The White Rabbit Project

Technical introduction and status report

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Outline

1. Introduction
2. Technology overview
   - Precision Time Protocol (IEEE1588)
   - Synchronous Ethernet
   - Phase tracking
   - White Rabbit Switch
3. Applications
   - WR in CERN's BE-CO-HT's Hardware Kit
4. Planning
   - Current status
   - Development plans for 2011

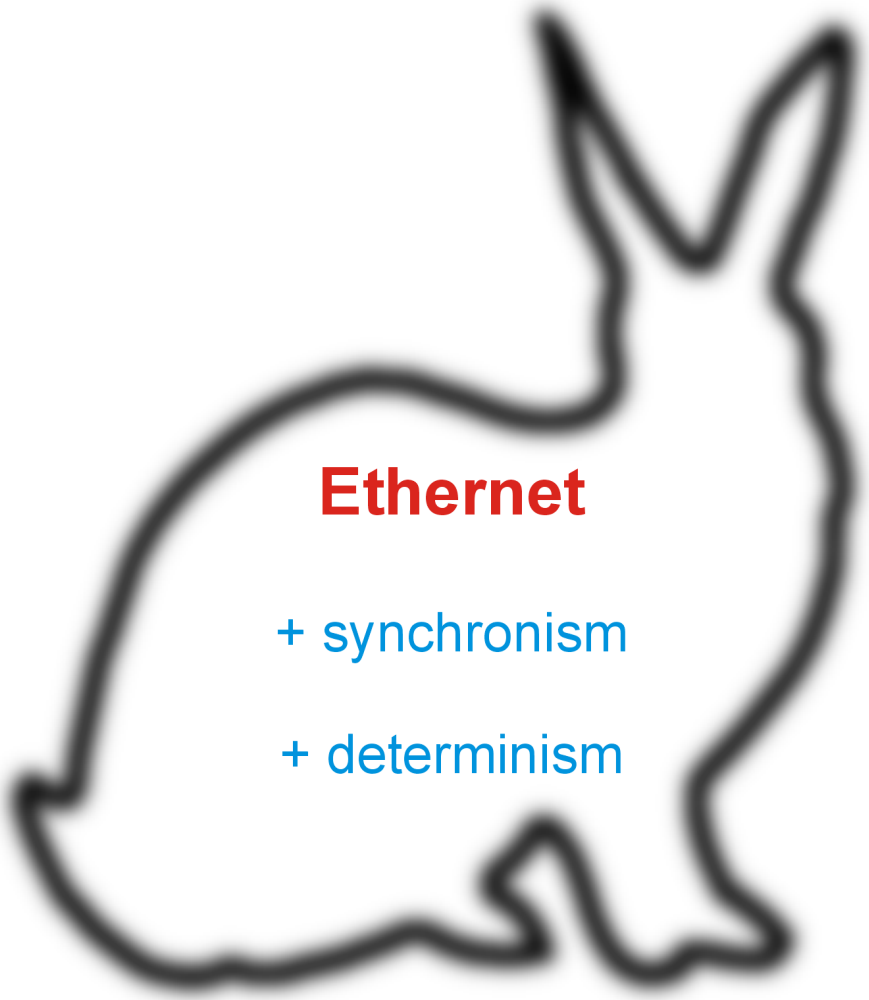
What's in a name?

Oh dear! Oh dear! I shall be too late!

Development model

- Developed in the frame of CERN's (and GSI's) renovation projects.
- Open source design done in collaboration with industry.
- Commercial production and support.

What is White Rabbit?



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.

Precision

1 ns time synchronization accuracy, 20 ps jitter.

