hellaPHY® OTDOA

A breakthrough positioning solution for IoT applications

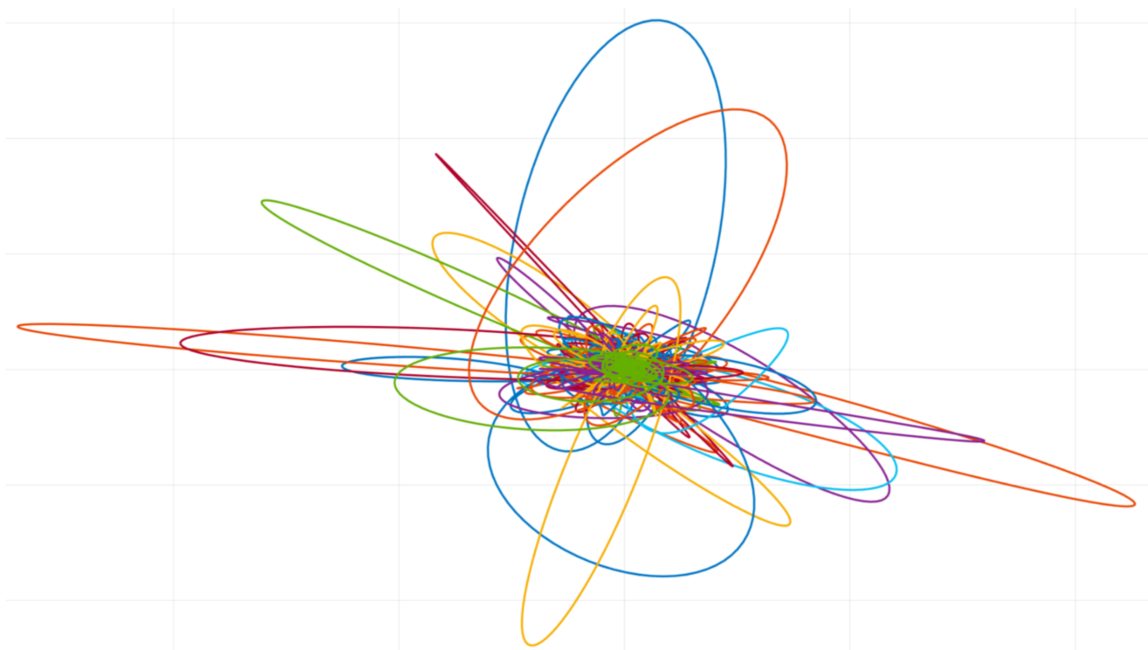

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Table of Contents

Executive Summary

Introducing hellaPHY® OTDOA from PHY Wireless, a breakthrough positioning solution for IoT

To achieve both data communications and positioning an existing IoT device might use an LTE modem for data, GPS for outdoor location, and WiFi for indoor location. An IoT device with hellaPHY OTDOA software eliminates the need for GPS and WiFi. Instead, positioning is performed using existing LTE signals. The reduction of components reduces cost and improves battery life.

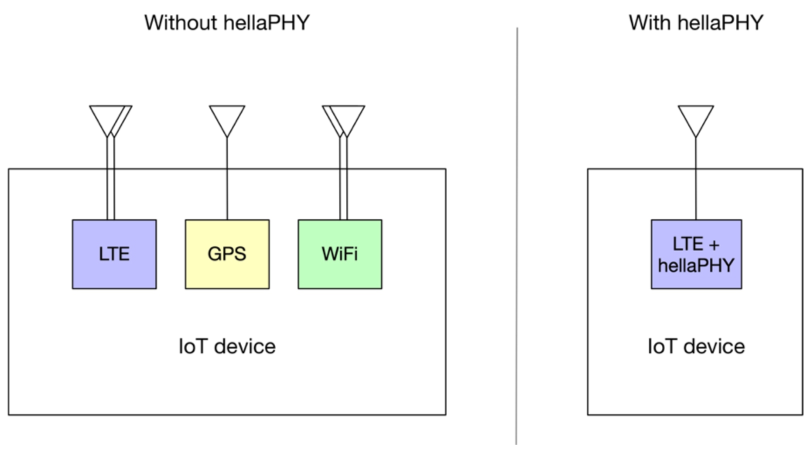

Figure 1: hellaPHY OTDOA eliminates components

hellaPHY OTDOA thus brings the power and scale of 4G-LTE cellular networks to the problem of the Location of Things. This offers an effective, low-cost solution for IoT applications.

hellaPHY OTDOA leverages existing downlink 4G-LTE positioning reference signals (PRS) as standardized by 3GPP Release 9. These terrestrial signals are typically 50dB more powerful than satellite GPS signals, offering a fast positioning fix for both indoor and outdoor applications.

hellaPHY OTDOA consists of advanced estimation and location algorithms designed to combat the degrading effects of multipath and interference routinely found in cellular environments.

Supporting the hellaPHY OTDOA protocol on the device is straightforward. It runs on an existing ARM processor, requiring only 6MHz of CPU bandwidth during a positioning session. The memory required is less than 100kB, and that is 1% to 2% the requirement for the standard LPP/SUPL protocol [2, 3, 5]. hellaPHY OTDOA is power efficient. It consumes 1/6th the energy of standard OTDOA and 1/60th the energy of GPS.

This paper describes the hellaPHY OTDOA system and analyzes these benefits.

System Architecture

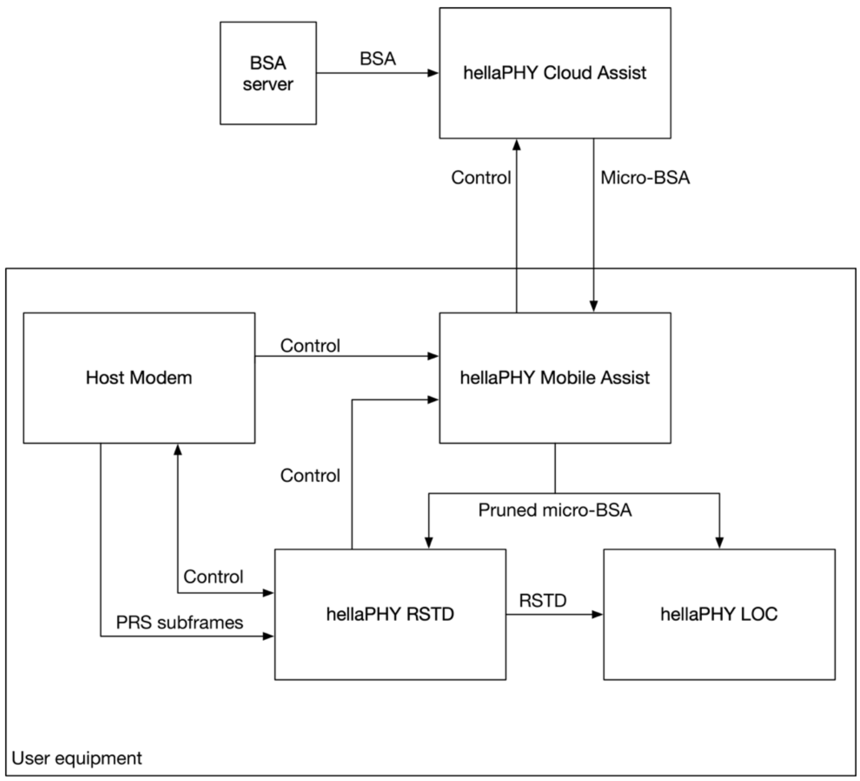

Figure 2: hellaPHY OTDOA system architecture

The hellaPHY OTDOA system architecture is shown in Figure 2. It consists of a cloud server **hellaPHY Cloud Assist** that provides micro-base station almanac (BSA) information to the user equipment (UE) device. The micro-BSA contains assistance data to perform the estimation and location algorithms on the device. **hellaPHY Mobile Assist** is software that runs on the device providing an optimized interface between the cloud and the UE. **hellaPHY RSTD** performs advanced reference signal time difference (RSTD) estimation designed to combat multipath and interference, and **hellaPHY LOC** performs hyperbolic time-difference of arrival (TDOA) estimation tailored for challenging cellular environments.

