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Relieving the Complexity of Multi-source Timing in Modern Military Ship

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ABSTRACT Aerospace & Defence (A&D) sector is adopting massively Ethernet as the standard fieldbus and data backbone. This approach offers to this critical systems interoperability among different sub-system vendors, low-latency, high-bandwidth, and a robust way to distribute accurate timing synchronization. However, the concurrence of different subsystems like in the modern military ships demands smart solutions to support dynamically different timing sources like GNSS or precision oscillators and to bridge between time distribution protocols like NTP and PTP. In addition, the complexity of the next generation Ethernet network may require distributing the time and synchronization over high-availability (HSR/PRP), Deterministic (TSN), multi-rate (1/10G) and multi-media (copper/fiber) Ethernet. In this paper, a generic architecture able to deal with multi-source and multi-protocol timing distribution is proposed. Additionally, a new generation equipment named RELY-MIL-TIME presented. It implements the proposed architecture for timing distribution and bridging combined with secure Layer-3 and Layer-2 switch supporting HSR/PRP or TSN protocols among others.

KEYWORDS
PTP
NTP
GNSS
ETHERNET
IEEE 1588
MILITARY
SHIP
WARSHIP

1. INTRODUCTION

A. The need for accurate synchronization in Military Systems

Sub-microsecond synchronization is more and more demanded in Military Systems (1). Accurate timing and synchronization are critical to many military electronic systems that manage real-time data in applications such as distributed sensor networks, distributed data acquisition from DAUs (5), weapons test systems, radar processing, signal intelligence, distributed RF systems, and automation control. The need for sharing a precise standard timing reference among multiple distributed devices is a crucial design factor in new military systems.

Thanks to the adoption of Ethernet (2) as the standard network link layer for ships, network-based time distribution mechanisms like NTP or PTP are common in these systems. Since Ethernet was standardized in 1983, it has evolved both from the technical and from the application point-of-view. 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), Transportation and military.

Section 2 presents a use-case for ships where a solution for a mixed PTP, NTP, and GNSS is required. Section 3 details how the use-case has been implemented using a COTS military Time Server/Switch equipment.

B. Network Time Protocol (NTP)

Network Time Protocol (NTP) allows computers to synchronize their clocks over an IP network. First deployed in the early 1980s, NTP is one of the oldest IP services still in use. Its use in Military Systems in general and in Shipboard is very wide (4). It offers timing synchronization from hundreds of milliseconds to seconds.

Even in an NTP configuration implemented on a local network, NTP may be able to achieve synchronization error of less than one millisecond between client and server within the system.

This synchronization is not enough for many real-time applications. Therefore, other alternatives like dedicated Irig-b wiring or distributed GPS receivers have been adopted increasing the complexity and cost of the final systems.

C. Global Navigation Satellite System (GNSS)

Global Navigation Satellite System (GNSS) signals are broadly used for time synchronization purposes in Military Systems. Each satellite in the constellation uses an atomic clock to maintain an extremely precise time of day, which is then broadcast to receivers. Receivers use the minute differences in the time received from different satellites to triangulate their position on or above the earth. Since GPS receivers use a highly accurate time of day in the process of calculating their position, they can also serve as a useful reference clock.

To enable high precision synchronization, many receivers will also provide a 1PPS (one pulse per second) output or a 10MHz signal that provides accuracy in the range of a few nanoseconds.

Relying all the synchronization of a distributed system only on discrete GNSS receivers has significant drawbacks. Apart from incrementing the cost and complexity of the solution, the risk of lack of GNSS coverage simultaneously in all the receivers increases.

D. Precise Time Protocol (PTP)

PTP is defined by the IEEE 1588 standard. Originally standardized in 2002, PTP received a major update in 2008. These two versions are often referred to as PTPv1 (1588-2002) and PTPv2 (1588-2008) (3) and they are incompatible.