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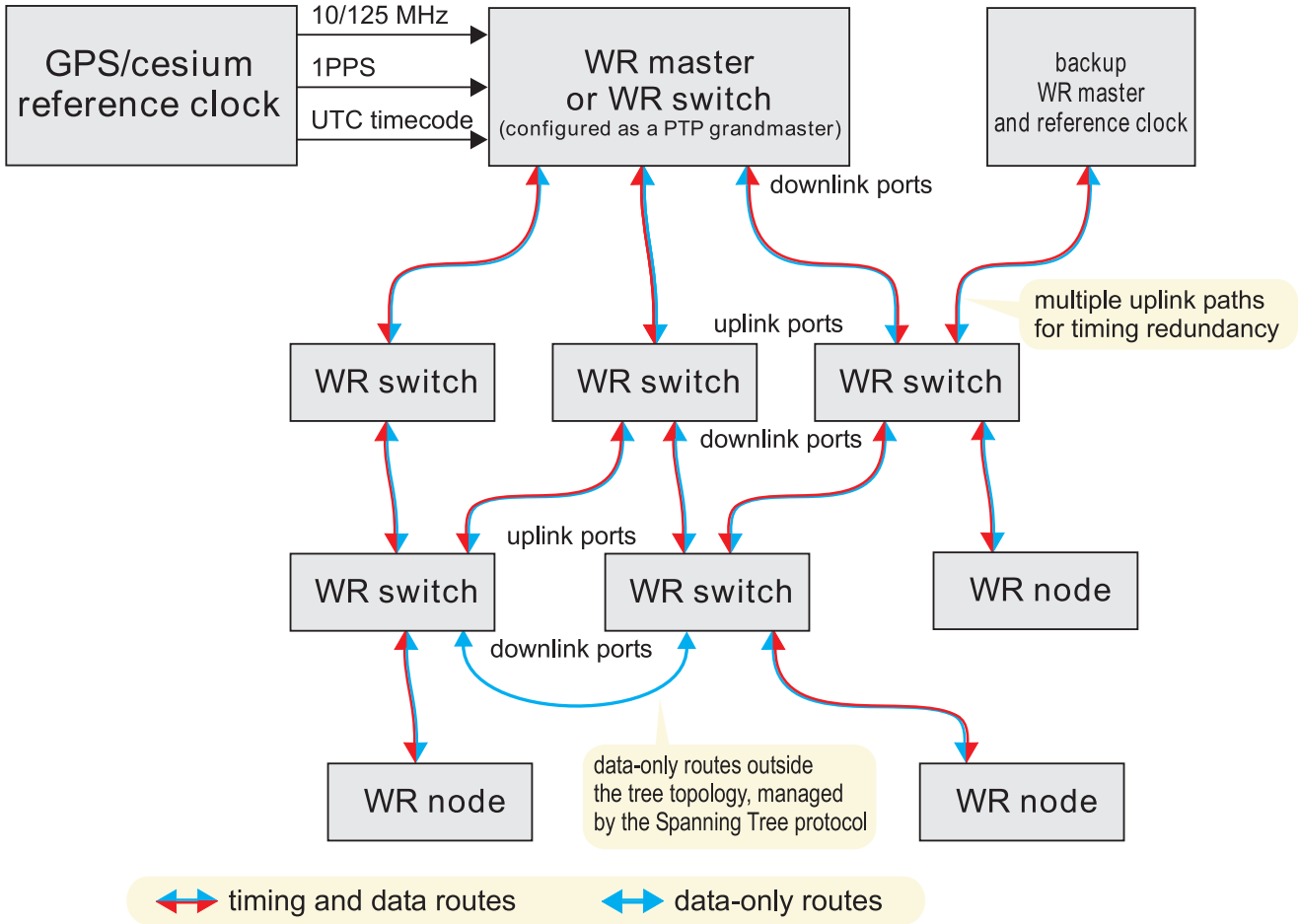
Technologies used in White Rabbit

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

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

Network topology



PTP Protocol (IEEE1588)

