by SoCe

# Easy Integration of High-availability Networking and Accurate Timing Synchronization in SCADA Systems

**RELYUM Team***
*https://relyum.com

**ABSTRACT** The Industry is converging on Ethernet. During latest year, some technology innovations have emerged to enhance the resilience of standard Ethernet network and to use it as a common link layer for Operation and Information technologies. Critical sectors, like the Electric one, with high-availability and strict timing requirement have pushed these developments.

The next step forward to allow diverse applications taking benefit from this innovation is providing to system integrators ready-to-use equipment. In this sense, this paper presents three use-cases of a Smart PCIe card that supports zero-delay recovery time Ethernet protocols (HSR and PRP) and Precise-Time-Protocol (PTP or IEEE 1588) for accurate time synchronization over Ethernet.

The extension of IEEE 1588 synchronization to Linux OS based SCADA is done using a native PTP solution. The synchronization of Windows-based SCADA is done using NTP in order to offer a transparent solution for all the applications and modules running on the server.

**KEYWORDS**
ICS
SAS
Ethernet
HSR/PRP
SCADA
PCIe
IEC 61850

## INTRODUCTION

### SCADA

Supervisory Control and Data Acquisition (SCADA) control systems allow a variety of local control units from different vendors. SCADA are typically composed by Supervisory Computers, PLCs, Remote Terminal Units (RTUs) inter-networked using standard or proprietary protocols. SCADA systems have evolved from the so-called first generation 'Monolitic´ till the current forth generation 'Internet-of-Things'. In the middle, the second and third revolutions, called 'Distributed' and 'Networked' define what nowadays is implemented in most of the Industry.

### Ethernet

Most of these Industrial Networks are Ethernet-based. Since Ethernet was standardized in 1983, it has evolved both from the technical and from the application point-of-view as well. The original use for computer networks has been extended to be the de-facto Data Link protocol for field-buses in Industry (Profinet, Ethernet IP, Ethercat, Sercos III, etc.), Aerospace (AFDX), Energy (IEC 61850), Automotive (Deterministic Ethernet) and Transportation.

Critical systems like Substation Protection, Automation and Control System (PACS) can benefit from Ethernet technology if it ensures no-frame lost in case of a network failure, effective integration of accurate timing synchronization schemes, inter-operability among vendors and some basic real-time operative capabilities.

In this sense, a very valuable standardization effort has been carried out at IEC organization releasing IEC 62349-3 'Industrial communication networks - High availability automation networks´ (3). In coordination with this work, a specific profile of the Precise Time Protocol -IEEE 1588- able to run in these redundant environments has been developed and released (1).

### High-availability Ethernet

Parts 5 and 4 of this standard IEC 62349-3 define High-availability Seamless Redundancy (HSR) protocol and Parallel-Redundancy-Protocol (PRP) respectively. Both offer zero-delay recovery time and no-frame lost over Ethernet Networks. HSR is oriented to Ethernet ring topologies and it ensures a known worst case scenario for frames delivery time, as shown in Figure 1. PRP works with two independent legacy Ethernet Networks as depicted in Figure 2 and it is not intended to work within real-time scenarios. Indeed, PRP, HSR and PTP can be combined to support time-aware networks.

### Precise Time Protocol (PTP)

Sub-microsecond synchronization is more and more demanded in Industrial Control Systems. As an example of the introduction of this combined approach in the Industry (Reliable Ethernet combined with IEEE 1588), the IEC Smart Grid Strategy Group recommends PTP, as defined in IEEE 1588-2008 standard (5), for high precision time synchronization in substations.

PTP distributes absolute time across a substation network directly over Ethernet, achieving synchronization accuracies in the range of nanoseconds. PTP systems follow a master-slave hierarchy, where the master imposes the time and the slaves synchronize to it in both phase and frequency (8). The propagation delay is automatically compensated by slaves and, in order to consider latencies introduced by network nodes, Transparent Clock (TC) functionality must be added in intermediate nodes.