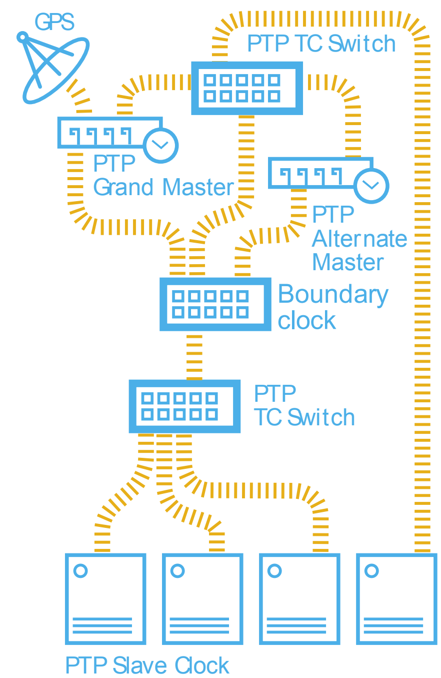

Figure 1 PTP basic network infrastructure

PTP distributes absolute time across the network directly over Ethernet, achieving synchronization accuracies in the range of tens 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. The propagation delay is automatically compensated by slaves and, to consider latencies introduced by network nodes, Transparent Clock (TC) functionality must be added in intermediate nodes.

Figure 1 summarizes a basic PTP network infrastructure. An PTP Master device provided with a very accurate clock reference source (usually a GNSS reference) is identified as a Grand Master. PTP allows Master redundancy in the network. In this Figure, an alternative Master is represented. It will take the master role if there is not present in the network any other Master with better clock quality than itself. This Master can be another Grand Master or an Ordinary Clock (OC) device provided with Master-Slave clock operation capability. As stated, 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

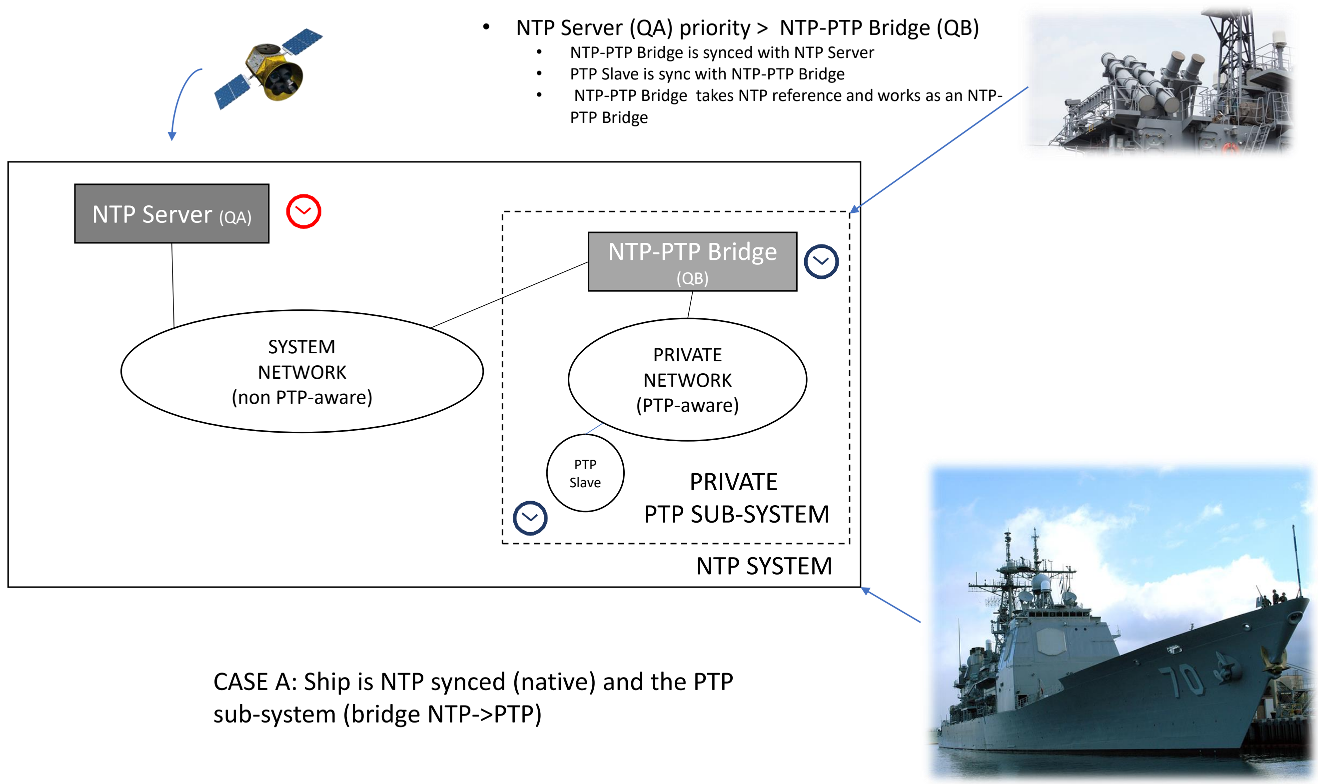

Figure 2 CASE A

Boundary Clock devices that separate different clock regions and PTP Ordinary Clocks capable of working as Master and Slave devices.

