Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary

Introduction to White Rabbit

Greg Daniluk, Maciej Lipiński

CERN BE-CO Hardware and Timing section

BE seminar 15 November 2019 Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary on Outline



- 2 Technology
- 3 Equipment
- 4 Management
- 6 Applications
- 6 Standardisation
 - Ongoing Work
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What	is Whi	te Rab	bit?				

CERN and GSI initiative for control & timing

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What	is Whi	te Rab	bit?					

- CERN and GSI initiative for control & timing
- Based on well-established standards
 - Ethernet (IEEE 802.3)
 - Bridged Local Area Network (IEEE 802.1Q)
 - Precision Time Protocol (IEEE 1588)

What is White Rabbit?

Technology

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CERN and GSI initiative for control & timing

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Applications

- Based on well-established standards
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 - Bridged Local Area Network (IEEE 802.1Q)
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Ongoing Work

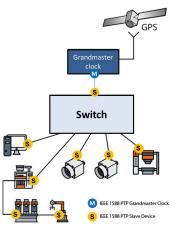
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What is White Rabbit?

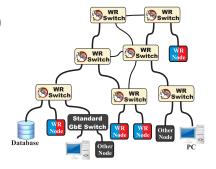
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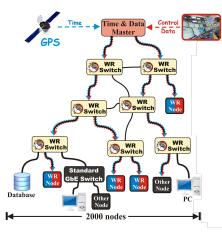
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- Extends standards to provide
 - Sub-ns synchronisation
 - Deterministic data transfer



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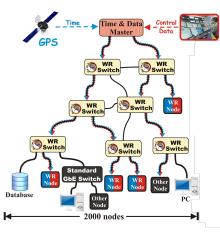
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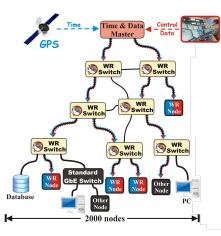
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 - Deterministic data transfer
- Initial specs: links ≤10 km & ≤2000 nodes
- Open Source and commercially available



Many users worldwide, including metrology labs...

Applications

Management

CERN and GSI

Technology

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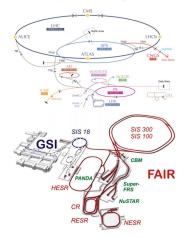
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CERN's accelerator complex

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Introduction Technology Equipment Management OCOCO Standardisation Ongoing Work Summary OCOCO Many users worldwide, including metrology labs...

CERN and GSI

• The Large High Altitude Air Shower Observatory



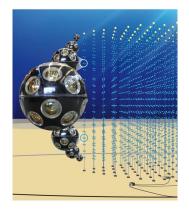
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- CERN and GSI
- The Large High Altitude Air Shower Observatory
- KM3NET: Cubic Kilometre Neutrino Telescope



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- CERN and GSI
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- German Stock Exchange



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Management

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- Mikes: Finish National Time Lab





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Institute





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See user page: http://www.ohwr.org/projects/white-rabbit/wiki/WRUsers

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White Rabbit technology - sub-ns synchronisation

Based on

- Gigabit Ethernet over fibre
- IEEE 1588 Precision Time Protocol

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White Rabbit technology - sub-ns synchronisation

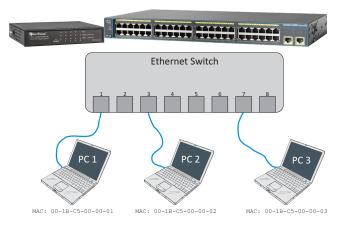
Based on

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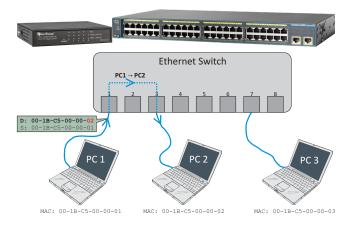
Enhanced with

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

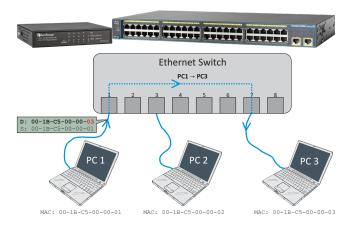
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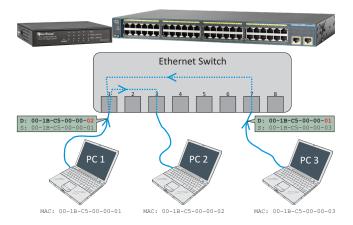
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Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary

