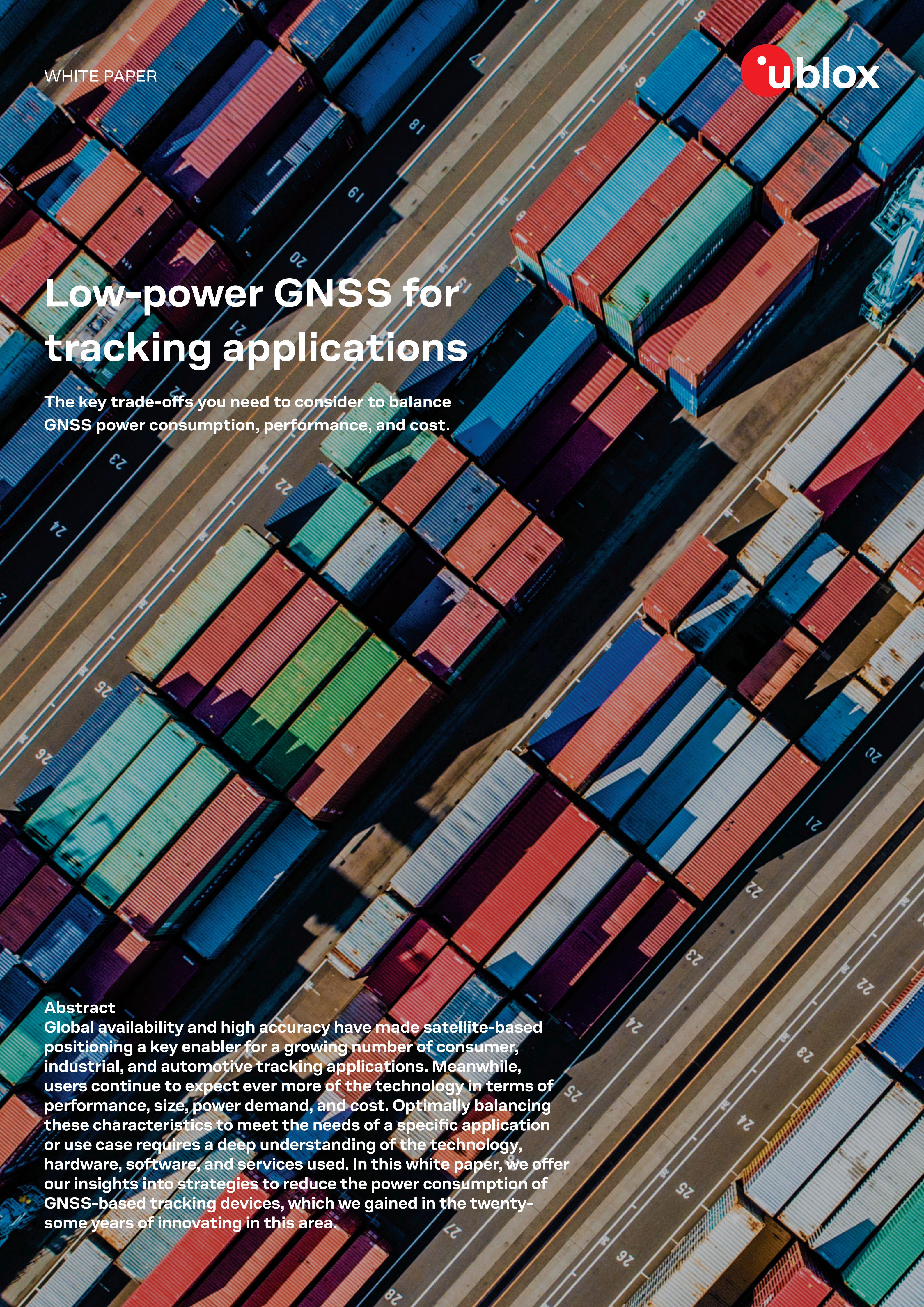

WHITE PAPER

Low-power GNSS for tracking applications

The key trade-offs you need to consider to balance GNSS power consumption, performance, and cost.

Abstract

Global availability and high accuracy have made satellite-based positioning a key enabler for a growing number of consumer, industrial, and automotive tracking applications. Meanwhile, users continue to expect ever more of the technology in terms of performance, size, power demand, and cost. Optimally balancing these characteristics to meet the needs of a specific application or use case requires a deep understanding of the technology, hardware, software, and services used. In this white paper, we offer our insights into strategies to reduce the power consumption of GNSS-based tracking devices, which we gained in the twenty-some years of innovating in this area.

