

IEEE/NIST Timing Challenges in the Smart Grid Workshop

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Time Synchronization Requirements and Challenges for Power System Applications

Aaron Martin and Brett Aguirre, Bonneville Power Administration

More and more, the reliability of the electric grid depends on intelligent electronic devices (IEDs) that require high accuracy time synchronization to operate quickly, reliably, and securely for all types of power system events and conditions. IEDs such as Phasor Measurement Units (PMUs), traveling wave fault locators, and line differential relays are manufactured with complex algorithms, sophisticated schemes, and programmable logic that depend on high accuracy time synchronization. The 60 Hz frequency of electric power grid dictates that micro-second accuracy is necessary for proper indication and operation of PMUs and Line Differential relays. As the data from these systems are aggregated together via Ethernet, the importance of an approved test plan allows utilities to be confident that the substation Ethernet clocks they choose for their timing needs, are not only compliant, but they are certified.

Precision Time Protocol (PTP) for Substation Synchronization at PG&E

Dr. Vahid Madani, Pacific Gas & Electric

Use of Precision Time Profiles in Distribution Systems

Anthony Johnson / Brendan Russell, Southern California Edison

With the advent of highly accurate, ubiquitous time available it is possible to change the method of distribution automation. It will be possible to enhance customer reliability while optimizing the configuration of the grid. The presentation will discuss how Adaptive Protection and Time Synchronized control can operate together to overall improve utility operations.

Precise Timing in Dominion's Electric Transmission System

Robert Orndorff, Dominion Virginia Power

This presentation will discuss how precise timing is used on Dominion's electric transmission system. In recent years, more and more substation devices and applications rely on precise timing. Additionally, there are Federal regulations (PRC-002-2) that mandate precise time synchronization on the Electric Transmission system. The increasing use of devices that require precise timing as well as the regulations have caused us to focus on having accurate time available inside the substation. Several areas will be covered in this presentation:

- Applications and devices that use precise timing.
- Issues at Dominion with timing and testing we have performed.
- Discussion of our past and present substation timing infrastructure and our plans for the future.

Timing Security Assessment and Potential Solutions

Glen Chason, EPRI

EPRI's Timing Security Assessment and Solutions project provides a progressive approach for addressing cyber security vulnerabilities in precision timing systems used in mission-critical utility operations. Project results are expected to provide significant power industry and public benefits, focused on improved power grid reliability and resiliency. Increasingly integrated synchronized operations lead to improved safety, flexibility, and reliability of electric power delivery. In addition, the results are expected to help build confidence in disparate sources of sensor data, such as smart inverters, and enable optimal, autonomous management of Distributed Energy Resources (DER) assets in utility grids.

The new learnings are expected to include:

- Developed guidance and methodologies for assessing cyber security vulnerabilities in systems relying on synchronized timing. This guidance and these methodologies can help equipment vendors and utilities improve the reliability of system operations and continuity of electric power delivery.
- Identify proactive methods for analyzing vulnerabilities.
- Develop guidance for selecting equipment and adopting practices deploying mitigations that will reduce the likelihood and duration of malicious manipulation of system timing infrastructure.

Testbed Capability at the Pacific Northwest National Laboratory

Jeff Dagle, PE Chief Electrical Engineer, Electricity Infrastructure Resilience

PNNL's Testbed Capability combines innovative technology with interdisciplinary teams to overcome electricity infrastructure challenges in the path towards grid modernization. Grid modernization is rapidly digitizing and networking the energy value chain, converging cyber and physical energy and controls that increasingly exchange information with grid that powers all our nation's critical infrastructures. As a result, securing our nation's electricity infrastructure becomes mission critical for the Department of Energy in its role as the day-to-day Federal interface for sector-specific activities to improve security and resilience in the energy sector. To support this mission, PNNL has a number of world-class test beds that can be leveraged by researchers and their partners. PNNL's test bed efforts benefit from close cooperation with industry and leverage tools, technology and findings from DOE-OE supported initiatives such as the North American SynchroPhasor Initiative (NASPI), Cybersecurity for Energy Delivery Systems (CEDS) and the Grid Modernization Lab Consortium (GMLC). Specifically, PNNL has previously hosted testing of synchrophasor susceptibility to GPS spoofing and will share the results of these tests, lessons learned, and future research directions at the workshop.

