POWER-EFFICIENT POSITIONING FOR THE INTERNET OF THINGS

MERGING GNSS WITH LOW-POWER CONNECTIVITY SOLUTIONS

WHITE PAPER

GALILEO EGNOS
NAVIGATION MADE IN EUROPE

European Global Navigation Satellite Systems Agency

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

01 INTRODUCTION

The world is embracing Internet of Things (IoT) applications. Billions of internet-connected devices are capable of sensing, communicating, interacting, computing and actuating, and are set to become even more integrated into our daily lives. By 2022, around 18 billion out of 29 billion connected devices will be related to IoT. While short-range IoT devices are connected via technologies such as Wi-Fi and Bluetooth, wide-area IoT devices are connected to the internet using cellular connections or Low-Power Wide-Area Networks (LPWAN), such as Sigfox, LoRa, NB-IoT or LTE-M.

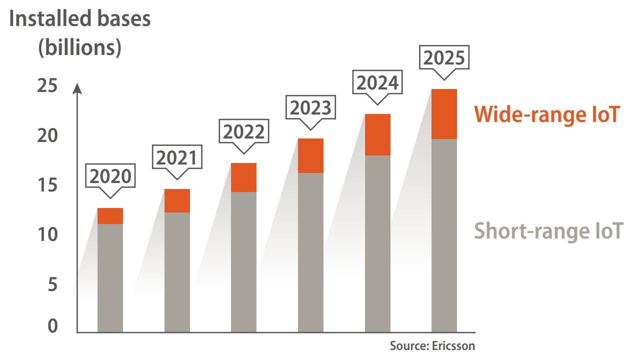


Figure 1: Projected growth of connected devices

In this relatively new but growing market of wide-area-IoT, positioning is key to provide non-stationary devices knowledge of their spatial location.

Terrestrial connectivity solutions often offer energy-efficient localisation based on their ground infrastructure. However, they lack the accuracy required to fully support the needs of all IoT applications.

In contrast, for outdoor applications, Global Navigation Satellites Systems (GNSS) provide the extremely precise, robust and ubiquitous positioning and timing information that the connectivity-based technologies lack. Despite these evident advantages, some IoT devices still use inaccurate infrastructure-based methods, due to stringent energy consumption requirements, which remain a challenge for standard GNSS chipsets.

However, there has been a successful push to significantly reduce GNSS energy consumption over the last few years, thanks to rapid advancements in receiver technology and the arrival of several innovative techniques. Consequently, GNSS is increasingly attractive for low-power IoT applications and is paving the way for new applications and markets.

Widely available solutions such as Assisted GNSS (A-GNSS) or long-term ephemeris predictions, and novel cloud-based approaches will lead to an increase in the uptake of GNSS for low-power IoT devices.

Depending on the chosen solution, either no connectivity to a network at all, or merely a downlink connection is required to determine position.

BY 2022, AROUND 18 BILLION OUT OF 29 BILLION CONNECTED DEVICES WILL BE RELATED TO IOT.

Novel solutions often require up- and downlink connectivity to determine the position in the cloud. Along with so-called "snapshot" techniques, the transmission of pseudoranges to the cloud for subsequent outsourced position calculation is an example of these innovative approaches.

This white paper provides an overview of relevant GNSS technologies for low-power IoT, including those that require hybridisation with different connectivity solutions.

02 GNSS AND ITS ROLE FOR LOW-POWER IOT

2.1 POSITIONING AS AN ENABLER FOR IOT APPLICATIONS

With millions of moving interconnected devices in the IoT environment, many applications require or benefit from knowing the location of an individual device. Low-power geolocated IoT devices can already be found in various industry verticals today and will enter multiple new fields in the future.

In manufacturing and the supply chain, tracking devices make it possible to locate containers, pallets, and various other objects. They also allow autonomous logistic trains to be guided on the most efficient routes through factories and will enable better planning of arrival windows for shipments.

Furthermore, geolocated devices will enable more efficient use of resources and goods in smart city applications. Besides enabling green mobility solutions, like rental bikes, positioning solutions can optimise waste management and help to tackle problems like theft and vandalism more efficiently.

Positioning also plays an important role in healthcare and the leisure industry. For example, wearables can be used by sports enthusiasts to track their activities, but can also enable the elderly to send a geolocated signal in case of an emergency.

In addition, ubiquitous positioning is already revolutionising traditional industries like agriculture, as small beacons support livestock and machinery tracking.

For many of the IoT applications mentioned, precise, ubiquitous and energy-efficient positioning of the mobile objects is a key enabling element.

2.2 WHAT POSITIONING SOLUTION BEST SUITS YOUR NEEDS?

2.2.1 LPWAN-BASED SOLUTIONS

IoT devices can be connected to the internet through various wireless telecommunication networks. These may already offer positioning services based on Received Signal Strength Indication (RSSI), Time Difference of Arrival (TDOA), or Observed Time Difference of Arrival (OTDOA) approaches. Although such geolocation technologies might be sufficient for some applications, they all share the common disadvantage that they can only be used in close proximity to network base stations and are usually only able to offer low positioning accuracy in the order of hundreds or even thousands of meters.

2.2.2 GNSS-BASED SOLUTIONS

In contrast, GNSS enables precise and reliable ubiquitous positioning all over the globe – independent of telecommunication network infrastructure. GNSS positioning depends on radio signals emitted by satellites in medium Earth orbit. Each satellite broadcasts signals that are picked up by receivers on the ground with a delay corresponding to the time it took the individual signals to travel from the satellite to the receiver. These signals also include information on the satellite's position. The receiver's position is then determined by trilateration across at least 4 satellites (for x, y, z, and time dimensions).

Multiple GNSS constellations

The accuracy performance of GNSS is a function of the satellites-to-receiver geometry quantified by the Geometric Dilution of Precision (GDOP) factor. A larger number of satellites in view results in a better GDOP (improved position accuracy) and higher signal availability, particularly in urban environments where the line of sight to the satellites might be partially obscured by buildings. Thus, multi-constellation receivers are always advisable so that satellites from all the available systems – Galileo, GPS, GLONASS and BeiDou- are leveraged.

> GNSS ENABLES PRECISE AND RELIABLE UBIQUITOUS POSITIONING ALL OVER THE GLOBE – INDEPENDENT OF TELECOMMUNICATION NETWORK INFRASTRUCTURE.

Multiple frequencies

While standard GNSS receivers utilise signals transmitted in one frequency band (L1/E1 band) and allow for position accuracy of a few meters, processing GNSS signals in multiple frequencies can provide significant benefits. Not only does this option allow for better positioning accuracy by cancelling out some propagation errors, it also provides a better protection against local disturbances such as interferences or multipath.

Multi-constellation multi-frequency receivers are therefore advisable for high end IoT applications. However, their higher performance currently comes at the cost of an increase in overall energy consumption and a higher price compared to a multi-constellation single-frequency receiver.

