White Rabbit

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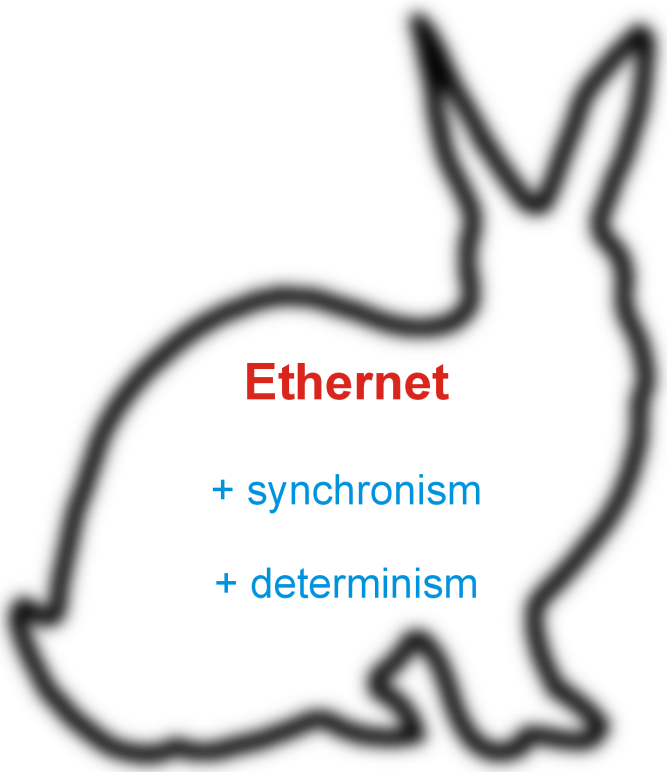
Outline

1 Introduction
2 Technology overview
3 WR PTP
4 WR Network Components
5 Tests and achievements
6 Applications
7 Summary

What is White Rabbit?

An **extension** to **Ethernet** which provides:

- **Synchronous mode** (Sync-E) - common clock for physical layer in entire network, allowing for precise time and frequency transfer.
- **Deterministic routing** latency - a guarantee that packet transmission delay between two stations will never exceed a certain boundary.



Design goals

Scalability

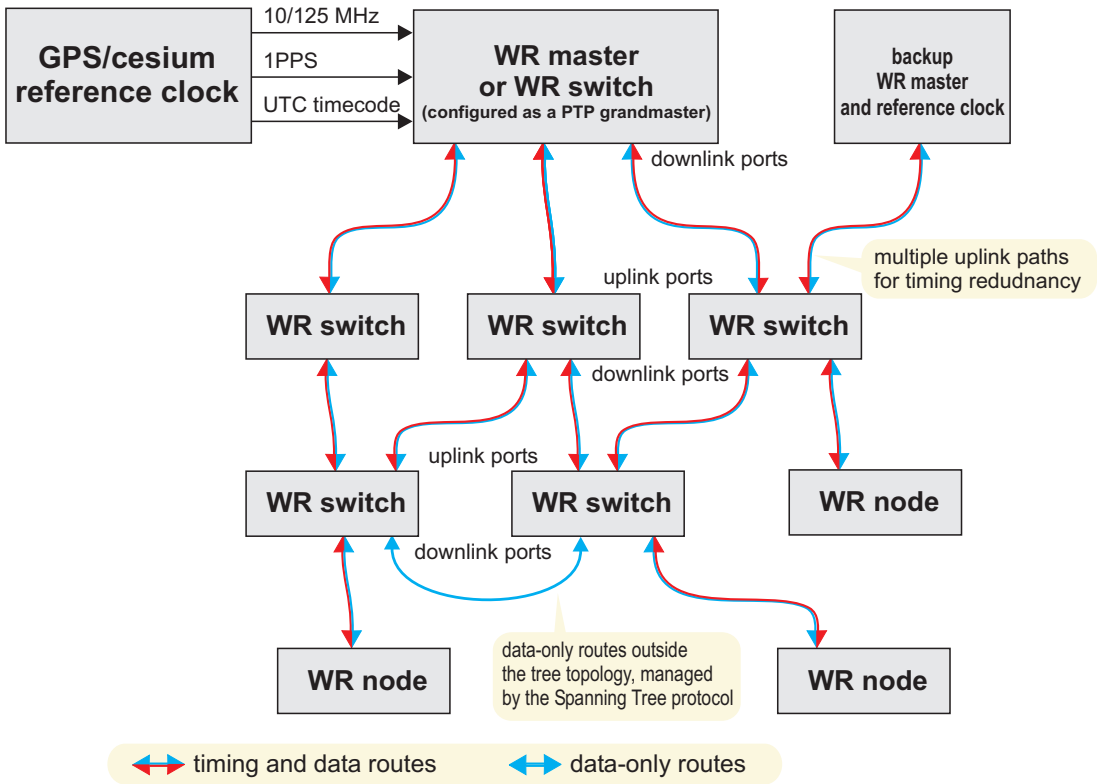
Up to 2000 nodes.