The interplay between the cloud and device software is optimized for performance and energy conservation.

hellaPHY OTDOA versus Standard OTDOA

OTDOA has been standardized in 3GPP since Release 9 [1]. The basic idea is as follows. Cells transmit PRS at regular intervals; for example, 1ms every 160ms. The target UE retrieves assistance data from a location server [2] then performs time-of-arrival (TOA) measurements of the surrounding cells using the downlink PRS. The UE RSTD algorithm selects one of the cells as the RSTD reference cell to form time-difference-of-arrival (TDOA) measurements:

$$RSTD_k = TOA_k - TOA_0$$

where TOA_k is the TOA estimate of the $k\mathrm{th}$ neighbor cell and TOA_0 is the TOA estimate of the RSTD reference cell. The RSTD measurements are then transmitted in the uplink back to the location server where the position of the UE is estimated. This standard method is called **UE-assisted OTDOA** since the UE assists the location server with RSTD measurements.

hellaPHY OTDOA has identified and solved three fundamental issues with standard OTDOA:

1. hellaPHY OTDOA avoids excessive uplink RSTD transmissions;
2. hellaPHY OTDOA RSTD measurements and position estimation is tightly coupled and optimized for performance and energy conservation; and
3. the hellaPHY OTDOA protocol is much lighter than the standard LPP/SUPL protocol [2, 3]

With standard OTDOA uplink RSTD transmissions shortens UE battery life and adds congestion to the network. hellaPHY OTDOA solves this problem by retaining the RSTD measurements on the device where the position estimation is also performed. This method is thusly called **UE-based OTDOA** since both the RSTD measurements and position estimation is performed on the UE. See Figure 3.

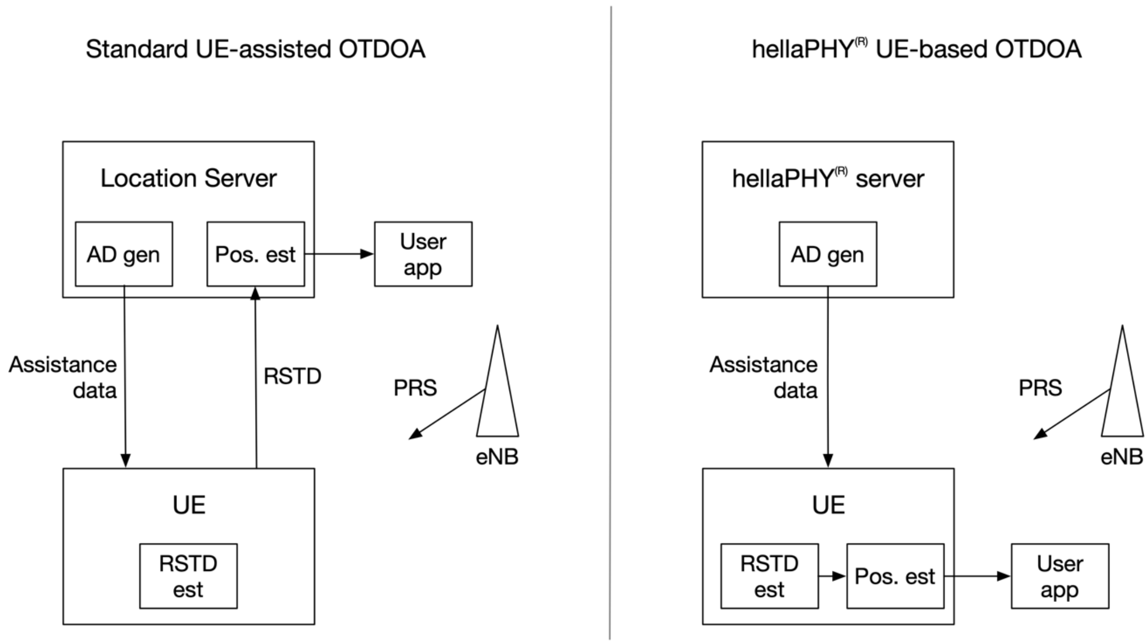

Figure 3: Standard UE-assisted OTDOA versus hellaPHY UE-based OTDOA

With standard OTDOA the RSTD measurements are performed by the UE vendor and the position estimation is performed by the location server vendor. To be certified by the mobile network operator, it is typically the case that the UE vendor RSTD measurement algorithm passes 3GPP minimum conformance tests. These tests, however, are based on ideal AWGN channel models [4]. AWGN channel models are useful for conformance testing since they are readily reproducible with laboratory test equipment. However, they do not capture the multipath degrading effects that impact OTDOA positioning accuracy.

It is therefore difficult for a mobile network operator to ensure OTDOA positioning accuracy based on UE conformance. This problem is amplified with the fact that there are no 3GPP conformance test for the position estimation done by the location server vendor. In short, there is no overall OTDOA accuracy conformance provided by 3GPP.

OTDOA positioning accuracy is greatly impacted by both the RSTD measurement quality and the position estimation quality. That is to say, a system with a good RSTD measurement quality provided by the UE vendor but a poor position estimation provided by the location server vendor will result in an under-performing system. The converse is of course true: a system with a sophisticated position estimation provided by the location server vendor coupled with minimal UE RSTD measurement quality will result in overall performance that falls short of expectations.

In other words, there is a division of responsibility in the signal processing task of OTDOA positioning shared between UE RSTD and location server position calculation. This leads to sub-optimal outcomes.

hellaPHY OTDOA solves this problem by coupling the RSTD measurements and position estimation. Having a single vendor responsible for the overall positioning accuracy leads to a better result than the current state of the art.

This solution has been tested extensively in both simulation and real-life network testing. This level of testing goes far beyond minimum AWGN conformance testing specified in 3GPP. The system is tested in simulation with realistic and challenging conditions. These conditions incorporate non-line-of-sight (NLOS) distortions, base station synchronization error, cell location error, and other factors that can greatly impair positioning performance. Moreover, the extensive live network testing provides invaluable insights for algorithm improvements. It has been observed, for example, that the common channel models used in academic and standards research studies are useful to a point, but fail to capture the subtleties that impact OTDOA performance. These common channel models (UMA, UMI, EPA, ETU, etc) have been developed historically for data communications analysis, but lack a positioning perspective.

In summary, and in response to issue 2 above, hellaPHY OTDOA provides a complete positioning solution that is optimized through extensive realistic testing.

Regarding issue 3, the hellaPHY OTDOA protocol is optimized for IoT applications. In [5] it is reported that a standard SUPL/LPP implementation requires 5MB to 10MB of memory. This inefficiency is credited to historical aspects of the protocol, and is difficult to resolve in the standards due to requirements to support legacy solutions across a wide range of use cases that do not pertain to IoT. In contrast, the hellaPHY OTDOA protocol is specially-tailored for IoT applications. UE support for the hellaPHY OTDOA protocol requires only 100kB. Thus, hellaPHY OTDOA is 50x to 100x lighter than standard LPP/SUPL.

The hellaPHY OTDOA protocol can be optimized for low latency applications. Consider the use case of geo-fencing. The target device is in some bounded geographical area, and an application alerts the user when the device extends beyond the region. In this use case the fixed geographical area and the semi-fixed BSA assistance data for the cells in the area is exploited by the hellaPHY OTDOA protocol. BSA assistance data is loaded via the hellaPHY Cloud Assist server and retained on the device, and the position estimate is regularly updated. After a startup period, the UE becomes location-aware and can quickly alert the user application when the target device extends beyond the specified location. This can be done with minimal interaction with the network since RSTD measurements are not transmitted in the uplink with each position estimate update.