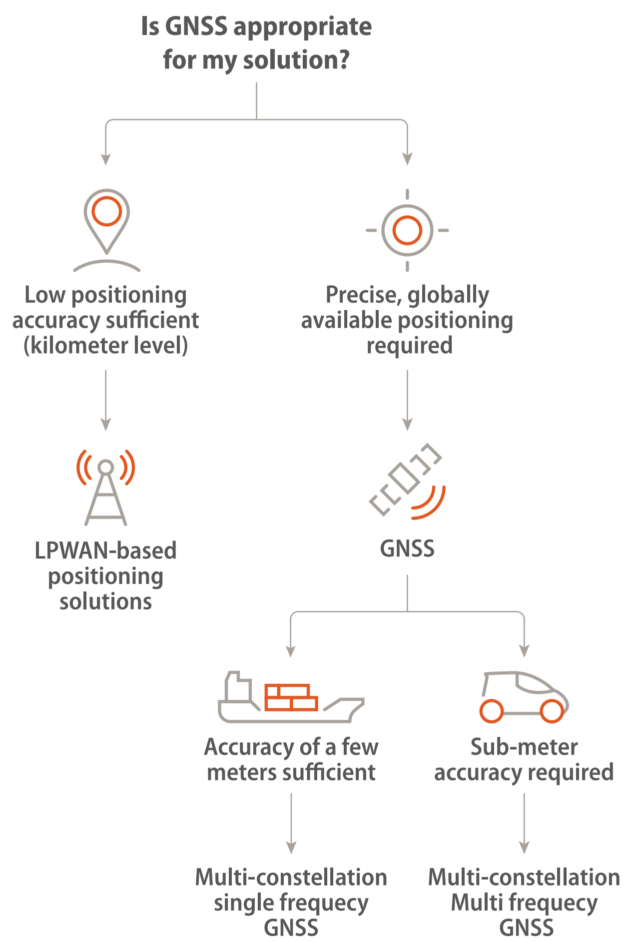


Figure 2: Decision tree. Is GNSS appropriate for my solution?

2.3 GALILEO DIFFERENTIATORS FOR IOT

As the European GNSS, Galileo offers users of its Open Service (OS) a reliable and free of charge service under civil control. Interoperability with other satellite navigation systems enhances availability, robustness and accuracy for multi-constellation users around the world. These benefits are acknowledged by both industry and users. Consequently, virtually all new receivers are capable of receiving Galileo signals.

2.3.1 A UNIQUE AUTHENTICATION FUNCTION

For commercially sensitive IoT applications, the soon-to-be-launched unique Open Service Navigation Message Authentication (OS-NMA) will improve resilience against spoofing and add security by allowing users to verify that a navigation message comes from a Galileo satellite and not a potentially malicious source.

2.3.2 THE HIGH ACCURACY SERVICE

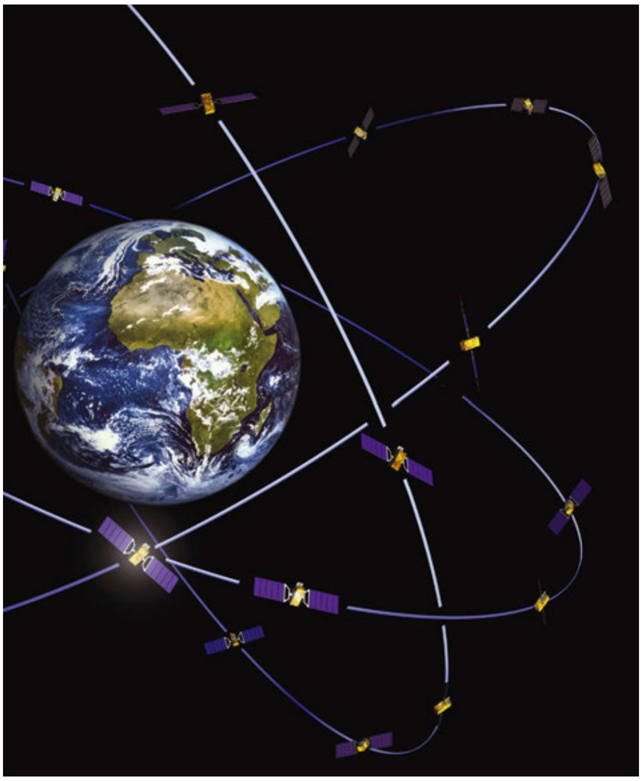
While the accuracy of multi-constellation single-frequency GNSS is sufficient for many IoT applications, those that prioritise higher accuracy over energy consumption and cost can benefit from multi-frequency GNSS. Applications requiring even higher accuracy will benefit from Galileo's forthcoming High Accuracy Service (HAS) in the near future, delivering centimetre level accuracy.

2.4 OPTIMISING GNSS POSITION DETERMINATION FOR IOT DEVICES

Although GNSS provides highly accurate and ubiquitous position and time information, the relatively high energy consumption of the technology in its typical use case[1] does not align well with the stringent constraints of battery-powered IoT devices which are often expected to function intermittently for multiple years without charging. Fortunately, multiple techniques exist to overcome this inconsistency.

Receiver duty cycling

Recognising that positions are in many cases required on demand rather than continuously, duty cycling consists in powering off all the components of a GNSS receiver except those required to react to a wake-up call, thus drastically reducing its power consumption. This technique is currently implemented in virtually all mass market receivers.



Extended and autonomous ephemeris prediction

The high energy consumption of GNSS receivers mainly comes from the so-called acquisition phase, covering both the signal acquisition and the navigation message retrieval. Broadcast by the GNSS satellites, the navigation messages include parameters needed to compute the satellites' positions and clock corrections. Even though such messages are small in size, their low transmission rate results in long download times during which the receiver must remain fully powered: for each so-called cold start, about 30 seconds elapse until the position is determined. To solve this problem, the navigation message can be obtained from an alternative source:

- Either computed by the receiver autonomously, based upon past data, or
- Received via the telecommunication network[2], possibly with an extended validity to reduce the frequency of the downloads.

Assisted GNSS

GNSS assistance consists in supplying the GNSS receiver through a communication network with data that will help during the acquisition phase:

- Acquisition assistance data includes coarse timing and Doppler information, used to shorten the power intensive signal acquisition;

1 Continuous tracking, position calculated on the device using as many satellites as possible.
2 Assuming an adequate download capability

- Clock and ephemeris assistance data replace the broadcast navigation message, as seen above.

Thus A-GNSS minimises the overall GNSS energy consumption by tackling its two main sources, albeit at the cost of more demands on the communications link needed to receive the assistance data.

Snapshot processing

Going forward, snapshot techniques can reduce energy consumption even further as they make it possible to determine the position by using only a minuscule interval of a GNSS signal that is subsequently processed with the help of assistance data to retrieve pseudorange information and compute the receiver position. These techniques however come at the cost of a reduced sensitivity and accuracy, and a proper balance must be found.

> SNAPSHOT TECHNIQUES CAN REDUCE ENERGY CONSUMPTION EVEN FURTHER AS THEY MAKE IT POSSIBLE TO DETERMINE THE POSITION BY USING ONLY A MINUSCULE INTERVAL OF A GNSS SIGNAL.

