Building national timing grids to mitigate GNSS vulnerabilities

Obtaining a reliable, robust, and accurate timing source is increasingly important in today's connected world. Everything from controlling, coordinating and protecting power distribution across a national power grid to managing the high volumes of financial transactions executed on a stock exchange relies on highly accurate and synchronized clocks. As the transfer rates of digital communication networks increase, so does the need for nanosecond accurate timing sources.

Critical infrastructures and large-scale communication networks increasingly rely on global navigation satellite systems (GNSS), such as GPS, Galileo, and Beidou, to provide accurate, reliable, and secure timing services. GNSS offers a convenient and easy-to-implement timing source. Each satellite in a GNSS constellation features multiple atomic clocks, continuously providing accurate nanosecond level timing signals to connected receivers.

The ease of globally distributing accurate timing information using orbiting satellites, while one of the most successful aspects of any GNSS constellation, also highlights a dependency that increasingly involves a degree of risk.

GNSS vulnerabilities

The extent of our dependency on GNSS for positioning, navigation, and timing is significant. From navigating our way to an appointment in an unfamiliar city to providing mobile communications from a cellular base station precise time synchronization using GNSS is ubiquitous. Other examples of GNSS use include aircraft navigation, fleet asset tracking, and a plethora of IoT applications.

With GNSS satellite constellations located thousands of miles above Earth, the signals received by our smartphones and other devices are extremely weak. Consequently, they are prone to jamming and spoofing. This trend has been increasingly of concern, particularly since more critical national infrastructure relies on accurate time and therefore has a high dependency on GNSS availability. For most governments, the resilience and availability of an authoritative and accurate time source is a matter of national security.

Some rogue nation-states and malicious actors are actively engaged in jamming and spoofing GNSS signals close to their country's borders. Further, with individuals now able to obtain GNSS jamming devices readily online, there are recorded cases of delivery drivers routinely using them to prevent their employers from tracking them.

Sophisticated jamming and spoofing mitigation techniques using advanced signal processing algorithms are increasingly incorporated into GNSS receivers and modules. Despite these countermeasures, governments are taking steps to ensure that critical national infrastructure is resilient against such GNSS vulnerabilities including the case of complete GNSS denial. The vital national infrastructure of most nations today which is overly dependent on GNSS time includes government civilian and defense agencies, telecommunications networks, aviation authorities, financial organizations, and utility operators. Many governments are looking to protect the source and utility of time by implementing a national timing grid.

UTC and role of BIPM

National metrology laboratories have worked together for decades to maintain a traceable and authoritative time source, known as universal coordinated time (UTC). Coordinated by the Bureau International de Poid et Mesures (BIPM), a time scale approach at each metrology lab uses atomic clocks to create a local instantiation of time that can be compared to the authoritative UTC source - see Figure 1. The country's local time scale is called UTC(k). BIPM provides time-offset corrections to each metrology lab to align UTC(k) to UTC. (please refer to image at: https://www.microchip.com/en-us/products/clock-and-timing/systems/time-scale-measurement)

