EPJ Web of Conferences **319**, 12011 (2025) https://doi.org/10.1051/epjconf/202531912011
RICAP-24

White Rabbit FMC mezzanine as an interface for the new 10G WR-NIC to remote WR DAQ nodes

Mateusz Bawaj[1,2,*], *Tommaso* Chiarusi[3,**], and *Riccardo* Travaglini[3,***]

[1]Università di Perugia, P.zza Università, 1, I-06100 Perugia, Italy
[2]INFN Sezione di Perugia, Via A. Pascoli, I-06123 Perugia, Italy
[3]INFN Sezione di Bologna, Viale Berti Pichat 6/2, I-40126 Bologna, Italy

Abstract. The White Rabbit protocol (WR), developed at CERN for the distribution of sub-nanosecond timing to thousands of nodes displaced over large geographic areas, is becoming increasingly reliable and is being utilized in various contexts, notably in modern multi-messenger astronomy experiments in progress such as KM3NeT, CTAO and ET. Currently, WR supports connectivity with 1 Gb/s Ethernet, both point-to-point and through WR-compliant network switches. However, the WR community is already planning new developments toward a full 10 GB/s infrastructure, with clear ideas on building a new PCIe network interface card (NIC) board to connect PCs to the WR network. Generally, WR compatible electronics for data acquisition are proprietary developments tailored to specific applications. INFN-Bologna and Perugia (University and INFN) are designing a set of low-cost electronic boards enabling versatile management and readout of commonly used sensors and actuators using WR technology for time-synchronization. We propose a lightweight dedicated mezzanine board, named Air-Plane, to complement the upcoming new NIC board and facilitate interface between legacy WR Node as well as with non-WR remote cards. This modular and highly scalable design will streamline the implementation of data acquisition systems in testing scenarios, such as ET mirror suspensions developments. In this contribution, we present the conceptual design of Air-Plane and its realization plan presented as parto of the M2TECH project, recently submitted to the HORIZON-INFRA-2024-TECH-01-01 call.

1 Introduction

The modern research field of multi-messenger astronomy requires a coordinate detection of different kind of signals emitted by the same astronomical source. Several detectors were built to detect so-called distinct "messengers" such as neutrinos, gravitational waves, electromagnetic radiation (l.e. photons from radio to γ-rays) and cosmic rays. These detectors are quite unlike each others, since they use techniques characteristic to the signal which they measure. Moreover, few ground based detectors span up to several kilometers. As an example, the KM3NeT project [1] ,[2] is the next-generation neutrino telescope which is currently

---

[*] e-mail: bawaj@pg.infn.it
[**] e-mail: tommaso.chiarusi@bo.infn.it
[***] e-mail: riccardo.travaglini@bo.infn.it

in installation phase under the Mediterranean Sea. Once it is completed it will aim at detecting particles from astrophysical sources by means of arrays of optical modules aligned in vertical strings, collecting Cherenkov photons. Finally, deployed in over a cubic kilometer volume of water, optical modules will transmit data from the detections synchronously. Modern detectors for gravitational waves are laser interferometers, with main arms long few kilometers and several suspended optical benches, as well as heavy mirrors and beam splitters at their ends. At the present time, there are 4 working interferometers all around the world, operating observational runs which lasts several months: two LIGO detectors in US (in Hanford, Washington and the other in Livingston, Louisiana), VIRGO in Italy and KAGRA in Japan. A next-generation project will be built in Europe, hopefully in 10 years from now, named Einstein Telescope (ET) [3] and it will consist of more interferometers in the same place, with arms long at least 10 kilometers.

From this glance at multi-messenger detectors, it becomes clear that timing and synchronization issues are relevant as it will be described in section 2.2:

The present experiments have developed ad-hoc solutions for timing and synchronization; however, a protocol called White Rabbit (WR) , is becoming of interest. It is already adopted in projects such a KM3NeT, while it is seen as a promising technology for ET.