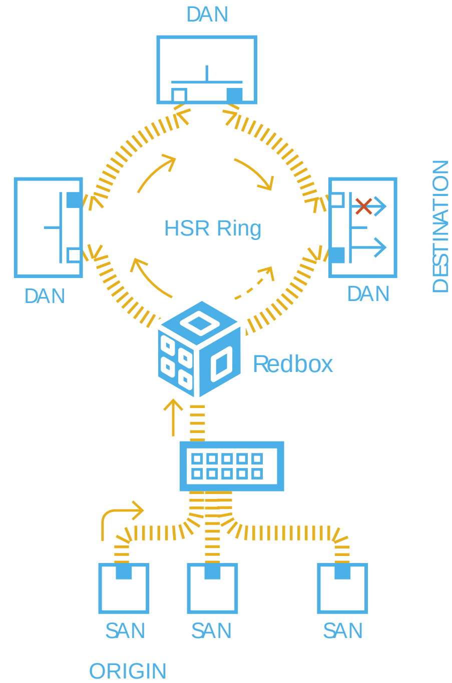


**Figure 1** HSR network topology

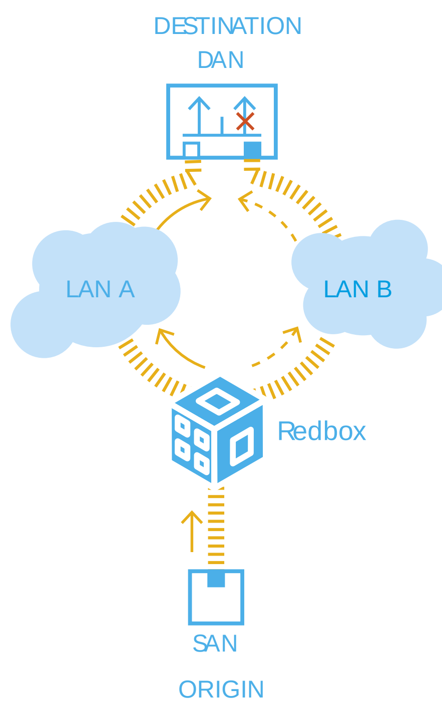


**Figure 2** PRP network topology

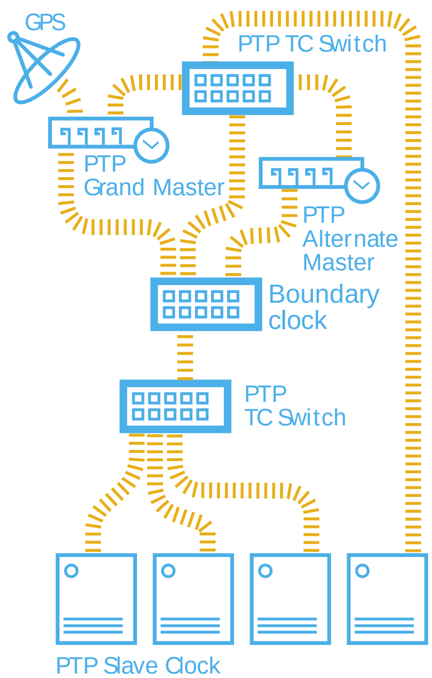


**Figure 3** PTP Infrastructure

Therefore, all switches in the network shall support TC operation to correct the PTP frames that are switched in order not to lose the expected accuracy. As shown in Figure 3, the set-up may be completed with PTP Boundary Clock devices that separate different clock regions and with PTP Ordinary Clocks that are capable of working as Master and Slave Devices.

Apart from this widely use in the Electric sector, IEEE 1588 is more commonly found in other scenarios. As an example, some of the targeted applications are distributed sensor data acquisition for Gas&Oil (2), time reference for Deterministic Ethernet (9; 4), phase and frequency synchronization for motor drives (7) or distributed data acquisition from DAUs in Aerospace&Defence (6).