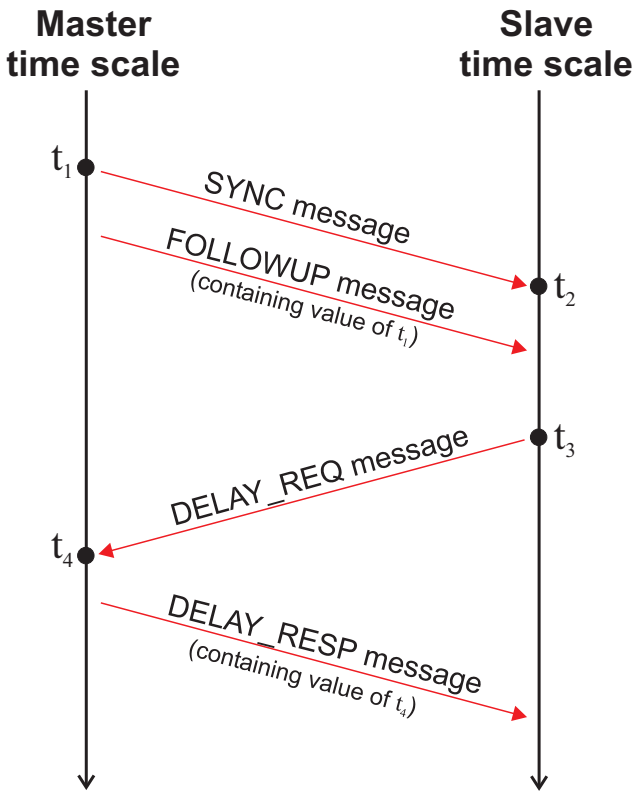
PTP

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.

PTP Protocol (IEEE1588)



Having values of $t_1 \ldots t_4$, slave can:

- calculate one-way link delay: $\delta_{ms} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$
- syntonize its clock rate with the master by tracking the value of $t_2 - t_1$
- compute clock offset: $offset = t_2 - t_1 + \delta_{ms}$