2. TIMING OPERATION IN THE MILITARY SHIPBOARD

A. CASE A: Ship is NTP synced (native) and the PTP sub-system (bridge NTP->PTP)

The use of NTP for clock distribution in ships is very usual (7). The main NTP Server offers a synchronization in the range of a few milliseconds for the different subsystems. However, the new subsystems adopt PTP as the primary mechanism for accurate timing distribution.

Figure 2 represents this situation. The main NTP Server is identified as `NTP Server Qa`. `Qa` stands for the quality level of the synchronization that this Server is capable of offering (mainly dependant on the clock source used). The general network of the shipboard is named `System Network - non-PTP-aware -`. A regular network with standard Ethernet switches is not capable of correcting PTP frames, and the potential sub-microsecond synchronization offered by PTP is not achievable. In this case, the network is identified as `- non-PTP-aware -`. However, the network of the new military subsystems is usually PTP capable of benefiting from the accurate timing synchronization offered by this mechanism. In this example, this network has been identified as `Private Network - PTP-aware -` in the Private PTP Sub-system.

A PTP network requires a PTP Master that distributes the accurate timing reference. This equipment is located in the Private PTP Sub-system and it is identified as `NTP-PTP Bridge Qb`. In this set-up, the roles of this equipment will be PTP Master for the subnet and NTP-PTP Bridge to use the sub-optimal base clocking reference provided by `NTP Server Qa`. Considering that this NTP reference is mandatory in many real set-ups, the bridging equipment shall process these clocking domain transitions optimally to minimize the coarse jumps on the synchronization of the slave devices in the Private PTP Sub-system.

B. CASE B: Ship is PTP synced (QA) and the PTP sub-system is synced with this reference (QA)

In some modern shipboard NTP->PTP bridging is no longer needed thanks to the system network being PTP-aware and the main clocking reference element is a PTP capable Grand Master.