White paper: Low-power GNSS for tracking applications
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Contents

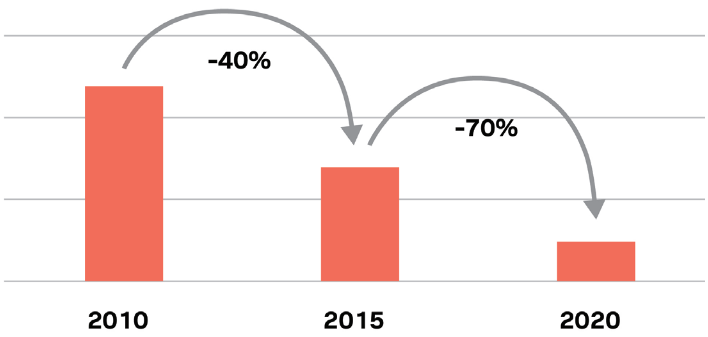
Optimal performance, minimal power demand

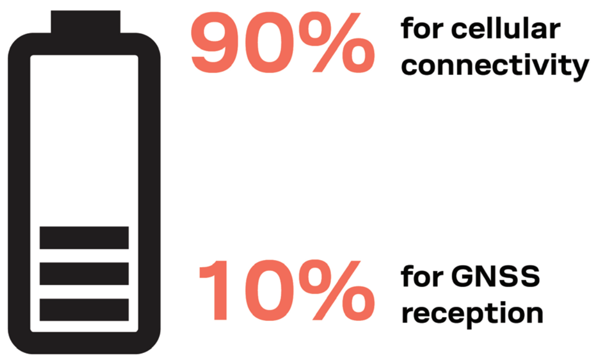
Because of its ability to deliver highly accurate position, velocity, and time data anywhere in the world, GNSS technology has found its way into an ever-growing range of smart, connected solutions. At the same time, users have come to expect more and more of the technology. To stand out today, GNSS-enabled devices need to outperform competing solutions in terms of accuracy, responsiveness, and power autonomy, often under strong pressure in terms of cost and size.

Particularly in consumer, industrial, and automotive tracking use cases, global navigation satellite system (GNSS) receivers were long considered power hogs. Back in 2010, a single band GNSS receiver in continuous tracking mode consumed just over 120 mW of power.[1] By 2015, that number had come down to around 70 mW.[2] Today, leveraging technological improvements, tracking applications can run on just 25 mW of power.[3]

The past five years have seen the technology's power autonomy climb to new heights. Today's low-power GNSS receivers can track a greater number of satellite constellations, each on multiple frequency bands, to deliver greatly improved accuracies faster and with far less power. In some use cases, the GNSS receiver's power demand can be reduced to a single-digit percentage of the end device's power budget.

GNSS receiver power consumption reduction over 10 years





Power split between cellular and GNSS for a tracker device using snapshot positioning technology.

But meeting ambitious power consumption targets can be challenging. Today, it is common for state-of-the-art GNSS receivers to offer a range of settings that can be configured to optimize their power consumption while meeting use case-specific performance requirements.

In this white paper, we present an overview of essential design considerations that can bring down a GNSS receiver's power demand to a mere fraction of that of a standard GNSS solution. Which of these design considerations applies to a specific use case will depend on a careful balancing of competing factors such as accuracy, dynamic performance, size, and cost.

1) u-blox MAX-6: 41 mA x 3 V
2) u-blox MAX-M8Q: 23 mA x 3 V
3) u-blox MAX-M10 tracking 3 GNSS constellations

The use case defines the power saving options

The power saving options that product developers have at their disposal to balance the GNSS receiver's accuracy, performance, size, and cost are largely dictated by the use case they are addressing. Because of their small size, sports watches, which lie at one end of the spectrum, typically only feature small antennas and batteries, and require a relatively high 1 Hz update rate with demanding GNSS performance constraints. Most sports watches offer only limited internet connectivity (via a smartphone).

Logistics goods trackers, on the other end of the spectrum, typically have more relaxed requirements in terms of update rate and GNSS receiver performance but are expected to run for months on a small battery. In between are handheld devices, as well as pet and kid trackers.

Automotive trackers form a category of their own, commonly characterized by having relaxed size constraints, access to a virtually endless power supply, and increasingly, continuous connectivity using cellular data communication.
The table below outlines common constraints for five classes of end devices. The exact constraints for a given end device will depend on the specific requirements dictated by its use case and may vary from the examples presented below.

	Automotive tracker	**Sports watch**	**Handheld device**	**Pet/kids tracker**	**Logistic goods tracker**
Update rate	10 / s	1 / s	5 / min	1 / min	1 / day
Position availability	● ● ●	● ● ●	● ●	● ●	●
Position accuracy	10 m	5 m	5 m	10 m	20 m
Small size	● ●	● ● ●	● ●	● ●	● ● ●
Power source	Big battery	Small battery	Medium battery	Medium battery	Small battery
Connectivity	Continuous	Limited	Continuous	Continuous	Limited

• • • very important • • moderately important • less important

Typical constraints for five common classes of end devices.

Performance versus power

As we will see, a GNSS receiver's power consumption is determined by a broad range of factors. Most power is consumed during start-up (satellite signal acquisition), which typically draws around 20 percent more power than continuous satellite tracking. The top drivers of power consumption are related to satellite signal acquisition and continuous satellite tracking.

In addition to the size and cost of the end device, performance requirements imposed by the final use case limit the options that are available to reduce power consumption. As we will see, each option comes with its own set of trade-offs that need to be carefully considered to optimally meet the needs of the target application.

Availability and accuracy

While some use cases demand highly accurate GNSS positioning at all times, others operate under less stringent constraints. Today's state-of-the-art GNSS receivers offer various approaches to balance the competing requirements of (1) positioning availability and accuracy and (2) power consumption.