## USE-CASE 1: ALL-IN-ONE HSR/PRP DAN AND REDBOX CAPABILITIES FOR HSR/PRP REDUNDANT ETHERNET

In an Industrial Control System (ICS) that combines single and redundant Ethernet networks it is necessary to analyze which elements are connected to each one. In addition, how to attach to the redundant networks each equipment or LANs also need to be carefully studied. The integrator shall evaluate when a Single-Point-Of-Failure (SPOF) is present and how to avoid it.

A basic set-up is connecting a server computer to a redundant Ethernet Network (HSR or PRP). A conventional approach is using an external Redbox equipment or, in some PRP limited cases, plugging two Ethernet NIC cards in the computer and running a software PRP solution. The use of another external equipment is not desirable in most of the cases, due to the reduction of the global MTBF of the system and from the cost perspective. A software solution for PRP processing, even for end-equipment, is not desirable due to the limitations in the acceptable data-rate and to the non-deterministic computation load that is added to the server CPU generated by the PRP frames preprocessing.

Another very common need in this mixed infrastructures is having some equipment in a conventional Local Area Network (LAN), that requires access to the high-availability network. For this situation, it is also common using an external RedBox equipment.

From an integrator point-of-view, an all-in-one Plug&Work solution for all these scenarios, multimedia (copper, 1G and 100M fiber) and PRP and HSR capable would be a very valuable piece. **RELY–**SYNC-HSR/PRP-PCIe , represented in Figure 4, is a universal PCIe card that comprises these functionalities. It embeds FPGA based hardware processing and a multicore-CPU to release the main CPU from the need of running any protocol specific software stack and it offers a switching performance of the 100% of the data throughput.

**Figure 4** **RELY–**SYNC-HSR/PRP-PCIe card

As an example, APERT customer has selected this board to attach its processing servers to a fibre optic HSR ring in its flexible power electronics laboratory set-up. Additionally, the third port of the board provides access to the ring to any standard regular equipment or LAN, without the need of additional RedBox or specific configuration. Figure 5 depicts a block diagram showing the setup. Figure 6 details the NIC boards plugged into APERT´s server unit.