Performance and energy consumption

Figure 4 shows the position accuracy of a Rel-13 Cat-M1 UE using Rel-13 PRS with $N_{\text{PRS}} = 1$ ms PRS occasions transmitted every $T_{\text{PRS}} = 160$ ms. See Appendix A for simulation details.

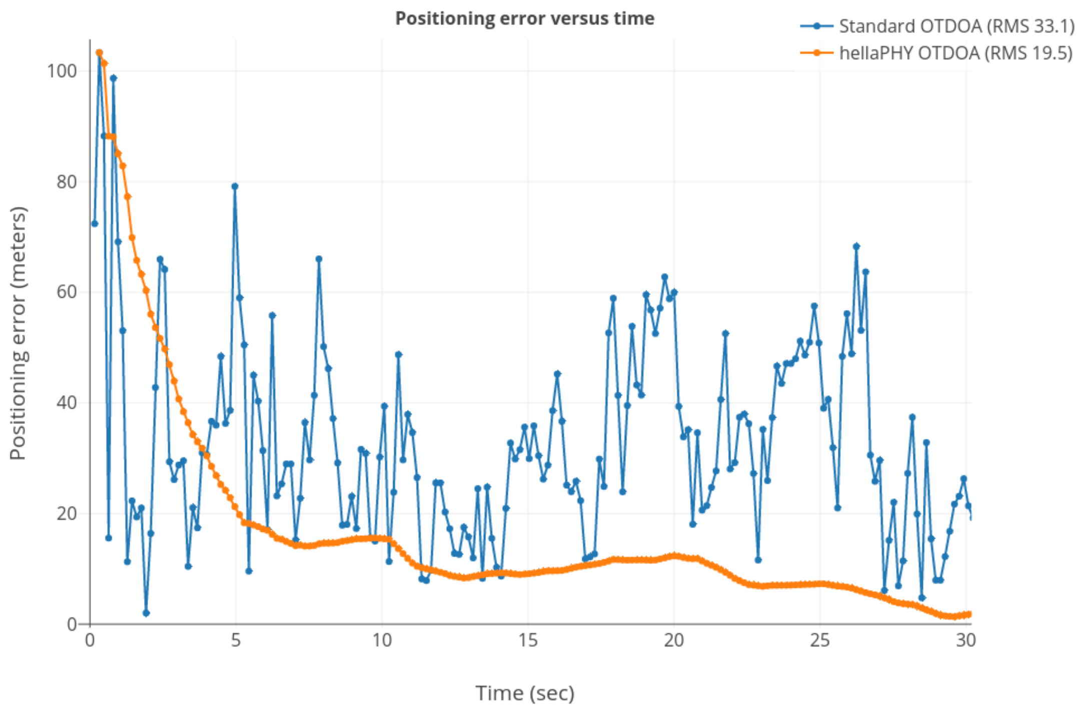

Figure 4: Cat-M1 performance of standard OTDOA versus hellaPHY OTDOA

In this result, hellaPHY OTDOA is compared to a standard OTDOA baseline. The baseline algorithm uses a max-peak TOA algorithm, a highest-estimated SINR cell for the RSTD reference cell, and the Gaussian maximum likelihood with Taylor-series expansion (GML-TE) TDOA position algorithm [6]. The hellaPHY OTDOA result uses a variety of tightly coupled proprietary algorithms. The synergistic on-chip interplay between hellaPHY RSTD and hellaPHY LOC is demonstrated. A fundamental feature of this interplay is *multi-shot position estimation.*

Single-shot versus multi-shot position estimation

Single-shot position estimation (SSPE) is a method where a single set of RSTD measurements are used to estimate the UE position. Multi-shot position estimation (MSPE) introduces memory to the signal processing, updating the position estimate across multiple RSTD measurements. Multi-shot can outperform single-shot since random variations in the measurements can be accounted for with adaptive filtering and machine learning algorithms.

Figure 4 demonstrates the convergent behavior of hellaPHY MSPE. Position error is reduced from 100m at the start of the session to 20m at 5s into the session, then maintains sub-20m error beyond 5s. Contrast this to the SSPE performance of the standard OTDOA result. In this case a new position estimate is performed each PRS occasion with the current snapshot of RSTD measurements. The SSPE method therefore has no memory from PRS occasion to PRS occasion. This results in an erratic position estimate across time that does not converge. For example, if the UE reports RSTD to the location server at 5s, the error is 80m; but if it reports at 7s, the error is 15m; and if it reports at 8s, the error is 50m; etc.

Standard UE-assisted OTDOA may perform MSPE for better convergence. However, this further increases uplink RSTD transmissions both wasting UE energy consumption and further congesting the network. For example, a typical uplink RSTD transmission consists of 1600 channel bits and a typical UE uplink grant is 140 channel bits per 1ms subframe. Therefore, to convey the RSTD report to the location server requires $\lceil 1600/140 \rceil = 12$ ms of uplink transmission. To be on par with hellaPHY UE-based OTDOA, the 12ms uplink RSTD transmissions must be performed every $T_{\mathrm{PRS}} = 160$ ms. Over a 5s positioning session, UE-assisted MSPE OTDOA consumes 6.5x more energy the hellaPHY UE-based OTDOA. See Appendix B for details on this analysis. The overall result is summarized in Figure 5.

