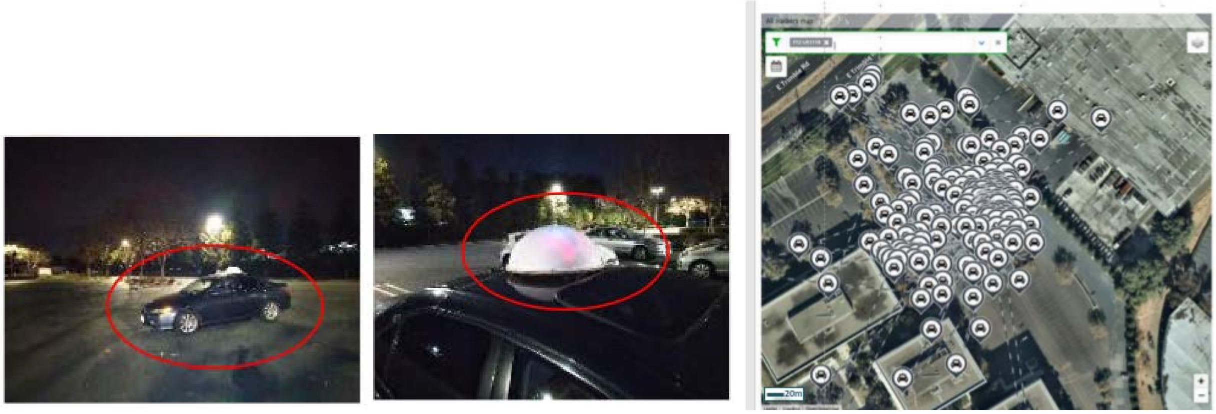


Figure 20. Test 6a and 6b Setup and Position Plot

Location accuracy (m)	Patch antenna	PCB antenna
@50 % CDF	8.4	9.2
@80% CDF	20.2	19.3

Figure 21. Test 6a and 6b Results for Single Scan over 24 h with 100 Points for each Antenna (100% solution rate)

4.5 Test Cases 7a and 7b (Urban-Canyon)

Figure 22. Test 7a Setup and Position Plot (16 points x 3 Trackers)

Location accuracy (m)	Patch antenna	PCB antenna
@50 % CDF	37.9	46.3
@80% CDF	146.3	94.7

Figure 23. Test 7a for 48 Data Points (Single Scan)

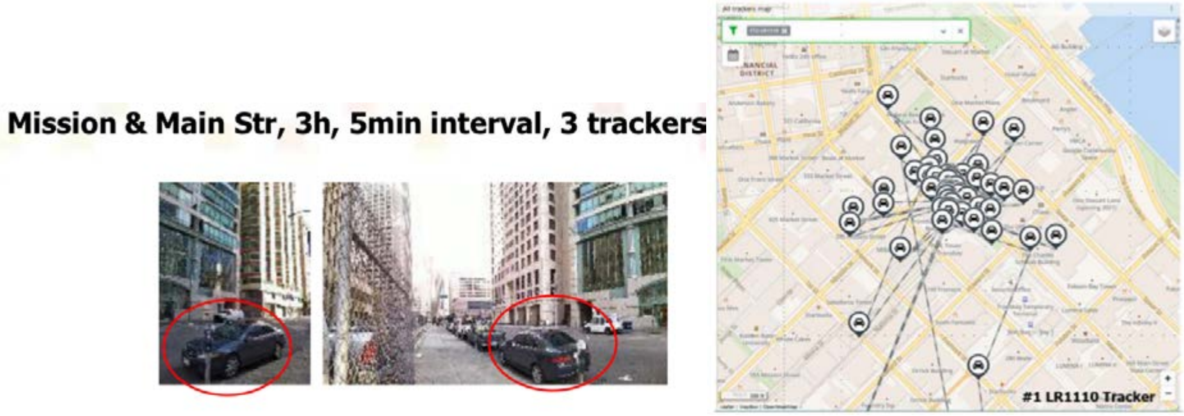


Figure 24. Test 7b Setup and Position Plot (36 points x 3 Trackers)

Location accuracy (m)	Patch antenna	PCB antenna
@50 % CDF	71.9	105.1
@80% CDF	147.4	222.2

Figure 25. Test 7b Results for 108 Data Points (Single Scan)