Disadvantages of traditional PTP

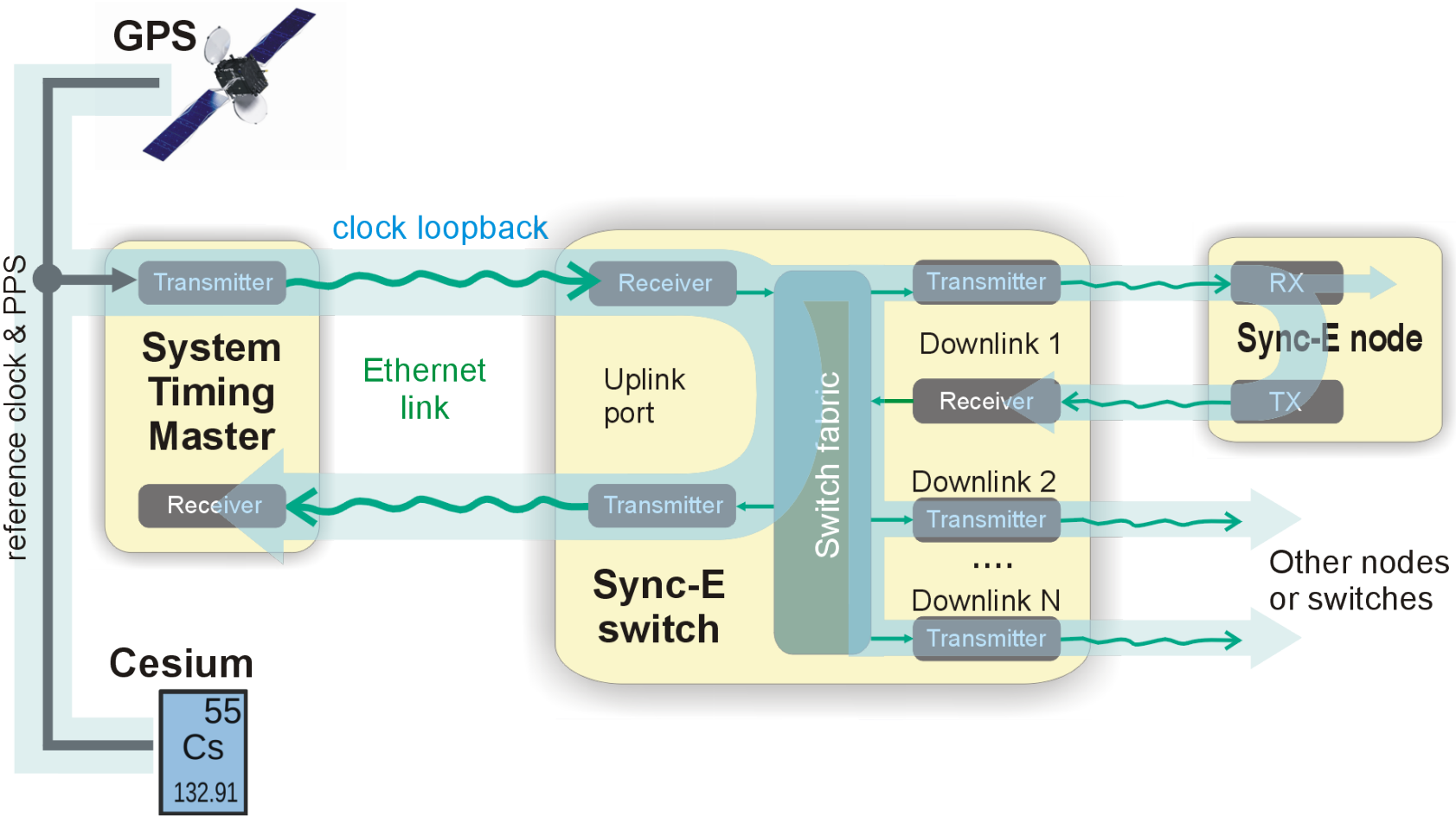
- All nodes have free-running oscillators.
- Frequency drift has to be continously compensated, causing lots of network traffic.
- That doesn't go well with determinism...

Synchronous Ethernet

Common clock for the entire network

- 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.

Synchronous Ethernet



Phase tracking

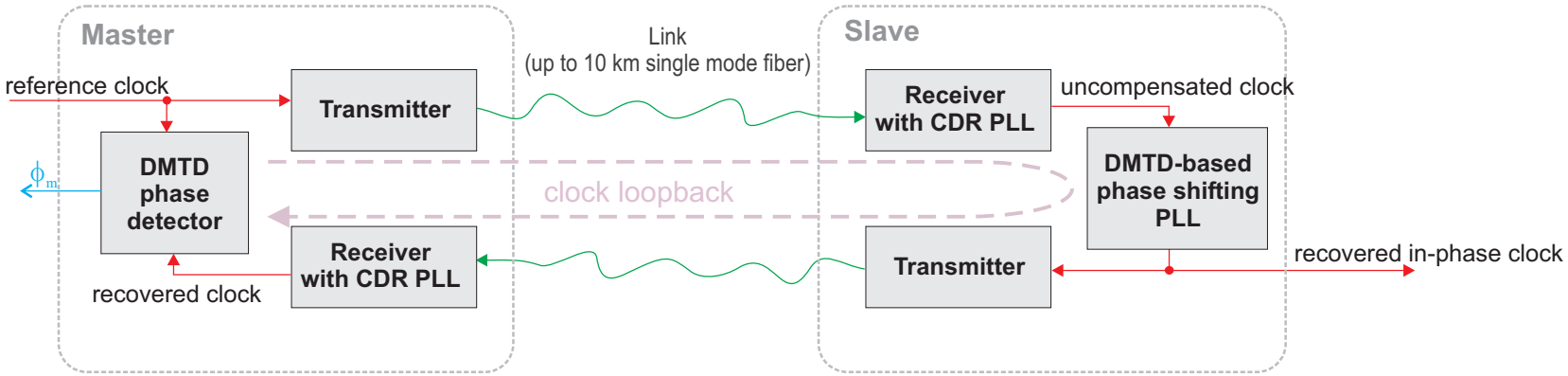
Plain PTP

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 Synchronous Ethernet.

