Introduction

Javier Serrano on behalf of the CERN WR Team

European Organisation for Nuclear Research
(CERN)

WR workshop and WR Collaboration Launch Event

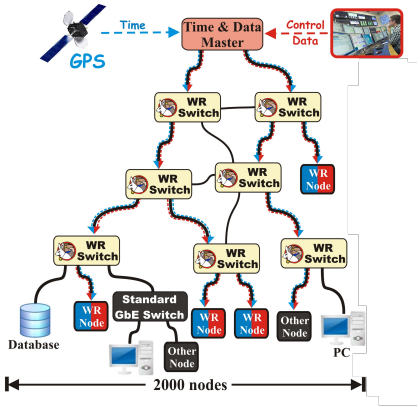
21 March 2024

Outline

Outline

What is White Rabbit?

- Initially meant for Big Physics facilities/projects: CERN, GSI, Nikhef...
- **Based on well-established standards**
  - Ethernet (IEEE 802.3)
  - Bridged Local Area Network (IEEE 802.1Q)
  - Precision Time Protocol (IEEE 1588)
- **Extends standards** to meet new requirements and provides
  - Sub-ns synchronisation
  - Deterministic data transfer
- Initial specs: links $\leq$10 km & $\leq$2000 nodes
- **Open Source and commercially available**



White Rabbit technology - sub-ns synchronisation

Based on

- IEEE 1588 Precision Time Protocol on Gigabit Ethernet over fibre

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Enhanced with

- Layer 1 syntonisation
- Digital Dual Mixer Time Difference (DDMTD)
- Link delay model

Outline

Short history of WR

- 2008: first meeting at CERN
- 2009: first switch prototype
- 2012: first COTS switch available (open-source hardware, gateware, firmware, software)
- 2012: first operational deployment of WR (Gran Sasso National Lab)
- 2013-2018: WR concepts standardised within IEEE 1588
- 2024: creation of the WR Collaboration

WR post-standardisation

A technology supported by a friendly community working on a fully open-source implementation of IEEE 1588-2019 High-Accuracy (HA) profile, with a guaranteed sub-nanosecond accuracy.

Outline

Entering a new phase

Post-standardisation issues

- How to maintain good support after the increase in uptake of the technology, both in industry and academia?
- How to ensure a high level of quality in the foundations of WR (switch and WR PTP core)?

White Rabbit Collaboration

See next presentation and visit
https://www.white-rabbit.tech/

Outline

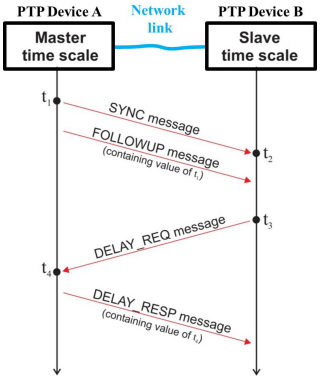
Logistics

- The Globe
- Lunch
- CERN visits this evening
- Dinner tonight
- Presentations:
  - See guidelines at https://ohwr.org/project/white-rabbit/wikis/Workshop-Presentation-Guidelines
  - Bear in mind times in schedule include Q&A and transition between speakers
- Let's start!

Backup slides

Backup slides

Precision Time Protocol (IEEE 1588)



- Frame-based synchronisation protocol
- Simple calculations:
  - link delay: $\delta_{ms} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$
  - offset from master: $OFM = t_2 - (t_1 + \delta_{ms})$

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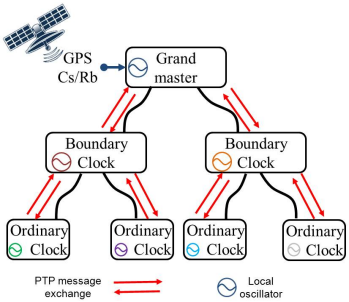

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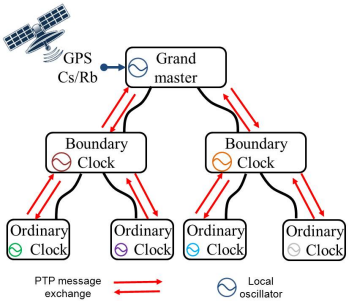

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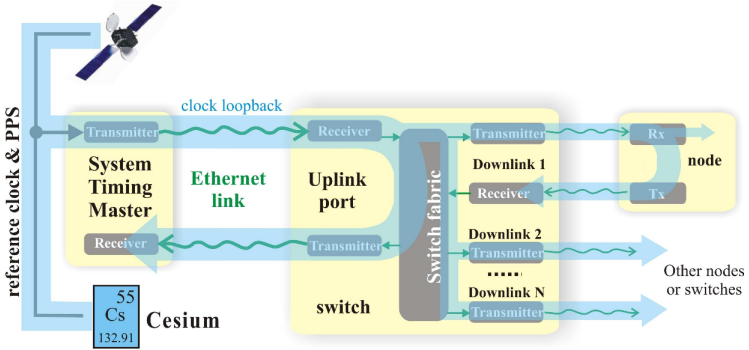
- Hierarchical network
- Shortcomings of traditional PTP:
  - devices have free-running oscillators
  - frequency drift compensation traffic can compromise determinism of other messages
  - assumes symmetry of medium
  - resolution of timestamps