4.6 Test Case 8 (Urban-Canyon WiFi)

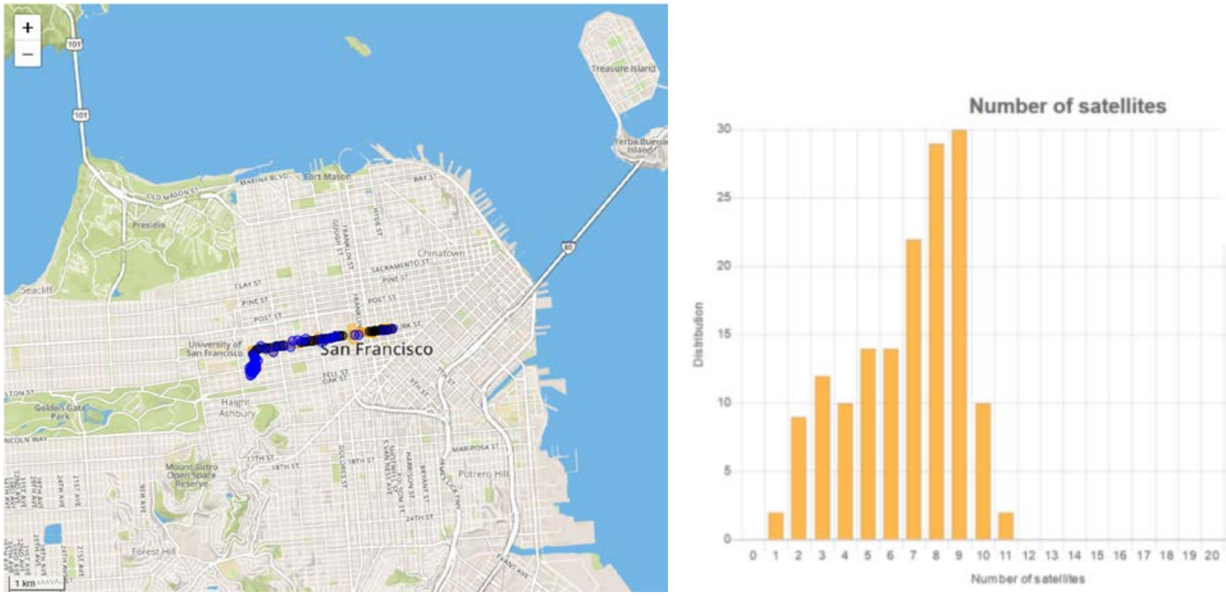
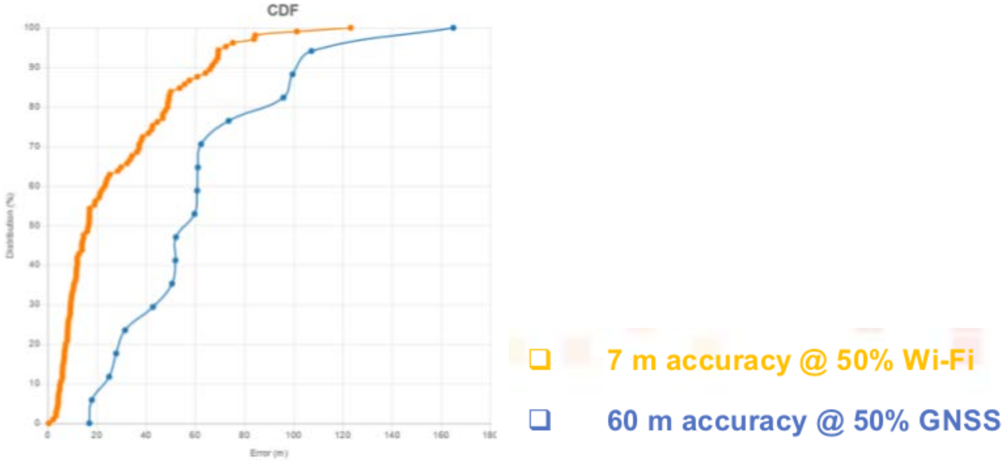


Figure 26. Test 8 Position Plot and Route with Number of GNSS Satellites Tracked



❑ 7 m accuracy @ 50% Wi-Fi

❑ 60 m accuracy @ 50% GNSS

Figure 27. Test 8 Results (150 points)

4.7 Analysis of the Captured Data

Test cases 1, 2 and 3 show that a substantial number of satellite measurements can be collected in a near open-sky condition. There is also significant improvement in location accuracy computations when it can be assumed that the receiver is stationary and the measurements can be collected over separate scans. It is also interesting to note that for both the LR1110 EVK and the Tracker form-factor EVK, when the device can be oriented with the patch facing upwards to the sky, the patch outperformed the PCB antenna in location performance. This is something to keep in mind when reviewing the multiple-orientation tests later on.

