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CIGRE US National Committee
2017 Grid of the Future Symposium

GPS and GLONASS Constellations for Better Time Synchronizing Reliability

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SUMMARY

Time synchronization is one of the important aspects in the development of modern critical infrastructure. The demand for the accurate, reliable and high availability source of time synchronization is ever high. Global Positioning System (GPS) is the most widely used time synchronization source. Since GPS is based on low power satellite signals and prone to advertent (Jamming, Spoofing) and inadvertent (Weather conditions, physical conditions) unavailability, critical infrastructure owners often seek ways to ensure high availability of the GPS clocks. One of such ways is to use redundant clocks in the system, use Precision Time Protocol (PTP) which allows multiple master clocks in the system. However, the above techniques have their limitations as the loss of GPS signal might affect all the receivers. A better way to ensure high availability of the time signal is to use multiple GNSS signals in addition to multiple receiver clocks.

This paper presents cases where the GPS satellite system reported bad quality and also mentions how spoofing attacks affect PMUs synchronized to GPS only. In addition, the paper demonstrates the benefits of having a clock tracking multiple satellites constellations, GPS and GLONASS.

KEYWORDS

Time synchronization, GPS, GLONASS, GNSS

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1.0 Introduction

The demand for accurate time synchronization available 24/7 increases with the growth of critical substation applications, such as phasor measurement, merging units, traveling-wave fault location and current differential protection schemes. In order to yield the best accuracy and granularity from such applications, the use of a common, reliable and precision-time reference is essential.

Currently, the Global Positioning System (GPS) is largely used by clocks as reference to provide a common and precise time stamp along devices worldwide. The GPS system counts with 31 satellites covering this planet, and it uses atomic clocks achieving ± 100 nanosecond accuracy. However, using only the GPS constellation as time reference may not be as reliable as it used to be, based on three main reasons.

Firstly, substation applications evolved and time reference is now critical to some solutions to work properly and as any other system, the GPS is also susceptible to errors. In January 26th of 2016, some PMUs reported what looked like errors in the time signals from some satellites. Observatories around the world confirmed a discrepancy in GPS timing of 13 microseconds when compared to grounded atomic clocks. Secondly, spoofing attacks on GPS is already a reality to PMU applications. A slight and continuous shift in the GPS time is hard to detect, and the attack results in an aggressive frequency deviation that may lead to open a circuit breaker of a transmission line. Last but not least, where the antenna is installed is an important point to be considered. Due to buildings or mountains, sometimes the antenna does not track the minimum required number of satellites visible during all day long to ensure time quality for critical applications, which may disable a current differential protection for instance.

Despite of been the most known, the GPS is not the only Global Navigation Satellite System (GNSS). GLONASS, Galileo and BeiDou are also GNSS, however only the first one is globally available along with GPS system. GLONASS (referring also to GLObal NAVigation Satellite System) achieved full global coverage in October 2011, with 24 active satellites providing ± 200 nanosecond time accuracy.

2. GNSS

Developed initially for military use, the GPS was the first operational Global Navigation Satellite System (GNSS). Nowadays there are other systems, been all accessible for personal purposes and and free of charge, such as the Russian Globalnaya Navigazionnaya Sputnikovaya Sistema (GLONASS), which is already available, the European Galileo and the Chinese BeiDou, both still under development.

All the GNSSs currently available operate under the same principle. The position calculation procedure is called trilateration or triangulation and consists of using the information of at least three satellites. The distance between an object to a satellite is determined by the delay in signals exchanged between them. With one distance it is possible to trace a circle of possible positions. When there are distances between the object to three different satellites, the intersection between the circles indicates the objects location. The satellites know their current position relative to Earth since they follow a fixed orbit and all the positions in their routes are previously stored. As the distance is calculated through the delay and the speed transmission may vary according to atmospheric conditions and obstacles in the way, a forth satellite is usually needed to grant greater accuracy to the system.

In order to have global coverage, the constellation or the group of satellites that composes the system needs to have at least 24 satellites. This ensures that there are always a minimum of 4 satellites above the horizon at every place on the planet.

The high accuracy of these systems is only possible because of the extremely stable clocks inside each satellite. All of them have an internal atomic clock with high stability and the mean between those clocks provides a time standard, derived from the global standard known as TAI. That is why the GNSS systems can be used as a global time reference with accuracy of up to nanoseconds, besides from providing geolocation.

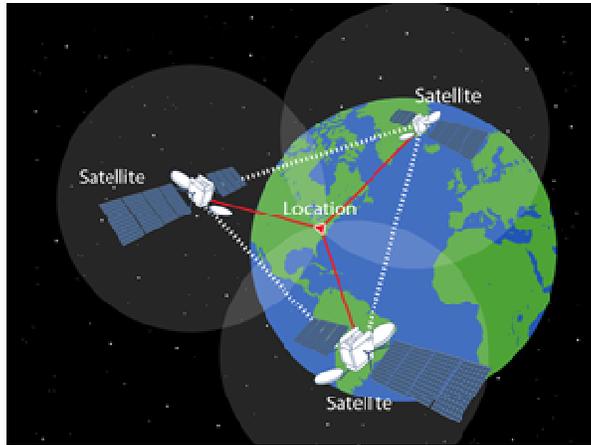


Figure 1 – Triangulation procedure used by GNSSs.