The first approach involves **selecting the number of tracked GNSS constellations**. Concurrently tracking multiple GNSS constellations increases the number of visible satellites at any given time and, as a result, the robustness of the position reading. In challenging environments, such as in deep urban canyons or under forest canopies, it can significantly improve the availability, accuracy, and reliability of the service.

On the flip side, tracking more GNSS constellations forces the receiver to spend more time acquiring satellite signals, thereby increasing power consumption. Additionally, receivers that track GNSS constellations that emit in different frequency bands require additional RF paths to capture the signals, which increases the power consumption as well.

The second approach focuses on **antenna selection**, i.e., selecting an antenna that meets the end application's performance requirements. Active antennas use a low noise amplifier (LNA) to increase the gain of the incoming RF signal. In weak signal scenarios, for instance, with poorly placed antennas or indoors, active antennas can be essential to pick up the weak satellite signals amidst the noise. This increased sensitivity comes at the cost of increased power consumption, as the active antenna's LNA draws considerable power to achieve the required antenna gain. For low-power use cases that require high performance in terms of position availability and accuracy, a large passive antenna can be used, albeit with compromises in terms of end-device size.

Tracking mode

While some use cases require **continuous tracking**, others require no more than one position reading per minute, per hour, or even per day. The position update rate, which defines the time interval between two position calculations, strongly impacts the GNSS receiver's power requirements.

On this spectrum, **continuous tracking mode** has the highest power consumption. In applications that combine GNSS positioning with LTE-based cloud connectivity, continuous tracking mode brings an additional challenge: **RF interference** between the transmitted LTE signals and the GNSS signals being received on nearby frequency bands.

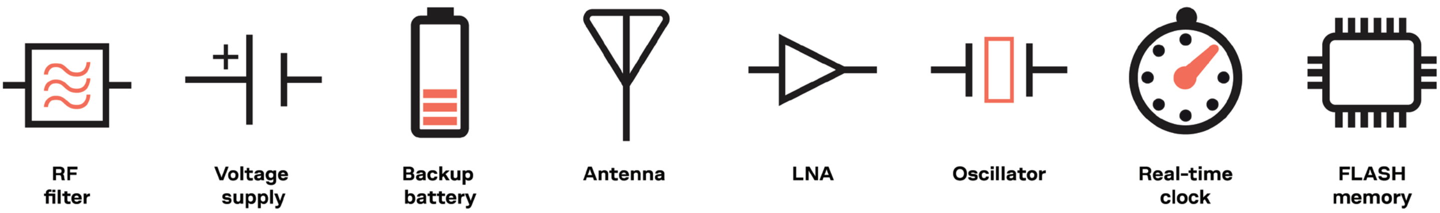
Effectively mitigating RF interference can help reduce a GNSS receiver's power consumption by preventing unwanted signal losses from forcing the receiver to re-enter the power-hungry signal acquisition phase. Mitigating RF interference requires upfront investment in careful board design and may require additional filters, which increase the signal attenuation in the RF path. When a passive antenna setup is used, it may be necessary to add a low noise amplifier (LNA).

For applications that do not require continuous tracking, many GNSS receivers offer **power save modes (PSM)** that dramatically reduce power consumption by limiting the tracking functionality of the GNSS receiver between position calculations.

Multiple PSMs exist, each with its advantages and drawbacks. Hitting the sweet spot between receiver performance and power consumption requires judiciously selecting the PSM that best meets the needs of the use case.

Hardware-based strategies to optimize power consumption

Tracking solution designers have a whole range of design strategies at their disposal to optimize the power consumption of their devices. Because each decision impacts not only power consumption but also the performance, size, and cost of the tracking solution, solution designers need to carefully balance the pros and cons of each strategy to find the lowest-power configuration that delivers the tracking performance that they require.



Optimal component selection

Selecting components with low power requirements (LNAs, oscillators, real-time clocks) results in small improvements in power consumption that add up during the operation of the GNSS receiver.

Voltage supply

While GNSS devices are designed to operate within a narrow voltage range, they all have an optimal voltage that minimizes their power consumption, indicated in the datasheet. The choice of components used to deliver the correct voltage also impacts the GNSS receiver's overall power consumption: Low-dropout regulators (LDOs) - the less costly solution - dissipate power as heat, making them a poor choice in terms of optimizing power consumption. Switched-mode power supplies (SMPS) are more efficient. Because they use a coil, they may cause undesired RF interference at the antenna front end.

Backup battery

Power interruptions cause GNSS receivers to lose their position fix as well as all downloaded time and GNSS orbit data, forcing them to undergo a complete cold start as soon as power is returned. By saving this data in backup RAM, GNSS receivers with a backup battery can recover more quickly from interruptions in power supply, thereby saving power. When the position update period is longer than two hours, which corresponds roughly to the validity of the ephemeris data, the back-up battery becomes unnecessary and can be left out, reducing power demand.

Real-time clock (RTC)

In the event of a power outage, integrating a real-time clock allows the GNSS receiver to start up more quickly when the main power source returns. This reduces the power consumption. As the RTC requires a battery as a back-up power source, it increases the size of the solution and adds cost.