GPS Timing in Critical Infrastructure

Sarah Mahmood, DHS

Accurate position, navigation and timing (PNT) is necessary for the functioning of many critical infrastructure sectors. Precision timing is one aspect that is particularly important for key sectors such as the electric grid, communication networks and financial institutions. Currently, the primary source of distributed and accurate timing information is through GPS. However, GPS signals are susceptible to both unintentional and intentional disruption. DHS discusses their risk management strategy and supporting programs for PNT vulnerabilities within critical infrastructure.

A DOE Research Laboratories View on Time Synchronization Needs and Challenges

Terry Jones, ORNL

We present a breakdown of timing needs from the perspective of the Department of Energy's (DoE) research arm. Our analysis includes: (a) performance factors; (b) security concerns; (c) resiliency aspects; and (d) business considerations. Our performance discussion includes quantitative requirements for timing uncertainty and scalability of design. Timing security includes ways to detect and defeat known cyber attacks. Among the items including in our resiliency discourse is support for multiple clock sources, inter-clock source communication, and uptime requirements. For business considerations, we elaborate on aspects related to the "investment versus payback" decision that utilities will need to make for all new technology deployments.

Time Distribution: Current Technologies and Future Visions

Dr. Marc Weiss, NIST Time and Frequency Division

This talk will cover the current and potential future technologies for distributing and measuring time across wide areas including GNSS, telecom network distribution technologies, WWVB, and TMAS. A mention of capabilities of local clocks for holdover will be done. Potential future technologies include eLORAN, other ground-based RF timing systems, and other satellite systems such as Iridium. The future need for distributed time will be increasingly used in critical infrastructure. Providing multiple sources will provide a means of redundancy and also as a check for potential anomalies with the primary source.

Clock Ensembling for Resilience

Dr. Dhananjay Anand, NIST Software Systems Division

This talk will cover theoretical underpinnings and initial progress on a research project intended to cross validate GNSS based timing against a belief filter comprised of low-cost oscillators organized as a maximum likelihood ensemble estimator (MLEE). In order to support other research efforts in residual and threshold based anomaly detection, we focus on the convergence properties of the ensemble. In particular, we will present results of our preliminary investigation along three formulations of the MLEE. The first being an Ensemble Kalman Filter applied to a linear voltage controlled oscillator (Type-1 PLL), the second is a mean-field coupling model for non-linear oscillators and the third considers clock models with discontinuous differential inclusions (Type-2 PLL).

Detecting Anomalies in Time and Frequency Data

Dr. Judah Levine, NIST Time and Frequency Division

The talk will cover the techniques that we have developed for detecting anomalies in time and frequency data. We use these techniques in evaluating the digital time stamps received from network time servers over the Internet, in computing the ensemble average of the atomic clocks that define and realize the NIST time scales UTC(NIST) and TA(NIST), and in comparing clocks at remote locations by using data from global navigation satellite systems in common view, where multiple ground stations receive data from the same source at the same time. The details of the implementation depend on the application, but all of the methods are based on a statistical comparison of the data that have been received with the expected results based on previous data and the statistical characteristics of the local hardware. In some applications, the statistical comparison is made more robust by the availability of nominally identical data from multiple remote sources.

PTP Power Profile Conformity Assessment

Bob Noseworthy, University of New Hampshire InterOperability Lab (IOL)

Potential for Time from CenturyLink

Carmine Chase, CenturyLink

This talk discusses the potential for the Power Industry to receive a timing signal from CenturyLink. This possibility is based on an on-going experiment with NIST, USNO and Microsemi. This experiment has shown that CenturyLink could provide the UTC time signal directly from NIST through the CenturyLink network with a stability of well under 100 nanoseconds. The method shows that if the signal could be calibrated, such as with GPS, the accuracy of calibration could be maintained indefinitely at the 100 nanosecond level.