Range

10 km fiber links.

Accuracy and Precision

Sub-ns time synchronization accuracy, 20 ps jitter.



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Technologies used in White Rabbit

Sub-nanosecond synchonization in WR is achieved by using the following three technologies together:

- Precision Time Protocol (IEEE1588).
- Synchronous Ethernet.
- DMTD phase tracking.

PTP Protocol (IEEE1588)

PTP

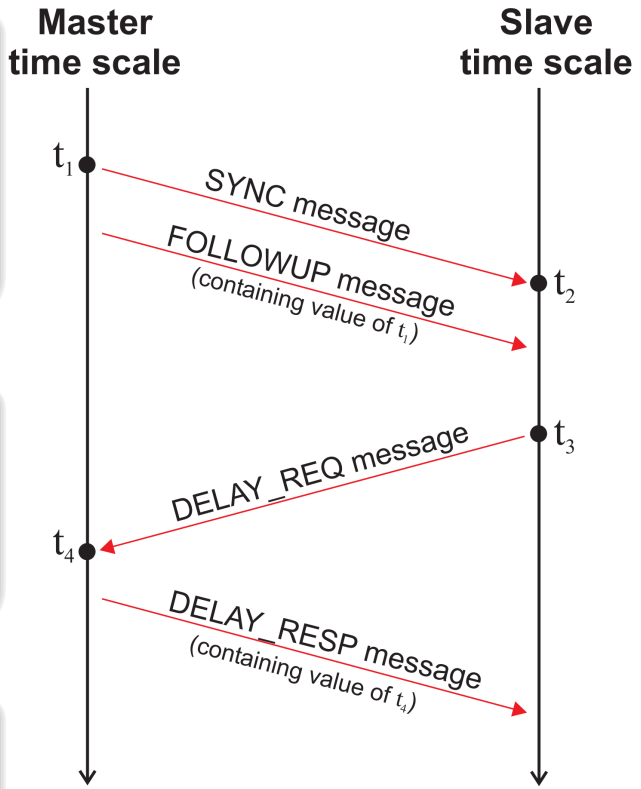
Synchronizes local clock with the master clock by measuring and compensating the delay introduced by the link.

Packet timestamping

Link delay is measured by exchanging packets with precise hardware transmit/receipt timestamps.

Disadvantages of traditional PTP

All nodes have free-running oscillators.
Frequency drift has to be continously compensated, causing lots of network traffic.
That doesn't go well with determinism...



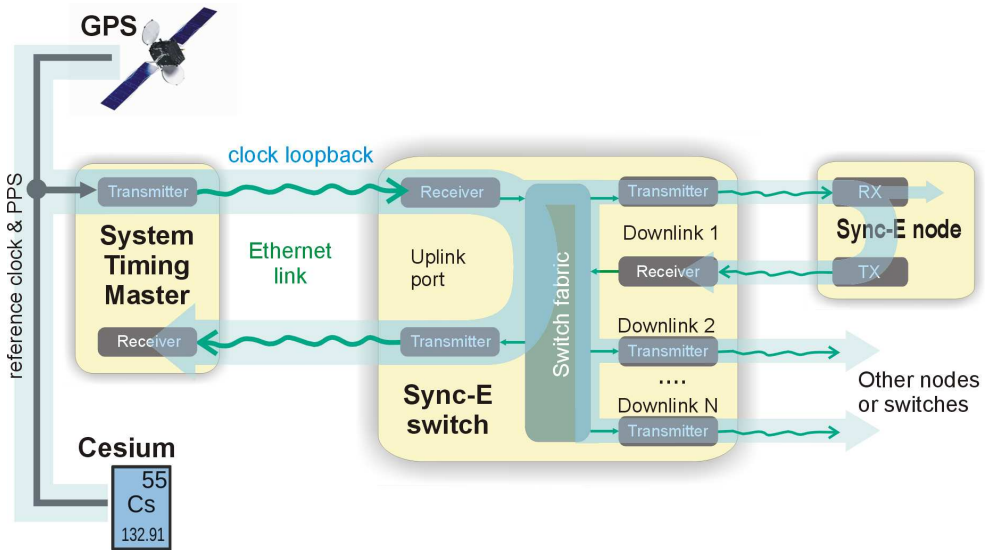
one-way link delay:

$$\delta_{ms} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$$

$$offset = t_2 - (t_1 + \delta_{ms})$$

Synchronous Ethernet

- All network nodes use the same physical layer clock, generated by the System Timing Master.
- Clock is encoded in the Ethernet carrier and recovered by the receiver chip (PHY).
- PTP is used only for compensating clock offset.
- Having the same clock frequency everywhere enables phase detector technology as the means of measuring time.