RF path

In scenarios with sufficient signal strength, passive antennas reduce power consumption compared to active ones. In use cases that require increased sensitivity, there may be no way around using an active antenna to increase gain along the RF path. In these cases, active antennas with external LNA control let the application switch off the LNA when the GNSS is not in use rather than leaving it on all the time. By adapting the gain along the RF path to environmental conditions, LNAs with internal power settings can reduce the power needed to deliver the required GNSS sensitivity and accuracy.

Oscillator

While crystal oscillators consume less power to output a stable frequency signal, temperature fluctuations can affect their frequency, impacting the GNSS receiver’s sensitivity and time to first fix, thereby increasing power consumption. Temperature controlled crystal oscillators (TCXOs) solve the problem of temperature sensitivity, reducing the power consumed to establish a position fix, but consume slightly more power in continuous operation. The choice of the oscillator depends on the required positioning performance and the specific set of components used. Use cases that rely on small antenna designs or are expected to operate in weak signals environments can increase GNSS receiver sensitivity by selecting a TCXO.

	TCXO	XTAL
Lower price		●
Lower power consumption		●
Lower power to first fix	●	
Higher tracking sensitivity	●	

Design considerations when selecting the oscillator.

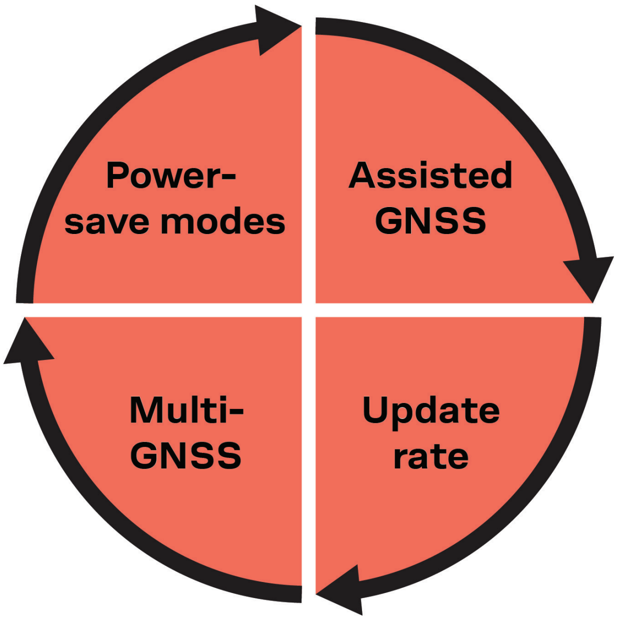
Memory

In some trackers, the GNSS receiver features flash memory to facilitate firmware upgrades or to store data on the device. By, instead, storing data in the host’s memory, devices can both shorten their bill of materials and reduce power demand.

Firmware-based strategies to optimize power consumption

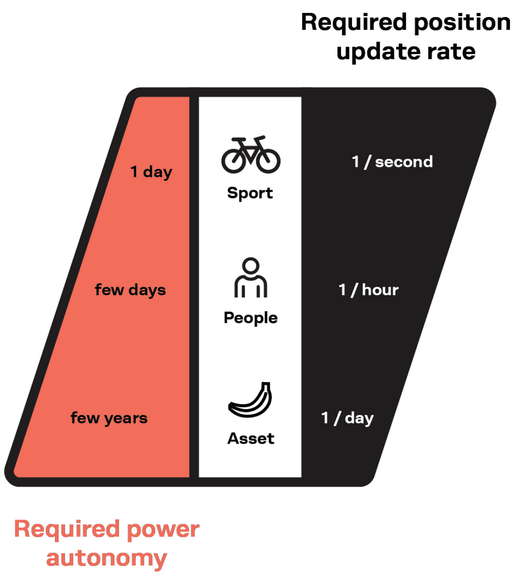
In addition to the hardware-based strategies to optimize power consumption presented in the previous section, product developers have a range of firmware-based strategies at their disposal.

While these vary from vendor to vendor, they typically fall into four categories illustrated here.