Cloud processing

Although the various implementations of assisted GNSS already reduce energy consumption, downloading assisted data from an external network is not always possible, or some applications have even stricter energy requirements that cannot be met by such techniques alone. To further reduce energy consumption in a significant way, a change of paradigm in the way the position is calculated is required. Instead of performing all GNSS tasks in a single receiver, energy-hungry functions, for example the position determination based on retrieved pseudoranges can be “outsourced” to the cloud, where sufficient energy, processing power and clock and ephemeris data are available in virtually unlimited quantity.

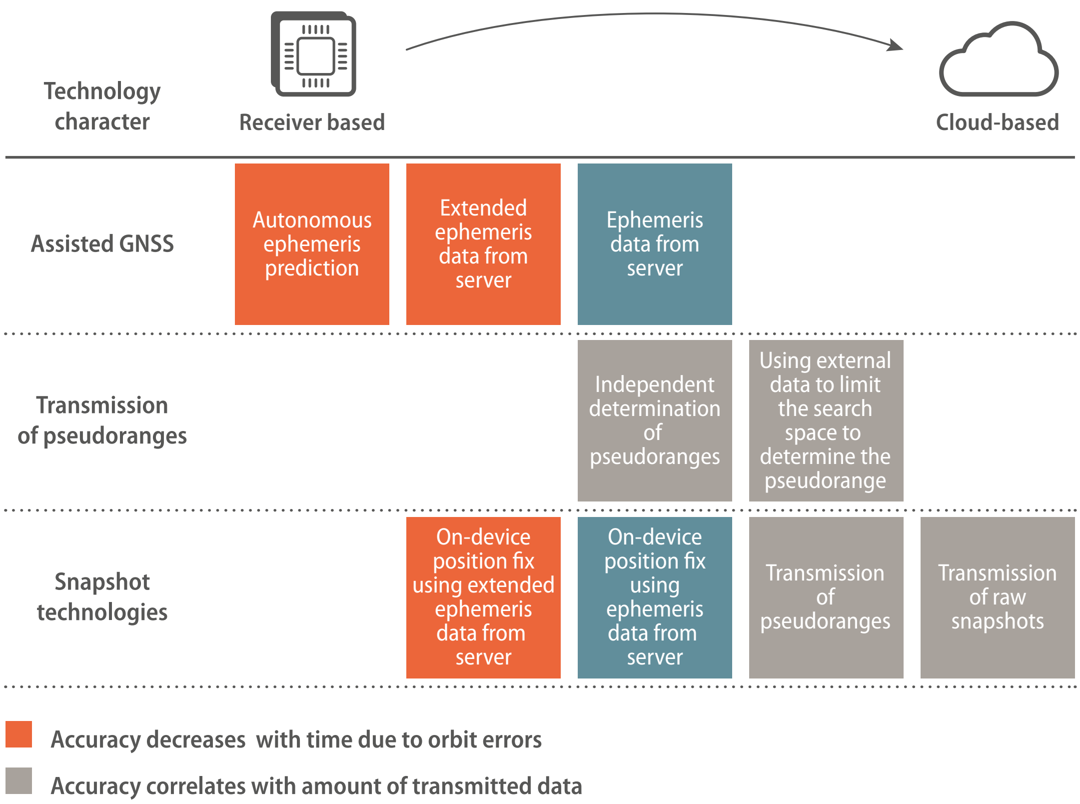


Figure 3: From receiver to cloud: GNSS optimisation techniques

2 Assuming an adequate download capability

2.5 LPWAN AS AN ENABLING CONNECTIVITY TECHNOLOGY FOR GNSS SOLUTIONS IN IOT

Most energy-efficient GNSS techniques require the exchange of data with a network to determine the device position. For low-power IoT applications, different Low-Power Wide-Area Networks (LPWAN) are the connectivity solution of choice, as they combine long-range, low-power with cheap connectivity and are therefore ideally suited to affordably connect battery-powered geolocated IoT devices on a large scale. The low data rates offered are often sufficient for many applications, but can result in difficulties when combined with novel GNSS positioning techniques, particularly when considering the severely limited downlink capability of proprietary solutions.

LPWAN vary significantly in their maximum up- and downlink capacity as well as energy efficiency and can be separated into proprietary and cellular-based networks.

The two highly energy-efficient proprietary LPWAN Sigfox and LoRa both operate in the unlicensed ISM (Industrial, Scientific and Medical) radio bands. Radio regulations in these bands limit the amount of daily uplink, and especially downlink data, allowing only for slow and infrequent data transmissions. The Sigfox network already covers large parts of Europe, and users can purchase subscriptions to connect IoT devices to the network. LoRa additionally offers users the possibility to deploy their own private network gateways. Both LoRa and Sigfox are very slow compared to cellular LPWAN.

> THE SIGFOX NETWORK ALREADY COVERS LARGE PARTS OF EUROPE, AND USERS CAN PURCHASE SUBSCRIPTIONS TO CONNECT IOT DEVICES TO THE NETWORK.

The cellular LPWAN NB-IoT and LTE-M are standardised by 3GPP and are based on widely available LTE technology and infrastructure. NB-IoT allows energy-efficient communication at medium data rates, while LTE-M enables fast communication at the cost of shorter battery life and more complex and expensive hardware. As both technologies operate in the licensed LTE bands, data throughput is not restricted by local radio regulations and a high quality of service and more reliable radio communication can be ensured.

	Sigfox	LoRa	NB-IoT	LTE-M
Used radio spectrum	Unlicensed ISM band		Licensed cellular band	
Uplink data rate	100 /600 bps	250 bps / 11 kbps	250 kbps	1 Mbps
Downlink data rate	600 bps	250 bps / 50 kbps	230 kbps	1 Mbps
Uplink limitation	1.68 kB / day	40 kB / day*	-	-
Downlink limitation	32 B / day	2.2 kB / day*	-	-
Common TX current	50 mA	50 mA	110 mA	140 mA

* Fair Access Policy of the Things Network

Table 1: Comparison of different LPWAN technologies

03 ASSISTED GNSS

3.1 ASSISTED DATA FROM EXTERNAL NETWORK

Instead of obtaining the navigation message directly from the satellite during a cold start, A-GNSS makes it possible to acquire the required information, including ephemerides data and clock corrections, from an external source such as an LPWAN or cellular network. Besides clock and ephemerides data, assistance messages also include support data (coarse time and position, Doppler) to speed-up the signal acquisition sequence of the GNSS receiver. Assisted GNSS (A-GNSS) is already widely used for smartphones and has found its way into many cellular-based LPWAN modules already. When utilising this technique, the user receives two major benefits:

- Faster position fix and therefore reduced energy consumption;
- Higher receiver sensitivity improves performance in difficult environments, such as indoor and urban.

These benefits make usage of the technique highly advisable for any IoT device that has access to a fast enough network. Unfortunately, with assisted data packages of several kilobytes in size, A-GNSS cannot be used with every LPWAN, as the downlink capacity is often highly limited. This is especially true for proprietary LPWAN operating in the unlicensed ISM bands, as they must comply with radio regulations. On the other hand, these regulations are not applicable to the downlink of cellular LPWAN, such as NB-IoT and LTE-M, making the transmission of assisted data possible. The technique is already implemented in several cellular-IoT modules and can be used today. The validity of the transmitted data is in the range of multiple hours, after which the download of the new assistance data is required.

