Array Time Synchronization -
First Tests with WhiteRabbit

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Outline

> Array Time Synchronization for large distributed arrays
  ▪ A generic job, for expt’s like CTA, HiSCORE, KM3Net, LHAASO, AUGER-Next, …
  ▪ Can we avoid custom solutions

> WhiteRabbit for Time Synchronization
  ▪ Synchronization & TimeStamping – WRabbit features & architecturs
  ▪ WRabbit is HiSCORE’s top candidate; final verification planned for summer 2012
  ▪ CTA would easily fit

> First Tests of WR-performance
  ▪ Results Lab- and field-tests

> Summary
Array Time Synchronization: The Task

> Time Synchronization of large distributed arrays
  - Experiments like HiSCORE (10km²), CTA (few km²), KM3Net, AUGERnext, LHAASO
  - Independent detector units (e.g., Cameras, PMT-DAQ-stations, Particle-Detectors)
  - They generate a “local trigger” - this needs to be time-stamped

> Two Tasks:

  (1) **Synchronize clocks in all detector units** to a common central clock with nsec precision;
      Focus: relative timing between detector units must be correct at any moment (not absolute time)

  (2) **Must verify timing precision: long-term monitor / control in-situ**, for at least a subset of the array.
      Verification by an independent system is as important as the synchronization; and a comparable in technical challenge

> White Rabbit

  - An excellent candidate
  - In reality: a system (still) under development; verification is needed
White Rabbit – a new CERN-based extension to Ethernet for:

- Synchronous mode (clock synchronization)
- Deterministic routing (package latency guaranteed)
- \(\sim 1\) ns precision, 20 ps jitter
- 10 km fiber links
- Up to 2000 nodes

- Development for CERN & GSI accelerator complex; much external interest
- Open Hardware Project with peer review (ie. open for extensions)
- Hardware is commercially available
- Standardization planned (IEEE…)
- A guaranteed large user community: will be well debugged
For concept + details, see eg:
Cern-WR-site  http://www.ohwr.org/projects/white-rabbit/wiki ;
(also http://znwiki3.ifh.de/TUNKA/ )
Basic Layout of a WhiteRabbit based timing DAQ

White Rabbit DAQ architecture:

(1) A WR-network
   >=1 WRSwitch + GPS/RbCl

(2) Many WR-Nodes (‘endpoints’)
    for time-stamping

Components
- WhiteRabbit Switches (WRS)
- White-Rabbit Nodes
  eg. SPEC (Simple PCIe FMC Carrier)
  (or build your own board: OWHR)

from June/2012
available
The White-Rabbit SPEC Card

- SPEC (“Simple PCIe FMC Carrier”) is the WR node currently available.
- For tests, it can also be configured as WR-Master.
- It carries the mezzanine-card for your DAQ:
  available/planned
    - Digital InpOutFMC / FMC DEL / FMC FADC(100MHz) / TDC;
    - eg. possible: design a DRS4-based mezzanine for HiSCORE/CTA
The *fmc-dio-5chttl* 5-channel digital I/O module is a simple board for digital I/O on LEMO connectors. It has been designed for testing White Rabbit functionality as part of the SPEC Demonstration Package for White Rabbit (*manual*), and it can be used for other applications too.

### Functional Specifications

- 5 input/output ports (Lemo 00 connectors)
- Output levels: LVTTL, capable of driving +3.3 V over a 50-Ohm load. At power-up the outputs should be in Hi-Z state
- Input levels: any logic standard from $V_{IH} = 1 \text{ V}$ to $V_{IH} = 5 \text{ V}$ (programmable threshold)
- Output Rise/fall times: max. 2 ns
- Input bandwidth: min. 200 MHz
- Programmable 50-Ohm input termination in each channel
- LVDS I/O on the carrier side
- One of the inputs shall be capable of driving a global clock net in the carrier's FPGA
- Inputs need to be protected against $+15\text{ V}$ pulses with a pulse width of at least 10μs @ 50Hz (with protection diodes if possible)
- Withstands a continuous short-circuit on all the outputs at the same time
Example Layout for HiSCORE (CTA)

HiSCORE / EA :  20-40 DAQ-Stations
CTA :  50-100 Telescopes

> Array center:
  WR-switches (18 x out) - with N=4  \(\rightarrow\) 67 Stations / Telescopes
  (+ central GPS; or Rub.Clock)
> Dedicated SM-fiber to every Station / Telescope
> Every Station / Telescope houses 1 WR-SPEC time-latching unit

> Price:  \(O(1300\text{Eur}) \text{ per station}\)
  = 1100 (SPEC+DIO) + 1/17 \times 3500 (WRS)
  (very conservative)
HiSCORE: DAQ Station + White Rabbit

Plan: Radio / FO for verification of timing

(still under development)
Other WR-application proposals:

- LHAASO: ~10000 nodes to synchronize

Design study
G.Gong, ICALEPCS, 2011.
Use the WR-link for

1. nsec-timing, and
2. Array-trigger request/confirm messages (1Gbs) with guaranteed latency.

Here, we considered just the baseline functionality: Time-stamping of Camera trigger. There are many more options, including development of CTA-WR boards; which could integrate FE/DAQ components with WR-cores. E.g.: a WR-Mezzanine with DRS4 (or NecTar).
Test Setup + Results

> Setup:

- 2 WR-SPECs: Master-Slave WR-link + 50m SM
- Time tests: comparing the master/slave 1-PPS output
- Setup emulates the basic element: WRS+SPEC

Not sensitive to (1) fluctuations at <<1sec scale, and (2) clocks in neighbouring nodes

> Result: TimeDiff (Master-Slave) rms < 0.2 ns !!

(reaching DT-measurement)

rms ~0.17ns
> Field tests at Tunka/HiSCORE site
  - April 2012: use DESY-Lab-setup
  - use the real 1+1 km Tunka-fibers

> Confirmed Lab-result: $\text{rms} < 0.2 \text{ ns}$
  - Routine operation/tests in summer 2012; slow drifts (temperature?), external noise. Like any in-situ verification of a new system.

$\text{rms} \approx 0.17 \text{ ns}!$ (+slow drift)
Summary

> First Tests of basic White Rabbit elements are very encouraging:
  - <0.2ns longterm stability is possible.
  - Next step: realistic setup WRS + 2-3 nodes

> White Rabbit is a realistic candidate as time-synchronization system in new APP projects.
  - WR: will be the HiSCORE / EA timing system
  - HiSCORE prototype, starting Oct.2012, can serve as reference system
  - Applications in current experiments is realistic and would be helpful (eg. backup-timing)

> Advantages, that make WR a top candidate for CTA:
  - A real standard, commercial support, synergies with other users (!)
  - Opens source, adaptable to specific needs
  - Reliability, easy maintenance, cost effective, scalability, field-applicable

> With its commitment to HiSCORE WR-DAQ, DESY is currently investigating a related CTA initiative. Any collaborators: very welcome !!
> Thanks.