A. GPS

Conceived for military purposes in 1973 by the United States, the system was declared totally operational in 1995. Today it counts with 31 satellites that were launched to orbit for years, starting in 1978. Despite of the total, only 24 satellites are available simultaneously; the other ones are operational only in case of a failure or for data checks.

The satellites orbit Earth at 20200 kilometers up in the sky and complete two full turns around the globe per day. They have a longitudinal trajectory with different angles for each satellite. Since the GPS is functioning for a longer period of time, being the only system available for many years, this is the most diffused and in many cases the single supported system.

B. GLONASS

The Russian navigation system GLONASS started to be developed in 1976 also for military purposes. The project was interrupted for many years after the end of the Soviet Union but it was reestablished and gained notoriety during the last decade, driven by the Russian president Vladimir Putin. GLONASS' constellation is composed of 24 functional satellites and their orbit is similar to that of the American ones.

3. Limitations of a Single GNSS Solution

Using a single GNSS as a time reference is the most used solution, commonly relying on the GPS, but using a single solution introduces some vulnerabilities and limitations to the system

A. Satellite failure ^{[1][2]}

Although being accurate and reliable, problems with satellites is a fact and may happen causing big problems for real-time systems. On 2016 January 26th, the Aalto University's Metsähovi radio-observatory located in Finland detected an error in time reported by the GPS system. The automatic monitoring system of atomic clock triggered an alarm reporting a deviation of 13.7 microseconds. Other radio observatories in Britain and Australia confirmed the 13 microsecond error.

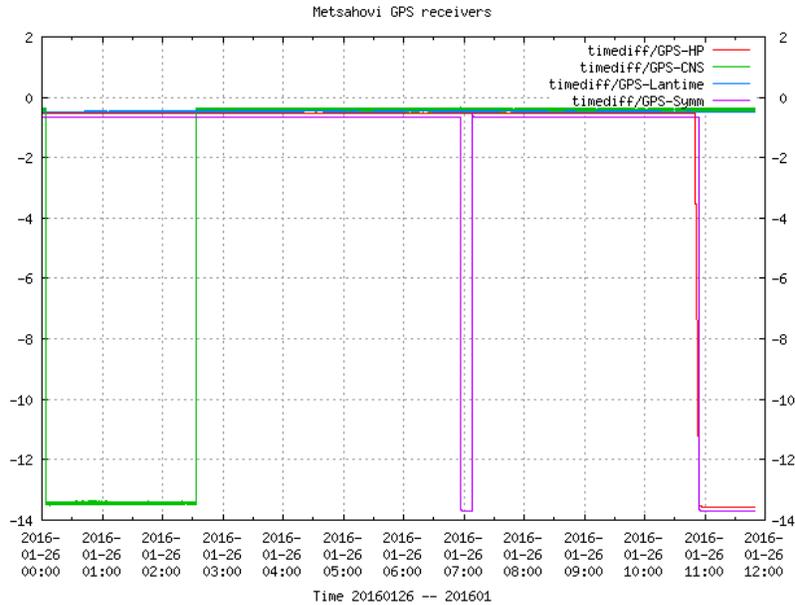


Figure 1 – Anomaly detected by Metsahovi GPS receivers.

The United States Air Force confirmed this anomaly occurred when the oldest GPS vehicle, SVN 23, was failing and being decommissioned from the constellation of satellites orbiting Earth and yet a spokesperson for the USAF 50th Space Wing said this issue in the GPS system only affected the time on legacy L-band signals.

While this was a tiny error, it was enough to bring hours of problems to telecom companies.

B. Spoofing Attacks ^[3]

In electric substations the antenna requires to be installed outdoors, with a clear view of the sky, but not necessarily with a significant elevation. Thus, usually the antenna is mounted attached to a wall of the substation control house, and because of the lack of elevation, spoofing attacks on antenna are possible without extraordinary efforts. Although spoofing may be performed in any GNSS constellation, the GPS is most commonly attacked as it is the oldest and GPS simulators are easily available.

The spoofing attack slightly increases or decreases the second pulse reference from satellites, occasioning error when calculating the electrical system frequency and consequently in the phase angle calculation for PMUs and protective relays. Simultaneous spoofing attacks in different locations are very unlikely to happen, as this requires sophisticate devices.

C. Satellite Coverage

Although 24 satellites guarantee a minimum of 4 visible satellites at any time and location, atmospheric conditions like in cloudy days and geographic obstacles such as mountains or buildings in cities can lead to bad signal reception and even complete loss of communication. Due to buildings or mountains, sometimes the antenna does not track the minimum required number of satellites visible during all day long to ensure time quality for critical applications, which may disable a current differential protection for instance.

4. Multi-GNSS Solution

This technique consists of using satellite data from different navigation systems and combining them as if it was a single system providing one time reference. Such a solution, besides not being expensive or difficult to implement, offers great advantages over using a single navigation system. There are many articles and studies that prove the solution's feasibility as well as its benefits.