Update rate

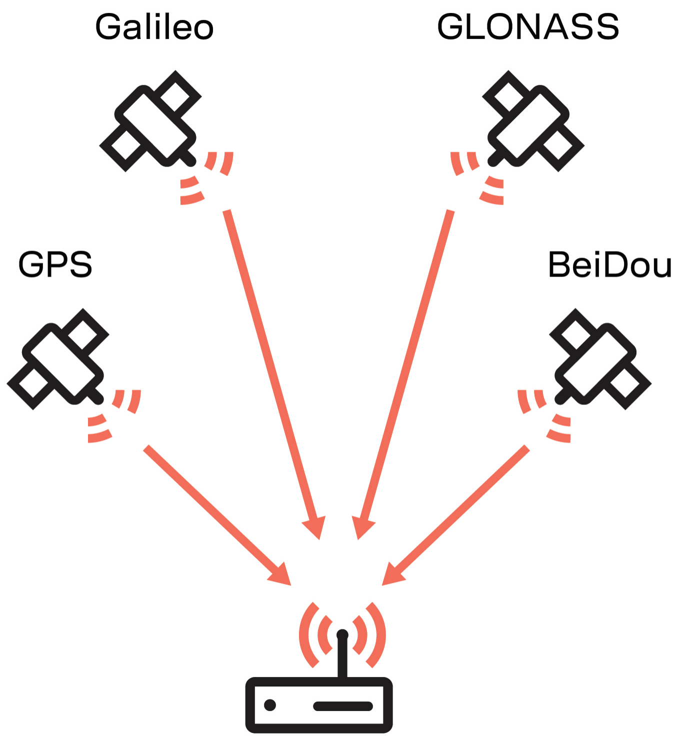
The update rate is the first place to look when seeking to reduce a GNSS receiver's power consumption. Most GNSS receivers in continuous tracking mode support update rates of 10 Hz or even more. Some common use cases only require position updates once per minute or once per day. By reducing the update rate to meet a use case's actual requirements and allowing it to enter power save mode (PSM) between updates, the GNSS receiver can dramatically reduce its power demand.



Multi-GNSS / Multi-band

The number of concurrently tracked GNSS constellations significantly impacts power consumption, particularly when the constellations transmit in different frequency bands. Again, it comes at a cost: tracking more GNSS constellations increases position availability, especially when sky view is limited or small antennas are used. In such challenging environments, receiving signals from multiple bands (L1, L2, L5) can increase the positioning accuracy by mitigating multipath effects. On the other hand, regionally constrained installations can save power without impacting performance by carefully selecting which constellations to track based on their geographic location.

When high position accuracy and short acquisition times are of the essence, GNSS receivers need to download satellite ephemeris data every 30 minutes for tracked satellites. The more constellations the receiver tracks, the more often this happens. Because the GNSS receiver needs to be switched on to download ephemeris data, this is only possible in continuous tracking mode, in which case the receiver cannot save power.



Tracking more GNSS constellations increases position availability

Power save modes

Advanced GNSS receivers offer one or several power save modes (PSMs) to maintain high levels of performance with reduced power consumption compared to continuous tracking. The PSMs differ in how they balance power consumption and GNSS receiver performance. It is, therefore, important to use the right mode according to the constraints given by the application.

Continuous tracking mode

In continuous mode, the GNSS receiver first acquires its position, establishes a position fix, and downloads almanac and ephemeris data. Once this is complete, the receiver switches to tracking mode to reduce power consumption, remaining in tracking mode unless it loses its position. For applications that require a few updates per second, continuous tracking mode optimally balances performance and power consumption.

Cyclic tracking mode

Some GNSS receivers offer a power save mode that saves power in between short position updates of less than ten seconds. These power savings are achieved by enabling a reduced power tracking mode that does not acquire new satellites. Cyclic tracking is particularly well suited for use cases in which signals are sufficiently strong or antennas sufficiently large: If signals become too weak, the receiver reverts to normal tracking mode with higher power consumption.

Super-E mode

Super-Efficient mode is a proprietary power save mode available on u-blox GNSS receivers – essentially an improved cyclic tracking mode. By reducing the resources required during tracking to a minimum, Super-E mode cuts overall power consumption with little impact on performance. When the signals are weak or only few satellites are visible, the full-power scheme is activated to maintain positioning performance. The power saving Super-E scheme is activated when sufficient and sufficiently strong satellite signals are available. In tests, Super-E has proven to increase power savings three-fold with minimal reduction in position and speed accuracy compared to standard u-blox 1 Hz full-power mode in rural environments.

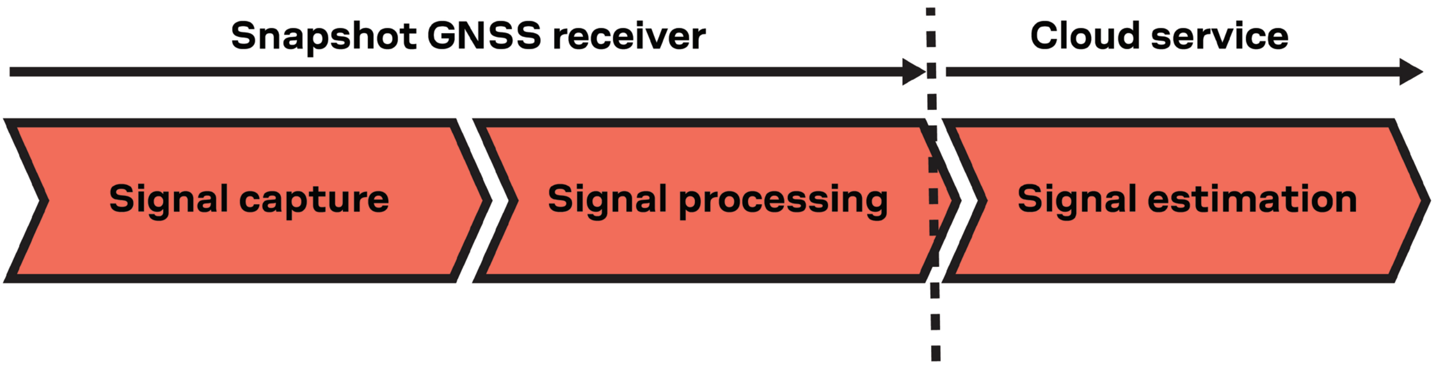
ON/OFF operation

Some GNSS receivers can switch between acquisition/tracking phase and sleep in what is known as ON/OFF operation. In the sleep phase (OFF), the receiver consumes very little power from the backup battery. This mode is a smart choice for longer sleep times. As in the case of cyclic tracking mode, ON/OFF operation requires strong satellite signals at the RF input to minimize the time (and power) required to get a first position fix after each OFF period.

