Buyer's Guide to Extended Ephemeris Technology

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Extended Ephemeris
Technology

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Contents

Chapter 1

Introduction

This eBook has been written for the engineering & purchasing professionals who are new to the subject of extended ephemeris and have a need to understand the basics relatively quickly. This eBook will help you navigate the ins and outs of extended ephemeris technology. After reading this eBook, you should be able to understand the basics as well as the current state of the art of extended ephemeris technology. Specifically, you will learn:

- What is ephemeris and how does it affect the time it takes to calculate a position?
- What is extended ephemeris & what are the benefits of using it?
- Why is it so hard to predict ephemeris?
- How is extended ephemeris delivered?
- How can your mobile device receive and use extended ephemeris?
- What is the most important technical jargon that you need to know and what is it that vendors don't tell you?

To set the stage, we all know that GPS is everywhere nowadays. In fact, GPS technology is so prevalent that even young children know how to operate their parent's in-car navigation system to find the nearest McDonald's. Despite the convenience, one of the least desirable attributes for GPS is that it may take a long time before a position is first available (also known as "time-to-first-fix" or "TTFF").

As you will see in the next chapters, the problem with long time-to-first-fix goes far beyond inconvenience. Considering a GPS receiver typically consumes the most power in the "Acquisition" stage (time between the initial power-on stage when it begins to acquire all the satellites in view and the final stage when a position is calculated), the longer this process takes, the more precious battery power is used up.

Acquiring satellites is a somewhat delicate matter for GPS receivers. This is especially true when the receiver is operating in a downtown corridor or under dense foliage where open sky can be intermittently blocked by surrounding high rise buildings or heavy tree canopy. The net effect is that a receiver will take even longer to calculate a position or sometimes may fail to calculate a position altogether.

By now, you have probably already guessed that the solution to the above problems is to equip the GPS receiver with extended ephemeris technology. As we proceed through the following chapters, you will begin to understand the power of extended ephemeris and discover only what a handful of people know in the GPS business. Enjoy!

"Despite the convenience, one of the least desirable attributes for GPS is that it often takes a long time before a position is first available"

Chapter

2

What is ephemeris?

Before a GPS receiver can calculate a position, it must know the locations of a minimum of four satellites in space. A standard receiver does this by receiving the broadcast signal from each satellite in view. Among many things, each received message describes the orbital trajectory (known as "ephemeris") and the corrections for the on-board clock of that particular satellite. Simply put, ephemeris data is a collection of parameters that help the receiver to accurately calculate where the satellite is at a given time. It is merely a mathematical description of the path the satellite is following as it orbits the Earth.

To understand why it takes a GPS receiver so long to first calculate a position, we have to understand how signals from the satellite work.

The message broadcast from GPS satellites is transmitted at a painfully slow rate of 50 bits per second (bps).

Factoid #1

At 50 bps, if a GPS satellite were to transmit Michael Jackson's best seller Thriller (8.54 MByte), it would take 16.58 days to receive it! Luckily, receiving the regular GPS broadcast takes nowhere near this long!

Each GPS broadcast message consists of one Master Frame of 37,500 bits which takes a receiver exactly 12.5 minutes to receive. Each

Master Frame consists of 25 equal sized Frames (1,500 bit, or 30 seconds) and each Frame is further sub-divided into 5 Sub-Frames (300 bit, or 6 seconds). In order for a GPS receiver to receive broadcast ephemeris, it must fully collect one Frame from each satellite. So if calculating a position requires a minimum of four ephemeris messages from four different satellites; a GPS receiver would remain in the acquisition phase for somewhere between 18 and 36 seconds, just to get ephemeris data.