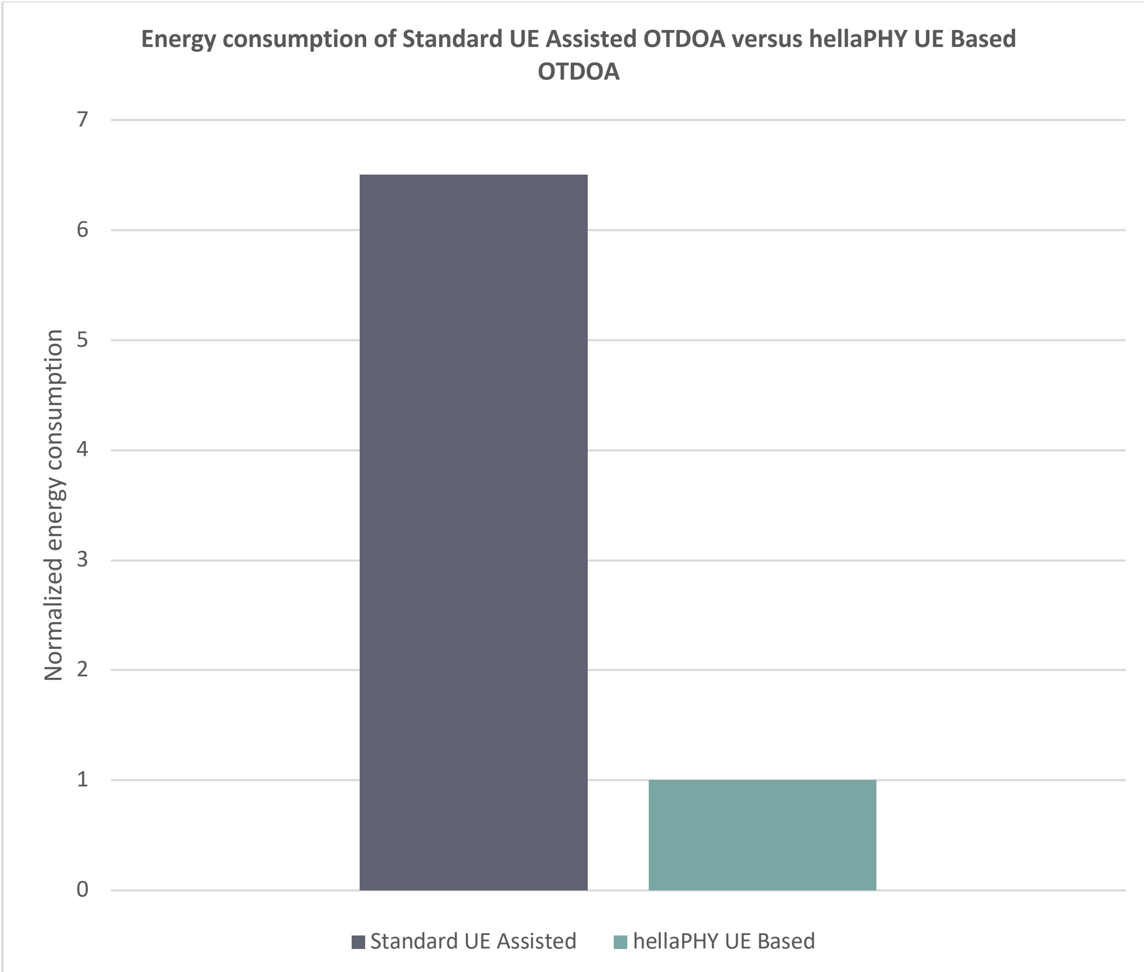

Figure 5: Energy consumption across a 5s positioning session

On-network testing

hellaPHY OTDOA is the result of extensive and on-going live network testing. Figure 6 shows an example result. For this indoor test, the position estimate is around 20 meters in error.

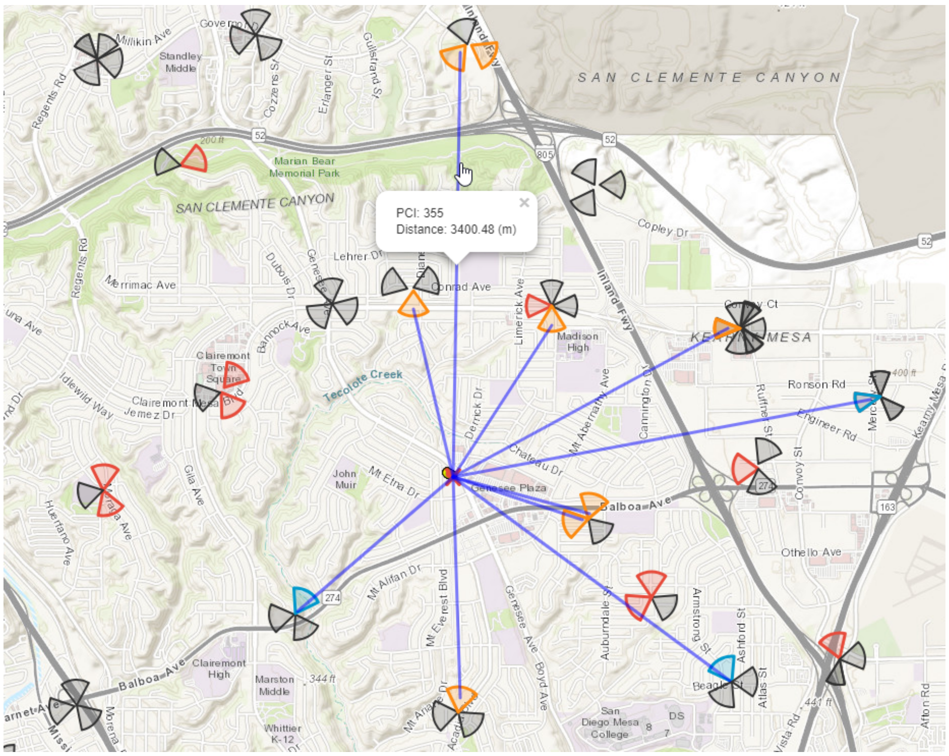

Figure 6: On-network testing of hellaPHY OTDOA

In a recent Tier-1 mobile network operator trial, a Cat-M1 UE with hellaPHY OTDOA was tested against a Cat-1 UE with standard OTDOA. The trial was conducted in dense urban (Manhattan, New York City), rural New Jersey, and suburban (San Diego, CA) environments both indoor and outdoor. The Cat-1 UE baseline makes use of the full 50 resource block system bandwidth and two receive antennas. The Cat-M1 UE with hellaPHY OTDOA is limited to 6 resource blocks and has a single receive antenna. The baseline Cat-1 device therefore has access $50 \times 2 / 6 \approx 16$ times more signals than the Cat-M1 hellaPHY OTDOA device. With only 6% as many signals hellaPHY OTDOA outperforms the reference device by a factor of 3.7.

Table 1: Tier-1 mobile network operator trial results

Reference device	Cat-1 UE with Standard OTDOA
Test device	Cat-M1 UE with hellaPHY OTDOA
Signal availability of test device versus reference device	1/16 = 6%
Operational environment	Dense urban (Manhattan, New York City); rural New Jersey; suburban San Diego, CA
PRS deployment	Rel-13, 1ms PRS transmitted every 160ms
hellaPHY position accuracy gain factor	3.7

Sparse PRS support

Observe that the on-network testing results show a Cat-M1 hellaPHY OTDOA device outperforming a Cat-1 standard OTDOA device on a Release 13 PRS deployment.

Release 13 PRS is considered "Sparse PRS" relative to the PRS enhancements that have been agreed for 3GPP Release 14. From Release 9 to Release 13, PRS density ranges from 1ms every 1280ms (0.07%) to 6ms every 160ms (3.75%). In Release 14, "Dense PRS" is supported for increased PRS density, up to 100% PRS. The motivation for the Dense PRS feature is to better support Cat-M1 devices. Since the Cat-M1 device is limited to 6 resource blocks in bandwidth and 1 receiver antenna, it has a lower sensitivity than a higher category device that makes use of the full system bandwidth (ie, 50 resource blocks) and has two or more receiver antennas. The idea with Dense PRS is to therefore improve Cat-M1 cell detectability by adding more time support.

However, this increased time support for positioning reference signals comes at the cost of decreased data capacity on the network. As spectrum is a scarce resource, network operators are generally reluctant to make modifications to the network that degrade capacity.

Therefore, a Cat-M1 OTDOA solution that does not require the network modifications and data capacity reductions inherent to a Dense PRS rollout is of interest to a mobile network operator.

Idle Mode support

For a standard LTE OTDOA session, the UE is in RRC connected mode. Once the UE retrieves assistance data over LPP/SUPL, it then performs RSTD measurements that are then reported back to the location server through uplink transmissions. During the RRC connected state, the UE monitors control channels to determine if and when data is scheduled.

The hellaPHY OTDOA protocol supports positioning in both the RRC connected mode and the RRC idle mode. This is a helpful feature for power-constrained IoT applications since the UE can consume less power in idle mode using eDRX/PSM for multi-year battery life.

Considering again the geo-fencing use case where a device periodically updates its position to test if it has roamed outside its given area. Once it has received assistance data from hellaPHY Cloud Assist (in RRC connected mode), it enters an aggressive power savings mode using eDRX/PSM features. hellaPHY OTDOA then updates its position estimate periodically by processing the downlink PRS subframes. To maximize battery life, it might do this infrequently, like once every 5 or 10 minutes. If a position change is detected, the UE then returns to RRC connected mode to report status to the user application.

hellaPHY OTDOA versus GPS

GPS is a satellite-based positioning method offering high precision accuracy for outdoor environments when the receiver has a clear line-of-site (LOS) view of the sky. It is considered the gold standard positioning method, and is in widespread use for a variety of use cases including vehicle navigation, smartphones, etc.

GPS has its limitations, however, particularly for IoT use cases. First, indoor coverage is problematic, as is performance in urban canyons characterized by multipath channel distortion. IoT devices that operate in these environments may not have a functioning GPS feature. Second, GPS circuity adds additional costs to receivers. For low-cost IoT applications this added cost may not be acceptable. Third, GPS is a power-hungry feature that drains batteries. For IoT application that require long battery life (ie, multi-year), GPS may not be viable.

