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Solving the Synchronization of NTP Referenced SCADA Systems Connected to IEEE 1588 High-availability Networks

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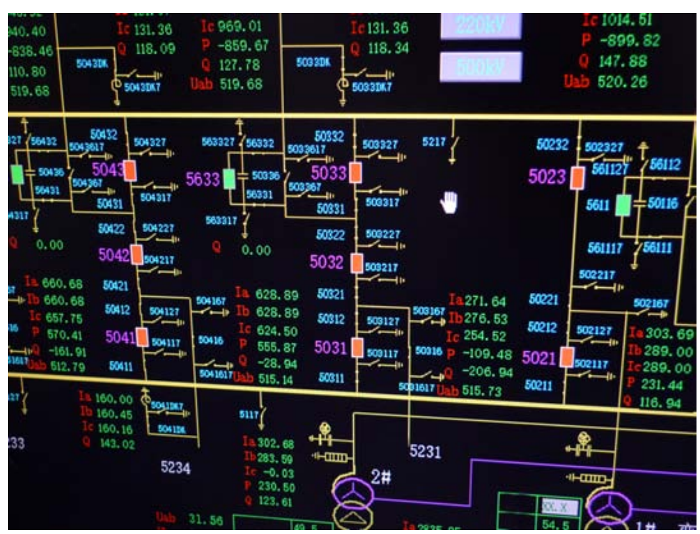
ABSTRACT The Industry is converging on Ethernet. During latest year, some technology innovations have emerged to enhance the resilience of standard Ethernet network and to use it as a common link layer for Operation and Information technologies. Critical sectors, like the Electric one, with high-availability 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 a use-case of a Smart PCIe card model, **RELY–**SYNC-HSR/PRP-PCIe , from **RELY–**PCIe product family. This solution supports zero-delay recovery time Ethernet protocols (HSR and PRP) and manages Precise-Time-Protocol (PTP or IEEE 1588) autonomously for accurate time synchronization over Ethernet. Additionally the board integrates the clock protocol gateway, simplifying the synchronization of legacy systems not compatible with the PTP reference.
As an example, the use-case presented solved the synchronization of a SCADA that takes the time reference from NTP synchronized Windows Operation System. This NTP reference is provided by the NTP master embedded on the **RELY–**PCIe card.

KEYWORDS
PTP
NTP
HSR/PRP
SCADA
PCIe

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, PLC, Remote Terminal Units (RTUs) inter-networked using standard or proprietary protocols. SCADA systems have evolved from the so-called first generation 'Monolithic´ 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. PRP works with two independent legacy Ethernet Networks 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.

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. The typical PTP network is 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: EXTENDING PTP SYNCHRONIZATION TO SCADA SYSTEMS

Having a common timing reference in a distributed control system is critical. Here again, the electric sector is a 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 common 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–**PCIe card and without the need of modifying any element on the SCADA software.

The approach is summarized in Figure 1. **RELY–**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.

With 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–**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 1 summarize the average measured Delay, Offset and Jitter for the set-up during three different days.

The PC server has one **RELY–**PCIe plugged-in, like the model shown in Figure 2. The Operating System version is Windows XP. The targeted NTP servers are:

- Local **RELY–**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–**PCIe PTP-to-NTP Bridge, significatively below 1 μs in average, offer an accuracy level valid for most of the SCADA applications. Table 2 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