The first benefit is the total number of available satellites. Using combined constellations greatly increases the number of satellites available and visible for data collection. Having a greater number of satellites guarantees greater chances of good signal reception thus expanding coverage and improving the user's experience under poor conditions such as bad weather and physical obstacles. Another advantage is the accuracy of the combined solution. As [4] has demonstrated in a real case study, the accuracy obtained by a multi-GNSS system is greater than a GPS-only solution. That can be explained by the greater number of satellites available that enables a better noise compensation. Different filters can be applied and the accuracy is mathematically improved. The single point of failure is not an issue in such a solution. Relying on different navigation systems, the solution remains totally functional even when only one system is available while still having the advantages already mentioned when more than one constellation can be used simultaneously. Also, the spoofing detection rely on availability of signals from multiple GNSS - GPS and GLONASS in this case, and the detection does not work in single GNSS mode. The spoofing detection monitors suspicious changes in the GNSS signal indicating external manipulation. Therefore, the detection is only successful when the signal is genuine first and when the transition to the spoofed signal is being observed directly. When a receiver is started up to a spoofed signal will not be recognized.

5. Implementation

To investigate the real improvements brought with this solution, a research project was conducted. A prototype board was developed to compare the performance of both solutions, single and multi-GNSS time reference based clocks.

There are already commercially available modules multi-GNSS developed for better timing performance. The prototype board developed was composed of a GPS-only satellite module and a multi-GNSS (being only GPS and GLONASS tested) satellite module.

Each receiver reports the number of satellites visible and the actually number used for location and timing calculations. The following pictures show the frequency for each total number of satellites, both visible and used, in a 24 hour test.

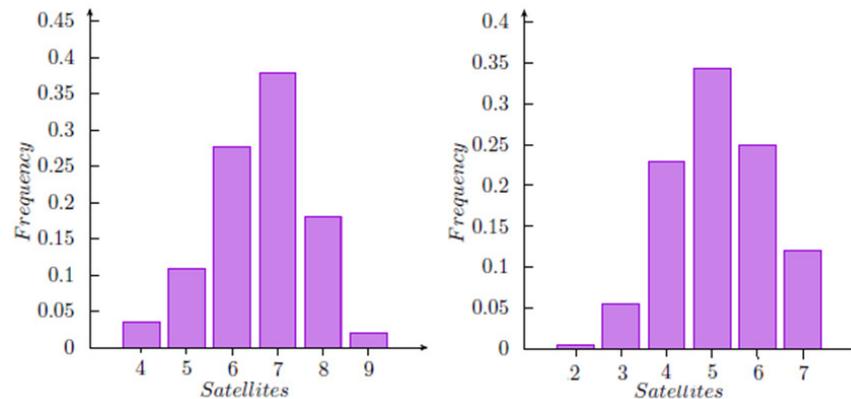


Figure 2 – Visible (left) and Used (right) number of satellites in 24h for GPS-only solution.

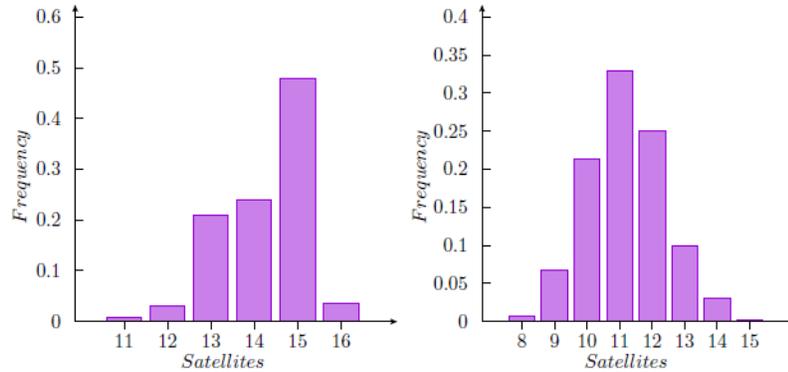


Figure 3 – Visible (left) and Used (right) number of satellites in 24h for GPS+GLONASS solution.

The results found were coherent with what the papers and studies had previously stated. The gain in satellite number is huge. The figures shows GPS+GLONASS solution is way better for having more satellites and offering greater accuracy, as the GPS-only solution offers a ± 60 nanoseconds accurate PPS signal while the multi-GNSS system offers a ± 20 nanoseconds accurate PPS signal.

6. Conclusion

As reliability is a common talk nowadays and substation applications are increasingly demanding accurate time for synchronization, choosing a clock that tracks both GPS and GLONASS increases time accuracy and coverage, as the clock can track a group of 48 satellites all across the globe. Besides, GPS+GLONASS systems adds the redundancy of having two satellites constellations available all day long 24/7. Whenever one constellation is lost, or reports bad quality, the clock will continue running in full synchronization based on the healthy source (with zero switchover time). Ultimately, when comparing the cost-benefit from GPS-only solutions with Multi-GNSS clocks, the price is not much more expensive considering the real benefits of time accuracy and reliability, which indicates Multi-GNSS clocks are becoming more and more common in substations these days.

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