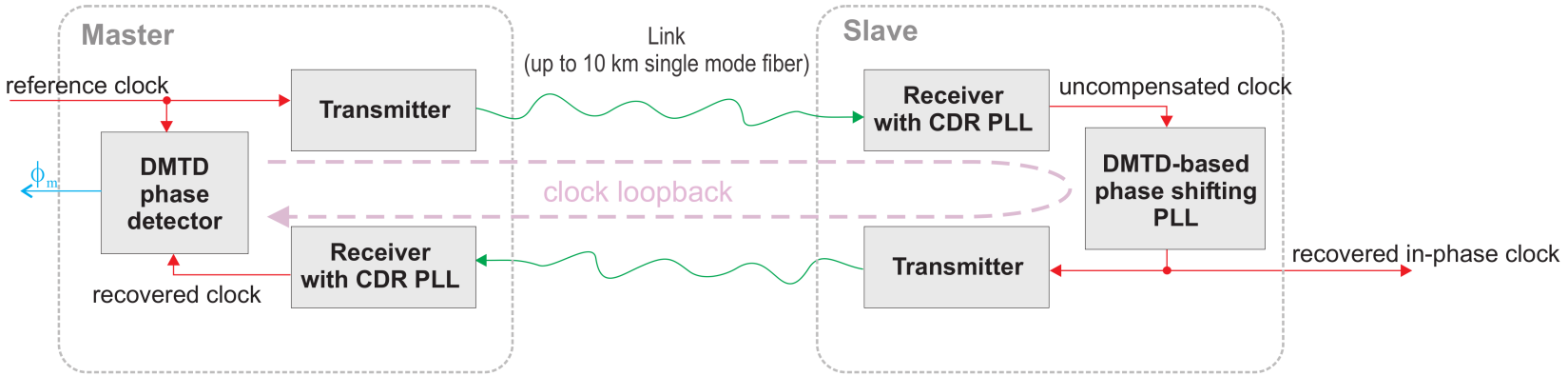
Phase tracking

Plain PTP

PTP alone is not enough if we want very good accuracy, because of the granularity of the timestamps.

Solution

Measure the phase shift between transmit and receive clock on the master side, taking the advantage of SyncE.



- Monitor phase of bounced-back clock continuously.
- Phase-locked loop in the slave follows the phase changes measured by the master.

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Overview

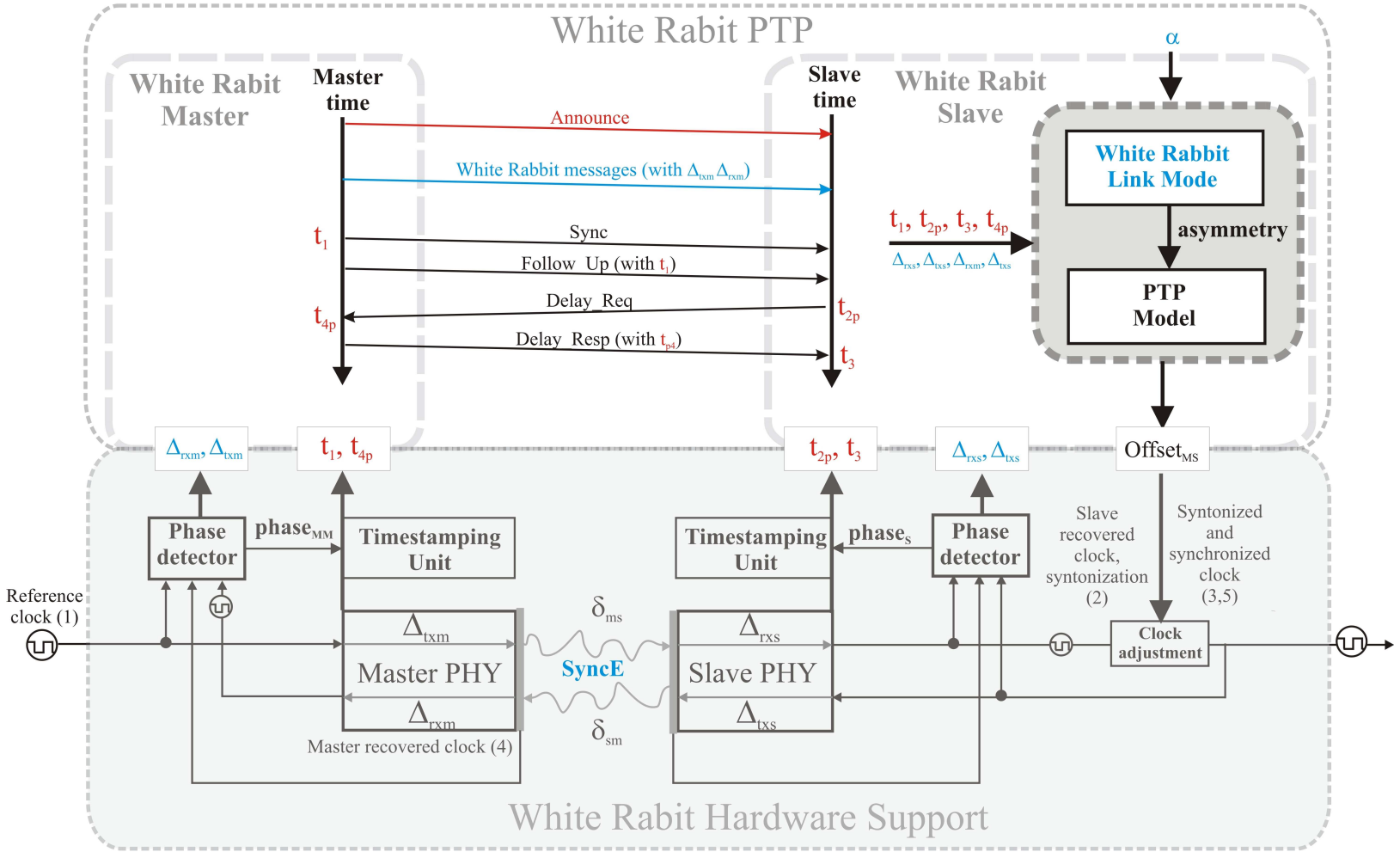
What is WR PTP?