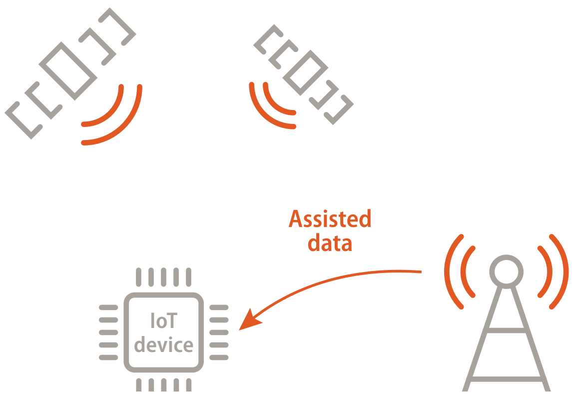


Figure 4: Assisted data flow

To further decrease energy consumption and increase autonomy, several companies offer the provision of assistance data with a validity of up to multiple weeks. While minimising the download frequency of data, resulting in lower energy consumption, this solution comes at the cost of decreased position fix accuracy with time. As the future orbital and clock parameters of the GNSS satellites are unknown and prone to perturbations, the extended ephemeris data provided can only be estimated based on models. With the size of the extended data often being proportional to the validity, the validity duration of the extended ephemeris package should be chosen according to the individual accuracy requirements, the network downlink capacity, and the use case.

TO FURTHER DECREASE ENERGY CONSUMPTION AND INCREASE AUTONOMY, SEVERAL COMPANIES OFFER THE PROVISION OF ASSISTANCE DATA WITH A VALIDITY OF UP TO MULTIPLE WEEKS.

3.2 AUTONOMOUS EPHEMERIS PREDICTIONS

As most proprietary LPWAN are too limited in their downlink, assisted starts using downloaded data from the terrestrial network are impossible. To reduce the frequency of time- and energy-consuming cold starts nonetheless, autonomous ephemeris predictions make it possible to independently predict the orbits of the GNSS satellites for a few days based on ephemeris data acquired from past navigation messages. The accompanying calculations are performed on-chip and enable receivers to perform fast start-ups even after multiple hours or days of inactivity.

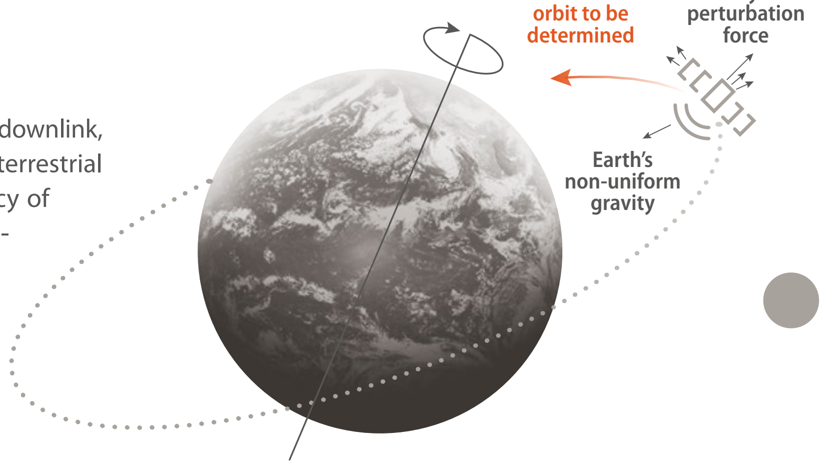


Figure 5: Perturbations in satellites' orbits

However, as orbits are subject to a vast number of uncertainties and perturbating environmental forces, autonomous ephemeris predictions can only roughly estimate the future orbits. Given the high computational effort required to solve the differential equations on a small chip, orbital models are simplified to the extent that only the most important perturbations, such as the Earth's non-uniform gravitational field, gravitational effects from celestial bodies, and solar radiation pressure, are taken into consideration.

As multiple other small perturbations are neglected, solar radiation pressure is not constant, and the random walk of Earth's pole is hardly predictable, the estimated orbits deviate from the real ones, resulting in degradation of the position fix accuracy over time. Consequently, a new cold start must be performed after several days to acquire fresh, precise orbits from the satellite signals once again, which are calculated by the GNSS ground infrastructure. These orbits are then used as the new input for autonomous ephemeris prediction. Several chip manufacturers have already implemented this technique into their hardware, allowing their GNSS receivers to save energy. Especially in combination with proprietary LPWAN and when accuracy is not the top priority, this technique is a good option for simple low-cost applications, such as tracking devices.

SEVERAL CHIP MANUFACTURERS HAVE ALREADY IMPLEMENTED THIS TECHNIQUE INTO THEIR HARDWARE, ALLOWING THEIR GNSS RECEIVERS TO SAVE ENERGY.

GALILEO OF THINGS: GNSS SIZED FOR NB-IOT-BASED SOLUTIONS

Funded by the European Union through the GSA's Fundamental Elements scheme, the R&D project Galileo-of-Things (GoT) leverages the expertise gathered by Ubiscale in the development of cloud-assisted GNSS solutions, such as UbiGNSS, in order to improve Galileo reception on NB-IoT based solutions.

The current UbiGNSS solution consists of ready-to-use and original GNSS sensing and processing functions for remote position determination. It aims at both minimising the duration of GNSS signal processing on the end-devices and decreasing the amount of transmitted data down to 10 bytes, without any need for downlink. When used with Sigfox/LoRa connectivity, it makes it possible to improve the total life span of GNSS trackers four-fold to eight-fold.

Looking to the future of the GoT project, the goal is to improve the technology to achieve an even greater life span and expand the offer to NB-IoT users while leveraging Galileo even further. By the end of the project, the consortium aims at having a power-optimised Galileo IP core that enables a cost-efficient System-on-Chip for next-generation NB-IoT trackers.

04 TRANSMISSION OF PSEUDORANGES FOR REMOTE POSITION DETERMINATION

A significant part of the energy consumption of a conventional GNSS receiver results from the long time required for decoding the navigation messages disseminated by the satellites. One solution to eliminate this time- and energy-consuming step is the transmission of pseudoranges to an external computing facility for outsourced position determination. The most common way of doing this external post-processing is to use cloud computing. The download of the navigation messages is not necessary in this case, as the remote computing facility has access to ephemeris and clock correction data. Therefore, the time needed to determine the position can be reduced to just a few seconds. During this period, pseudoranges and time are decoded from the signal and subsequently sent to the remote processing site.

One downside of this approach is the fact that the full signal acquisition step is still required in the device. Therefore, a fair amount of signal processing must be performed in order to find the satellites in view, and this task is also energy intensive. To simplify this step and further reduce battery consumption, the acquisition search space can be limited by providing the receiver with helpful support data such as the Doppler range of satellites in view, a process known as acquisition assistance.