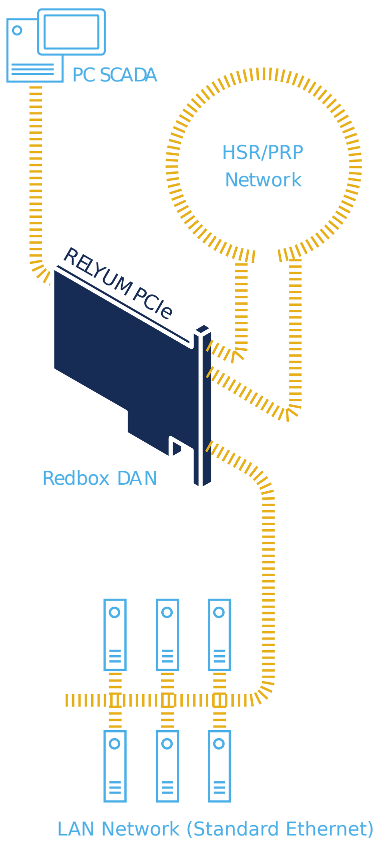


**Figure 5** **RELY–**SYNC-HSR/PRP-PCIe providing Dual-Attach-Node (DAN) and RedBox functionalities simultaneously

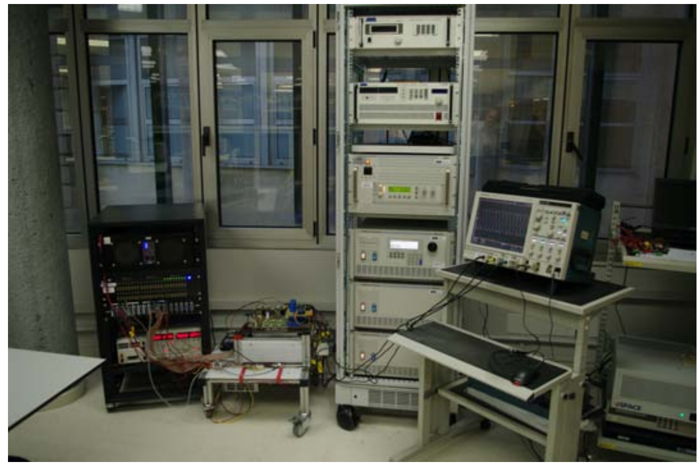

**Figure 6** APERT Power Electronics set-up with High-availability Networking capbilities

## USE-CASE 2: SEAMLESS MERGING OF PRP AND HSR NETWORKS

Critical infrastructures that require fully redundant paths in real-time sections and in non-real time ones can benefit from combining PRP and HSR networks. PRP is composed by two standard Ethernet networks, and the PRP capable equipment is in charge of sending and receiving duplicates frames through both LAN networks. This approach is very adequate to reuse regular Ethernet infrastructure, but it lacks from any mechanism to ensure the worst case delivery time for a given frame. HSR allows calculating this parameter. Therefore it is an standardized and inter-operable solution suitable for control oriented communications. As an example, the typical zero-delay recovery time topology for IEC 61850 substations is based on implementing PRP in the Station bus section and HSR rings for the Process bus areas. The connection of a PRP network with an HSR ring must be done through two different points, avoiding the previously mentioned SPOF. The IEC 62349-3 standard defines how shall be the behaviour of the equipment that is doing the interconnection. Specifically, they need to support the PRP-HSR mode to manage correctly the sequence number field when the frames pass through one network to the other. From the integrator point of view, one option is combining and configuring PRP-HSR capable standalone RedBox equipment with support for an IEEE 1588 profile able to deal with (combined) redundancy.

Another alternative, implemented in the Aeronautics Advanced Manufacturing Center plant (CFAA , Figure 8), consists of using the **RELY–**SYNC-HSR/PRP-PCIe cards plugged in the industrial computers of the plant to interconnect the PRP section with the HSR one. Figure 7 summarizes the set-up diagram. For this setup, the HSR rings are fiber optic ones, while the PRP network is a GbE copper one. Each PRP branch is connected to the Ethernet