These areas of weakness for GPS are areas of strength for hellaPHY OTDOA. First, hellaPHY OTDOA is based on LTE OFDM technology that is designed for robust multipath operation both indoor and outdoor. Second, additional cost to the receiver is minimal. This cost is low since hellaPHY OTDOA reuses the existing LTE radio components, unlike GPS that requires its own radio components. Third, hellaPHY OTDOA is highly power efficient allowing for long battery life operation.

Energy consumption analysis

The distance between a GPS satellite and the UE is roughly 20,000km. Consequently, the received GPS signal power is very low, around 15dB below the thermal noise floor [8]. To overcome the low received power, the GPS signal is a direct-sequence spread spectrum (DSSS) waveform occupying roughly 1MHz with an underlying bit rate of 50 bits per second. The processing gain is therefore roughly

$$10\log_{10}\left(\frac{1\mathrm{e}6}{50}\right) = 43 \text{ dB}$$

With the processing gain, the achievable receiver SNR is around $-15+43=28$ dB.

An LTE base station (eNB) is much closer to the UE than a GPS satellite, on the order of 1km. This results in an LTE received signal power that is much higher than the received signal power of GPS. For example, a typical received power of a 46dBm 10MHz eNB transmission undergoing a 115dB path loss is

$$46-10\log_{10}(10\mathrm{e}6)-115+174=35 \text{ dB}$$

above the -174dBm/Hz thermal noise floor. This is around 50dB higher than the received GPS signal power as shown in Figure 7.

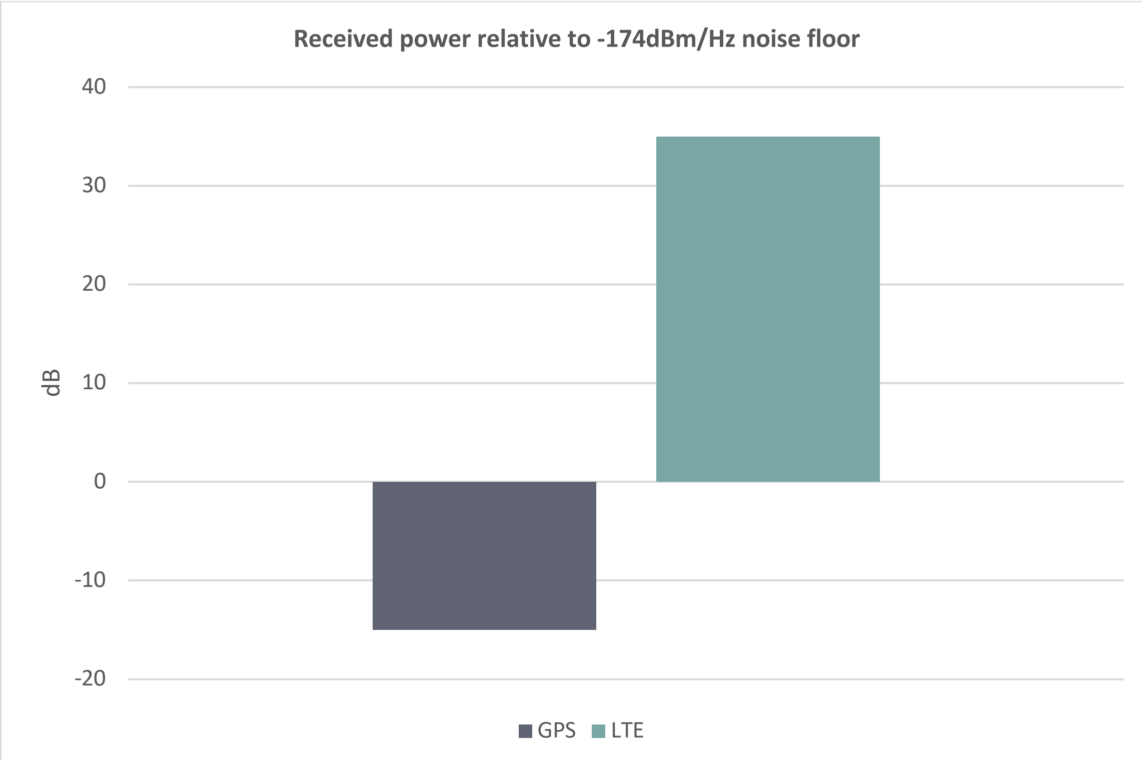

Figure 7: A typical received LTE signal is roughly 35dB above the thermal noise floor, while a typical received GPS signal is roughly 15dB below. This 50dB difference impacts the receiver processing energy consumption of the two methods

In terms of waveform design, LTE is based on orthogonal frequency division multiplexing (OFDM), a format designed for robust operation in non-line-of-sight (NLOS) multipath environments.

These signal differences impact the energy consumption of the two methods. Consider the 5s positioning session depicted in Figure 8. GPS requires continuous processing across the 5s duration to recover the DSSS signal. On the other hand, hellaPHY OTDOA performs burst processing of the OFDM signal. The burst processing is possible since only the PRS occasions are considered. In this example the typical PRS configuration of $N_{\mathrm{PRS}} = 1$ ms PRS occasions transmitted every $T_{\mathrm{PRS}} = 160$ ms is applied.

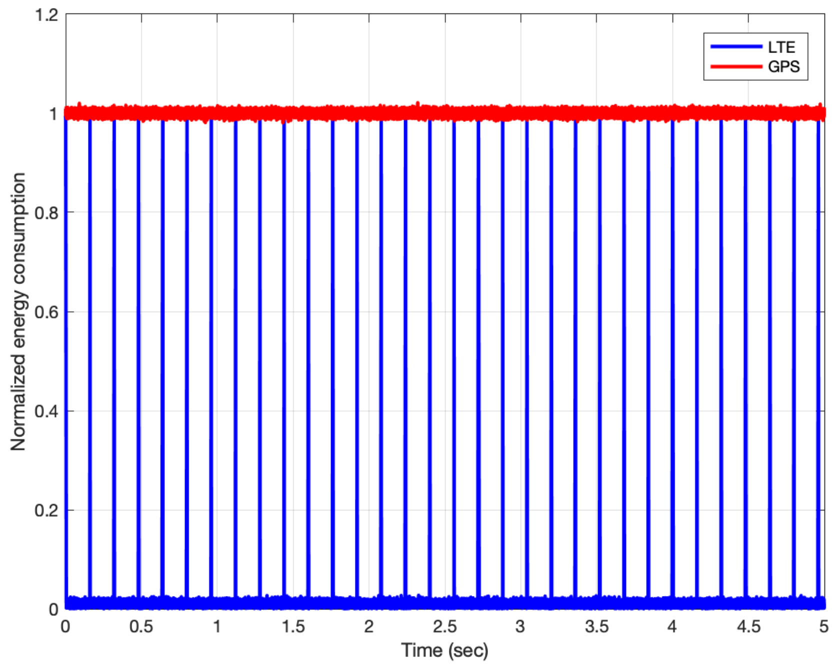

Figure 8: Continuous GPS processing versus burst LTE processing over a 5-second positioning session

To quantify the advantage, suppose the energy consumed for the GPS signal processing is $E_{\mathrm{RX,GPS}}$ joules per 1ms. Then suppose the energy consumed for the LTE PRS bursts is $E_{\mathrm{RX,LTE,A}} = F_A E_{\mathrm{RX,GPS}}$ per 1ms, and the energy consumed in between PRS bursts is $E_{\mathrm{RX,LTE,B}} = F_B E_{\mathrm{RX,GPS}}$ where F_A and F_B are scaling factors. The burst processing is such that $E_{\mathrm{RX,LTE,A}} \geq E_{\mathrm{RX,LTE,B}}$. Over a 5000ms positioning session the GPS receiver processing consumes

$$E_{\mathrm{GPS,total}} = 5000 E_{\mathrm{RX,GPS}}$$

joules. Over the same period of time, 32 PRS bursts are processed by hellaPHY OTDOA and the remaining 4968ms in in the lower energy consumption mode. This totals

$$E_{\mathrm{LTE,total}} = 32 E_{\mathrm{RX,LTE,A}} + 4969 E_{\mathrm{RX,LTE,B}} = \left(32 F_A + 4968 F_B\right) E_{\mathrm{RX,GPS}}$$

joules. The fractional energy difference

$$G = \frac{E_{GPS,total}}{E_{LTE,total}} = \frac{5000}{(32F_1 + 4968F_2)}$$

therefore depends on the scaling factors F_A and F_B. Table 2 shows that hellaPHY OTDOA consumes 61 times less energy than GPS with $F_A = 1$ and $F_B = 1/100$.