It is an extension to PTP which is described as a PTP Profile and a set of implementation recommendations. It results from the combination of PTP with two further requirements: precise knowledge of the link delay and clock syntonization over the physical layer.

What do we add to PTP?

- **Link Setup** - process which enables to recognize WR devices, measure and exchange hardware parameters, controlled by WR State Machine, it uses...
- **Messages** - means of exchanging WR-specific data
- **Link Model** - enables to calculate link asymmetry
- **Data Sets** - used to store WR parameters
- **Modified Best Master Clock Algorithm** - to allow redundancy and immediate switch-over

How does it work?



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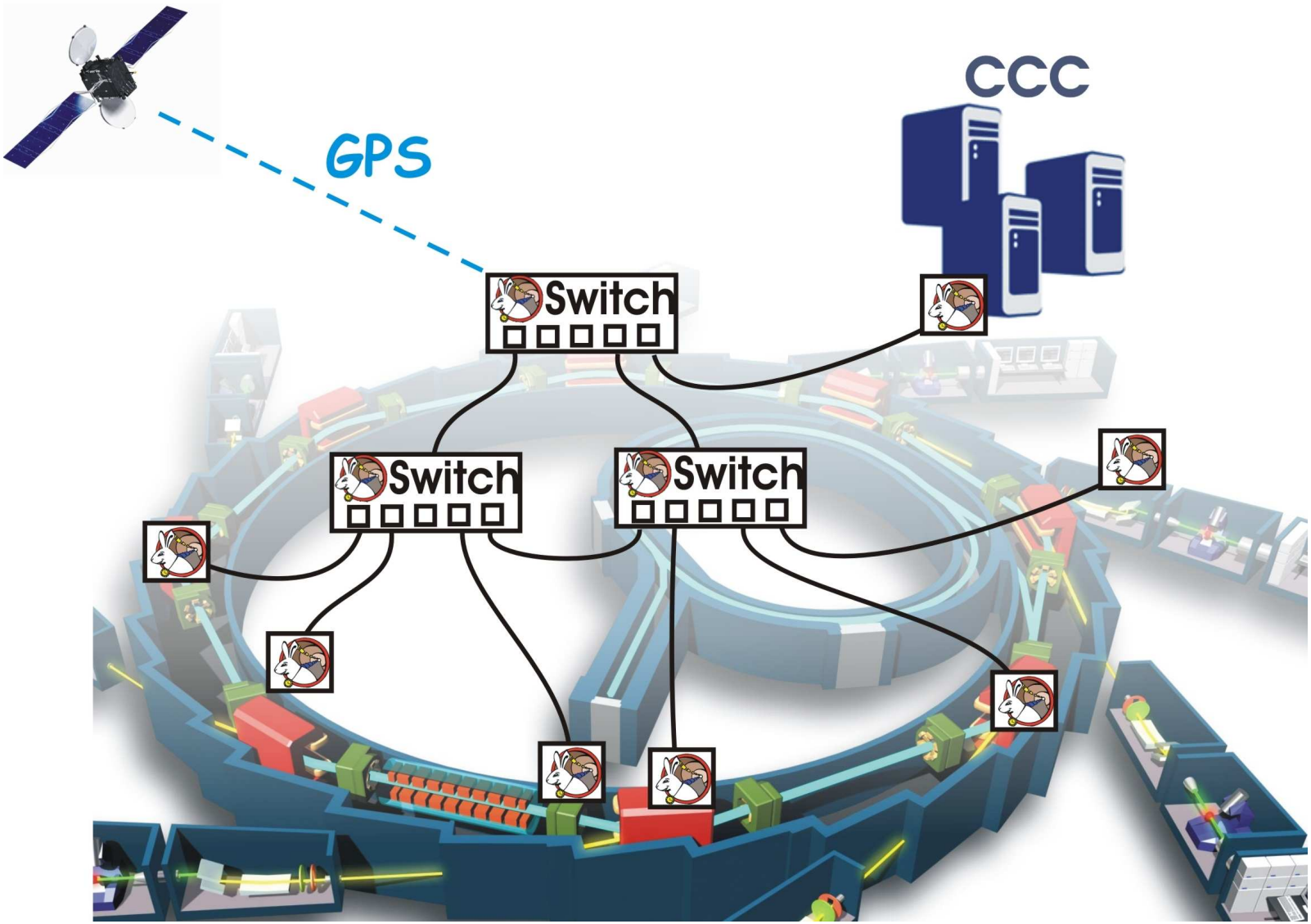
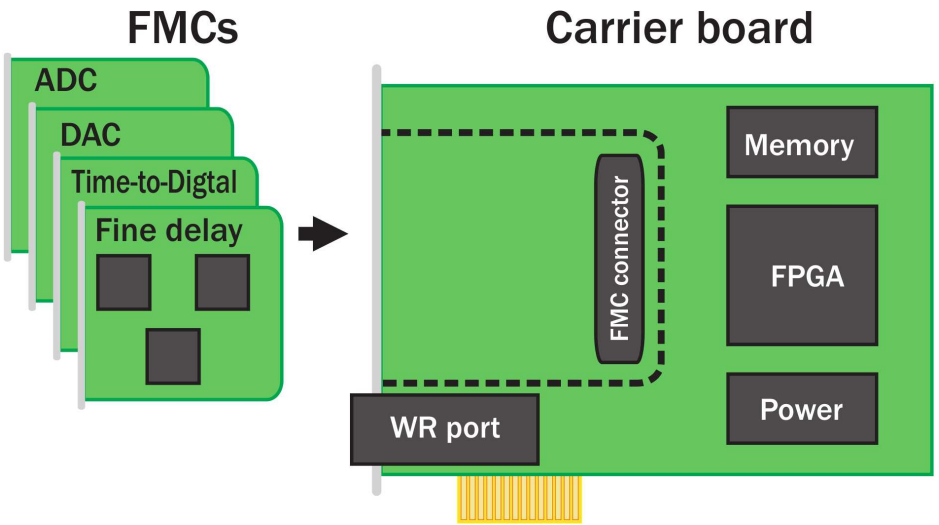
White Rabbit Network



White Rabbit Switch

- Central element of WR network.
- Fully custom design, designed from scratch.
- 10 1000Base-LX ports, capable of driving 10 km of SM fiber.
- Compatible with IEEE standards: 802.3, 802.1Q, PTP.

White Rabbit Node



CERN's BE-CO-HT FMC-based Hardware Kit:

- FMCs (FPGA Mezzanine Cards) with ADCs, DACs, TDCs, fine delays, digital I/O.
- Carrier boards in PCI-Express, VME and uTCA formats.
- All carriers are equipped with a White Rabbit port.