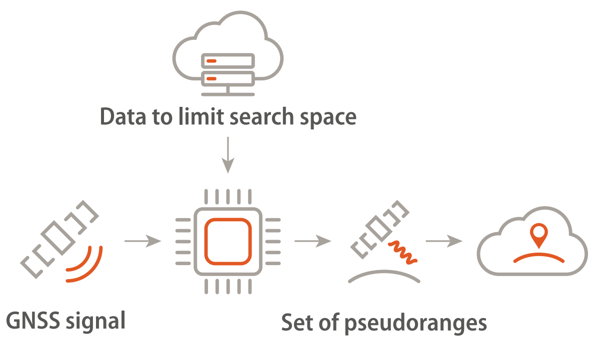


Figure 6: Remote position determination

Since this technique only requires small amounts of data to be sent to and from the device, the transmission of pseudoranges is a promising solution, especially for proprietary LPWAN. Although it has been used for animal tracking for several years, only a few start-ups currently offer cloud-based positioning based on transmitted pseudoranges for IoT applications.

ACCURATE GNSS POSITIONING FOR LOW POWER AND LOW-COST OBJECTS

- The ability to calculate the GNSS position of IoT objects with a very small energy footprint will pave the way for a market of tens of millions of moving objects each year.

- SYNTONY, SIGFOX and LDL team up to offer unique performances in terms of cost and energy consumption:
    - A 100% **software GNSS receiver**, getting rid of chipsets and their related constraints;
    - An optimised and adaptable location algorithm with unequalled computation speed: between 3s and 10ms to acquire the data necessary on the receiver side to compute the object's PVT in the Cloud. **From 10 to 100 of saving in power consumption*** for PVT computation;
    - GALILEO/GPS multi-constellation management ;
    - Algorithm running on COTS processor with only an RF front **end dividing by 4 the cost** of GNSS function.

* Ratio between the actual power (computed in mWh) needed to compute a position by a chipset in cold start and the processing time needed to do the same in the object with the APOLLO solution. Actual value dependant on the level of pre-processing of the GNSS signals digitalized.

05 SNAPSHOT TECHNIQUES

Unlike the other GNSS techniques described above, snapshot techniques are unique as they make it possible to determine position by using only a minuscule interval of a GNSS signal. This highly flexible approach allows for multiple configurations, including the outsourcing of energy-intensive computations to cloud servers, resulting in cheaper, simpler, and more energy-efficient hardware. Although innovative snapshot techniques have multiple advantages, their real-world adoption is currently only starting.

Snapshot techniques work by sampling the GNSS signal for as little as a few milliseconds. Alongside other parameters like the sampling rate and the bit depth, the sampling duration influences the position fix accuracy and reliability. During the short sampling period, a digital copy of the received analog signal is recorded in real-time.

In post-processing, the digital sample is then used to determine both the frequency and code of the logged signal. For the subsequent calculation of the pseudoranges, a very rough device position and time input is required to solve arising ambiguities. When using snapshot techniques in conjunction with LPWAN, both inputs are usually available due to message transmissions to known base stations. Alternatively, Doppler measurements can help to eliminate ambiguities. To calculate the position based on the determined pseudoranges, ephemeris data is required. As this data cannot be extracted from the short digital sample itself, all snapshot configurations require some form of data exchange with an external network. For low-power applications, snapshot technologies are best implemented using a single-frequency and multi-constellation approach, because single-frequency offers the best compromise between energy consumption and accuracy, while multi-constellation allows for a significant increase in reliability and accuracy at the cost of only a slight increase in energy consumption and snapshot size.

When implementing snapshot-based position determination, several configurations are feasible depending on multiple factors, with the up- and downlink capacities of the network being the most important.

Snapshot configuration	Most proprietary LPWAN	Most cellular LPWAN
Transmission of raw snapshot	✗ Insufficient network uplink	✓
Transmission of pseudoranges	✓	✓
Position determination on device	✗ Insufficient network downlink	✓

Table 2: Proprietary vs cellular LPWAN concerning snapshot data transmission

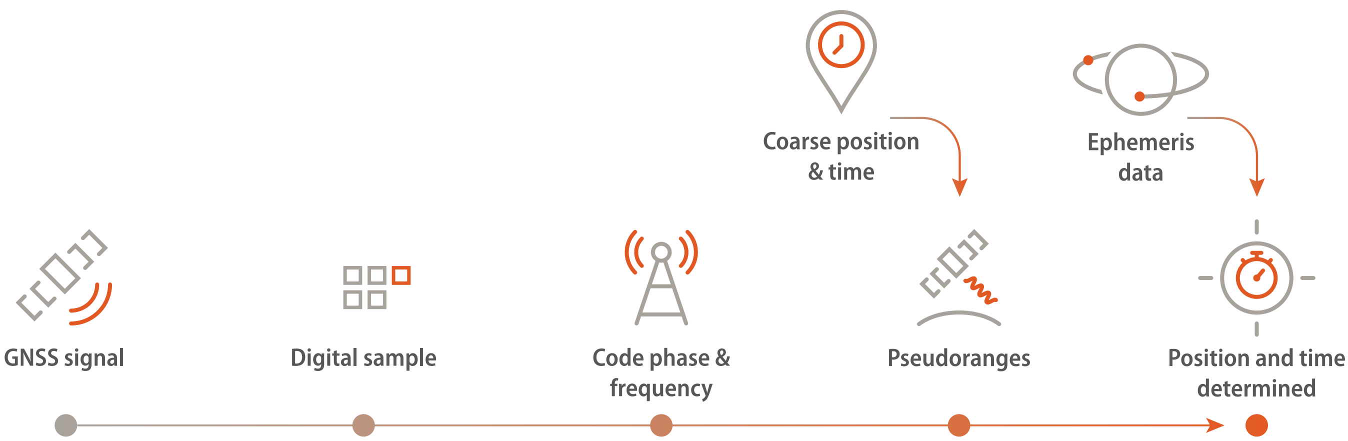


Figure 7: Snapshot positioning

The most known configuration is the **transmission of raw snapshots**. Here, the digital sample is transmitted directly to the cloud where all of the post-processing, as well as the position determination itself, is performed. Requiring only a simple radio front end to receive signals, this configuration is the cheapest and most energy-efficient snapshot implementation. However, with a raw snapshot size of at least multiple kilobytes, this configuration can only be realized in conjunction with networks offering a large enough data uplink capacity. This is not the case for most proprietary LPWAN. For cellular LPWAN however, the technique is technologically feasible and should be considered when aiming for the maximum energy efficiency and the lowest hardware cost.

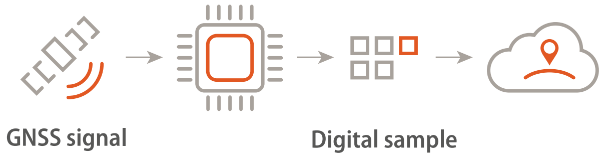


Figure 8: Transmission of raw snapshots

As the transmission of raw snapshots is not possible for proprietary LPWAN such as Sigfox or LoRa, alternative configurations like the **transmission of pseudoranges based on a snapshot of the signals** must be used instead. When doing so, the signal processing partly remains on the device, resulting in a significantly reduced amount of data that needs to be exchanged with the cloud: the uplink to the remote server comprises mainly a set of pseudoranges of just a few bytes. As the device must derive the pseudoranges from the signal snapshot, this configuration requires a downlink to receive a very small set of acquisition assistance data.

