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GNSS

as Critical Global Infrastructure

Imagine a blanket of satellites constantly buzzing with location and time info! That's GNSS, used everywhere: planes, ships, trains, even your phone's maps. These "space clocks" tell your receiver exactly where you are on Earth and exact time.

GNSS as Critical Global Infrastructure

There are two main GNSS systems right now:
- ▶ **GPS**: Made by the USA.
- ▶ **GLONASS**: Russia's system.

But more are coming! Europe's **Galileo**, China's **BeiDou**, and others are joining the party.

The primary time synchronization sources for critical infrastructure systems are signals broadcast by GNSS, such as GPS satellites. This WP provides an overview of how timing systems work discusses the GNSS timing dependencies of critical infrastructure systems operating in the financial, telecommunications, and electric power sectors.

The 2001 Volpe Report found that GPS was being used for timing synchronization in transportation-related digital communication links and other applications. It also found that GPS was the most frequently selected method for precise synchronization in telecom systems. The report concluded that backup systems were necessary for all GPS applications involving the potential for life-threatening situations or major economic or environmental impacts.

Three categories of time and frequency measurements are important to critical infrastructure:

Time synchronization: This in critical infrastructure ensures clocks agree with a reference UTC clock. This is achieved by measuring and/or adjusting the clock under test to minimize its time offset. The reference clock provides a signal (OTM, time code, or both) at the UTC second, often sent on a 1 pps signal or embedded in the time code.

Time Stamping: Critical infrastructure systems record event timestamps as OTM-linked UTC labels, requiring accuracy within system timing tolerances.

Frequency Synchronization: Critical infrastructure systems may rely on precise oscillator frequency, analogous to time synchronization. This "synchronization" involves measuring and potentially adjusting the clock's frequency against a reference UTC clock within strict limits.

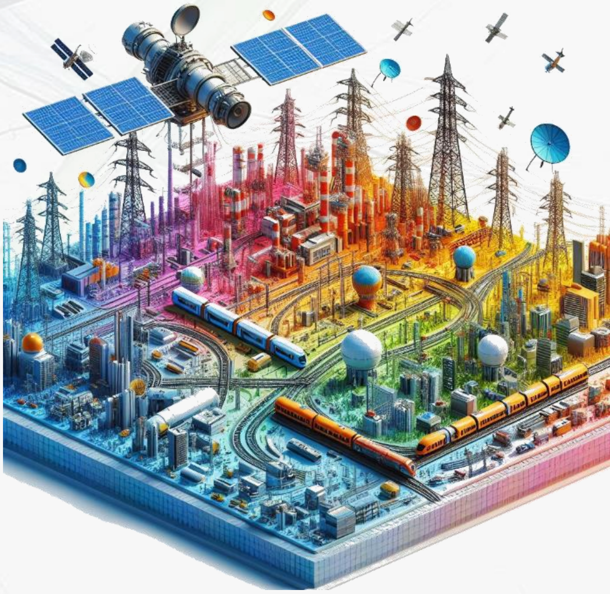
Key Terms

Time Accuracy: 1 μs threshold, measured vs UTC, max deviation matters (MTIE)

Frequency Accuracy calculated from time difference changes (slope of fitted line).

Stability indicates potential accuracy if calibrated, estimated by Allan/Modified Allan deviations/Time deviation (TDEV).

Resolution defines smallest measurable change (digits after decimal).



Free running clocks vs disciplined clocks

There is critical differences in timekeeping mechanisms and their implications, Free running clocks rely on internal oscillators with inherent frequency inaccuracies, leading to a gradual accumulation of time errors over periods of operation. Despite their affordability and widespread use, they are deemed unsuitable for critical infrastructure due to significant time offsets, even with advanced rubidium oscillators.

Disciplined clocks eliminate time errors by continuously adjusting the oscillator frequency to match a reference clock, such as GPS signals. While some GPSDCs with lower-end oscillators may transition into free running mode during signal loss, advanced models equipped with rubidium oscillators exhibit superior holdover performance. Despite the unmatched holdover capability of cesium clocks, their limited deployment in critical infrastructure systems is attributed to factors like cost, size, and maintenance requirements.