Snapshot positioning

Another way for a GNSS receiver to save power that is gaining traction is to delegate computationally expensive processes involved in computing the position output to the cloud. In snapshot positioning, GNSS signal reception and signal processing are performed by the GNSS receiver, while the estimation of the position is outsourced to a cloud-based service. While this requires an internet connection, it can reduce the power consumption on the GNSS side by a factor of ten.

Snapshot positioning is an ideal solution for use cases in which the GNSS receiver can be put to sleep over long periods (e.g., requiring only a few position updates per day) and that do not need position information to be available to the device itself. In scenarios with an update period of one hour or less, the benefits of putting the receiver to sleep are outweighed by the power required to establish a cellular connection and transfer data to the cloud.



For setups using LTE-M to connect to the internet, roughly 10 percent of the power is consumed by the GNSS receiver, with the remaining 90 percent used by the cellular modem.

The following overview provides rough guidance on which power save mode is best depending on the update rate.

For update rates between one per min and one per hour, it may be worth calculating the energy consumption to determine the most suitable power save mode. As we will explore below, using assisted GNSS to save power during a cold start is also valid approach.

Update rate	**Sub-second**	**Seconds**	**Minutes**	**Hours**
Power-save mode	Continuous tracking	Cyclic tracking	On/Off operation	Snapshot positioning

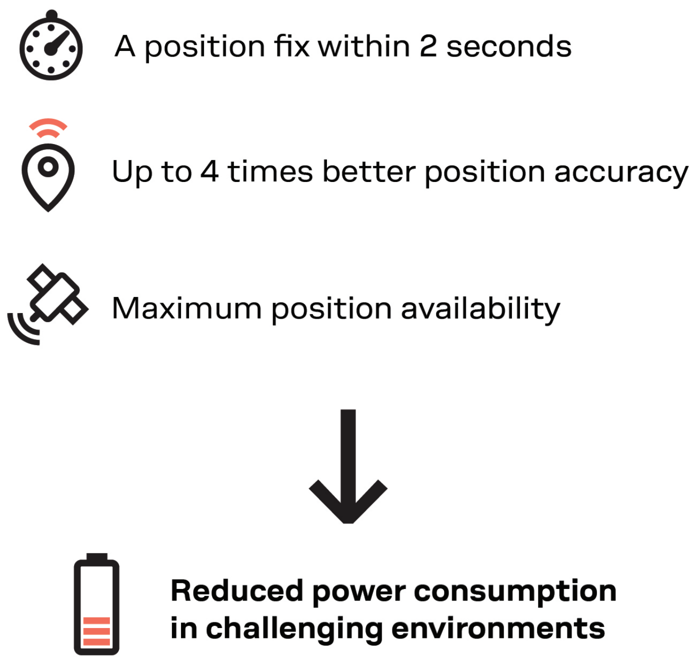
Rough guidance on the appropriate power save mode as a function of the update rate.

Assisted GNSS

The most obvious way to save power is to cut the power supply to the device. But switching the device off entirely forces the receiver to initiate a cold start the next time it is switched on. This involves a roughly 30-second acquisition phase to acquire a first position - the time to first fix (TTFF), which can take minutes if the RF signals are weak due to the challenging environment, the antenna size, or its placement. The GNSS receiver typically attempts to get a first position fix as quickly as possible, impacting the accuracy of the first reading.

A good way to significantly shorten the TTFF is to use an assisted GNSS service, which provides ephemeris, almanac, and accurate time and satellite status correction data for the satellite systems. Assisted GNSS comes in various flavors, including assistance data that is downloaded over the internet in real-time or in bulk for use several days at a time. u-blox also offers an autonomous mode, where GNSS orbit predictions are directly calculated by the GNSS receiver itself without requiring external aiding data or connectivity.

The figures in the table are given for good signal conditions (-130 dBm). If the RF signal level is lower, acquisition times increase. A good antenna and careful antenna placement are very important to achieving optimal results.



Overview of the benefits of assisted GNSS

The shorter the acquisition phase, the less power the GNSS receiver consumes. In cases that benefit from continuous connectivity, online assistance is the best option. Offline and autonomous assistance are next in line, keeping in mind that autonomous assistance requires the GNSS receiver to be switched on occasionally for a few seconds to one minute to download ephemeris data.

