An Efficient Timing System for IFMIF-DONES Facility Based on Ethernet Time Transfer Protocols

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***Summary*— This work analyses the synchronization requirements of the IFMIF-DONES infrastructure systems and proposes a cost-effective solution based on standard protocols: Network Time Protocol (NTP) and IEEE-1588 profiles, which are compliant with Ethernet networks. This approach simplifies the deployment of the timing system and its integration in already existing networks, being able to provide high scalability in the number of devices and limiting the number of time-aware devices or independent timing networks in the solution. The proposal takes full advantage of the capabilities of White-Rabbit technology to disseminate low phase noise frequency over the network without requiring wired radiofrequency solutions. Final considerations are made to understand the simplicity and viability of this solution.**

Keywords—synchronization; time; timing system; IFMIF-DONES; IEEE-1588; NTP; PTP; White-Rabbit

I. INTRODUCTION

The main objective of IFMIF-DONES, which stands for International Fusion Materials Irradiation Facility-DEMO Oriented NEutron Source, is to provide an accelerator neutron source for evaluating the utilization of materials in future fusion power reactors. The facility is made up of five groups of systems of different nature which are: accelerator systems, lithium systems, test systems, control data access and communication systems, and site buildings and plant systems. Each group is decomposed in what are called LICS (Local Instrumentation and Control System) which have access to the three networks that make up the complete DONES network architecture (one for control, one for machine protection and the third for safety functions). All these LICS are managed from the CICS (Central Instrumentation and Control Systems). Due to the different nature of the subsystems, the synchronization requirements have been analyzed individually for each LICS.

The timing and synchronization system is an indispensable part for critical real-time operations that must be jointly coordinated by different subsystems in DONES. Facilities such as CERN (European Council for Nuclear Research), GSI Helmholtz Centre or ITER (International Thermonuclear Experimental Reactor) have adopted a general networking approach for their timing distribution, whereas others such as ESS (European Spallation Source) have adopted time specific solutions based on nonstandard technologies [1].

The proposed timing transfer solution relies on Ethernet-based networking protocols. The use of standard protocols for synchronization benefits from the support of the academia and manufacturers, and from the high availability of different devices. Because of budget constraints, interoperability purposes, and network integration and utilization optimization, the solution of distributing the highest level of time accuracy for all the devices in the infrastructure has been discarded.

This paper presents a cost-effective timing system solution based on standard protocols for IFMIF-DONES facility.

II. SYNCHRONIZATION ANALYSIS FOR IFMIF-DONES

A LICS can be a client of one or more time servers depending on the synchronization requirements of the devices connected to them. Each LICS has its own local network topology that connects all its devices, while the LICS are interconnected through the CICS. The different devices of the infrastructure have been categorized in three main groups according to their synchronization accuracy needs, from the most demanding to the least demanding: TTP (Tight Time-related Parameters), LTP (Loose Time-related Parameters) and IP (Information Parameters). This classification has been performed according to the information provided by experts of each system of the infrastructure.

Systems included in the TTP class require a minimum synchronization precision of 10 nanoseconds. The IEEE-1588 High Accuracy profile, which can achieve sub-nanosecond precision, has been proposed as the chosen protocol to supply their timing data [2]. This protocol is based on the White-Rabbit technology, with further profile changes for IEEE-1588 interoperability. For the systems included in the LTP class, the maximum clock offset from the time server to the client which can guarantee the proper operation of the systems is about 1 microsecond. The IEEE-1588-2008 synchronization protocol has been designated to distribute these timing data [3]. Lastly, the IP systems expect a minimum synchronization accuracy of 1 millisecond. To achieve this accuracy, the NTP protocol has been chosen (pure software IEEE-1588-2008 could also be an alternative) [4]. A separated redundant time server as backup for each protocol is included in this solution. A layered representation of the timing architecture is shown in Fig. 1.