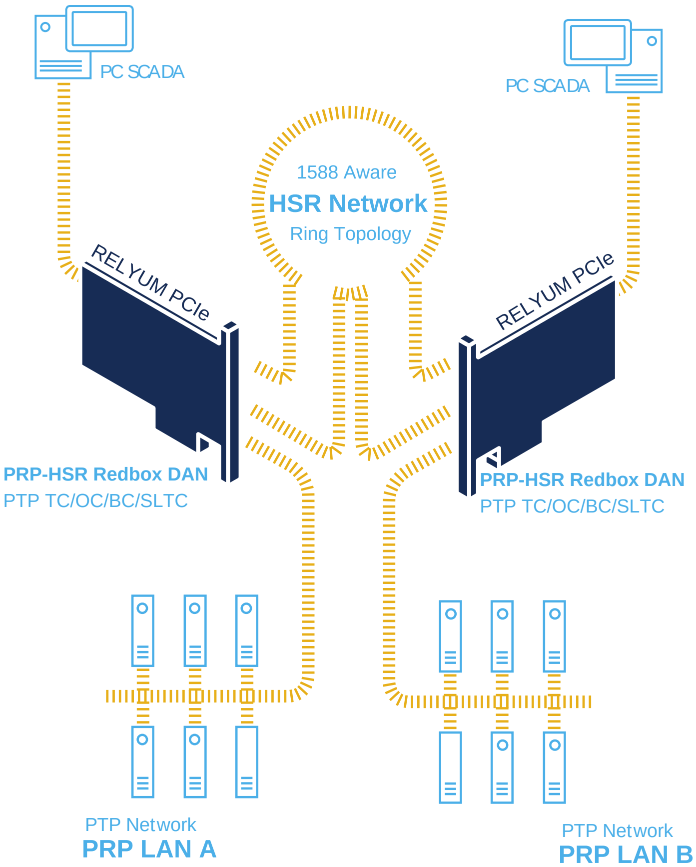


**Figure 7** Merging PRP and HSR networks using **RELY**–SYNC-HSR/PRP-PCIe solution

input that regularly is used to attach the standard LAN in a RedBox operation. The configuration is done in few minutes and only once: the operator connects to the Web application embedded in the PCIe card and selects PRP-HSR operation as shown in Figure 9. That is all!

## USE-CASE 3: EXTENDING PTP SYNCHRONIZATION TO SCADA SYSTEMS

Having a common timing reference in a distributed control system is critical. Here again, the electric sector is good example to illustrate the level of accuracy demanded with the new generation of digital substations. The applications based on synchrophasors or the protection tasks located in the process bus section demand sub-microsecond range accuracy. In order to achieve this level of precision, the adoption of IEEE 1588 (PTP) over Ethernet or over High-availability Ethernet is the solution proposed by the IEC 61850 standard.

Within these IEEE 1588 synchronized infrastructures, there are several SCADA systems implemented. As an example, within the Power Substations it is com-


**Figure 8** RELYUM at CFAA center

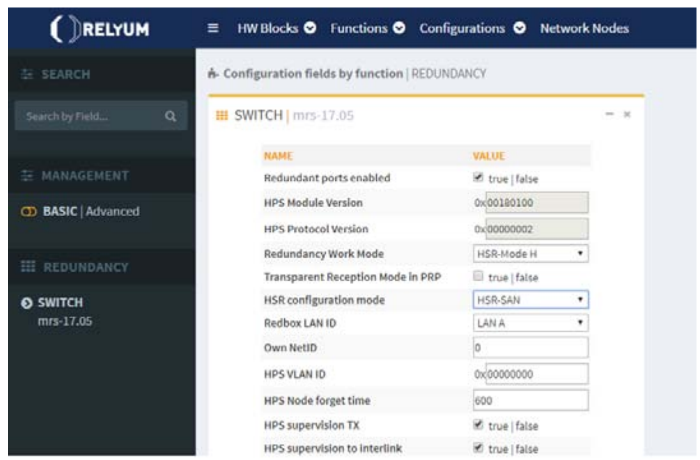


**Figure 9** Snapshot of the embedded Web-based configuration tool

mon locating a Supervision Server running an IEC 61850 SCADA software in charge of controlling and monitoring the station. This SCADA is able to perform control operations locally or remotely from the the operations control room.

Attending the experience in field, these SCADA users demand a comprehensive solution to attach these servers to the IEEE1588-aware redundant ethernet networks. Additionally, they need using the time reference as the remaining IEEE 1588 equipment for the SCADA events time-stamping operations in the PC. The state-of-the-art of these servers are multi-version Windows based OS with a plethora of SCADA software.

RELYUM Team has engineered a simple solution to synchronize these Windows based PCs with the IEEE 1588 reference in the millisecond range using **RELY–**SYNC-HSR/PRP-PCIe card and without the need of modifying any element on the SCADA software.

**RELY–**SYNC-HSR/PRP-PCIe is synchronized from the IEEE 1588 clock source, in most of the cases from a Grand Master equipment. This synchronization is done autonomously from the Server CPU thanks to the hardware and software infrastructure embedded on the card. This sub-microsecond range time reference maintained within the board can be used to extend the PTP clock to other PTP-aware systems, like a Linux OS based SCADA.

Within Windows-OS based systems, it is not straightforward the introduction of PTP stacks or appliances. On the other hand, Network Time Protocol is fully supported. NTP offers millisecond range synchronization. However, the accuracy can vary significantly depending on the network topology, distance to the NTP master, etc. These limitations are overcome in this solution thanks to the integration of the NTP Server in the **RELY–**SYNC-HSR/PRP-PCIe board. The card runs as a bridge between the IEEE 1588 Clock domain and the NTP one. The server PC only needs a NTP Client software.