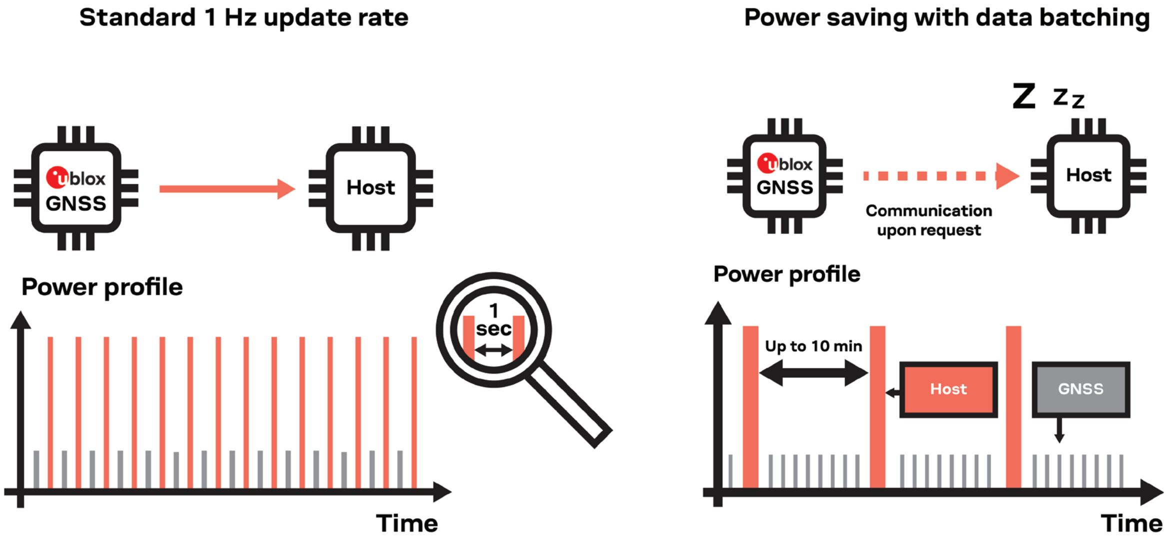
	None	Online	Offline	Autonomous
Data download frequency	None	Every start-up	Once every x days	None
Data validity	n/a	Up to few hours	Up to 1 month	Up to few days
Acquisition phase (TTFF)	~30 s	~ 1 s	< 10 s	~ 10 s
When to use	No connectivity, short on-time	Continuous connectivity	Limited connectivity	No connectivity, long on-time

Key characteristics of three common flavors of assisted GNSS

Data batching

Transferring only the essential messages can help bring down power consumption, as the number of messages transferred between the GNSS receiver and the host MCU increases the processor load on both sides. GNSS receivers typically offer two configuration options: users can (1) select which messages should be sent and (2) set the update time interval for continuous messaging.

Another way of reducing the power consumption on the host side is to let the GNSS receiver collect a certain amount of data before initiating the data transfer to the host in what is referred to as **data batching**. Because the host consumes significantly more power than the GNSS receiver, batching data transfers from the GNSS receiver to the host MCU makes it possible to put the host to sleep as much as possible, positively impacting the power profile (see image below).



Comparing the power profile of continuous messaging (left) and data batching (right)

The right measures for each application

The table below gives guidance on the hardware and firmware options that are useful for each group of use cases introduced earlier. The recommendations presented are for common implementations of each use case and offer an overview of the factors that product developers must consider optimizing the power consumption of their tracking devices.

Rather than offering a definitive recommendation, it aims to offer a starting point for discussions with the component supplier. Ultimately, however, the optimal settings can only be determined by considering the precise specifications of the target use case.

	Automotive tracker	**Sports watch**	**Handheld device**	**Pet/kids tracker**	**Logistic goods tracker**
PSM	Continuous	Cyclic	Cyclic	On/Off	Snapshot
Assisted GNSS	Online / Autonomous	Offline	Offline	Offline	None
RTC, backup battery	Yes	Yes	Yes	Yes	Yes
Oscillator	TCXO	TCXO	TCXO	XTAL	XTAL
Multi-GNSS	4	2-4	2	2	2
Data batching	No	Yes	No	Yes	No
Chip external LNA	Yes	Yes	Yes	Yes	No
Flash memory	No	Maybe (firmware update)	No	No	No

Example for the sports watch

Cyclic tracking mode and data batching save significant power. Assisted GNSS offline can be downloaded when connectivity is given and will shorten the startup time, requiring a backup battery and a real-time clock. For most sports watches, using a TCXO and concurrent reception of 2 GNSS constellations offers the best trade-off between power consumption and performance.

Logistic goods trackers

Logistics goods trackers prioritize long battery life over position accuracy and reduce the bill of material to a minimum to achieve small size and low cost.