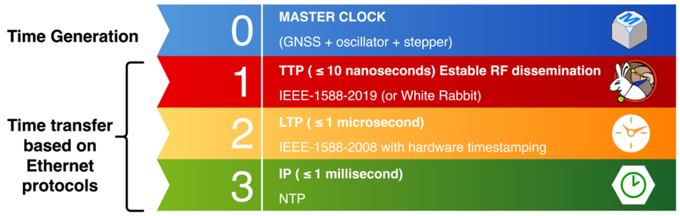

Fig. 1. Layered timing solution representation, showing the common time reference and the three levels of synchronization accuracy.

These time servers are fed with a common time reference, which is generated using a maser device (master clock). This device, together with a frequency stepper, a GNSS (Global Navigation Satellite System) receiver and a computer, perform the common view operation to replicate another time reference (e.g., a metrology institute). This master clock system provides long term stability, allowing the operation in holdover in case of connection failure or detection of jamming or spoofing on the GNSS receiver, as well as offering a low phase noise reference for frequency dissemination without requiring additional master oscillators in the facility.

III. Timing Solution

The DONES network topology is initially conceived as three independent networks. These networks reach all the LICS of the scientific infrastructure. The first network is in charge of control operations, monitoring and coordination, whereas the second network oversees the routing of interlock packets and signals, and the third one deals with signaling and monitoring of the personnel safety and delivery of protection commands. This first network can be considered a soft real-time network where quality of service mechanisms, redundancy capabilities or guaranteed packet delivery are needed but without determinism requirements. These features make this network a good candidate for NTP and IEEE-1588-2008 timing signals distribution. This is the starting point for our timing system.

The new traffic coming from the NTP and IEEE-1588 time servers is incorporated to this network. These synchronization data do not interfere with the information and operation of the systems connected to this network since timing signals are sent periodically, not requiring a high bandwidth. Additionally, the overall timing data traversing the network can be reduced if a local Boundary Clock (BC) is included for those LICS that require high bandwidth for the synchronization of their clients. With this approach, the synchronization signals can reach all the devices with minimum network adjustments and avoiding the deployment of a time-specific physical network that reaches all the LICS, reducing cost and maintenance operations.

Apart from the integration of these protocols into the pre-existing networks, an additional independent network would be needed for the distribution of the IEEE-1588-2019 High Accuracy profile for those LICS requiring very high accuracy requirements of timing and frequency dissemination. The total number of devices, which may change in the future, demanding this synchronization quality is expected to be small (about 40 clients), compared to NTP (about 5200 clients) and IEEE-1588 (about 1200 clients). Thus, the number of network components for this high accuracy timing distribution would also be small.

IV. Discussion

The maximum number of hops from the time server to the LICS and the occupation bandwidth of the links are the most determinant design considerations. The proposed solution relies on the capacity of IEEE-1588-2008 to keep the synchronization accuracy of the devices under 1 microsecond without using IEEE-1588 compliant switches or the implementation of BC, leading to a simpler network and reducing the cost of its deployment. The existence of the high accuracy timing-only network has the additional benefit of relaxing the requirements of the switches of the pre-existing network that distributes NTP and IEEE-1588-2008. It may happen that this generic Ethernet network degrades the performance of NTP or IEEE-1588-2008 to a level not admissible to some LICS. In this case, BC or Transparent Clock capabilities should be considered, increasing the cost of deployment. Another solution for those LICS can be to trace a direct connection to the high synchronization quality IEEE-1588-2019 High Accuracy profile network, and the implementation of time protocol gateways to obtain cleaner and more accurate versions of IEEE-1588-2008 or NTP signals.

Alternatively, the additional IEEE-1588-2019 High Accuracy profile timing-only network can be designed to reach all the LICS of the infrastructure. The LICS would implement different time protocol gateways to obtain the corresponding NTP or IEEE-1588-2008 synchronization signals, distributing them to their corresponding clients. This solution increases the cost of deployment but solves the synchronization signals degradation. It can be an alternative to be considered when more details about IFMIF-DONES networks become available.

V. Conclusions

This contribution has briefly presented a study of the synchronization requirements of IFMIF-DONES. A timing solution based on NTP and IEEE-1588-2019 basic (2008) and High Accuracy profile has been presented, as well as some design considerations and deployment alternatives.

Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work was supported in part by the Spanish Programa de Garantía Juvenil and by the Formación de Profesorado Universitario (FPU) Ph.D. Programme Grant.

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