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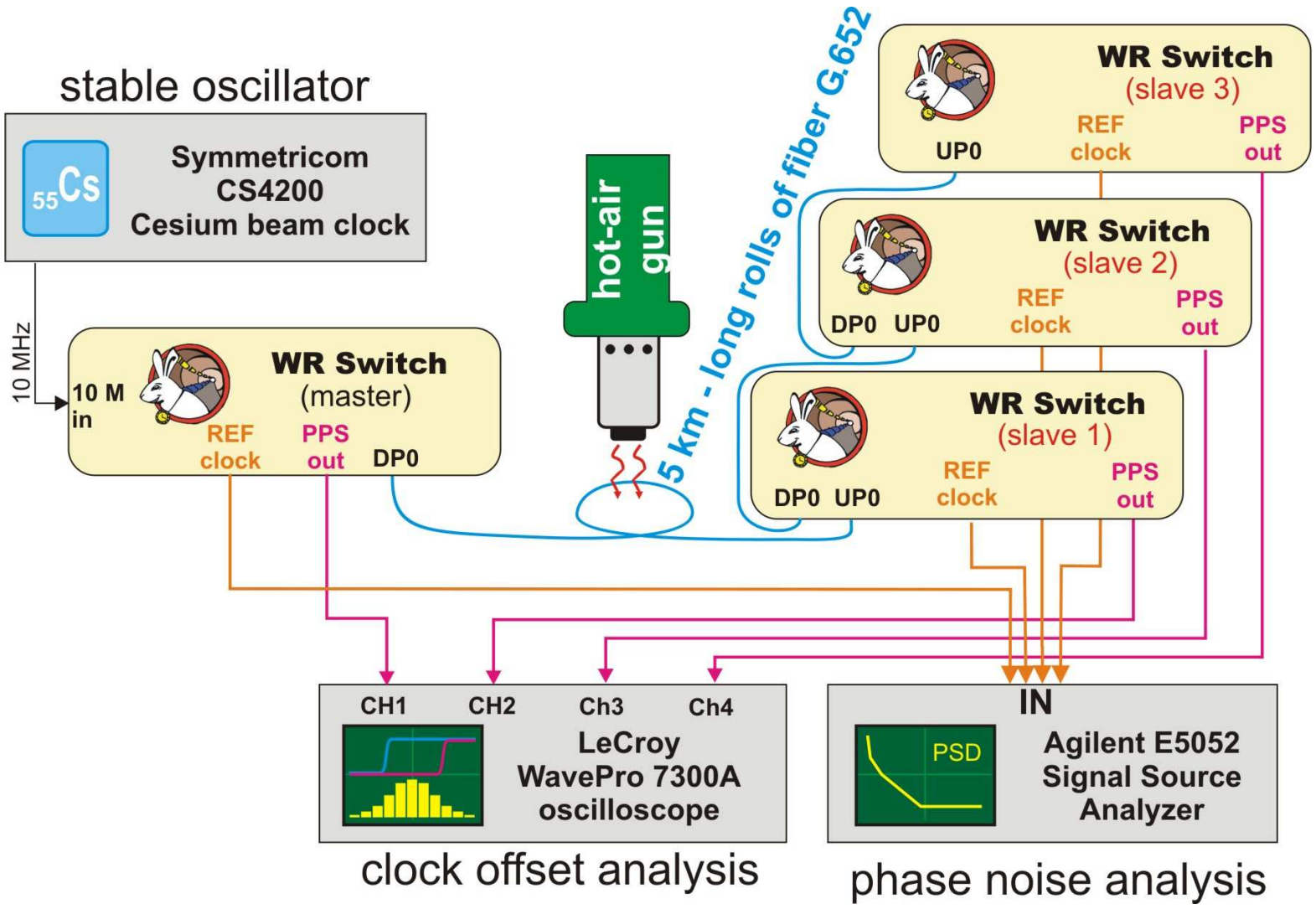