Table 2: Energy consumption analysis

F_A	1
F_B	1/100
hellaPHY OTDOA gain over GPS, *G*	61

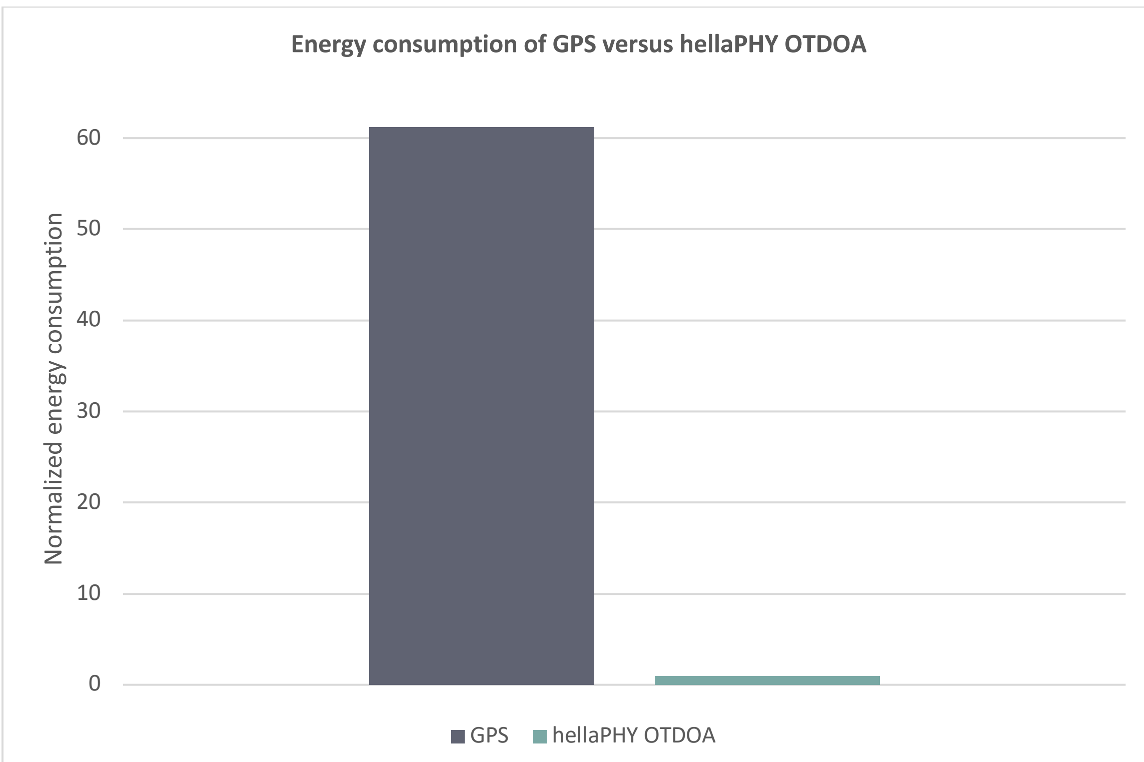

Figure 9: Energy consumption across a 5s positioning session normalized to $E_{\mathrm{LTE,total}}$

Appendix A: Simulation details

The simulation result in this document adopt the outdoor macro cell network parameters from the 3GPP Technical Report 37.857: "Study on indoor positioning enhancements for UTRA and LTE". Table 3 lists key parameters.

Table 3: Simulation parameters

Layout	19-site hexagonal layout with 500-meter inter-site distance, 3 cell sectors per site
System BW	10MHz
Carrier frequency	2GHz
Total BS TX power	46dBm
Distance-dependent path loss	3D-UMA
Fast fading channel between eNB and UE	3D-UMA
UE speed	3km/h
PRS muting	Random 16 bits
PCI planning	Yes

Note that the UE assumptions for 3GPP TR 38.857 is Category 1 and above, where the UE has two receiver antennas and the ability to process the full PRS bandwidth. The results in the current document are for a Category M1 UE having a single receiver antenna and is bandwidth limited in that it can only process six resource blocks per PRS occasion.

Appendix B: OTDOA energy consumption analysis

Consider a UE that consumes E_R joules for the active reception and processing of a 1ms subframe, and E_T joules for the active processing and transmission of a 1ms subframe. During inactivity the UE consumes E_0 joules per 1ms. This UE is to be located using one of two methods:

- Method 1: Standard UE-assisted OTDOA.
  - Step 1.1: The UE receives $N_{\mathrm{AD},1}$ ms of assistance data from the location server.
  - Step 1.2: The UE receives N_{PRS} ms of positioning reference signals from surrounding cells every T_{PRS} ms.
  - Step 1.3: Every T_{PRS} ms the UE transmits $N_{\mathrm{meas},1}$ ms of RSTD measurement data to the location server where the position estimate of the device is updated.
  - Step 1.4: This process continues for the duration of the positioning session $T_{\mathrm{POS}} = N_{\mathrm{POS}} T_{\mathrm{PRS}}$ ms.
  - Step 1.5: At the end of the positioning session a user application retrieves the position estimate from the location server.
- Method 2: hellaPHY UE-based OTDOA.
  - Step 2.1: The UE receives $N_{\mathrm{AD},2}$ ms of assistance data from the location server.
  - Step 2.2: The UE receives N_{PRS} ms of positioning reference signals from surrounding cells every T_{PRS} ms.
  - Step 2.3: Every T_{PRS} ms the RSTD measurements are retained on the device where the position estimate is updated.
  - Step 2.4: This process continues for the duration of the positioning session $T_{\mathrm{POS}} = N_{\mathrm{POS}} T_{\mathrm{PRS}}$ ms.
  - Step 2.5: At the end of the positioning session the UE transmits $N_{\mathrm{meas},2}$ ms of position estimate data to the location server.

- Step 2.6: At the end of the positioning event a user application retrieves the position estimate from the location server.

The energy consumed by the UE for Method 1 is

$$E_{\mathrm{POS},1} = E_R\left(N_{\mathrm{AD},1} + N_{\mathrm{PRS}}N_{\mathrm{POS}}\right) + E_T N_{\mathrm{meas},1} N_{\mathrm{POS}} + E_0 N_{0,1}$$

joules where $N_{0,1}$ is the number of non-active subframes during the positioning session. The energy consume by the UE for Method 2 is

$$E_{\mathrm{POS},2} = E_R\left(N_{\mathrm{AD},2} + N_{\mathrm{PRS}}N_{\mathrm{POS}}\right) + E_T N_{\mathrm{meas},2} + E_0 N_{0,2}$$

joules where $N_{0,2}$ is the number of non-active subframes during the positioning session.