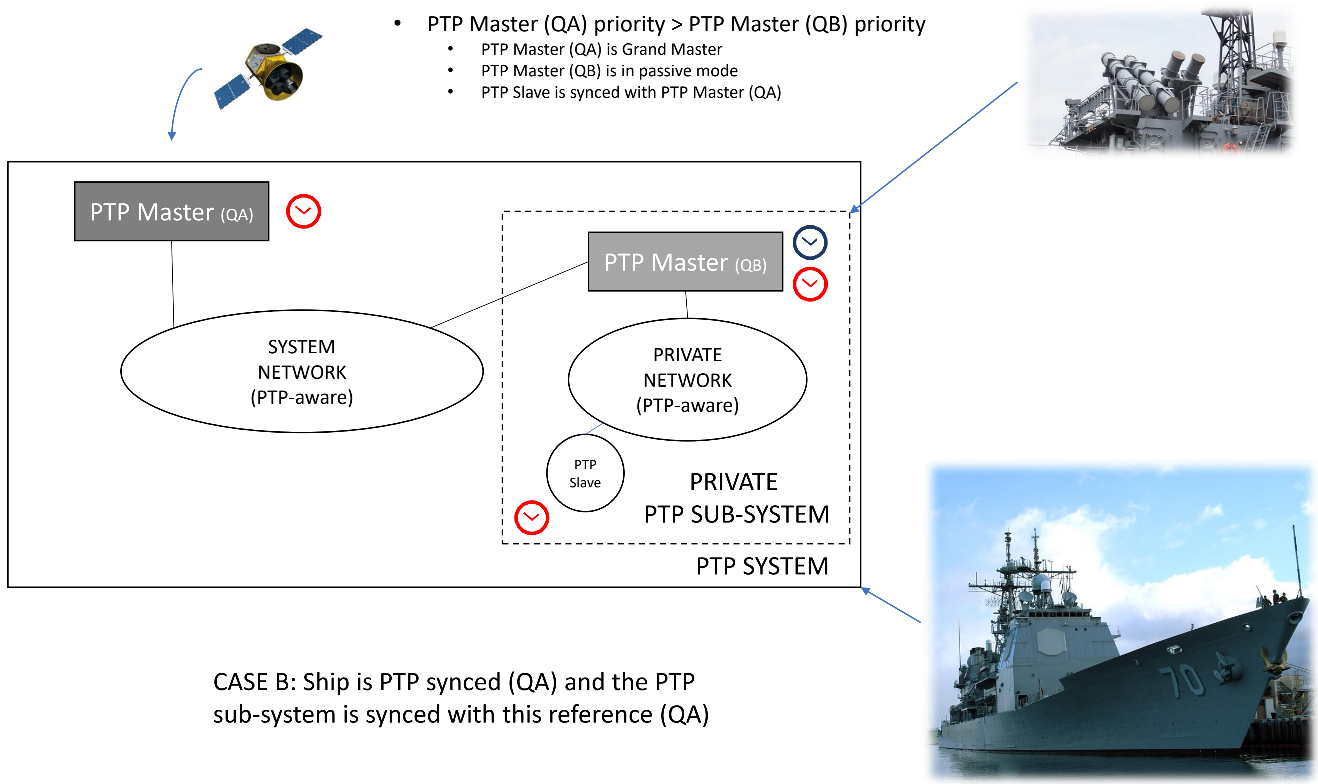

Figure 3 CASE B

Figure 3 represents this situation. The PTP Grand Master Server is identified as `PTP Master Qa`. `Qa` stands for the quality level of the synchronization that this PTP Master is capable of offering (mainly dependant on the clock source used). The general network of the shipboard, in this case, is named `System Network - PTP-aware -`. It includes PTP-aware Ethernet switches capable of correcting PTP frames. The network of the Private PTP Sub-system is identified as `Private Network - PTP-aware -`.

In this PTP set-up, while the quality `Qa` is higher than `Qb`, `PTP Master Qa` will has Master clock role and `PTP Master Qb` will stay in passive mode working only as an Ethernet PTP capable switch. `PTP Master Qb` may adopt also a PTP slave clock role in using the clock reference for any internal application, but it is not necessary to distribute the PTP reference sent by `PTP Master Qa`.

Finally, as shown in 3, the PTP slaves of the Private PTP Sub-system will synchronize with the `PTP Master Qa` PTP reference as desired.

C. CASE C: Ship is PTP synced to (QB) due to a failover of QA or less priority, and the PTP sub-system is synced with this reference (QB)

Figure 4 shows a potential situation in the shipboard where `PTP Master Qa` fails or the clock quality is degraded to a situation where the quality `Qb` of the `PTP Master Qb` is higher than `Qa`. In this case, based on the Best Clock Master Algorithm defined in PTP, `PTP Master Qb` will acquire Master clock role. In this context, `PTP Master Qb` provides PTP clock reference to slaves of the Private PTP Sub-system. `PTP Master Qb` may use GNSS as clock input if it were available or its internal reference if not. Typically, due to subsystem isolation requirements, the broadcast of PTP clock reference to system network shall be blocked by `PTP Master Qb`.