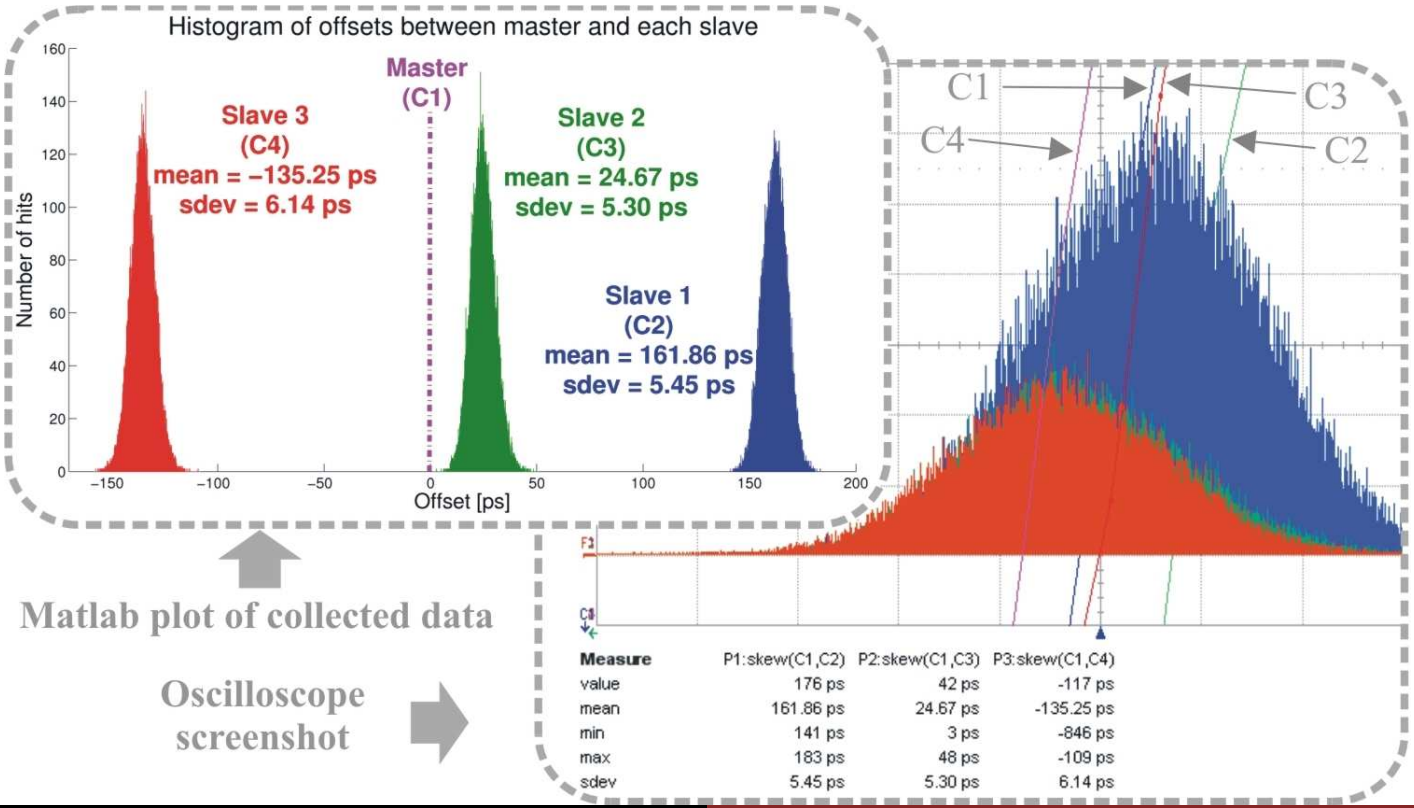
Tests Setup