The IEEE 1588 slave, the NTP Server and the NTP Client are installed within the same equipment. Therefore, the setup is optimum in terms of length and path variability for NTP computations. The results presented in Table 2 summarizes the average measured Delay, Offset and Jitter for the setup during three different days. The server has one **RELY–**SYNC-HSR/PRP-PCIe plugged-in. The Operating System version is Windows XP. The targeted NTP servers are:

- Local **RELY–**SYNC-HSR/PRP-PCIe PTP-to-NTP Bridge: IP Address 192.168.2.180. Refid LOCL.
- Remote NTP Server 1: IP Address 193.225.126.78. Refid 121.131.112.137.
- Remote NTP Server 2: IP Address 69.36.182.57. Refid 204.48.58.50.

As it can be noticed, the synchronization values measured for the **RELY–**SYNC-HSR/PRP-PCIe PTP-to-NTP Bridge, significatively below 1 $\mu$s in average, offer an accuracy level valid for most of the SCADA applications. Table **??** summarizes the maximum and minimum values measured for the measured parameters during these three days on the setup.

Once the Windows OS is synchronized using NTP, the use of this timing reference by the SCADA software is seamless. This application uses the time reference of the OS for its timestamping and logging operations. Therefore, it is not necessary to configure anything or to install any additional plugin or software on the SCADA package.

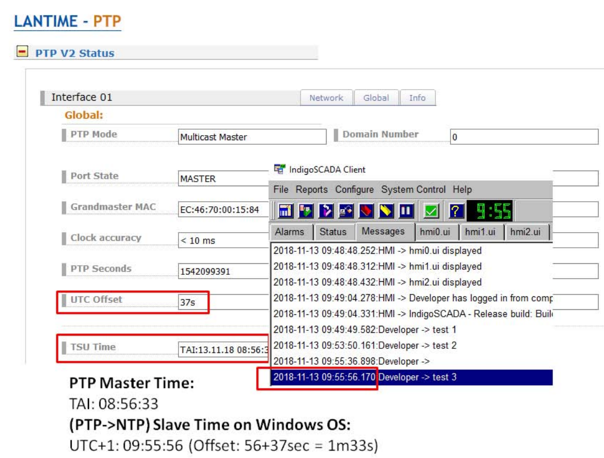


**Figure 10** Snapshot of PTP synchronized timestamping done at Windows OS

In order to illustrate how this timing reference is used by an SCADA system, Figure 10 shows an snapshot of IgnionSCADA software running on the server. This Figure corresponds to a event logging operation with Windows OS NTP synchronization powered by the **RELY–**SYNC-HSR/PRP-PCIe PTP-to-NTP Bridge. As it can be noticed comparing with the PTP Grandmaster Management screen, the SCADA is able to timestamp within the milisecond range with values consistent with the global IEEE 1588 timing reference used in the Power Substation or in the Smart Factory.

## CONCLUSIONS

This paper has summarized the concepts of the high-availability protocols, HSR and PRP, in combination with PTP. Additionally, a ready-to-use PCIe product for seamless integration into any industrial computer is introduced. In order to illustrate the applicability of these smart devices, three real use-cases have been described: *All-in-one HSR/PRP DAN and RedBox capabilities for HSR/PRP Redundant Ethernet*, *Seamless merging of PRP and HSR Networks* and *Extending PTP synchronization to SCADA Systems*. The contributions presented in this paper aim to simplify and to reduce the overall