In an ideal world where a GPS receiver is operating under an open sky environment, there would be no blockages or multipath interference due to reflections from nearby buildings or trees etc. and receiving broadcast ephemeris would be quite simple. However, imagine if you were driving through a downtown core with lots of high rise buildings around, the signals to your GPS receiver would be blocked intermittently whenever driving past a building. What would happen if the GPS receiver was in the middle of receiving a Frame? The answer is, in most cases, the receiver is forced to wait for the next Frame to fill in the missing data. You should see by now that depending on how frequently the signal is blocked, the GPS receiver could take even longer receiving ephemeris. In some harsh environments, a receiver may never be able to fully receive a minimal set of four sets of ephemeris to begin calculating a position.

To make this problem worse, ephemeris data is only usable for up to 4 hours – after that the satellite has moved too far. Can you imagine how frustrating it must be for someone who has to constantly operate a receiver in harsh environments like taxi cab or delivery truck drivers who must repeat the ephemeris receiving process 6 or more times a day?

Factoid #2

GPS receiver needs at least 4 satellites for a 3D position or 3 satellites for 2D. To get a reliable position, 5+ satellites are often needed.

"Simply put, ephemeris data is a collection of parameters that help the receiver to accurately calculate where the satellite is at any given time"

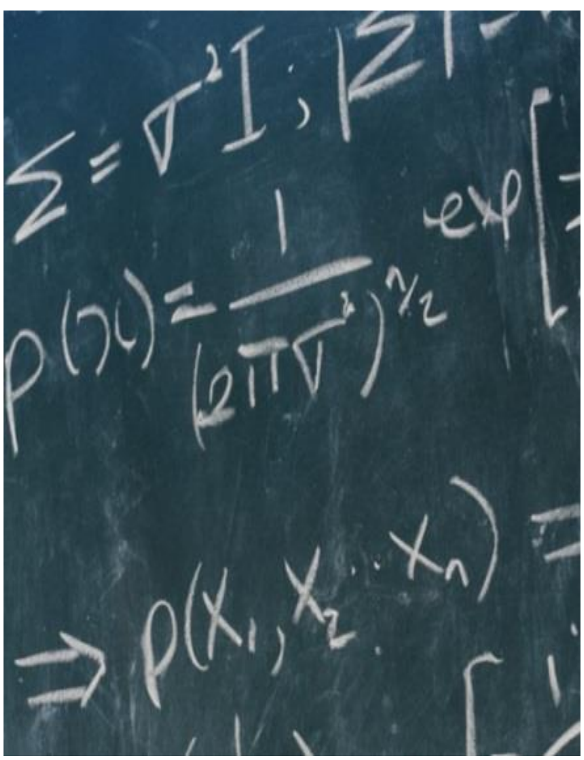
Chapter

3

What is extended ephemeris?

Instead of relying on receiving ephemeris from satellite broadcast and suffering through the limitations that we discussed in the previous chapter, extended ephemeris (or satellite prediction) technology offers many benefits.

While broadcast ephemeris is valid for only up to 4 hours, depending on the vendor you choose, extended ephemeris can last for up to one month. This means once you've downloaded an extended ephemeris file, there is no need to download it again for another month.



To put this in perspective, we have learnt from the previous chapter that for a GPS receiver to calculate a position, it must first of all identify where the satellites are by receiving broadcast ephemeris from 4 different satellites. In locations where it is difficult to get a clear view of the satellites, there may be reduced signal strength which could introduce errors and intermittent gaps in the decoded ephemeris data. Until and unless the receiver can receive a minimum of four sets of broadcast ephemeris, the receiver cannot proceed to the next position calculation stage. With extended ephemeris, a satellite's ephemeris is always usable and there are no data errors and gaps. In other words, satellites with much lower signal strength may still be included for positioning calculation.

Factoid #3

In addition to ephemeris, for a GPS receiver to compute a position, it must also know the time of receiving timing information (known as "HOW") which repeats once every 6 seconds. But, on average, timing can be obtained within 3 seconds.