Reliable GPS-Based Timing for Power System Applications: A Multi-Layered Multi-Receiver Approach

Dr. Grace Gao, University of Illinois Urbana-Champaign

In recent years, there has been a major push by the power industry to utilize phasor measurement units (PMUs) for wide area monitoring and control. Global Positioning System (GPS) provides precise timing and synchronization to PMUs. However, the low received signal strength and unencrypted nature of the civil GPS signals leaves PMU reliability susceptible to non-malicious interference as well as malicious spoofing attacks. The security and reliability of GPS-based timing for PMUs are essential to the future of the power grid.

In this presentation, we provide a multi-layer multi-receiver approach to reliable GPS-based timing for power system real-time monitoring and control applications. By exploiting the static and networked nature of GPS receivers in PMUs, our approach achieves the following benefits: 1) robust against spoofing; 2) robust against jamming; 3) robust against receiver errors; 4) practical to implement; and 5) inexpensive. We have validated the effectiveness of our proposed approach with numerical and experimental results.

Quantum Technologies for Secure Wide-Area Time Distribution

Phil Evans, Oak Ridge National Laboratory

Quantum mechanics is central to time keeping - the narrow linewidth transitions in hyperfine ground states of cesium vapor defines the primary frequency standard. The same quantum theory, responsible for strange behavior such as entanglement and superposition, can also be practically applied to the distribution of time in a secure manner. Quantum key distribution involves the generation and distribution of encryption keys between parties and is provably secure. Quantum random number generators are sources of random number streams that do not depend on computational algorithms or deterministic classical processes. In this talk, I will introduce ORNL's research into quantum information science and show how it is being applied to realize secure, resilient, and wide-area time synchronization for the Grid.

Computation of Link Delays to avoid 1588 performance issues due to Link Asymmetry

Satheesh Kumar S, Juniper Networks

This paper presents a method for transporting 1588v2 message using one-way mechanism by estimating the Link Delay or Delays of one or all the links that forms the part of a single link or Link Aggregation Group. It is proposed a new MAC frame with correction field included to estimate the one-way delays of the links with an accuracy of nano-second. Using these computed delays, the slave can be time synchronized to Master using only SYNC messages. This paper also proposes to select the best link for PTP flow based on the LINK TABLE populated using the proposed MAC frame. The LINK TABLE could include parameters such as Link Delay, Link Utilization, Link State and Link Priority (Manually Configured). The method also provides seamless switch over when active chosen link fails due to any reason without effecting the PTP performance. This proposal thus avoids link asymmetry issues exists today for 1588 two-way mechanism over Link Aggregation Group completely and helps the servo for faster alignment of time without the need of two-way handshake.

Improved IEEE 1588 Synchronization Performance Bound and Attack Mitigation Using Estimation Theory

Rick S. Blum, Anand Guruswamy, and Anantha K. Karthik, Lehigh University*

Precise synchronization of events is essential to ensure the proper functioning of a distributed system. The IEEE 1588 precision time protocol (PTP), built on the classical two-way message exchange scheme, provides a mechanism for synchronizing devices in a network with sub microsecond precision. PTP is utilized in important applications including (but not limited to) smart grid, industrial control and sensor networks. Packet-based synchronization techniques based on PTP offer a cheap alternative for achieving sub microsecond precision between cell towers in 4G Long Term Evolution (LTE) mobile networks. These techniques are cost effective as they utilize the existing backhaul network infrastructure. However, the background traffic generated from other users in these networks often result in random queuing delays for the synchronization packets. An important challenge in the deployment of PTP in these networks lies in combating the degrading effects of these random queuing delays, given that the synchronization requirements are expected to grow more stringent in the future.

Due to the randomness of the end-to-end delays, the recovery of clock phase and frequency from the packet timestamps in PTP can be treated as a statistical estimation problem. In our work, we derive previously unavailable performance lower bounds for the phase offset estimation (POE) problem. These lower bounds are useful for evaluating the POE schemes available in the literature. We then describe minimax optimum phase- and frequency offset estimators, that are optimum in terms of minimizing the maximum mean squared error, along with a computationally efficient POE scheme (based on a linear combination of order statistics) which achieves performance close to that of the minimax optimum POE scheme, while requiring lesser statistical knowledge of the queuing delays. We also present a robust POE scheme which uses a combination of the Expectation-Maximization algorithm and the minimax optimum estimator to combat delay attacks in PTP.