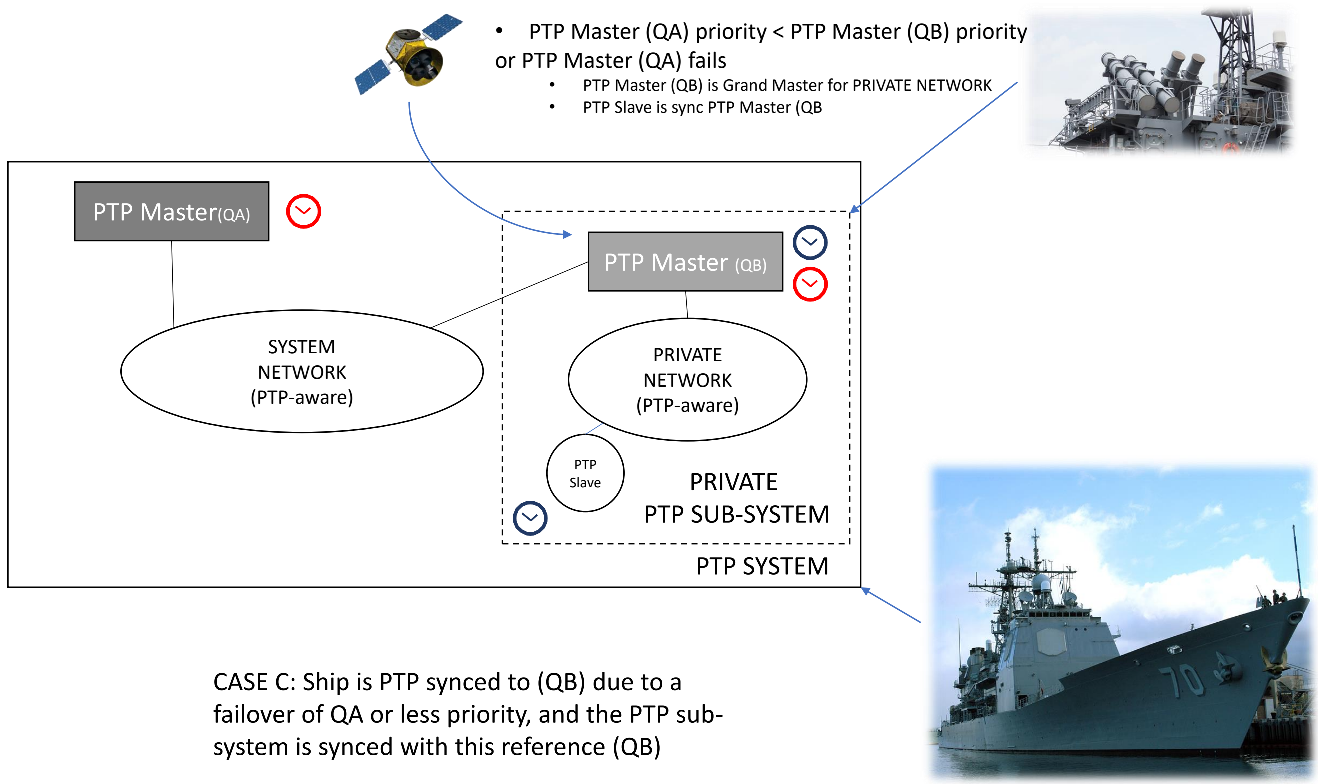

Figure 4 CASE C

3. IMPLEMENTATION EXAMPLE

Figure 5 `RELY-MIL-TIME-SERVER` under MIL-STD-810G tests

The flexibility required to provide a unique solution to the use-case presented demands a new equipment concept. The boundaries of time server, switch, router, and firewall equipment are broken. Additionally, the strict environmental, mechanical and electric requirements in Military systems must be taken into account.

An example of this new generation of platforms RELYUM offers the device `RELY-MIL-TIME-SERVER` (6). It embeds high-end Ethernet networking, time server, and cybersecurity capabilities in the same equipment. The technology core of this product is a reconfigurable platform that combines multiple CPU (4x ARM Cortex-A53, 2x ARM Cortex-R5, and a MALI-400 GPU) and FPGA in the same Integrated Circuit. This tight integration enables a combined hardware and software processing for high-speed switching and routing, accurate timing synchronization, and intelligent operation to mitigate potential security threats.

The switching and PTP/NTP synchronization electronics are fully implemented on the FPGA. `RELY-MIL-TIME-SERVER` addresses these challenges offering different personalities to support tens of 1G copper ports combined with Short and Long Range 1/10G Fiber Optic links. Latest media features, like single fiber bidirectional links, are also supported. High-availability and Deterministic Ethernet, like HSR, PRP or TSN can be implemented to support zero-delay recovery time at the network level and real-time communications.

`RELY-MIL-TIME-SERVER` is certified military equipment. This certification includes environmental, mechanical, and electromagnetic aspects according to MIL-STD-810G and MIL-STD-810F. Additionally, a specific personality has obtained the cybersecurity certification Common Criteria-LINCE by the Spanish National Cryptologic Centre. Figure 5 shows a general overview of the equipment

Figure 6 shows the interconnection diagram to test the set-up required for `CASE A`, `CASE B` and `CASE C`. The connection to the `System Network` is made through 2x 1/10GbE LR Fiber Optic links. MSTP redundancy ensures the availability of this link in case of a single network failure. The equipment is configured to block the PTP traffic through these ports if the equipment is working in `CASE C`.

The connection to the `Private Network` combines 2x 1/10GbE BX (single Fiber Optic) links and 20x 10/100/1000Base-T copper ports. The high number of interfaces combined with multi-media support reduces the complexity and the cost of the network infrastructure drastically in the `Private Network`.