With extended ephemeris technology, regardless of how poor the surrounding environment is, the receiver can by-pass the process of receiving broadcast ephemeris and can go directly to acquiring the satellite signal, generating Doppler, and code phase and ultimately proceeding to the position calculation stage. By allowing the receiver to skip pass the broadcast ephemeris receiving stage, the time the receiver takes to calculate a first position can be decreased to around 3 seconds.

As we saw, extended ephemeris technology can reduce the normal TTFF of a GPS receiver from 18-36 seconds down to around 3 seconds. This significant improvement not only increases the usability from the users' point of view, it also greatly reduces the power consumption of an integrated GPS receiver within a cell phone or other device.

Factoid #4

SiRFstar-IV consumes about 81 mW of power (45 mA @ 1.8V) during the ephemeris receiving ("acquisition") stage. Energy saving using extended ephemeris can be significant.

"While broadcast ephemeris is valid for only up to 4 hours, depending on the vendor you choose, extended ephemeris can last up to one month."

Chapter

4

Why is it so hard to predict ephemeris?

In a perfect world, it would be simple to predict a satellite orbit and clock for any arbitrary time in the future, satellite position could be calculated using the formulas which Johannes Kepler developed 400 years ago and satellite clock could be extrapolated from model parameters. However, in this perfect world, the Earth would need to be a perfect sphere of uniform density, with no atmosphere, no Sun or no Moon. The satellite would need to have a flawlessly steady clock. We would also need to know the exact satellite position, velocity and clock information at the start time. Clearly, this is not the world that we live in. In the real world:

- Different physical forces act on a satellite at every moment, causing it to diverge from the expected orbit. While these forces can be modeled with varying degrees of success, the remaining errors affect the accuracy of orbit predictions. Some of the forces that affect the satellite orbit are:
    - variations in the gravity field from the uneven distribution of the Earth's mass, along with the pull of the Sun, Moon, and even other planets;
    - drag from the small amount of atmosphere that still exists at orbital heights; and
    - pressure from the solar wind on the satellite body, which can change unexpectedly due to solar activity

- Although the atomic clocks used in GPS satellites are extremely accurate, their frequency is still subject to noise and drift. This limits how well the clock offset can be predicted. Further:
    - Some satellites have less reliable clocks than others since the frequency will drift at different rates depending on the age and type of clock. It must be determined for each satellite individually,

how long the clock prediction will be trustworthy.
    - Atomic clocks on the satellites are reset from time to time or swapped over during maintenance.
- There is a limit to the accuracy with which satellite trajectory and clock bias can be determined
- Maintenance activities on the satellites from the system controllers may not have been anticipated at the time of prediction

As you have just read, extended ephemeris or the prediction of ephemeris over a period of one month requires a deep level of understanding in the behavior of satellite motion and the ability to employ advanced mathematics to model such motion. No wonder why there are only a handful of companies possessing patentable techniques to do this well to date.

"In a perfect world, it would be simple to predict a satellite orbit and clock for any arbitrary time in the future... Clearly, this is not the world that we live in"

Factoid #5

Atomic clocks on board the GPS satellites are stable within "1 part in 10^{12}". This means an observer would have to watch a GPS clock for 10^{12} seconds or almost 32,000 years to see it gain or lose a single second.

Chapter

5

Generation of extended ephemeris

The most basic building block of an extended ephemeris service is data from a globally distributed reference network of high-accuracy GNSS reference stations. In order to achieve highly accurate predictions of satellite orbits and clock offsets, a large number (100+) of reference stations are required and they must be distributed around the globe. Due to the mission critical nature of this data, the reference network should obviously be secure and monitored for high (99.999%) reliability. The purpose of the network is to continuously track GNSS satellites 24/7/365 to allow sophisticated algorithms to model satellite dynamics to determine their orbits and clocks. The end result is a complete set of satellite orbit and clock predictions.

Factoid #6

While many people know that JPL (Jet Propulsion Laboratory) is NASA's (National Aeronautics and Space Administration) lead center for technology development and operations for many NASA missions and infrastructure, JPL is also one of the most respected and trusted suppliers of GNSS reference station data.