Given the small amounts of exchanged data, this working mode can be used for most LPWAN with both up- and downlink capability. As of today, a few companies already enable the implementation of this highly promising technique that has the potential to revolutionise positioning for low bandwidth LPWAN.

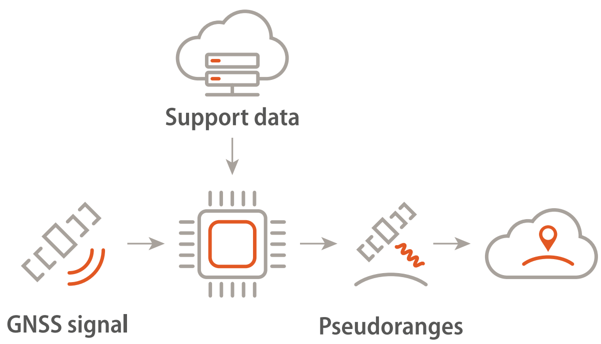


Figure 9: transmission of pseudoranges based on a snapshot of the signals

A third configuration, which is especially viable for LPWAN with a high downlink capacity, such as cellular LPWAN, is the **snapshot-based position determination on the device**. In this setup, the cloud server is only needed to provide the device with the assistance data. All the post-processing and position determination is then performed on the device. To minimise the frequency of data downloads, extended ephemeris data can also be used for this snapshot configuration. This technique differs from the standard assisted GNSS only by the replacement in the device of a full signal acquisition stage with a more energy effective snapshot acquisition.

All variants of the snapshot technique allow significant energy savings. However, these come at the cost of reduced sensitivity and accuracy, and a proper trade-off must be found between the positioning performance and the energy efficiency, depending on each application's specific needs.

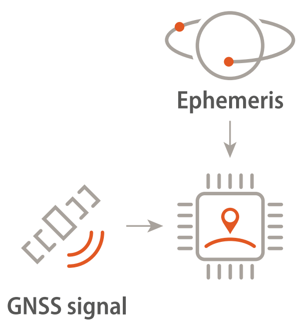


Figure 10: Snapshot-based position determination on the device

06 CONSIDERATIONS WHEN SELECTING A GNSS SOLUTION

Different low-power IoT applications have vastly different requirements in terms of performance that must be met by the chosen solution. With different levels of energy efficiency and dependency on the communication network, the diverse GNSS-based techniques vary in their usefulness for different applications as well as in their suitability for combination with different LPWAN.

As most solutions rely on external data, the data throughput of the LPWAN determines which GNSS technique is best suited for the purpose.

High bandwidth networks such as cellular LPWAN are compatible will all GNSS techniques discussed here.

Proprietary networks like Sigfox or LoRa, despite their limited data throughput, can still be combined with some highly efficient GNSS-based techniques as the required amount of data transmitted from cloud to the device (downlink) or from the device to the cloud (uplink) can remain within the capacity of the network. This is the case for the A3, P1, P2 & S2 solutions shown in the figure on the right.

The total energy consumption of a position fix is comprised of the energy consumed by the GNSS hardware as well as the energy needed for sending and transmitting of the related data. Depending on the technique, the network itself strongly influences the energy efficiency, as the energy consumed for transceiving positioning-related data in some

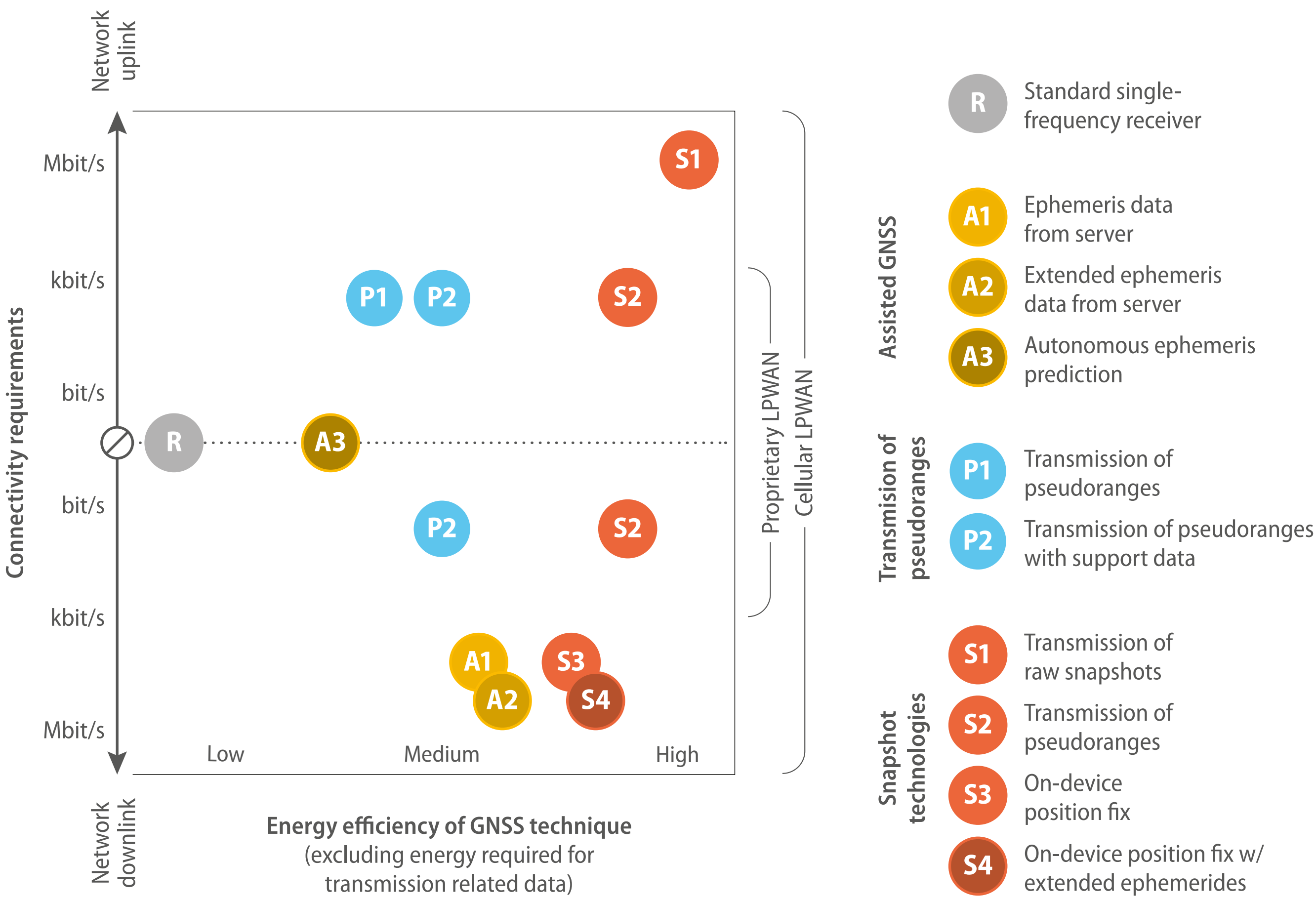


Figure 11: Connectiity requirements vs energy efficiency

cases even exceeds the energy needed for the acquisition, tracking, and processing of the GNSS signal.