Phase tracking



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

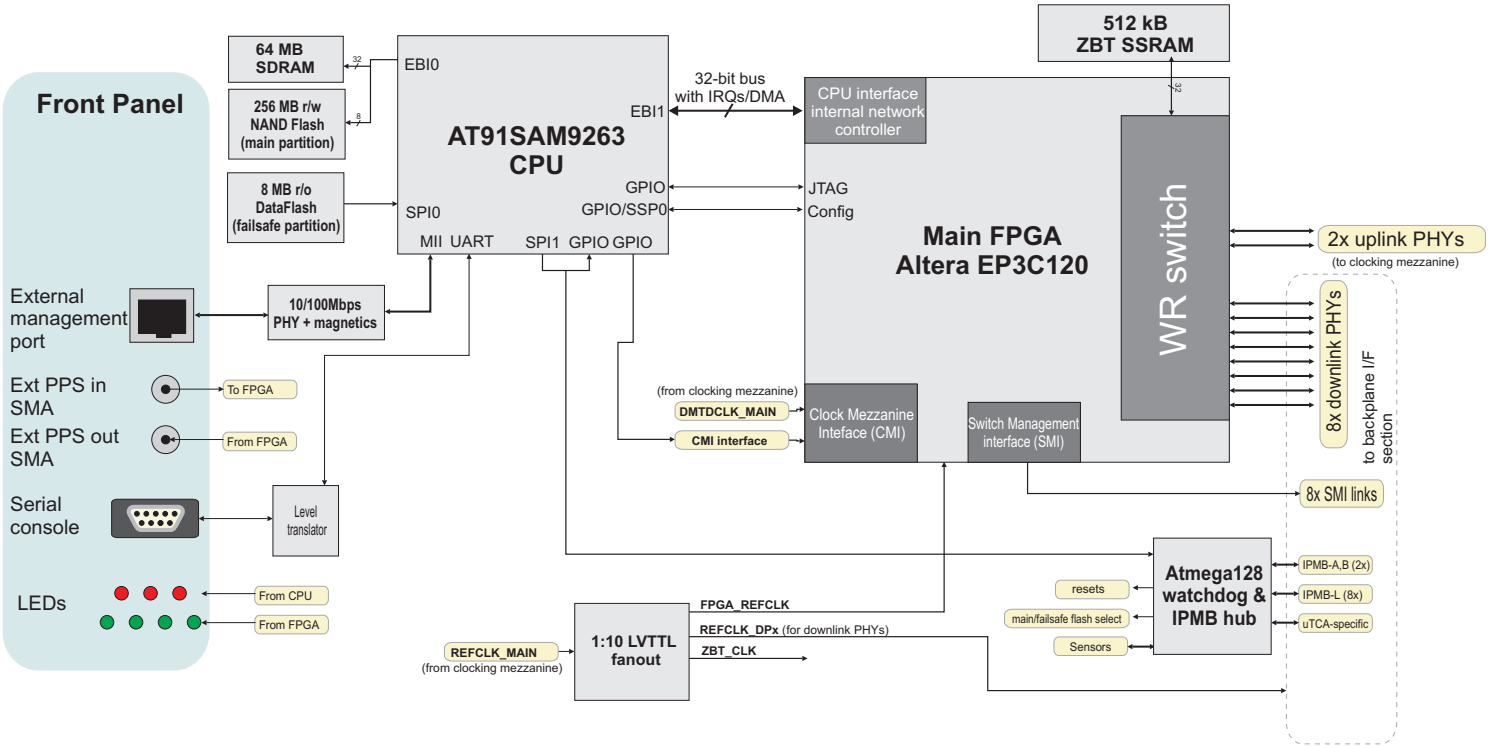
White Rabbit Switch

- Central element of WR network.
- Fully custom design, designed from scratch.
- 10 1000Base-LX ports, capable of driving 10 km of SM fiber.
- 200 ps synchronization accuracy.