In its raw form, this complete set of satellite orbit and clock predictions is very large – over 71 KByte for the GPS constellation each week. Not only is transmitting this much data over the wireless network to millions of mobile phones very inefficient, it is also very costly in terms of bandwidth for network operators. As such, prior to transmitting, this data is typically compressed to a compact format while keeping conversion loss or degradation to a minimum.

Once the extended ephemeris information is generated, compressed, and formatted for delivery, the resulting package is provided by way of a wireless network via distribution servers.

A mobile client residing on a user's device can download new extended ephemeris by periodically contacting an extended ephemeris distribution server. The distribution server network is typically designed to service many clients over a large geographical area.

In the next chapter, we will examine what software is required on the mobile client device.

Factoid #7

Methods to efficiently transmit extended ephemeris are very heavily patented, so the chances of seeing any new methods in the future may be quite low.

"In its raw form, this complete set of satellite orbit and clock predictions is very large… prior to transmitting, this data is typically compressed to a compact format while keeping conversion loss or degradation to a minimum"

Chapter

6

Software client for the device

The software client is a piece of code that resides on a mobile device; it is responsible for interfacing between the GPS chipset in the mobile device and an extended ephemeris distribution server over the internet via a wireless connection.

More specifically, the purpose of the software client is to fetch the extended ephemeris data from the server, and then decompress that data into a format that the GPS chipset can use.

Factoid #8

The CPU & RAM loading for a software client vary greatly across different technology vendors. For the low power requirements of today's mobile electronics, the higher the CPU or RAM loading, the more precious battery power a software client will use.

While the integrated GPS chipset in a mobile phone doesn't typically know anything about when to download extended ephemeris, it is the software client's responsibility to run in the background and decide when to download new data. How often the device downloads new data will depend on how much error due to ephemeris age is allowable and how often a data connection is available.

When new extended ephemeris is required, the software client will initiate communication and authenticate itself with the extended

ephemeris server and, ultimately, receive a compressed format of the extended ephemeris.

Once the compressed extended ephemeris file is downloaded to the mobile device, the software client will decompress the downloaded file into a more computationally efficient form. Then, whenever the GPS chipset is called upon to calculate a position, the software client is ready to inject the ephemeris parameters that the chipset needs for rapid TTFF.

"The CPU & RAM loading of a software client vary greatly across different technology vendors..."

Chapter

7

What technical jargon do you need to know?

Although GPS is everywhere these days, the mathematics that are being used in GPS algorithms still may seem “rocket science” to some people.

While we are not going to teach advanced GPS concepts in this eBook, in order to understand and be able to get the most out of reading data sheets from extended ephemeris vendors, you should at least know the following:

Time-To-First-Fix (“TTFF”): Indicates how long it will take for the receiver to get a position.

- What it doesn’t say: All receivers of the same model will have the same TTFF in the same environment as long as the ephemeris is relatively accurate and are operating in open sky.

Prediction duration: Is the duration for which prediction data is valid.

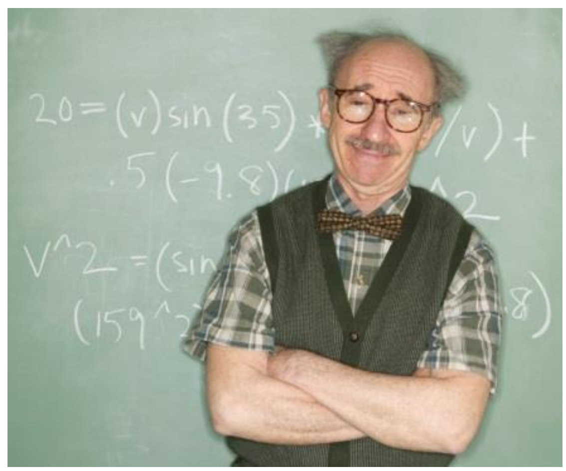
- What it doesn’t say: Does not indicate how accurate the data is over the duration of the prediction period.