The displayed total energy savings of each technique only serve as an approximation when comparing different GNSS techniques, as the actual required energy for determining the position varies significantly with the frequency of position fixes, the configuration of the LPWAN, environmental factors, the hardware and algorithms used, as well as many other adjustable parameters and external factors. For many techniques, the amount of transmitted data not only impacts accuracy and reliability, but also the overall energy efficiency.

Raw snapshot sizes are always larger than ≈20 kB and therefore much larger than the minimum message size. The maximum payload length of a single NB-IoT message is, for example, 1600 bytes. One raw snapshot is therefore made up of multiple single NB-IoT messages.

Energy reduction realised by the different GNSS techniques

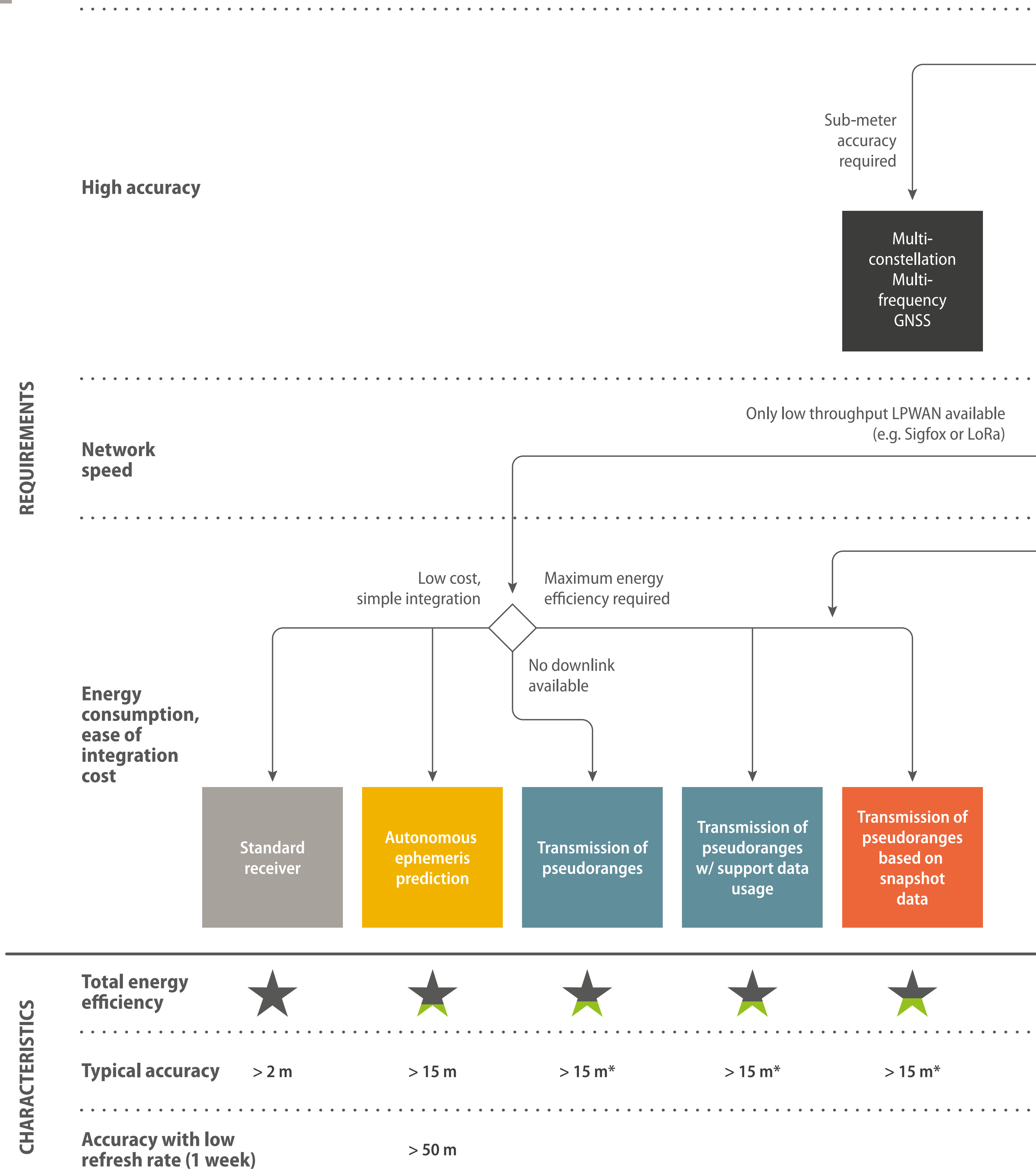
Combined power consumption savings for GNSS and connectivity layer (est.)*

			Sigfox	LoRa	NB-IoT	LTE-M
	R	Standard single-frequency receiver	1x (base case)[a]			
Assisted GNSS	A1	Ephemeris data from server	Not feasable due to downlink limitations		10x[b,c,d]	
	A2	Extended ephemeris data from server				
	A3	Autonomous ephemeris prediction	3x[b,e]			
Transmision of pseudoranges	P1	Transmission of pseudoranges	2x[f,g]	4x[f,h,i]	Not advisabel (alternative: P2)	
	P2	Transmission of pseudoranges with support data	3x[b,c,g]	6x[b,c,h,i]	10x[b,c,j]	
Snapshot technologies	S1	Transmission of raw snapshots	Not feasable due to uplink limitations		15x[k]	25x[k]
	S2	Transmission of pseudoranges	4x[b,g,l]	10x[b,h,l,l]	25x[b,j,l]	
	S3	On-device position fix	Not feasable due to downlink limitations		Very rarely used, energy saving in between A1/A2 & S2	
	S4	On-device position fix w/ extended ephemerides				

* Only indicative; real energy saving varies with transmitted amount of data, position fix frequency, data transmission configuration, environmental factors, hardware and algorithms used, and other parameters