Test case 4 isolates BeiDou performance in China. The number of satellites in this test was smaller than the combined GPS+BeiDou of the first three tests, and the corresponding accuracy was lower as a result. Again, enabling multiple scans collected for the device with a stationary receiver performed extremely well for determining a static location.

Tests 5a and 5b investigate how the antenna orientation of the Tracker EVK impacts GNSS location performance for the two different antennas. The key observation here is the variation compared to the average. While the average error for the Patch antenna was lower, the PCB antenna showed less variability at both the 50% and 80% CDF measures. In the case of 80% CDF, the Patch antenna varies -7.7 to +4.6 m from the average, while the PCB varies only -0.8 to +1 m from the average. The interpretation of this result is that the PCB does not have any “preferred” direction, as opposed to the Patch antenna (which prefers to be pointed towards the sky). The Patch antenna has its highest gain when pointing upward and drops off significantly when it points off-axis. As a result, pointing the Patch antenna “away” from the sky significantly impacts its performance with respect to determining the location of a device. In contrast, because the PCB has no preferred orientation, it performs similarly well in every orientation. Another interesting observation about this data is that there is a noticeable degradation in location performance and solution availability when going from the relatively open sky conditions of 5a to the semi-urban conditions of 5b. This is a trend that was also observed in other test results.

Tests 6a and 6b provide data on combined GNSS performance information, at street-level in a semi-urban environment, for the two antennas in the Tracker EVK. The devices were placed on the top of a car under a plastic hood for weather protection. In this case only a single GNSS scan was used to compute the position solution and the results were degraded by about 50% relative to the mostly open-sky conditions of Tests 1, 2, and 3. This data was taken at ground-level with several nearby tall trees and buildings. These results suggest that there is a significant influence of buildings and trees in the position determination solution.

Tests 7a and 7b provide data on location performance of the Tracker EVK with combined GNSS performance in an urban-canyon environment. These test conditions are in the most challenging environment of all of the tests. In this case, only a single GNSS scan data was used and the performance metrics were substantially worse than for Tests 6a and 6b. The availability of the GNSS solutions (number of solutions per scan) dropped below 100% for this challenging urban environment. These test results show a continued trend of degradation in GNSS performance in increasingly urban environments.

Test 8 provides location performance data for Wi-Fi scans as compared to the performance of GNSS scans in an urban-canyon environment while a device is moving. As was noticed on the previous urban-canyon tests, the GNSS results (for a single scan) have a very large error radius. In comparison, the Wi-Fi location data has substantially fewer errors. Indeed, the Wi-Fi error rate is in-line with the best performance characteristics of open-sky GNSS results. This suggests a complementary nature of the two location estimates in different environments with GNSS performing well in open spaces and Wi-Fi doing substantially better in urban locales. It is important to note that the Wi-Fi availability was 100% in this test case.

5 Power-consumption Measurement Data

5.1.1 GNSS Scan Energy Consumed

As was previously discussed, Indoor/Outdoor classification can be performed with very low-power scans of GPS signals. The availability of high-power signals is a good indication that the receiver is located outdoors. The GNSS scans themselves consume very small amounts of power as well. This enables long battery life for devices determining their own location.

- A single GPS capture will consume 24.5 mJ of energy at the LR1110 when assistance data is up-to-date.
- The consumed energy for the device is 34.0 mJ when using recommended LNA and TXCO.

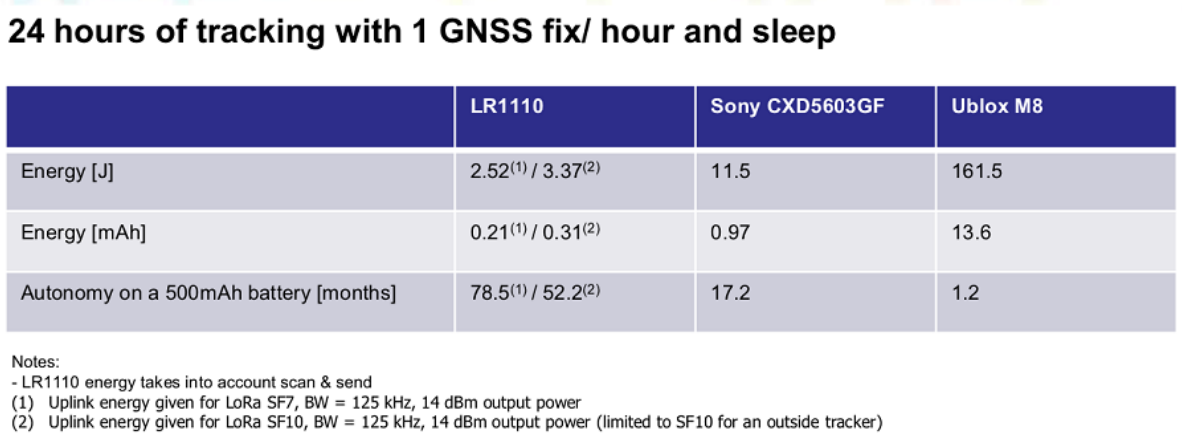
In our example, with a 100 mAh battery, you could perform $1.332\text{x}10^6$ /34.0= 39,176 GPS-only scans with that small battery. Similarly, the values for BeiDou-only scans are 34.2 mJ for the chip and 51.5 mJ for the entire device. When the two scans are performed together, the chip will use 24.5+34.2 mJ=58.7 mJ and the total process, including a necessary wait time when the LNA is turned off but the TCXO is powered between the two scans, will result in a total scan energy of 94.6 mJ.