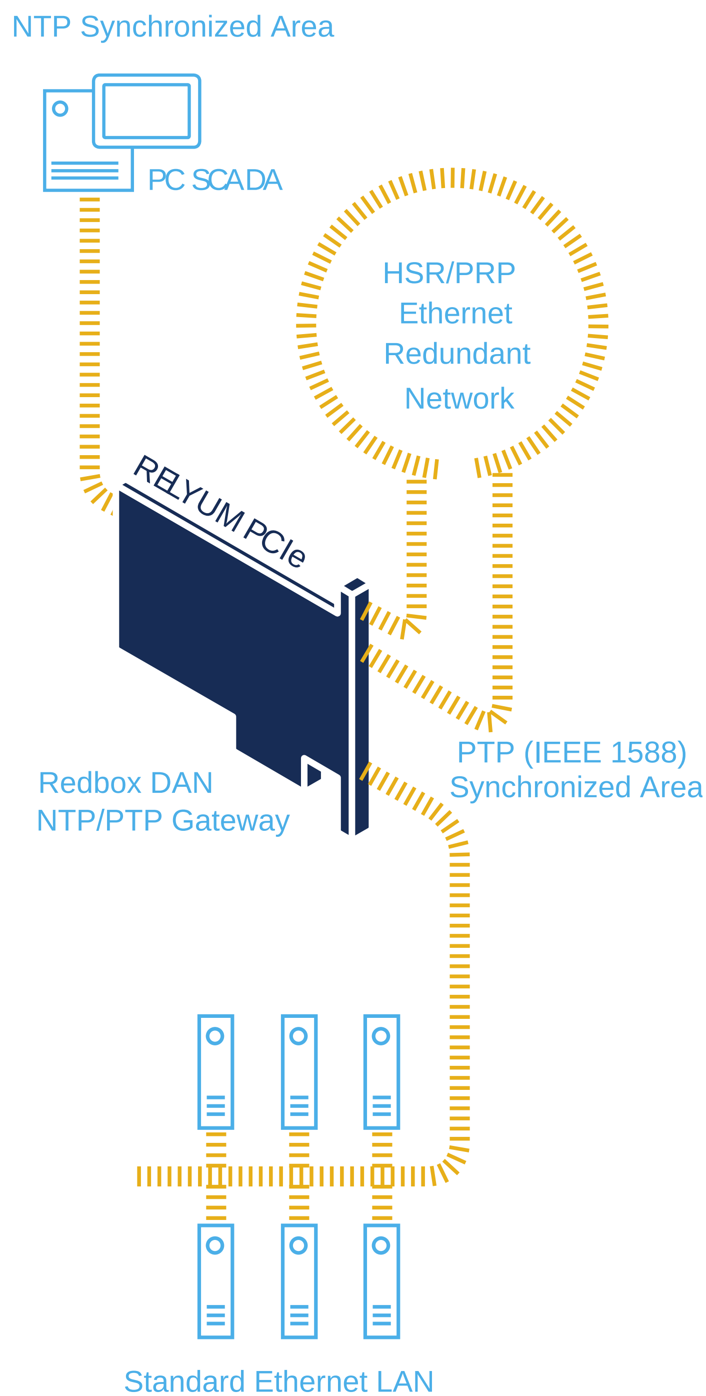


Figure 1 Merging PTP Networks (legacy and high availability) with NTP synchronized systems.

Table 1 Synchronization achieved using **RELY–**PCIe IEEE1588 to NTP embedded bridge

NTP Source & Day	Avg. Offset (sec)	Avg. Jitter (sec)	Avg. Frequency Deviation (PPM)
RELY–PCIe PTP-to-NTP Bridge (Day 1):	-42.76E-06	184.48E-06	8.80E+00
RELY–PCIe PTP-to-NTP Bridge (Day 2):	-4.71E-06	88.66E-06	8.82E+00
RELY–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

Figure 2 **RELY–**SYNC-HSR/PRP-PCIe card plugged on the PC Server.

Table 2 Maximum and minimum values over **RELY–**PCIe IEEE1588 to NTP embedded bridge setup

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**

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.

In order to illustrate how this timing reference is used by an SCADA system, Figure 3 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–**PCIe PTP-to-NTP Bridge. As it can be noticed comparing with the PTP Grandmaster Management screen, the SCADA is able to timestamp in the millisecond range with values consistent with the glo-

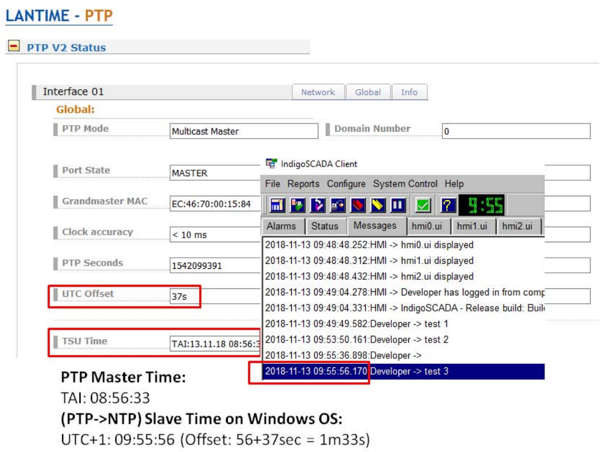


Figure 3 Snapshot of PTP synchronized timestamping done at Windows OS

bal 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, a real use-case has been described. The contribution presented in this paper aims to simplify and to reduce the overall 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 has 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.

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