In the first part of this paper the WR project will be shortly introduced, highlighting how it is used in KM3NeT and where it could benefit both timing distribution, data acquisition and detector control in ET. A preceding short overview of the current ad-hoc system for VIRGO will be useful to point out the requirements and to understand how the White Rabbit could accomplish them. Then, in the second part of this paper, the conceptual design of the Air-Plane card will be presented, as a proposed electronics board in the context of a future WR upgrade and it will be pointed out how its modular design will favour the realization of several test cases. Finally, a development plan will be discussed.

2 The White Rabbit project

2.1 Overview

The White Rabbit [4] (WR) provides synchronization for large distributed systems made up of devices interconnected in a network topology with typical distances of 10 km between network elements. WR can deliver sub-nanosecond accuracy and picoseconds precision; it also allows for deterministic and reliable data delivery with a Gigabit rate of data transfer. It worth noticing that data and timing information are transmitted through the same network. WR technology consists of a set of open-source basic blocks that can be used to implement WR Switches and WR Nodes. When interconnected, WR Switches and WR Nodes create a WR network. Such a network is a PTP-enabled Bridge Local Area Network based on Gigabit Ethernet over optical fiber. The sub-nanosecond synchronization is provided only between WR Switches and WR Nodes. Servers and PCs can be transformed into WR Nodes thanks to the SPEC board [5]: a 1 Gb/s PCI-express NIC-card developed by CERN (under Open HW License). The WR project was started by the CERN community around 2008 as a proposal upgrade for the timing system of scientific facilities. Nowadays, thanks to a spread consensus and following several successful use cases, a scientific collaboration[1] has been set up to guarantee quality and sustainability of the project as well as to support strategies for upgrades. INFN joined the collaboration in 2024.

---

[1] https://www.white-rabbit.tech

2.2 White Rabbit for multi-messenger experiments: the KM3NeT and gravitational interferometer cases

Since the establishing of the WR project, there have been numerous deployments in domains as diverse as particle accelerators, cosmic ray detection, metrology and financial transaction networks. In the field of multi-messenger astrophysics we can cite the KM3NeT case, where a custom implementation [6] has been be adopted to synchronize the optical detection modules with a precision of less than one nanosecond. The WR network consists of custom electronics on the offshore nodes and WR Switches at the onshore stations, organized in layers with different functionality.

To better understand why the WR has seen as an interesting technology for both timing and data acquisition systems for present and future detectors for gravitational wave as well, let's have a look to the requirements and the implementation in the present experiments.

The task of timing distribution systems is to deliver absolute timing and low jitter/phase noise clock to the readout system, relative timing accuracy to the interferometer controls and low phase noise clock to the servo loops. As an example the present solution to the VIRGO interferometer is based on distributing IRIG-B signal from GPS together with 10/100 MHz signals. The timing system is separated from the data acquisition and control system.

The absolute timing accuracy in reconstructing gravitational waves is important for sky localization of sources. For the present configuration of the VIRGO interferometer (called AdvancedVirgo+) it should be better than 10 μs, while an accurate estimation for ET is of the order of 1 μs. Relative timing requirements are constrained by the bandwidth of the control loops implemented to actively suppress noise and increase interferometer stability and the correspondent maximum latency. The bandwidth of the hardware real-time loops range from few MHz (the servo loops stabilising the laser) and few tenths of kHz (f.i. the ones for the local control of the suspended masses like mirrors and the beam splitter). The phase noise and the jitter of the distributed clock are constrained from the sampling and actuation rate required for digital electronics. Since in ET it would be beneficial to have ADCs sampling at several hundreds of MHz, a sub-picosecond clock precision is needed to limit the noise contribution at a reasonable level. Moreover, the amount of data produced in gravitational wave detectors won't be a big issues, for instance when compared to experiments at the accelerators like LHC. In the recent runs, VIRGO acquired a raw data quantity of ~1 PB/year, while for ET it is expected ten times more. However, to accomplish the needed peak data rate and the low latency requirements (this impact on the control loops bandwidth), a network with multi-gigabit links is unavoidable. As an example VIRGO uses 2.5 Gb/s per link.