Signal In Space Range Error (“SISRE”): Is the ranging error due to the combined effect of orbit and clock prediction errors.

- What it doesn’t say: Does not account for other error sources such as atmospheric delay, multipath errors, and receiver noise. Also cannot be directly translated to position accuracy.

Percentiles: Indicates that % of the time, the error will be within acceptable accuracy bounds

- What it doesn’t say: Does not tell you how large the errors are outside of the bounds - they could theoretically be infinite!



Execution code size: The amount of memory required to store the software client.

- What it doesn’t say: May not specify whether the code includes external static/dynamic libraries. Also may vary greatly in size depending on the platform it is used on.

Run-time: The duration required to perform a task in software.

- What it doesn't say: The microprocessor may not necessarily be the limiting factor. Could also be limited by memory bandwidth.

Receiver sensitivity: Describes the minimum signal strength required for a receiver to acquire and/or track a signal from a satellite.

- What it doesn't say: GPS receivers often publish 'Tracking Sensitivity' which describes how strong a signal is needed for the receiver to track the signal. However, manufacturers seldom publish a separate acquisition sensitivity figure which describes how strong the signal must be for a receiver to initially acquire the satellite signal. ***The acquisition sensitivity value is generally much higher than the tracking sensitivity figure*;** this means that the signal must be stronger for a receiver to acquire a signal than to track a signal. Since many receivers are not turned on until a position is needed, the acquisition sensitivity figure is extremely important as signal tracking cannot begin until a signal has been acquired. Once the signal is acquired, a receiver can then track the signal and generate ranging measurements to determine its position.

Dilution of precision ("DOP"): This is the effect that the satellite geometry – relative to the user's position – has on a receiver's position accuracy.

- What it doesn't say: DOP can vary greatly depending on user location and time. Also it is only one component of position accuracy – it can tell you the position is bad, but not necessarily that it's good.

Factoid #6

While In order to determine the accuracy of the predicted ephemeris information, one must compare it against accurate reference information. Reference information typically comes in the form of precise ephemeris information provided by sources such as the International GNSS Service ("IGS").

Be sure to check with your vendor to see if they have automated tools for you to evaluate their product against such reference information.

Chapter 8

Conclusion

We hope that by reading this eBook, you've gained an understanding of how extended ephemeris can significantly improve the TTFF, and as a consequence how it can help to reduce the energy consumption of your GPS-enabled product.

You have learnt the basics of broadcast ephemeris including its limitations and the benefits of using extended ephemeris. You now also understand the purpose of the software client and how extended ephemeris is delivered over the wireless network.

Congratulations! You are now one of the few people in the industry who understand how this whole thing works.