Table 5. Comparison of Energy Consumed for GNSS Scan Types

	LR1110 Energy Consumed (mJ)	**LR1110+LNA+TCXO Energy Consumed (mJ)**
GPS-Only	24.5	34.0
BeiDou-Only	34.2	51.5
GPS+BeiDou Combined	58.7	94.6

It is important to understand that, while the energy consumed by the LR1110 is important, the total energy consumed in a real implementation (second column) is the critical factor in the consumption of power on the device.

Figure 28 shows a real-world example, where a comparison was made between the power consumption using the LR1110 (including the power to send the GNSS scan results) compared to two different GNSS solutions which solely compute location (with no allotment for sending results to the network). It is clear that, in terms of years of battery life, the LR1110 is at a strong advantage. The LR1110 boasts a battery life of between 10.4 and 15.7 months per 100 mAh, compared to 3.4 and 0.24 months per 100 mAh for comparative devices—devices that do not even send data.



24 hours of tracking with 1 GNSS fix/ hour and sleep

	LR1110	Sony CXD5603GF	Ublox M8
Energy [J]	2.52(1) / 3.37(2)	11.5	161.5
Energy [mAh]	0.21(1) / 0.31(2)	0.97	13.6
Autonomy on a 500mAh battery [months]	78.5(1) / 52.2(2)	17.2	1.2

Notes:
- LR1110 energy takes into account scan & send
(1) Uplink energy given for LoRa SF7, BW = 125 kHz, 14 dBm output power
(2) Uplink energy given for LoRa SF10, BW = 125 kHz, 14 dBm output power (limited to SF10 for an outside tracker)

Figure 28. Comparison of LR1110 Scan & Send vs. alternative GNSS local-compute (no send)

5.1.2 Wi-Fi Energy Consumed

As discussed in the GNSS and Wi-Fi Scan times and End-to-End Latency sections, the Wi-Fi scan time can vary quite widely depending on the settings chosen. We showed an example for the following test conditions:

- a busy channel
- a maximum MAC setting of 6
- 3 channels at 1,6 and 11
- 802.11b only
- beacon only;

This test resulted in a scan time less than 75 ms. The scan time results in an energy consumption of 2.5 mJ.

An interesting part of the Wi-Fi scan energy cost is that it usually takes more energy to send the scan results than to collect them in the first place.

6 Conclusions

The LoRa Edge Asset Management System with the LR1110 and LoRa Cloud services offers a compelling solution for location and data communications in one package. As discussed, the low-power GNSS and Wi-Fi scanning enable location applications that can last for years on a small battery. The combination of long-range communications with the localization capability puts everything in a single package on a mobile device with the LR1110. The LoRa Cloud services provide flexible location computation that can scale for single solutions or be combined in the network for enhanced position accuracy. The testing showed how multiple scans can be combined for a much more accurate GNSS fix in some applications where a static location is being computed.

We also provided data to show the advantages in position accuracy for a directional patch compared to an omni-directional PCB antenna, and how certain applications might benefit from using one versus the other. Real-world single-scan fixes have been shown to be as accurate as 7 meters CEP (50% CDF) for both GNSS and Wi-Fi.

In challenging environments where GNSS solution accuracy and availability are strained, the complementary Wi-Fi scan results have shown to be very accurate. Battery life estimates of more than 1 year per 100 mAh of battery capacity have been shown to be possible, while competitive offerings struggle to meet even a fraction of this. For system designers and architects, this solution offers a myriad of options to provide powerful and compelling solutions for your customers.

7 Revision History

Revision	Date	Applicable to	Modifications
1.0	Sep-2021		Initial Version

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