Case Study 1: US Stock Exchange

Stock exchanges, like the NYSE and NASDAQ, facilitate trading of financial assets globally. The NYSE lists larger companies, resulting in a market capitalization of over $20 trillion, while the NASDAQ's market capitalization exceeds $10 trillion. These exchanges significantly impact the U.S. and global economies, with billions of shares traded daily. Time synchronization is crucial for stock exchanges, and their reliance on GPS underscores their importance .

The need for time synchronization arose due to the widespread adoption of electronic trading platforms and automated stock exchanges in the late 1990s. These changes significantly reduced transaction times, led to smaller spreads, and ultimately influenced the decimalization of stock prices on the NYSE and NASDAQ.

High-frequency trading (HFT) has made accurate time stamps crucial for stock exchanges and trading platforms. To prevent fraudulent activity and market manipulation, precise time synchronization ensures fair and transparent trading. For instance, consider a scenario where a retail investor submits an order based on displayed bid and ask prices, only to have a large investor execute a trade ahead of them, causing immediate financial losses

In 2012, the SEC introduced Rule 613, mandating FINRA and U.S. stock exchanges to establish a Consolidated Audit Trail (CAT). The CAT plan includes synchronization requirements, equivalent to **50 ms** for automated orders and **1s** for manual orders, with respect to the National Institute of Standards and Technology (NIST). Additionally, the CAT demands granularity of at least one millisecond, ensuring precise sequencing of reportable events. In contrast, the European Union's MiFID II imposes even stricter requirements, with **100 µs** for HFT synchronization and **1µs** resolution.

GPS time is therefore essential to prevent frauds in U.S. stock exchanges.

While losing GPS would mean losing synchronization after a while, it wouldn't necessarily crash the markets. Why? Unlike in other systems, stock exchange synchronization is mainly for investor protection, not technical requirements. So, without it, fraud and manipulation become more likely, but trades could still happen..

Note: GPS time is not exactly the same as NIST time, but the difference is negligible and traceable. GPS time is preferred over other time signals from NIST, such as WWVB, ACTS, and ITS, because it is more accurate, economical, and future-proof.

Case Study 2: Power Grid

Due to its vast geographical reach and interconnected systems, the power grid relies heavily on a readily accessible, unified UTC reference clock for synchronized operations. Power companies identify locating faults on transmission lines as the one with the strictest synchronization requirements. This method leverages the high-frequency pulse generated at the fault point, analyzing the arrival time measured at both line ends by synchronized clocks with microsecond resolution. GPSDCs ensures microsecond-level synchronization, allowing for identification of the exact tower closest to the fault based on time-stamped data.

Another application is in **disturbance monitoring equipment (DME)** on the power grid. DME includes relays, sequence of event recorders, and digital fault recorders that use GPS or PTP for time synchronization. DME helps protect grid assets, record incidents, and analyze events with high accuracy and precision.

The **August 14, 2003 blackout** underscored the importance of time-synchronized recording devices, prompting recommendations for their widespread implementation.

Case Study 3: Telecommunication

Synchronization in Telco aligns clocks of transmission and switching equipment to ensure correct timing and order of operations, crucial for data integrity and network reliability.

Telco dependency on GPS surpasses that of stock exchanges or the power grid.

To enhance timing system diversity, some U.S. Telco providers are adopting global navigation satellite system (GNSS) clocks, receiving signals from multiple satellite constellations including GLONASS, Galileo, and Beidou. Despite concerns about non-U.S. control and potential vulnerabilities to jamming, engineers recognize the advantages of multi-constellation reception for improved resilience against disruptions.

The increasing deployment of GPSDCs, already numbering in the hundreds of thousands and expected to rise with **5G expansion**, underscores the network's susceptibility to widespread GPS outages and the critical need for diversified timing solutions to ensure uninterrupted service.

Ji-Won (지원)

For enhancing resiliency, diversity in timing solutions across all sectors is critical to mitigate vulnerabilities and to protect normal socio-economic life.
Read NIST TN 2189.