The current WR technology provide sub-nanosecond synchronization between nodes, delivers both high precision clocks with picosecond precision and absolute timing from GPS with the required accuracy. Starting from the current technology for a WRS, which exploits onsolidated connections ad Gb/s Ethernet, the WR community is already planning to conceive new innovations toward a full 10 Gb/s infrastructure. The gravitational wave community is participating in this effort as it's seen as really promising for present and future detectors.

3 The Air Plane Project

The proposed upgrade of WR into a full 10 Gb/s infrastructure has to include: enhancement of the WR Switches and development of a 10 Gb/s Ethernet pluggable PCIe network-interface card. In this landscape, the Air Plane project aims to develop a FMC mezzanine to transform this new network interface card into a hub for both WR-based and no-WR external devices. This way, remote low-cost electronics boards (with specific sensors/actuators) can act as WR

Nodes interfaced with the new 10Gb/s network. A picture of the proposed card can be seen in figure 1.

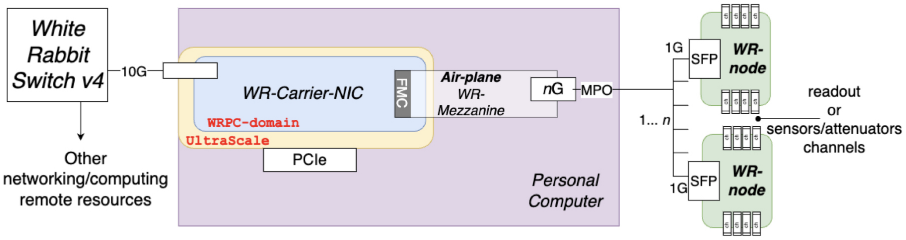

Figure 1. Diagram representation of the Air Plane mezzanine, plugged into a WR 10 Gb/s Network Interface Card (NIC) which is hosted by a PC. Several board can be connected (see on the right) through a multiple optical fiber link, in a nG (multi-gigabit) to 1 Gb/s connection.

INFN-Bologna and Perugia are going to design a set of low-cost electronic boards for versatile management and readout of the most common sensors or actuators for gravitational wave detectors; they will be used for standalone test benches (e.g. for R&D on vacuum squeezing techniques) as well as to control and monitoring of new infrastructures devoted to develop the technology for ET.

At the present time, there are still open technicalities in the project to be finalized: defining a proper fiber optics layout, scaling the number of remote nodes to be connected, defining the amount of "intelligence" in the mezzanine (f.i. is a FPGA needed?) and consequently the appropriate firmware or protocol for interfacing with the main processing device (FPGA) of the hosting PCIe card. The Air Plane project has been submitted as a task of the HORIZON-INFRA-2024-TECH-01-01 call and, in addition, institutional funding is going to be reviewed. The submitted plan is made up of the following steps: design the FMC mezzanine, design at least 2 different types of WR Node prototypes, develop a customized firmware version running on the main processing device of the hosting card to read/write/control remote WR Nodes and test the system with at least 5 WR Nodes connected.

References

[1] S. Adrian-Martinez *et al.* [KM3Net], Letter of intent for KM3NeT 2.0, J. Phys. G **43** (2016) no.8, 084001 doi:10.1088/0954-3899/43/8/084001 [arXiv:1601.07459 [astro-ph.IM]].

[2] R. Coniglione, KM3Net status and recent results, this proceedings

[3] T.Bulik, Science perspectives with the Einstein Telescope, this proceedings

[4] J. Serrano, P. Alvarez, M. Cattin, E. G. Cota, P. M. J. H. Lewis, T. Włostowski et al., The White Rabbit Project in Proceedings of ICALEPCS TUC004, Kobe, Japan (2009).

[5] Simple PCIe FMC carrier (SPEC) White Rabbit Open Hardware project https://www.ohwr.org/projects/spec

[6] T. Chiarusi, E. Giorgio, The Software Defined Networking in KM3NeT, EPJ Web Conf. **207** 06009 (2019). https://10.1051/epjconf/201920706009