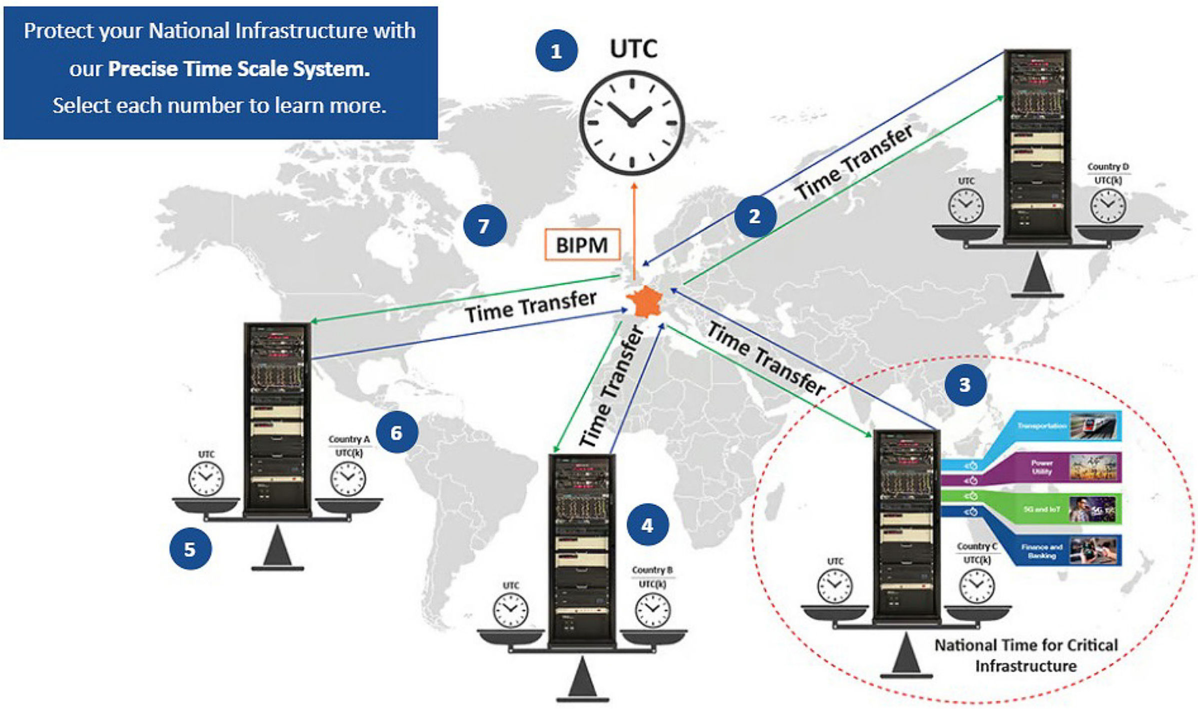

Figure 1 - The realization and distribution of UTC (source Microchip)

National metrology labs have historically provided calibration and measurement services alongside collaboration with BIPM on UTC. However, faced with a landscape of local and national GNSS disruption, the expertise within metrology labs is being called on to provide a national time scale for critical infrastructure and essential services. Provisioning a time scale, to provide time-as-a-service, can mitigate a nation's critical infrastructure from being overly dependent on GNSS and reduce national security risk from GNSS vulnerabilities and service outages.

National Standards Authority of Ireland implements country's first national timing grid

Ireland's National Metrology Laboratory (NML), part of the National Standards Authority of Ireland (NSAI), launched its first national timing grid (NTG) in 2023. With an increasing part of the country's economy created online, the Irish government viewed the resilience of timing to Ireland's digital networks and services as paramount. The distribution of accurate timing nationally is vital for Ireland's critical infrastructure services and partners.

Ireland's NML uses Microchip's 5071A cesium atomic clocks and has been recognized as an official traceable contributor to UTC by the BIPM since 2020.In an official announcement launching Ireland's NTG, David Fleming, NSAI Technical Manager for Time, said, "We are so excited to be launching the country's first every National Timing Grid. Keeping Ireland's networks on time is crucial in supporting its day-to-day operations as more and more of our services are moved online. We are now also distributing NTP time derived from our cesium atomic clock (over the internet). We are keen to support Irish businesses in any way that we can, and this time has been made freely available for use by any organization that could benefit from utilizing time directly traceable to UTC (NSAI)."

Ireland's new officially recognized time scale is now known as UTC (NSAI), and the NTG comprises six cesium atomic clocks from large telecommunications companies based in Ireland inked via GPS satellites. The clocks automatically send clock data for direct comparison against UTC (NSAI) and thus are now traceable to UTC (NSAI). The NTG includes near real-time tracking of clock stability against Coordinated Universal Time (UTC), the primary time standard by which the world regulates clocks and time, early warnings in case of timing drift, enhanced resilience in case of jamming or spoofing of GPS systems and redundancy in case of clock failure.

Implementing a national timing grid begins with deployment of a time scale system

The build out of a timing grid begins with having control over the source of time to the point that the generation of time is operating within a country's territory (e.g., on a country's soil) providing an unmatched level of security. This is driving countries, and in particular, the metrology labs, to revisit their time scale infrastructure, not only for performance qualities such as accuracy and stability, but also for operational qualities such as reliability, robustness and fault tolerance as these systems need to run 24 x 7 x 365 days/year.