White Rabbit Switch

- Designed in microTCA MCH (Management Carrier Hub) format.
- Multi-PCB design: base board with main big FPGA and CPU and Clocking Mezzanine, which handles the timing.
- Can work in standalone mode (without a microTCA crate) via mini-backplane.

Switch block diagram - main part



- System FPGA handles all packet processing.
- CPU implements PTP stack and management functions (SNMP, Spanning Tree).

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Possible applications of White Rabbit

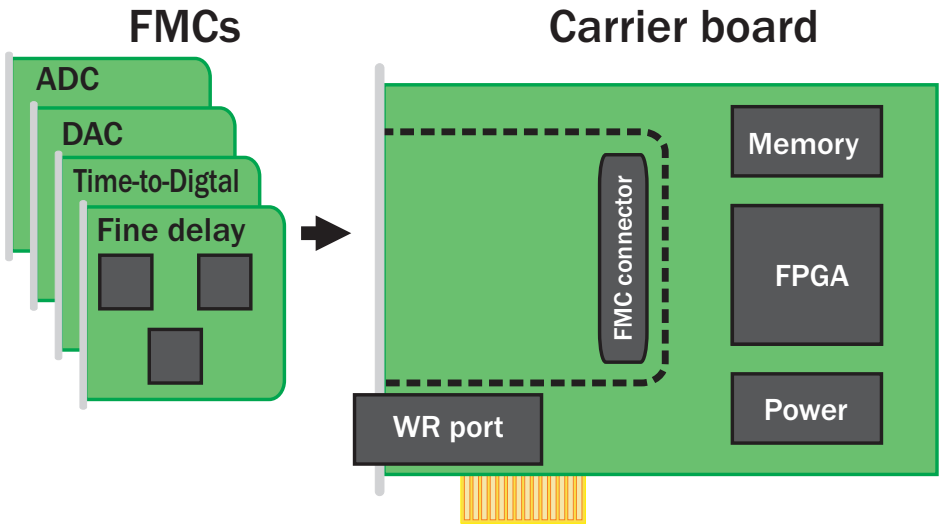
Large-scale data acquisition systems

Precise time tagging

Clock & trigger distribution

Robust event delivery

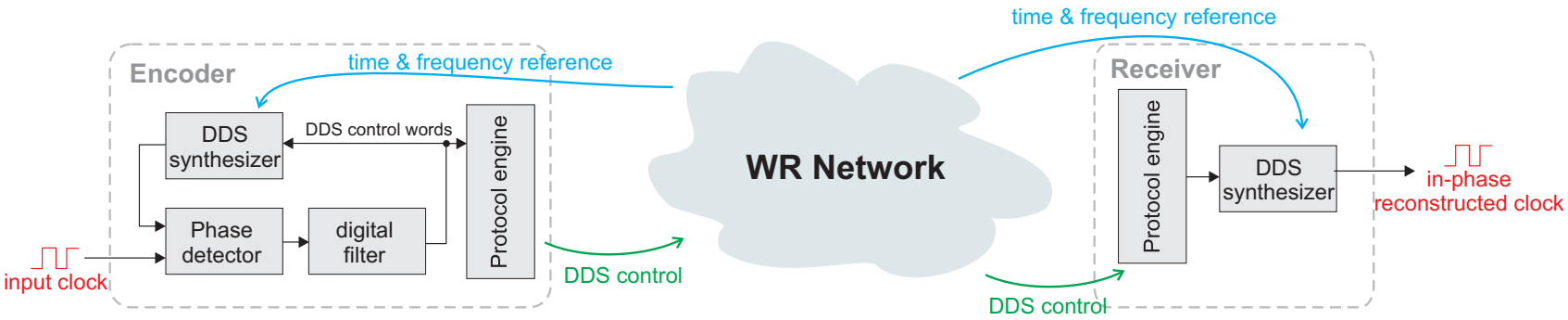
WR in CERN's BE-CO-HT Hardware Kit



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.