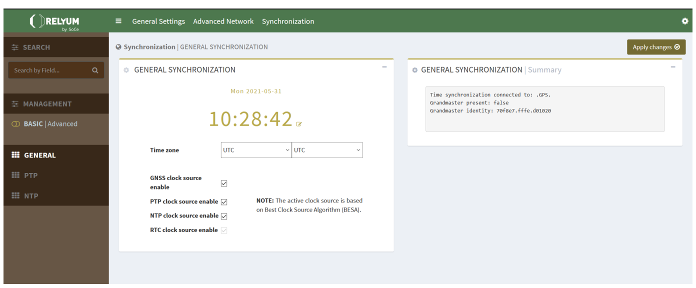

Figure 7 Time Server operation general view

Figure 7 shows the Time Server operation summary. It shows Windows, **`GENERAL SYNCHRONIZATION`** and **`GENERAL SYNCHRONIZATION Summary`**.

`GENERAL SYNCHRONIZATION` Window, as shown in Figure 8, displays the current date and time information. It also summarizes the potential clocking sources available for synchronization and timing purposes. The internal clock source provided by the Real-Time Clock (RTC) cannot be disabled. However, the operator can enable any of these three additional clock sources:

- **`GNSS clock source`**: Clock and synchronization information provided by a GNSS satellite constellation.
- **`PTP clock source`**: Clock and synchronization information provided by a remote PTPv2 (IEEE 1588v2) Master.
- **`NTP clock source`**: Clock and synchronization information provided by a remote NTP Server.

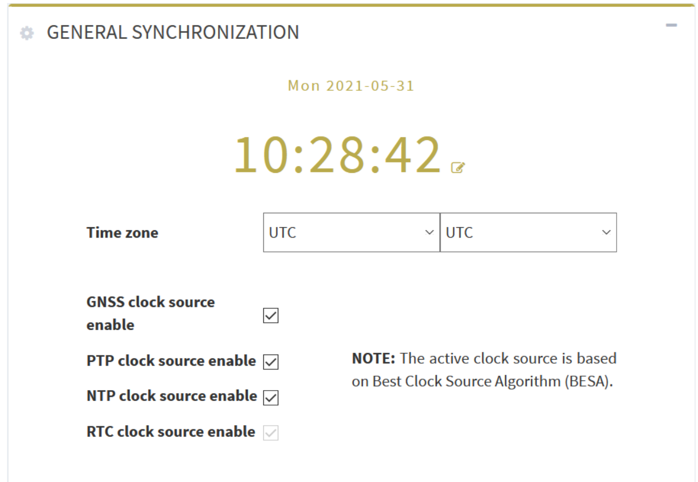

Figure 8 `GENERAL SYNCHRONIZATION` Window

`RELY-MIL-TIME-SERVER` runs a clock selection algorithm, named Best Clock Selection Algorithm (BCSA), that automatically selects the best clock source among the enabled ones. To force the use of a specific clock source, it is feasible disabling the remaining ones (except RTC and the desired one). After selecting the proper configuration, it is necessary to apply the changes selecting the **`Apply Changes`** icon located in the the top right corner of the Window.

An overview of the Time Server configuration running at any time is shown in the Window detailed in Figure 9. By default, the equipment is connected to a GPS source, and there is no available PTP Master in the network with higher priority than this equipment one. Therefore, **`RELY-MIL-TIME-SERVER`** is the PTP Master for the enabled ports with the identity shown in summary. Additionally, **`RELY-MIL-TIME-SERVER`** is an NTP Server available in the network providing this reference.

Attending the operation defined by the combination of `CASE A`,`CASE B` and `CASE C`. A PTP Master with higher priority present in the network it should be the master for the public and private networks. If this PTP Master were not present but yes an NTP Server, the equipment should take NTP as clock source. Finally, it should work as a stand-alone PTP Grand Master using a GNNS clock reference if it were available or the internal one.