The construction of a time scale system starts with connecting to individual autonomous clocks that each generate a frequency reference with excellent accuracy and stability. First, the time scale makes measurements by comparing the individual clocks to each other. The relative differences between them are used to create a clock ensemble which is superior to any of the component clocks in accuracy and stability and is used to generate the time scale frequency.

Generating the time scale frequency reference is critical and poses a significant challenge since the only measurements available are the relative differences between independent clocks. Based on these measurements, a modern time scale algorithm offers considerable advantages over prior-generation time scale algorithms in its use of clock weighting factors. These factors primarily center on phase and frequency characteristics, and offers two key benefits:

• The phase and frequency noise, which are independent of each other, are properly apportioned between clocks based on the time-difference measurements

• The short- and long-term stabilities of the time scale are optimized simultaneously. In addition, the time scale algorithm also uses analysis statistics to reject outlier events such as bad measurements or phase time steps.

As a result, the time scale takes advantage of each clock's performance to achieve the best clock ensemble performance over short observation windows while simultaneously delivering excellent long-term stability.

Truth Source Steering and System Outputs

Steering of the time scale outputs is done in two steps. First, the user can select a truth source, which represents the source of time that the system is being aligned with. The truth source is typically UTC as provided by the BIPM. The difference between UTC as computed by the BIPM and the time scale is described with the equation: [UTC – UTC(k)] where the letter "k" represents the contributing laboratory. This calculation is provided every five days, and these comparisons are published in a monthly report known as BIPM Circular T. In support of evolving needs, BIPM implemented a rapid realization of UTC known as UTCr which provides a daily value as well.

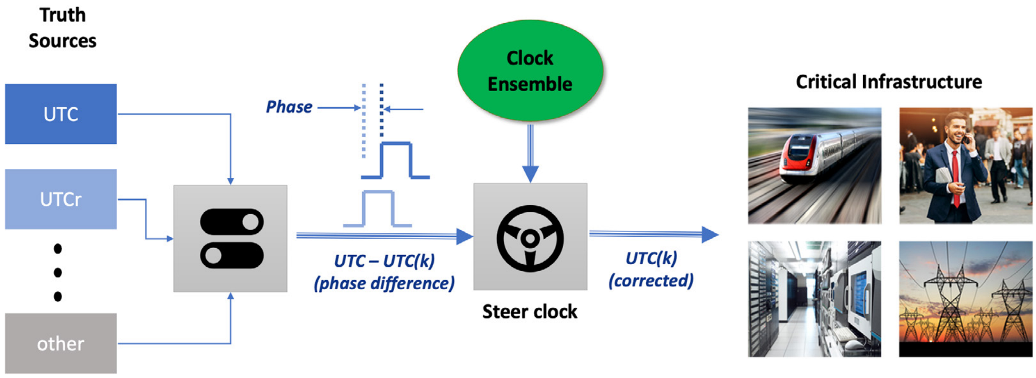

Figure 2 - Time scale coordination with a truth source is vital for an accurate and traceable national timing grid (source Microchip)

An example of a complete time-scale solution is illustrated in Figure 3. The Microchip Precise Time Scale System (PTSS) integrates atomic clocks, multi-channel measurement system and ensemble algorithm to combine clock measurements to form a time scale. This time scale can be compared to an authoritative time provider such as UTC from BIPM. The PTSS is also constructed with a high level of redundancy and fault tolerance all contained in a single rack.

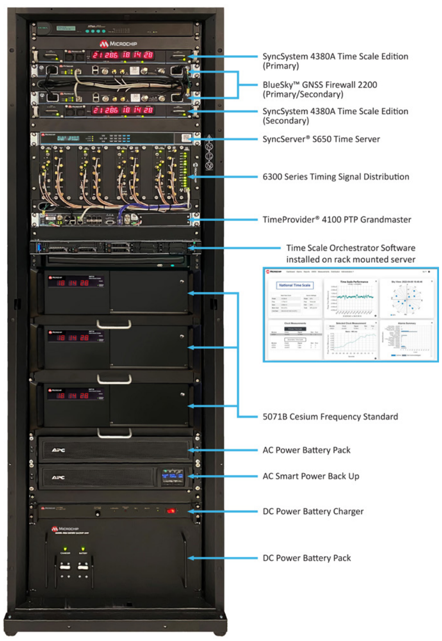

Figure 3: Precise Time Scale System.