stable oscillator
Symmetricom
CS4200
Cesium beam clock
10 MHz
10 M
in
WR Switch
(master)
REF
clock
PPS
out
DP0
hot-air
gun
5 km - long rolls of fiber G.652
WR Switch
(slave 3)
UP0
REF
clock
PPS
out
WR Switch
(slave 2)
DP0 UP0
REF
clock
PPS
out
WR Switch
(slave 1)
DP0 UP0
REF
clock
PPS
out
CH1
CH2
Ch3
Ch4
LeCroy
WavePro 7300A
oscilloscope
clock offset analysis
IN
PSD
Agilent E5052
Signal Source
Analyzer
phase noise analysis

Tests Results

High accuracy and precision achieved

200ps accuracy and 10ps precision over 5km of fiber.
Sub-nanosecond accuracy and 10ps precision over daisy-chain of 3 switches, total of 15km of fiber.



Tests Results

Interoperability

..verified with other PTP devices on ISPCS 2010 Plug Fest

According to ISPCS Plug Fest results ...

... White Rabbit is the most accurate PTP implementation in the world!

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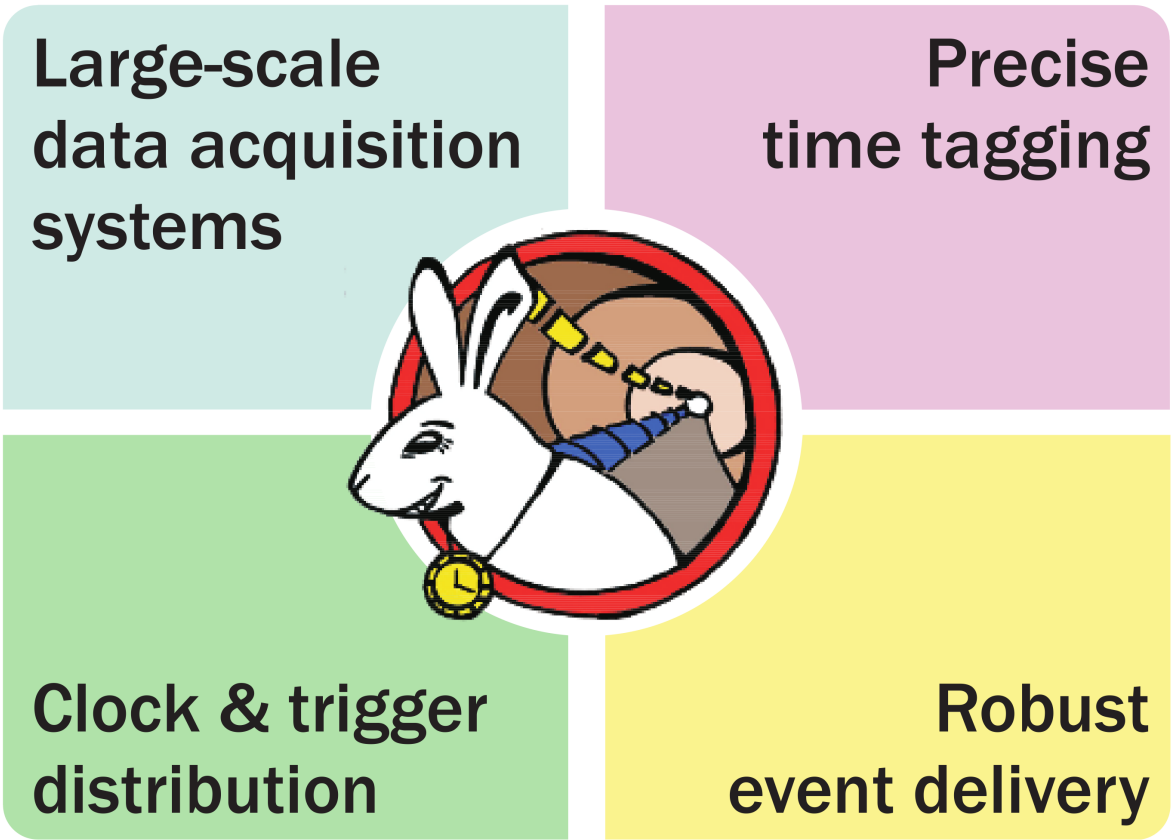
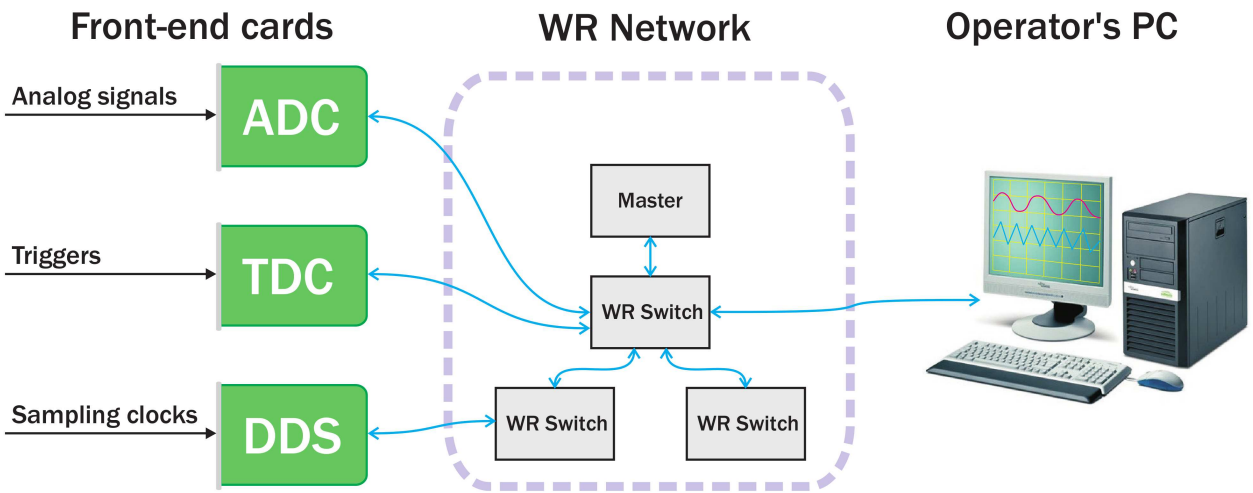