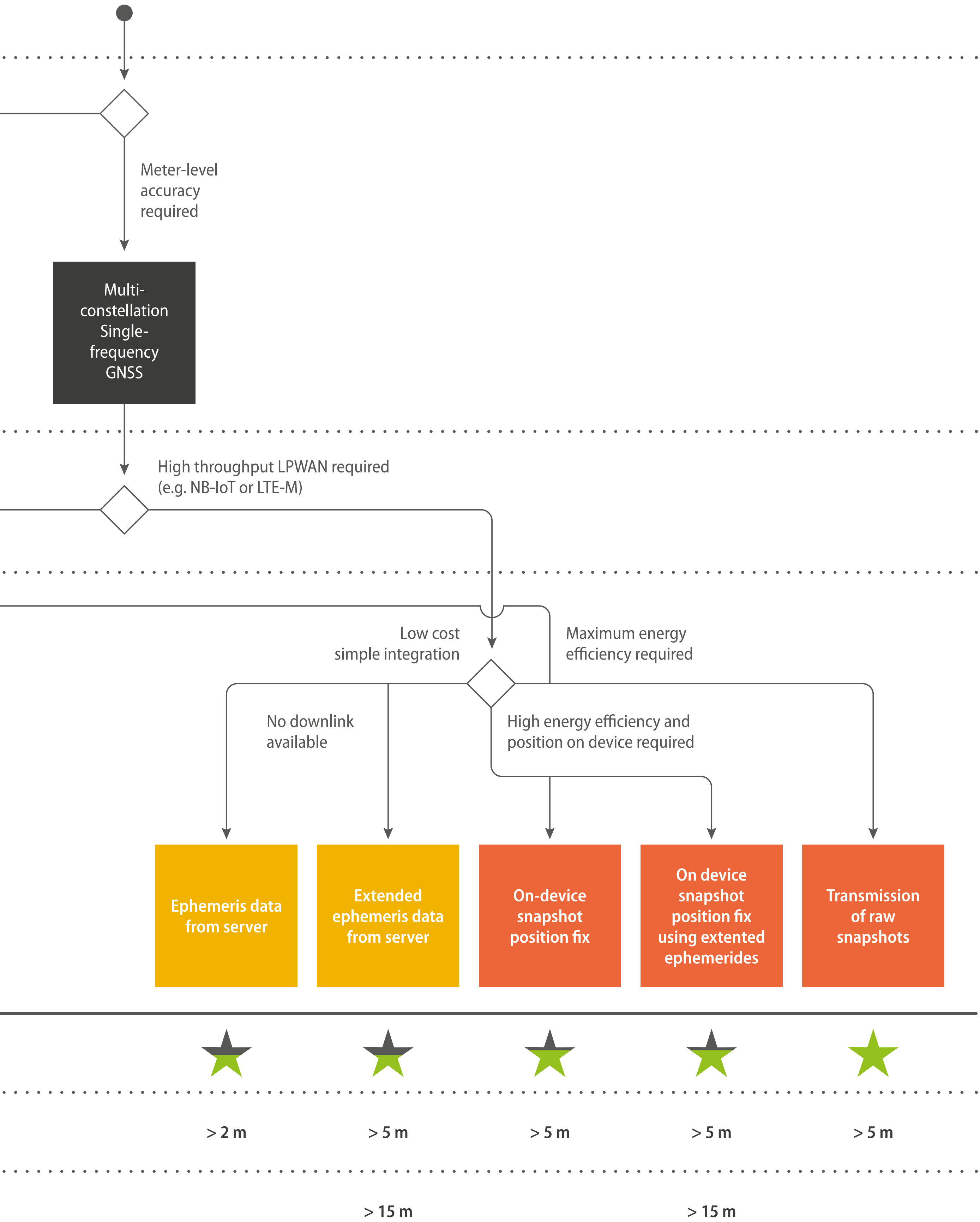
a Cold start, acquisition time: 24 s
b When performing position fix every 4 h
c Acquisition time: 2 s
d Extended ephemeris: validity: 35 d, file size: 135 kB
e Cold Start (a) required every 6 d
f Acquisition time: 5 s
g Transmitted data: 4 pseudoranges x 3 B
h Transmitted data: 8 pseudoranges x 3 B
i using SF10/DR2
j Transmitted data: 12 pseudoranges x 3 B
k Snapshot size: 20 kB
l Energy required to calculate PRs: 100 mWs

Figure 12: Energy savings for different GNSS-based positioning techniques



* Accuracy strongly correlates with amount of transmitted data

Figure 13: Detailed decision tree


Meter-level
accuracy
required
Multi-
constellation
Single-
frequency
GNSS
High throughput LPWAN required
(e.g. NB-IoT or LTE-M)
Low cost
simple integration
Maximum energy
efficiency required
No downlink
available
High energy efficiency and
position on device required
Ephemeris data
from server
Extended
ephemeris data
from server
On-device
snapshot
position fix
On device
snapshot
position fix
using extented
ephemerides
Transmission
of raw
snapshots
> 2 m
> 5 m
> 5 m
> 5 m
> 5 m
> 15 m
> 15 m

When deciding on a GNSS-based solution for a given application, numerous factors play a role including target accuracy, selected LPWAN, desired battery life, ease of integration, and hardware and implementation cost.

Applications that require a position accuracy of one meter or less are advised to use a multi-constellation multi-frequency receiver. However, as most low-power IoT applications prioritise extending battery life, a multi-constellation single-frequency receiver is sufficient when positioning accuracy of multiple meters is acceptable.

When deciding on an energy-efficient GNSS technique, the choice of the terrestrial network limits the possible options, as most described solutions rely on external data to determine the position via GNSS.

For bandwidth-limited proprietary LPWAN, autonomous ephemeris predictions should be considered. Fortunately, this technique is already implemented by many manufacturers into their GNSS receivers. In particular, when a trade-off of accuracy vs. efficiency is acceptable, autonomous ephemeris predictions can offer the implementer an efficient, yet highly autonomous method to reduce overall energy consumption. Not surprisingly, this solution is already being used for some LoRa and Sigfox tracking devices. If the use case demands even lower energy consumption, the shift to novel techniques must be made, making it possible to outsource the position determination by transmitting pseudoranges to the cloud. However, when these cloud-based technologies are being used in conjunction with uplink-throttled LPWAN like Sigfox, the number of pseudoranges that can be transmitted is limited, negatively impacting the accuracy of the position fix. Thus, the amount of sent data and therefore energy consumption, is directly correlated to the achievable accuracy.

As the throughput of cellular-based LPWAN is, for practical purposes, not limited, the downlink is sufficient to use assisted GNSS data. For most IoT applications relying on cellular-based LPWAN the usage of this popular technique is strongly advised. For applications that require positioning in remote areas where a permanent connection to the cellular LPWAN cannot be guaranteed or that need to further increase battery life, enhancements such as extended ephemeris data are useful to minimise data download frequency. Ultimately, when the application demands the maximum device autonomy on a single battery charge, innovative solutions like snapshot techniques should be considered.

To learn more about the benefits of using Galileo, get a comprehensive overview of the GNSS market and gain in-depth insights on emerging GNSS trends and developments in various sectors, visit the market report section on the GSA website.

To find Galileo-enabled receivers and modules specifically aimed at IoT usage, take a look at usegalileo.eu or contact GSA directly at market@gsa.europa.eu.

07

LIST OF ACRONYMS

A-GNSS	Assisted GNSS
ETSI	European Telecommunications Standards Institute
GDOP	Geometric Dilution of Precision
GNSS	Global Navigation Satellite System
HAS	High Accuracy Service
IoT	Internet of Things
ISM	Industrial, Scientific and Medical
LoRa	Low Range
LPWAN	Low-Power Wide-Area Network
LTE	Long Term Evolution
LTE-M	Long Term Evolution for Machines
NB-IoT	Narrowband Internet of Things
OS-NMA	Open Service Navigation Message Authentication
OTDOA	Observed Time Difference of Arrival
RSSI	Received Signal Strength Indication
TDOA	Time Difference of Arrival
3GPP	3rd Generation Partnership Project

NOTES

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- Designing and enabling services that fully respond to user needs, while continuously improving the European GNSS services and infrastructures;
- Managing the provision of quality services that ensure user satisfaction in the most cost-efficient manner;
- Engaging market stakeholders to develop innovative and effective applications, value-added services and user technology that promote the achievement of full European GNSS adoption;
- Ensuring that European GNSS services and operations are thoroughly secure, safe and accessible.

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