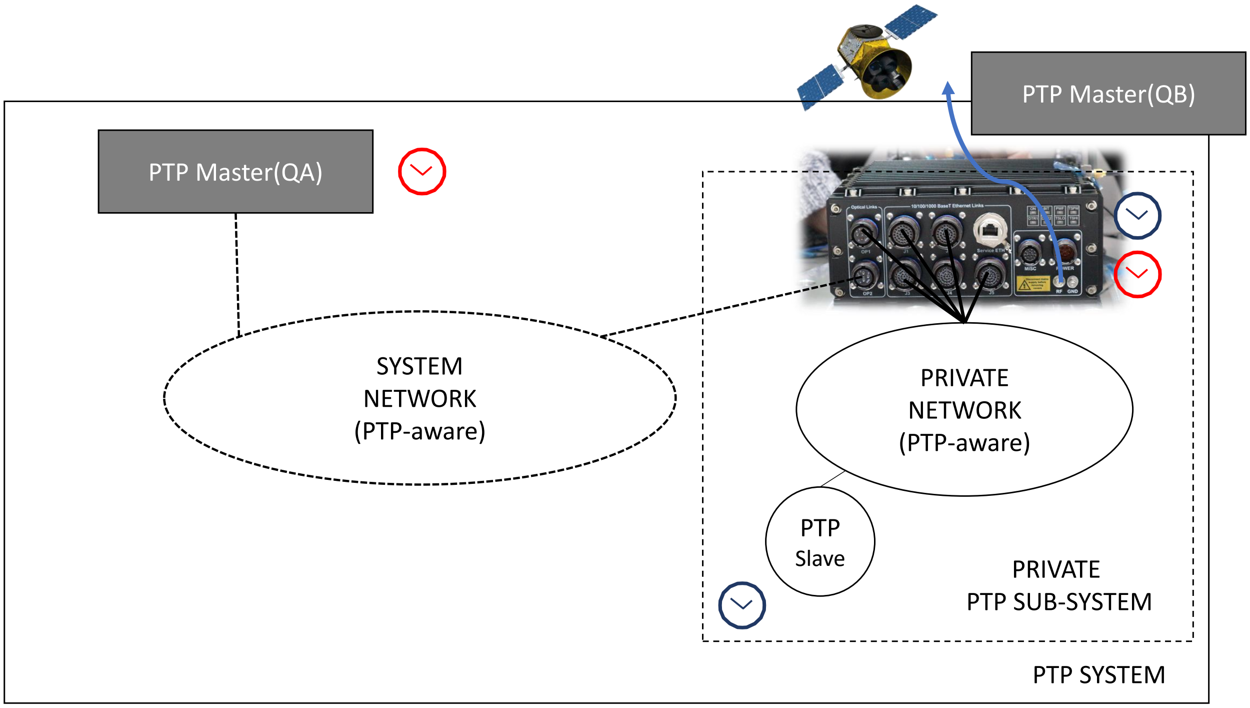

Figure 6 Time Server operation general view

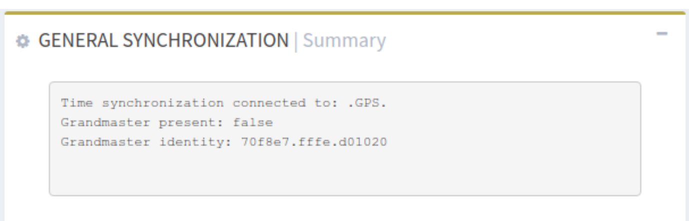

Figure 9 `GENERAL SYNCHRONIZATION|Summary` Window

For this last situation, when **RELY-MIL-TIME-SERVER** has acquired the role of PTP Master, the PTP timing distribution can be blocked using the PTP distribution enabling/disabling feature selectable by port. When a given port is included in the list of **master_capable_ports**, the equipment is allowed to be PTP Master through these designated ports. This feature ensures that **RELY-MIL-TIME-SERVER** is not a PTP master in a Network area where it is not allowed to operate. Anyway, all ports monitor the presence of other PTP Masters in the Network continuously. When receiving a PTP Master with higher priority than **RELY-MIL-TIME-SERVER** , it will drop the current Master clock mode and spread the PTP synchronization mechanism controlled by this Master over all Ethernet ports applying the corresponding PTP Transparent Clock corrections.

4. CONCLUSIONS

In this paper, a common problem in military ships where different timing and synchronization mechanisms concurred is faced. This use-case is split into three different scenarios that need to be solved with unique equipment and network infrastructure. A field-proven solution based on RELYUM **RELY-MIL-TIME-SERVER** equipment is detailed. This approach simplifies the network topology and management, and it reduces the overall cost and the number of equipment required for the setup.

Relyum was born to provide innovative networking, synchronization, and cybersecurity solutions 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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