In this model, it is assumed that the energy consumed during an active transmission is related to the energy consumed during an active reception as

$$E_T = M_T E_R$$

where M_T is a scaling factor. Likewise, it is assumed that the energy consumed during inactivity is related to the energy consumed during an active reception as

$$E_0 = M_0 E_R$$

where M_0 is another scaling factor. Thus, the energy consumed by the UE for Method 1 normalized to E_R is

$$\frac{E_{\mathrm{POS},1}}{E_R} = N_{\mathrm{AD},1} + N_{\mathrm{PRS}}N_{\mathrm{POS}} + M_T N_{\mathrm{meas},1} N_{\mathrm{POS}} + M_0 N_{0,1}$$

and for Method 2 is

$$\frac{E_{\mathrm{POS},2}}{E_R} = N_{\mathrm{AD},2} + N_{\mathrm{PRS}}N_{\mathrm{POS}} + M_T N_{\mathrm{meas},2} + M_0 N_{0,2}$$

The comparative energy consumption between the two methods therefore depends on the time required to receive and transmit the various data elements. This time depends on the data payload size and the capacity of the communications link. These aspects are considered next.

Data payload size analysis

Assistance data for Method 1

Rel-13 LTE Positioning Protocol [2] is used for a baseline for the Method 1 assistance data. Table 4 shows the calculation of 4120 channel bits (including FEC).

Table 4: Rel-13 LPP as baseline for Method 1 assistance data

Assistance data size				
OTDOA-ReferenceCellInfo				
LPP IE	**Common name**	**Num. possibilities**	**Num. bits**	**Note**
physCellID	PCI	504	9	
cellGlobalId	ECGI	0	0	Optional, not included
antennaPortConfig		2	1	
cpLength	CP	2	1	
prs-Bandwidth		6	3	
prs-ConfigurationIndex	I_PRS	4096	12	
numDL-Frames	N_PRS	4	2	
po16-r9	Muting bits	65536	16	Worst case.
Total bits			44	
OTDOA-NeighbourCellInfoList				
physCellID	PCI	504	9	
cellGlobalId	ECGI	0	0	Optional, not included
antennaPortConfig		2	1	
cpLength	CP	2	1	
prs-Bandwidth		6	3	
prs-ConfigurationIndex	I_PRS	4096	12	
numDL-Frames	N_PRS	4	2	
po16-r9	Muting bits	65536	16	Worst case
slotNumberOffset		20	5	
prs-SubframeOffset		1280	11	
expectedRSTD		16384	14	
expectedRSTD-Uncertainty		1024	10	
Total bits			84	
Assistance data totals				
Max. num. neighbor cells	24			
Max. num. bits	2060			

Margin, including FEC (%)	100			
Total max. num. FEC bits	4120			

Measurement data for Method 1

Rel-13 LTE Positioning Protocol [2] is used for a baseline on the Method 1 measurement data. Table 5 shows the calculation of 1642 channel bits (including FEC).

Table 5: Rel-13 LPP as baseline for Method 1 measurement data

Measurement data size		
OTDOA-SignalMeasurementInformation		
LPP IE	**Num. possibilities**	**Num. bits**
systemFrameNumber	1024	10
physCellIdRef	504	9
OTDOA-MeasQuality		10
Total bits		29
NeighbourMeasurementList		
physCellIdNeighbour	504	9
rstd	12712	14
OTDOA-MeasQuality		10
Total bits		33
Measurement data totals		
Max. num. neighbor cells		24
Max. num. bits		821
Margin, including FED (%)		100
Total max. num. FEC bits		1642

Assistance data for Method 2

The Method 2 assistance data assumes the same assistance data from Method 1 plus additional items that enable UE-based OTDOA. Table 6 shows the calculation of 6920 channel bits (including FEC).

Table 6: Method 2 assistance data payload size using Method 1 plus additional items

Additional assistance data for UE-based OTDOA		
Item	**Num. bits**	**Notes**
Latitude	14	Supports +/-90 with 6 fractional bits, sub-meter granularity
Longitude	15	Supports +/-180 with 6 fractional bits, sub-meter granularity
Altitude	15	Supports a 30km vertical range
Aperture width	6	10 degree granularity
Orientation	6	10 degree granularity
Total bits	56	
Assistance data for UE-based OTDOA totals		
Max. num. neighbor cells	24	
Max. num. bits	3460	
Margin, including FEC (%)	100	
Total max. num. FEC bits	6920	

Measurement data for Method 2

For Method 2, the uplink measurement data is the latitude/longitude position estimate. From Table 3, this information requires 29 bits. With a 100% margin, include FEC, the requirement is 58 bits.

Communication link capacity

For this analysis 1412 channel bits per ms is assumed as shown in Table 7. This assumes a Cat-M1 6RB device with QPSK subcarrier modulation.

Table 7: Data capacity assumption

Per subframe data capacity (Cat-M1)		
Parameter	**Value**	**Notes**
Num. RBs	6	
Num. REs per subframe	1008	
Data efficiency	0.7	1 minus this number is due to control/pilot overhead
Num. data REs per subframe	706	
Num. bits per data RE	2	FEC-encoded bits
Num. bits per subframe	1412	

Comparative energy consumption analysis

Consider a 5-second positioning session where the UE is granted 10% of the communication link capacity. Table 8 shows that Method 1 consumes 6.5x more energy than Method 2.

Table 8: Scenario 1: 5-second position session

	Method 1	**Method 2**
Data RE access (%)	10	10
Num. UE bits per ms	141	141
$M_T = E_T / E_R$	2	2
$M_0 = E_0 / E_R$	1/100	1/100
N_{PRS}	1	1
T_{PRS}	160	160

N_{POS}	32	32
T_{POS}	5120	5120
N_{AD}	30	50
N_{meas}	12	1
$N_{\mathrm{meas\ total}}$	384	1
N_0	4674	5037
E_{POS} / E_R	877	134
E_{POS} / E_R normalized	6.5	1

To further illustrate the energy consumption advantage, Figure 10 shows simulated energy consumption of the two methods using the assumptions from Table 8. Figure 11 is a zoomed-in version of Figure 10 illustrating the extra energy consumed in the uplink transmissions of the RSTD measurements. Figure 12 shows the accumulated energy consumption of the curves from Figure 10, and Figure 13 shows the ratio of the two curves from Figure 12 showing how the gain of Method 2 grows with time.

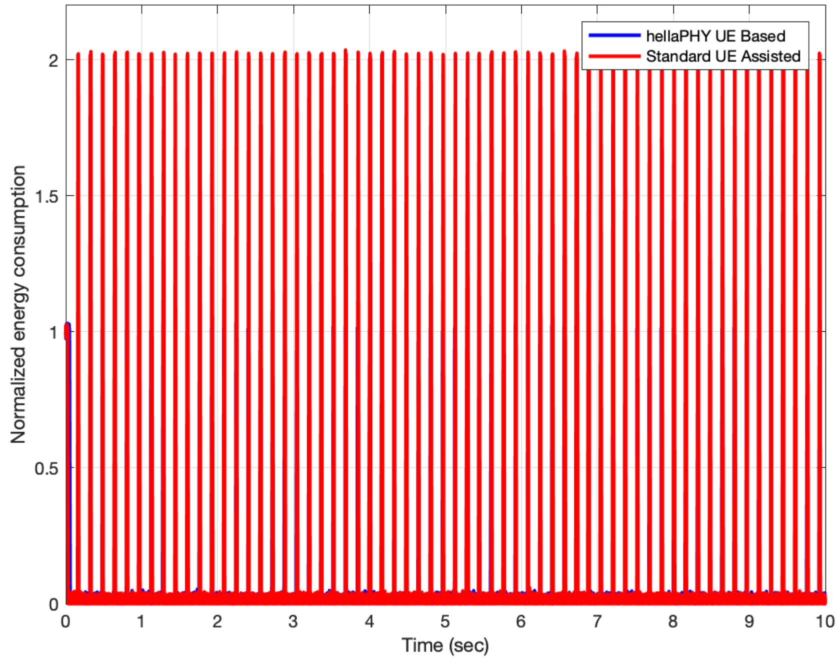

Figure 10: Simulated energy measurements of Method 1 Standard UE-Assisted OTDOA and Method 2 hellaPHY UE-Based OTDOA