Possible applications of White Rabbit



Distributed oscilloscope



- Common clock in the entire network: no skew between ADCs.
- Ability to sample with different clocks via Distributed DDS.
- External triggers can be time tagged with a TDC and used to reconstruct the original time base in the operator's PC.

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Who are White Rabbits

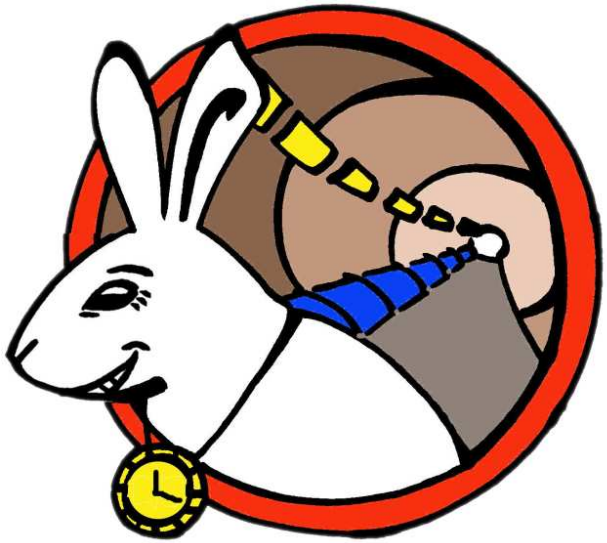
⇐ CERN geeks :)
All the family
⇓

Conclusions

- Innovative:
  - Open Hardware and Software.
  - New trends in cooperation between public institutions and companies.
  - Successful cooperation.
- Based on well-established standards to ensure its long lifetime, wide support and commercial feasibility.
- Sub-ns accuracy of synchronization - the most accurate known PTP implementation.
- Growing number of possible applications, partners and colaborants.

Thank you

Thank you for your attention



Questions?