Link: https://www.microchip.com/en-us/products/clock-and-timing/systems/time-scale-measurement/national-timing-infrastructure

At the heart of the Microchip solution is the SyncSystem 4380A Time Scale Edition - see Figure 4. This unit provides superior time and frequency performance in a highly configurable 1U rack-mountable package. With clock inputs taken from cesium clocks or active hydrogen masers, long-term synchronization with UTC is assured.

Link: https://ww1.microchip.com/downloads/en/DeviceDoc/00004496A(002).pdf

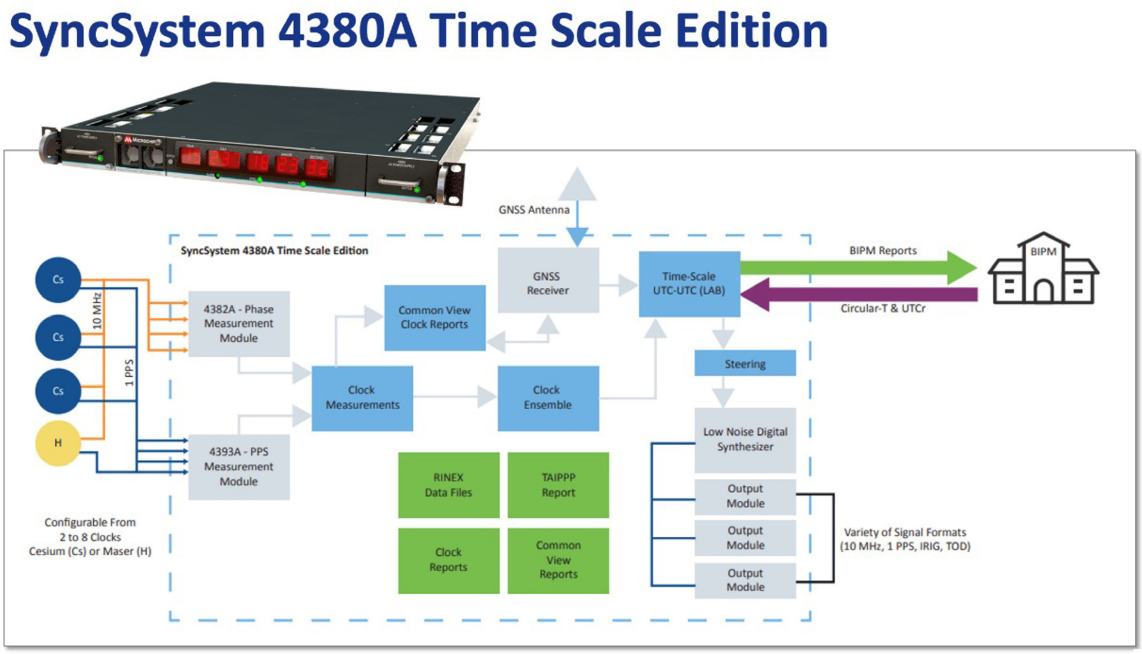

Figure 4 - The Microchip SyncSystem 4380A Time Scale Edition provides all the core functions which drive the overall Precise Time Scale System (source Microchip)

For many time scale implementations, additional components are included such as the BlueSky GNSS Firewall, Time Scale Orchestrator software, 6300 Series signal distribution, the SyncServer 650 and TimeProvider 4100. Details of these products can be found on the Microchip web site.