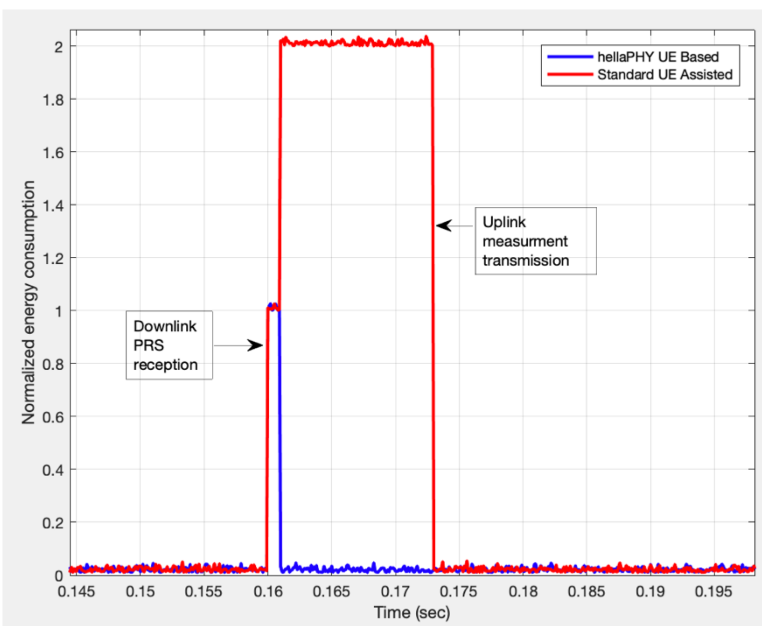

Figure 11: A zoomed-in version of Figure 8 illustrating the extra energy consumed in the uplink transmissions of the RSTD measurements

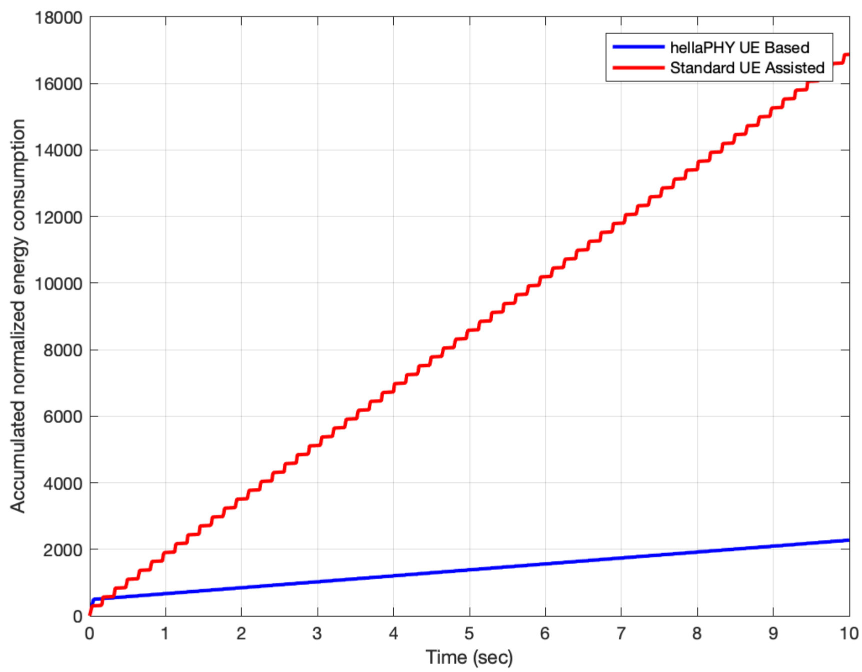

Figure 12: The accumulated energy consumption of the curves from Figure 8.

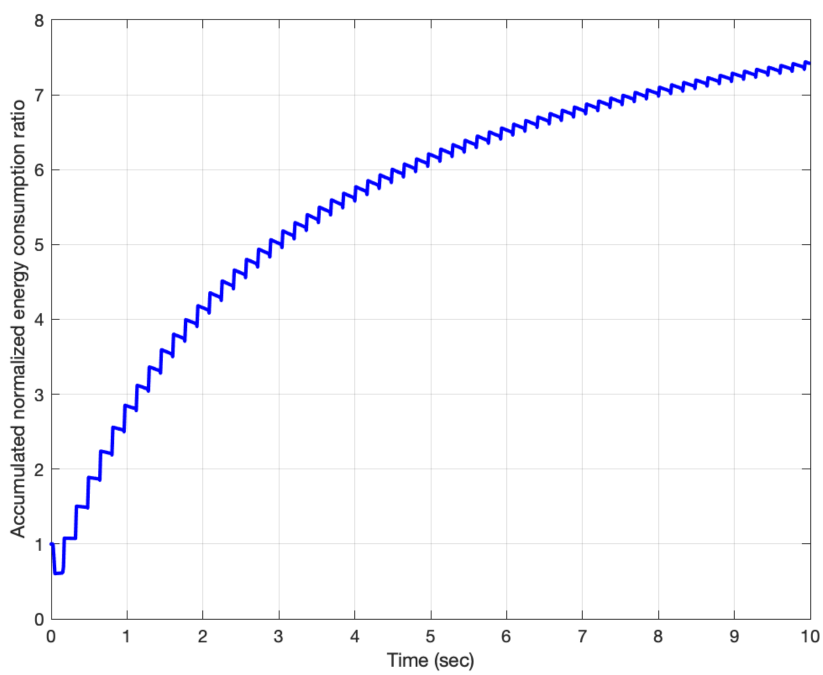

Figure 13: Method 1 standard UE-assisted OTDOA energy consumption relative to Method 2 hellaPHY UE-based OTDOA energy consumption. The ratio of the two curves in Figure 10

Abbreviations

For the purposes of the present document, the following abbreviations apply.

3GPP	3rd generation partnership project
AD	Assistance data
BSA	Base station almanac
DSSS	Direct-sequence spread spectrum
eDRX	Extended discontinuous reception
EPA	Extended pedestrian A
EVA	Extended vehicular A
FEC	Forward error control
FFT	Fast Fourier transform
GML-TE	Gaussian maximum likelihood with Taylor-series expansion.
GPS	Global positioning system
GNSS	Global navigation satellite system
IoT	Internet of things
LOS	Line of sight
LoT	Location of things

LPP	LTE positioning protocol
MCU	Microcontroller
MEO	Medium Earth orbit
MNO	Mobile network operator
MSPE	Multi-shot position estimation
NLOS	Non line of sight
OFDM	Orthogonal frequency division multiplexing
OTDOA	Observe time difference of arrival
OTT	Over the top
PRS	Positioning reference signal
PSM	Power save mode
RB	Resource block
RSTD	Reference signal time difference
SNR	Signal to noise ratio
SSPE	Single-shot position estimation
SUPL	Secure user-plane location architecture
TDOA	Time difference of arrival

TR	Technical report
UE	User equipment
UMA	Urban macrocell
UMI	Urban microcell

References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

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[5] RP-170662: "Motivation for Higher Layers Positioning Enhancement for IoT", Sequans Communications, 3GPP TSG RAN Meeting #75, Dubrovnik, Croatia, March 6—9, 2017

[6] D. J. Torrieri, "Statistical Theory of Passive Location Systems," *IEEE Trans. On Aerospace and Electronic Systems*, AES-20(2):183-198, Mar. 1984

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[8] B. W. Parkinson, J. J. Spilker Jr, et al, *Global Positioning System: Theory and Applications, Volume 1,* Progress in Astronautics and Aeronautics, 1996