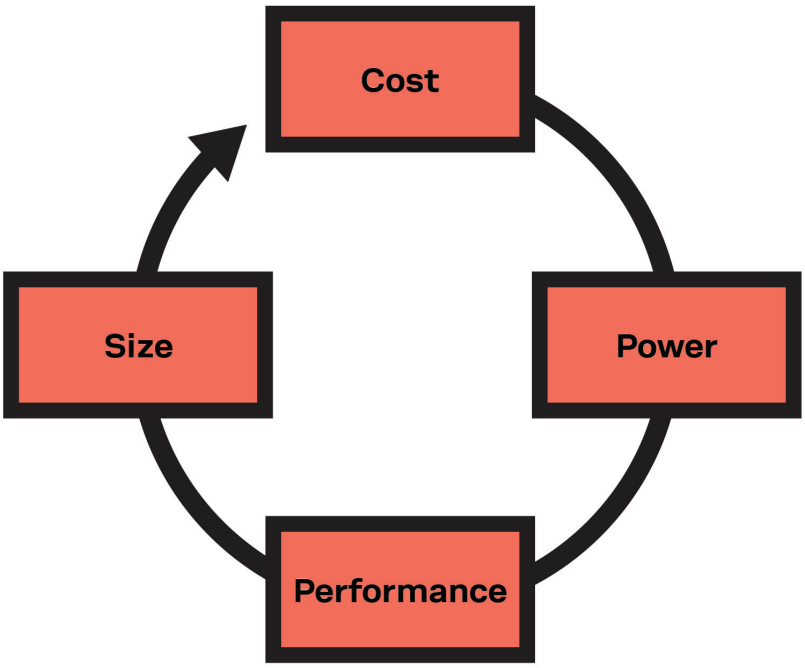
Automotive trackers

Automotive trackers are typically connected to the car battery through the OBD interface. Models that rely on a small, embedded antenna tend to struggle with RF signal availability. An LNA and multi-GNSS combined with assisted GNSS help to cope with the situation.

Summary

As more and more consumer, industrial, and automotive tracking applications leverage satellite-based positioning, customers are expecting more than ever from their solutions, in terms of performance, size, cost, and power consumption. Because these four factors are intimately connected to each other, any measures to reduce power consumption will impact a product's performance.

Today's state-of-the-art GNSS receivers typically offer many means of optimizing their power consumption while meeting use case specific performance requirements. Precisely which of these design considerations and device configurations apply to a specific use case will depend on carefully balancing these four competing factors.

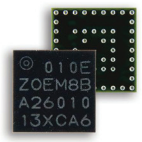


In this white paper, we highlighted how the right hardware choices, firmware settings, and service options can significantly reduce power requirements for a variety of common use cases.

For more detailed information or to have a discussion with our subject matter experts, please get in touch: info@u-blox.com

A.1 u-blox solutions

u-blox offers a range of positioning and services solutions that are tailored to the needs of tracking applications. Below is a list of specific GNSS hardware and location service recommendations for common implementations of the use cases presented in this white paper. Of course, the optimal choice of hardware and services will depend on the specific constraints and requirements of the intended use case.



ZOE-M8B module
4.5 x 4.5 x 1.0 mm

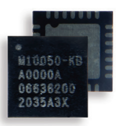
Ultra small, ultra low-power GNSS SiP with Super-E mode

- Ultra small size SiP (System-in-Package) 4.5 x 4.5 x 1.0 mm
- Fully integrated and complete solution, reducing total design efforts
- As low as 12 mW power consumption thanks to Super-E mode
- Ideal for passive antenna, due to built-in SAW and LNA
- High accuracy thanks to concurrent reception of up to 3 GNSS
- Pin-to-pin compatible with ZOE-M8G

MAX-M10S module
9.7 × 10.1 × 2.5 mm

Ultra low-power GNSS receiver for high-performance asset tracking applications

- Less than 25 mW power consumption without compromising GNSS performance
- Maximum position availability with concurrent reception of 4 GNSS
- Proven excellent performance, even with small antennas
- Advanced spoofing and jamming detection
- Pin-compatible with previous MAX products



UBX-M10050-KB chip
4.0 x 4.0 x 0.55 mm

Ultra low-power GNSS receiver for high-performance asset tracking applications

- Less than 15 mW power consumption without compromising GNSS performance
- Maximum position availability with concurrent reception of 4 GNSS
- Proven excellent performance, even with small antennas
- Advanced spoofing and jamming detection

Real-time online A-GNSS service with assured global availability

- Fast Time-To-First-Fix
- Improved accuracy and position availability
- Lower power consumption
- Backed by our warranty and support
- Easy to integrate, even for products without SUPL compliance
- Data privacy protected from service to the enterprise

AssistNow
u-blox A-GNSS service

Extends the life of energy constrained IoT applications

- Up to 10X energy savings over stand-alone GNSS power savings approach
- Expand market reach by building enterprise solutions that leverage CloudLocate
- Guaranteed global availability with warranty and support
- End-to-end solution works with any connectivity technology
- Increase device fielded lifetime and lower operational burdens

CloudLocate
Positioning in the cloud

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About u-blox

u blox (SIX:UBXN) is a global provider of leading positioning and wireless communication technologies for the automotive, industrial, and consumer markets. Their solutions let people, vehicles, and machines determine their precise position and communicate wirelessly over cellular and short range networks. With a broad portfolio of chips, modules, and a growing ecosystem of product supporting data services, u blox is uniquely positioned to empower its customers to develop innovative solutions for the Internet of Things, quickly and cost effectively. With headquarters in Thalwil, Switzerland, the company is globally present with offices in Europe, Asia, and the USA.

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