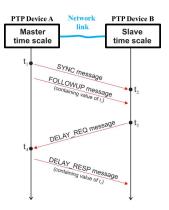


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Introduction Technology Equipment Management Applications Standardisation Ongoing Work

Precision Time Protocol (IEEE 1588)



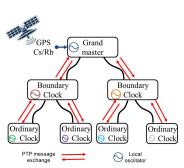
- Frame-based synchronisation protocolSimple calculations:
 - link delay: $\delta_{ms} = \frac{(t_4 t_1) (t_3 t_2)}{2}$
 - offset from master: $OFM = t_2 (t_1 + \delta_{ms})$

Summary

Precision Time Protocol (IEEE 1588)

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• Frame-based synchronisation protocol

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Simple calculations:

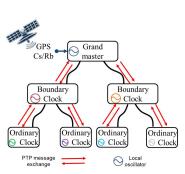
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- Hierarchical network

Precision Time Protocol (IEEE 1588)

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Simple calculations:

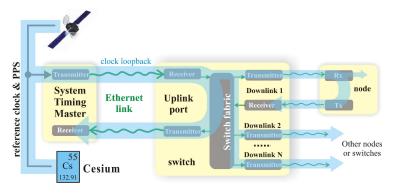
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- offset from master: $OFM = t_2 (t_1 + \delta_{ms})$
- Hierarchical network
- Shortcomings:
 - devices have free-running oscillators
 - frequency drift compensation vs. message exchange traffic
 - assumes symmetry of medium
 - timestamps resolution

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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)

Applications

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Precise phase measurements in FPGA

Management

WR parameters:

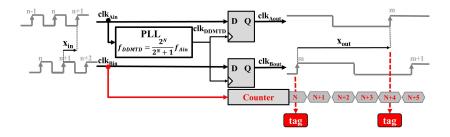
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clk_{in} = 62.5 MHz

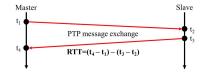
Equipment

- *clk_{DDMTD}* = 62.496185 MHz (N=14)
- *clk_{out}* = 3.814 kHz
- Theoretical resolution of 0.977 ps



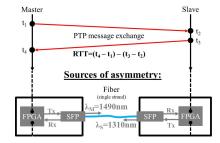
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Link d	elay m	nodel			

• Correction of RTT for asymmetries



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Link delay model								

- Correction of RTT for asymmetries
- Asymmetry sources: FPGA, PCB, SFP electrics/optics, chromatic dispersion

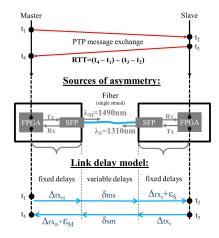


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Link delay model								

- Correction of RTT for asymmetries
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- Link delay model:
 - Fixed delays FPGA, PCB, SFP
 - Variable delays fiber:

$$\alpha = \frac{\nu_g(\lambda_s)}{\nu_g(\lambda_m)} - 1 = \frac{\delta_{ms} - \delta_{sm}}{\delta_{sm}}$$

• Calibration procedure to find fixed delays and α



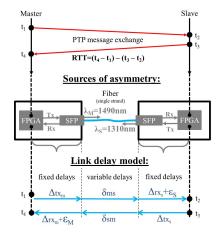
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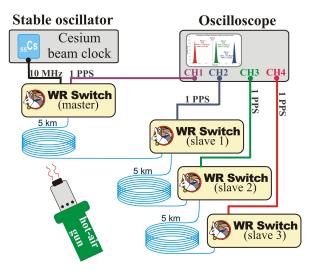
- Calibration procedure to find fixed delays and α
- Accurate offset from master (OFM):

$$\begin{split} \delta_{ms} &= \frac{1+\alpha}{2+\alpha} \left(RTT - \sum \Delta - \sum \epsilon \right) \\ OFM &= t_2 - \left(t_1 + \delta_{ms} + \Delta_{txm} + \Delta_{rxs} + \epsilon_S \right) \end{split}$$



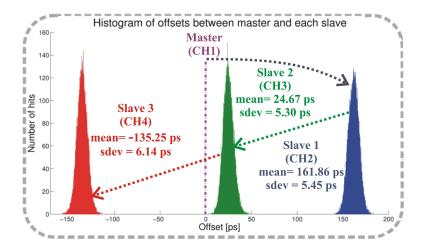
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Out-of-the-box performance