**Table 1** Synchronization achieved using **RELY–**SYNC-HSR/PRP-PCIe IEEE1588 to NTP embedded bridge

| NTP Source & Day | Avg. Offset (sec) | Avg. Jitter (sec) | Avg. Frequency Deviation (PPM) |
|---|---|---|---|
| **RELY–SYNC-HSR/PRP-PCIe PTP-to-NTP Bridge (Day 1):** | -42.76E-06 | 184.48E-06 | 8.80E+00 |
| **RELY–SYNC-HSR/PRP-PCIe PTP-to-NTP Bridge (Day 2):** | -4.71E-06 | 88.66E-06 | 8.82E+00 |
| **RELY–SYNC-HSR/PRP-PCIe PTP-to-NTP Bridge (Day 3):** | 48.48E-06 | 75.14E-06 | 8.78E+00 |
| **Remote NTP Servers (Day 1):** | -232.24E-06 | 973.60E-06 | 9.11E+00 |
| **Remote NTP Servers (Day 2):** | 484.23E-06 | 1.04E-03 | 9.67E+00 |
| **Remote NTP Servers (Day 3):** | -808.94E-06 | 1.30E-03 | 9.19E+00 |

**Table 2** Maximum and minimum values over **RELY–**SYNC-HSR/PRP-PCIe IEEE1588 to NTP embedded bridge set-up

| NTP Source & Day | Offset | Jitter | Frequency Deviation |
|---|---|---|---|
| Min (Day 1): | $787.00E-09$ | $30.90E-06$ | $8.53E+00$ |
| **Max (Day 1):** | **1.51E-03** | **988.26E-06** | **9.00E+00** |
| Min (Day 2): | 17.00E-09 | 30.64E-06 | 8.55E+00 |
| **Max (Day 2):** | **633.15E-06** | **277.20E-06** | **9.16E+00** |
| Min (Day 3): | 134.00E-09 | 28.09E-06 | 8.56E+00 |
| **Max (Day 3):** | **2.27E-03** | **543.25E-06** | **9.14E+00** |

costs of the implementation of HSR/PRP Networks. Additionally a practical and effective mechanism to synchronize legacy Windows OS based PC computers with the IEEE 1588 clock reference is presented and evaluated.

Relyum is born to provide innovative solutions for networking, synchronization and cybersecurity in critical systems. If you want to receive more detailed information about the solutions presented in this paper or any additional inquiry, do not hesitate to contact us at info@relyum.com.

## REFERENCES


[1] 2016 IEC61850-9-3-2016 - Communication networks and systems for power utility automation Part 9-3: Precision time protocol profile for power utility automation. https://ieeexplore.ieee.org/document/7479438/.

[2] Eidson, J. C. and K. Lee, 2003 Sharing a common sense of time. IEEE Instrumentation Measurement Magazine **6**: 26–32.

[3] (IEC), N. E. C., 2016 IEC 62439-3:2016, Industrial communication networks: High availability automation networks Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR). http://www.iec.ch/.

[4] IEEE Time Sensitive Networking Task Group, 2018 IEEE 802.1 Standards. http://www.ieee802.org/1/pages/tsn.html.

[5] Institute of Electrical and Electronics Engineers, 2008 Ieee 1588-2008 standard for a precision clock synchronization protocol for networked measurement and control systems.

[6] Mei, Q. and H. Jiang-gui, 2010 Implementation of synchronization measurement in warship power monitoring and control system based on ieee 1588.

In *2010 International Conference on Electrical and Control Engineering*, pp. 2797–2800.
[7] Moldovansky, A., 2005 Industrial Automation and Motion Control Systems. https://www.nist.gov/sites/default/files/documents/el/isd/ieee/tutorial-industrial-1.pdf.
[8] Moreira, N., A. Astarloa, J. Lazaro, A. Garcia, and E. Ormaetxea, 2013 IEEE 1588 Transparent Clock Architecture for FPGA-based Network Devices. In *Proceedings of the IEEE International Symposium on Industrial Electronics (ISIE)*.
[9] Winkel, L., 2005 IEEE 1588 Workshop Tutorial Industrial and Motion Control Applications. https://www.nist.gov/sites/default/files/documents/el/isd/ieee/tutorial-industrial-2.pdf.