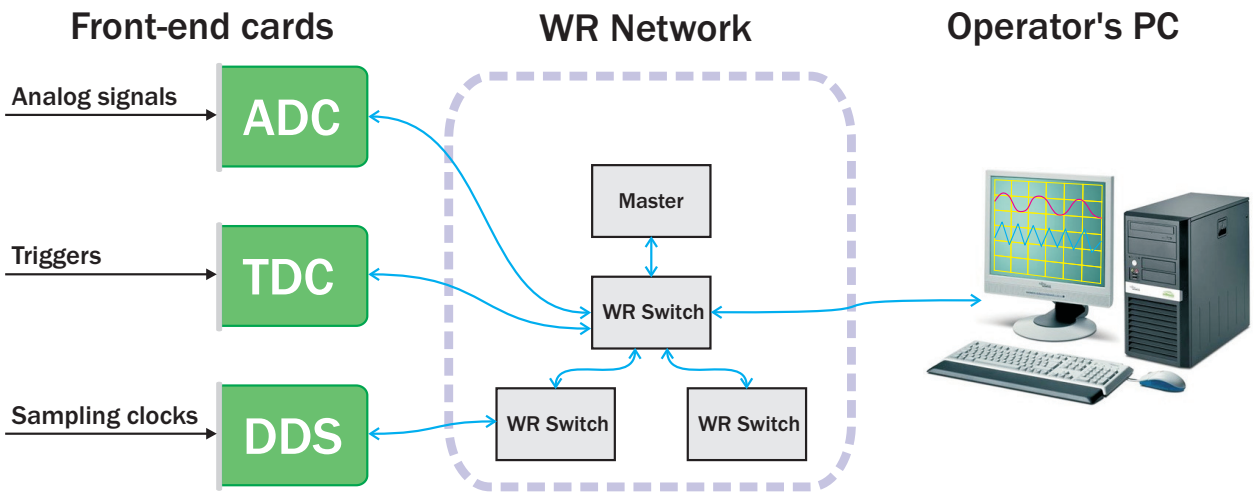
Ethernet Clock distribution a.k.a. Distributed DDS



Distributed Direct Digital Synthesis

- Replaces dozens of cables with a single fiber.
- Works over big distances without degrading signal quality.
- Can provide various clocks (TTC, RF, bunch clock) with a single, standarized link.

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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WR Switch development status

Switch hardware

- Working and debugged V2 hardware prototype.
- Tested on 10-km fiber links.
- Interoperates with standard Ethernet gear.

Switch software

- Done the Hardware Abstraction Layer and PTP daemon.
- Sub-nanosecond accuracy over PTP has been achieved.
- Verified interoperability with other PTP devices on ISPCS 2010 Plug Fest.

Already achieved...

According to ISPCS Plug Fest results ...

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

Foreseen milestones

WR Switch

- Full basic functionality of HDL and software already achieved, code cleanup foreseen during Q1 2011.
- V3 prototype: Q3 2011.
- Commercial product: Q1 2012.

WR Ecosystem

- FMC Carriers: VME and PCIe prototypes done, moving to rev 2 Q2 2011.
- WR timing node in VME and PCIe: commercially available Q2 2012.
- Mezzanines: Full set of cards available Q4 2011.

Summary

- A data link fulfilling all our needs in **synchronization** and **determinism**.
- A successful **collaboration** including institutes and companies.
- Full system commercially available **mid-2012**.

For more information, visit
http://www.ohwr.org/projects/white-rabbit/wiki