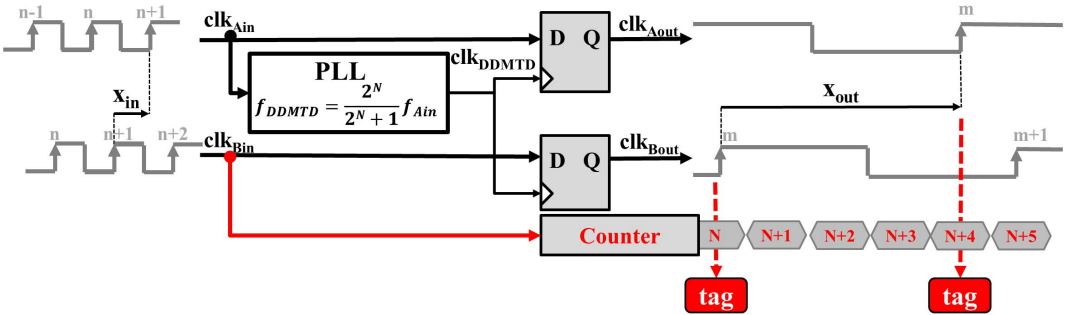
Layer 1 Syntonisation

- Clock is encoded in the Ethernet carrier and recovered by the receiver chip
- All network devices use the same physical layer clock
- Clock loopback allows phase detection to enhance precision of timestamps



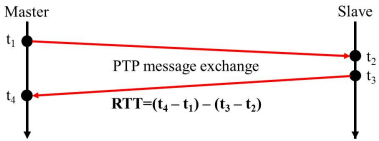
Digital Dual Mixer Time Difference (DDMTD)

- Precise phase measurements in FPGA
- WR parameters:
  - clk_{in} = 62.5 MHz
  - clk_{DDMTD} = 62.496185 MHz (N=14)
  - clk_{out} = 3.814 kHz
- Theoretical resolution of 0.977 ps



Link delay model

- Correction of Round Trip Time (RTT) for asymmetries



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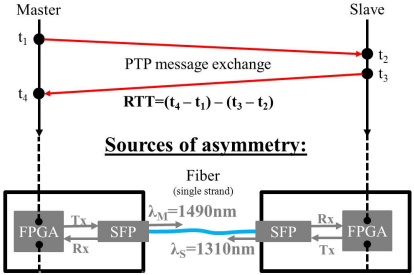

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  - **Fixed delays** – calibrated/measured
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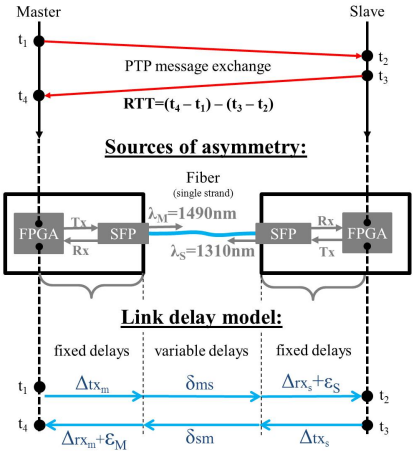
$$\alpha = \frac{\nu_g(\lambda_s)}{\nu_g(\lambda_m)} - 1 = \frac{\delta_{ms} - \delta_{sm}}{\delta_{sm}}$$



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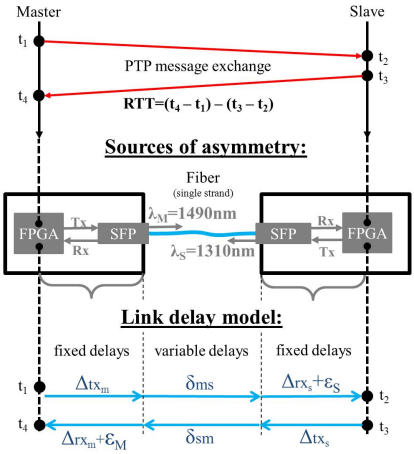
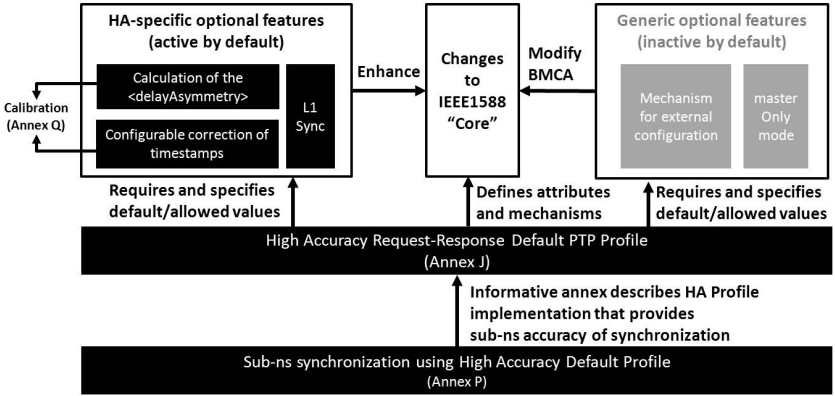
- Accurate offset from master (OFM):