Development of a Time & Frequency Lab at the Bureau of Standards Jamaica

The Bureau of Standards Jamaica (BSJ) has embarked on a journey to establish a time and frequency laboratory to provide time and frequency needs of the private and public sectors in Jamaica. This effort is aimed at obtaining international recognition through certification from the International Bureau of Weights and Measures (BIPM). This will allow the BSJ to be equipped for the continuous realization of the UTC(BSJ) time scale and the continuous distribution of UTC(BSJ) time signals through various broadcast and calibration services. Establishing a time and frequency laboratory within the BSJ represents a proactive step to lay the foundation that will provide the government, business community and the public with time that can be trusted anywhere in the world. To ensure that Jamaica is fully prepared for international, hemispheric and regional trade under the World Trade Organization (WTO), Technical Barriers to Trade (TBT) and other free trade arrangements by having the traceable time and frequency measurement infrastructure in place. Furthermore, the successful development and operation of a logistics based economy will require that the financial sector, stock exchange, telecommunications, aviation, utilities, etc. have access to affordable time and frequency capabilities to support their safe and competitive operation.

The BSJ employs the use of Microchip's Precise Time-Scale System (PTSS), which is a turnkey timing system that is comparable to the international laboratories using commercial hardware and software. The system is capable of establishing a real time synchronization source for communications and navigation systems as well as establishing a national timing reference. The system in its full configuration is used by the BSJ and is equipped with every feature and capability used by similar international timing laboratories today such as NIST and CENAM as discussed above.

Development of a Time & Frequency Lab at the Bureau of Standards Jamaica.
Paper on Establishing a Time and Frequency Lab at the BSJ.

Timing Grid Distribution

There are a variety of methods available to enable time distribution across large geographies. For many applications, where high accuracy is not the requirement, the Network Time Protocol (NTP) can be a cost-effective national time distribution method. Using strong authentication methods and stringent auditing of client usage, NTP can be an adequate distribution method of time directly from a national time scale.

A second alternative, although counter intuitive, is leveraging GNSS as a medium for time dissemination using the well-proven method of common view. GNSS common view performs two-way-time-transfer weekly or daily using the GNSS on-board satellite clocks versus using the satellite signal as a continuous timing reference. When paired with a time scale, common view can be a good first step towards build-out of a national timing grid with much higher accuracy as compared to NTP.

A third proven method is the use of geostationary satellites for two-way-satellite-time-transfer (TWSTT), which has been in operation for many years. TWSTT provides a reliable linkage for time transfer, especially between metrology labs and timing authorities, such as BIPM. Additionally, TWSTT can provide reliable links between diverse locations so that multiple time scales can be interconnected to build-out a fault tolerant timing backbone. Interestingly, todays' lower cost of geostationary satellite links and the ability for satellite time modems to share satellite links has made TWSTT significantly more cost effective and easier to deploy.

There are also terrestrial methods for transferring time, leveraging industry standards such as PTP (Precision Time Protocol). Using PTP, different optical transport methods can be used such as dark fiber or other fiber based broadband services.

The virtual Primary Reference Clock (vPRTC) has been providing an all-optical resilient distribution of precise time services commercially for over five years and is fully compliant with all relevant International Telecommunications Union (ITU) standards.

Link: https://www.microchip.com/en-us/products/clock-and-timing/systems/virtual-primary-reference-time-clock

Also ground-based RF solutions are emerging and, in some cases, like with Loran, they have "re-emerged" with updated specifications, such as eLoran. Operating at about 100 kHz, eLoran provides the benefit of having broad reach and indoor reception without being dependent on satellites.

Protecting national critical infrastructure

With global disruptions to GNSS increasing, establishing a national time grid is prudent to ensure that accurate time is available and resilient to disruptions. In many countries, governments are looking to their national metrology labs to be a vital part of the solution by generating time through the implementation of a time scale system. Operation of an autonomous time scale system provides the ability to constantly maintain traceability to UTC despite GNSS jamming and spoofing events.

The conflict between a nation's dependency on GNSS as a source of time and the risk of how a GNSS disruption could impact critical infrastructure that depends on GNSS timing has become a national security concern. Across the globe countries and national agencies are taking action to protect and defend the utility of "time" by deploying a national timing grid as part of a homeland security strategy.

Find out more: https://www.microchip.com/en-us/products/clock-and-timing/systems/time-scale-measurement/national-timing-infrastructure