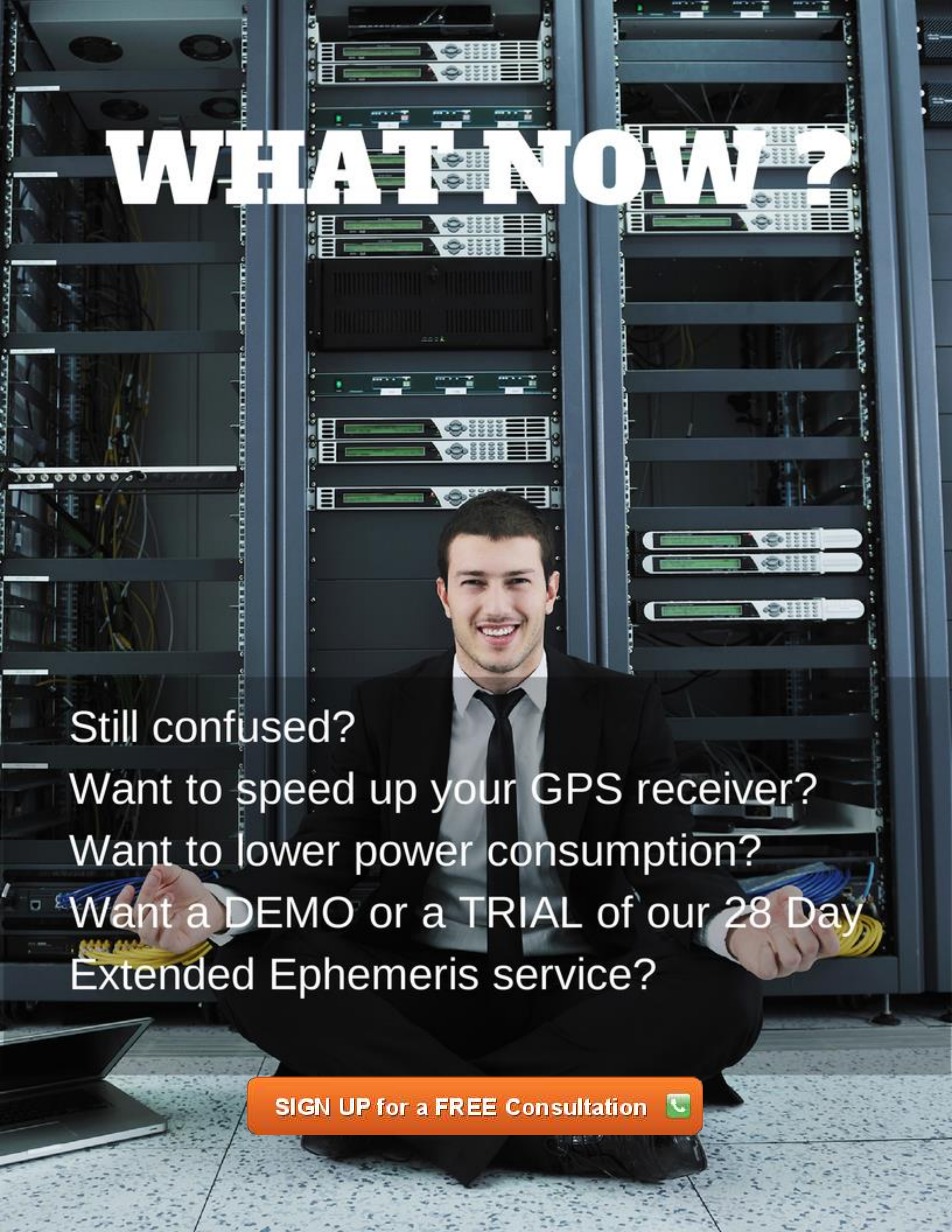
Final Thoughts

If there is one thing to take away from this eBook, more than anything else, it is that extended ephemeris technology is about providing the best user experience (in terms of speed, accuracy and energy saving) to your customers, and that experience translates to how pleased they are with you and with your product.

Many years ago, there used to be a saying in the tech world that "No one ever got fired buying from IBM". This phrase meant that managers in charge of purchasing may feel psychologically more secure to make a decision buying from a well-known vendor like IBM. Buying from anyone else, even if the specification was higher and the price lower, was perceived to be "too risky". And, indeed, IBM sales people would be more than happy to take advantage of that fear during their presentations, and often demanded prices 2-3 times higher. The customer is in fact paying a hefty risk premium based on the logic that "No one ever got fired buying from IBM".

When buying extended ephemeris or any technologies for that matter, you should always ask yourself if it is worth paying so much more for an insurance policy that may not provide your customers with the best experience? The moral of the story is - if a vendor can deliver a technology better/cheaper/faster, you may want to take a serious look. After all, isn't your career more important than just not getting fired?

"Simply put, ephemeris data is a collection of parameters that help the receiver to accurately calculate where the satellite is at a given time"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Index

D

E

N

P

R

S

T