$$\delta_{ms} = \frac{1+\alpha}{2+\alpha}\left(RTT - \sum \Delta - \sum \epsilon\right)$$

$$OFM = t_2 - (t_1 + \delta_{ms} + \Delta_{txm} + \Delta_{rxs} + \epsilon_S)$$



High Accuracy in IEEE 1588



Outline

Status

Fundamental building blocks

- Recent release of WR PTP Core v5.
- Upcoming software/gateware release (v7) for WR switch v3 hardware.

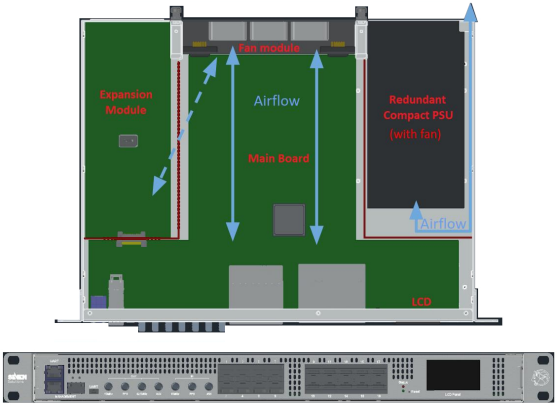
Plans

WR Switch v4

- GbE and 10GbE support
- Redundant and serviceable fans and power supplies
- Based on Xilinx/AMD Zynq UltraScale+ System-on-Chip (SoC)
- Expansion board slot for enhancements (low phase noise, hold-over...)

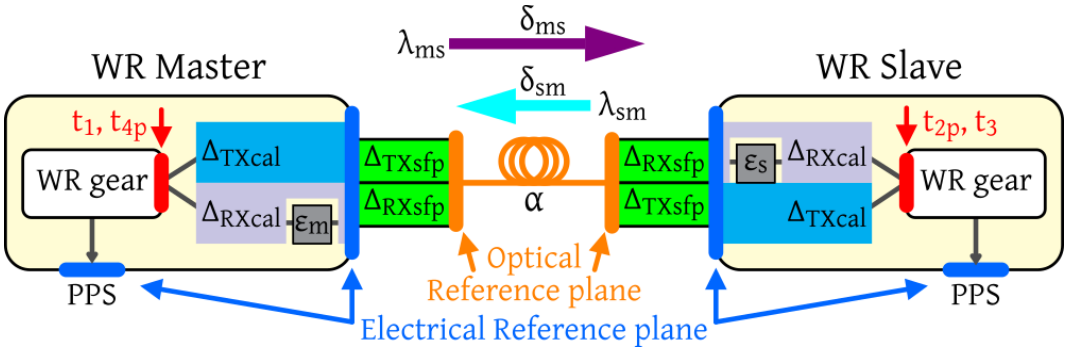
See https://ohwr.org/project/wr-switch-hw-v4/wikis for more details.

WR Switch v4



Prototypes next month, v3 functionality before the end of the year.

Standardisation++



Courtesy Henk Peek and Peter Jansweijer

Standardisation++ (P. Jansweijer, M. Lipiński)

Amendments to IEEE 1588-2019

- Absolute calibration
- In-situ calibration of asymmetry

Within the SNIA SFF working group

Storage of calibration parameters in SFP EEPROM

Future developments

My guess at a WR user wishlist

- Monitoring: switch front panel and programming interface
- Robustness of hardware
- Seamless system redundancy (clock ensemble)
- More automation in calibration
- Evolution of link delay model
- Standardisation/profiles
- Set of best practices for long-distance WR
- Lower barrier to entry: training, starting kit, documentation...

Join the newly-created White Rabbit Collaboration to help us shape the future of WR!

The White Rabbit Collaboration in a nutshell

Ensuring sustainability

- Members pay a yearly fee and shape the future of the technology.
- Fees are used to pay the WR Collaboration Bureau, which offers support (including training) and ensures WRS and WRPC are always in good health.

The White Rabbit Collaboration in a nutshell

Letting information flow

- Collaboration with vendors ensures coherent growth of the WR ecosystem
- Keeping members well informed: online presentations, forum, regular meetings...
- Connecting people, institutes, companies (e.g. connecting NRENs with industry)

The White Rabbit Collaboration in a nutshell

Ensuring high-quality

- Making the evolution of WRS and WRPC the main task of the Bureau
- Teaming up with laboratories to establish a set of tests and qualification criteria
- Connecting the use of the WRC logo to the successful passing of those tests

The White Rabbit Collaboration in a nutshell

Projects!

- Mobile (e.g. TDD on 5G)
- Quantum: see e.g. CERN's Quantum Tech Initiative at https://quantum.cern/
- Smart grids
- <your project here>

Open **and** commercially available off-the-shelf