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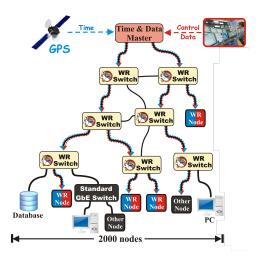
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Introduction Technology Equipment Management OCON Standardisation Ongoing Work Summary OCON Typical WR network



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WR Switch

Technology



- Central element of WR network
- 18 port gigabit Ethernet switch with WR features
- Default optical transceivers: up to 10km, single-mode fiber
- Fully open, commercially available from 4 companies

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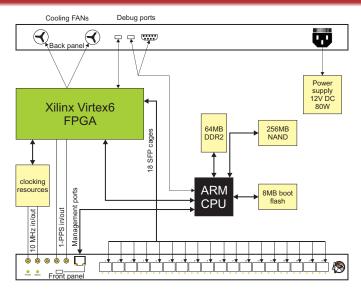
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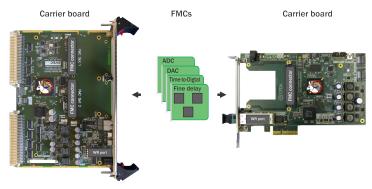
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WR Switch: hardware block diagram



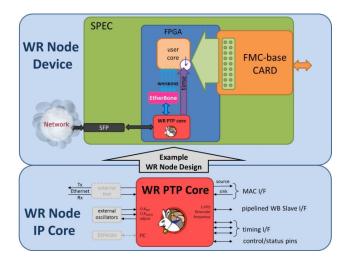
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WR Node: carriers + mezzanines



- All carrier cards are equipped with a White Rabbit port
- All carrier cards instantiate WR PTP Core
- Mezzanines can use the accurate clock signal and timecode (synchronous sampling clock, trigger time tag, ...)

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WR PTP Core								



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Open and commercially available off-the-shelf



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• White Rabbit is an extension of Ethernet



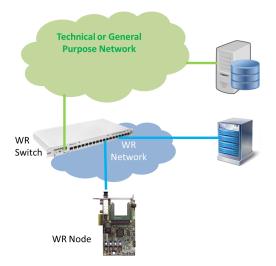
- White Rabbit is an extension of Ethernet
- It can be managed using standard protocols and tools:
 - Simple Network Management Protocol (SNMP)
 - Syslog
 - Link Layer Discovery Protocol (LLDP)
 - Kerberos-based authentication

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- White Rabbit is an extension of Ethernet
- It can be managed using standard protocols and tools:
 - Simple Network Management Protocol (SNMP)
 - Syslog
 - Link Layer Discovery Protocol (LLDP)
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- It can be debugged using standard tools:
 - Wireshark
 - Tcpdump
 - Professional Ethernet testers

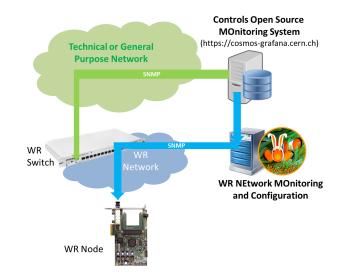
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WR Network vs. TN/GPN Network



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 BE-CO services:
 Monitoring with COSMOS/Grafana



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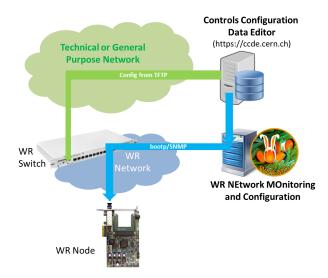
Summary

BE-CO services: Monitoring with COSMOS/Grafana

🌀 - 🗱 White Rabbit Switch - \star 🕫 🖻 💠			✓ Zoom Out > ② Last 30	minutes Refresh every 30s 🏾 🎜						
WRS Hostname All • Building All • Mode PRO •										
PRO WRS ping status by building										
Time	Building									
2018-02-27 11:25:19		ctdwa-193-cttad								
2018-02-27 11:24:03		ctdwa-sm18-ctts1								
2018-02-27 11:24:58		ctdwa-sr4-clist1								
2018-02-27 11:24:03										
2018-02-27 11:25:01										
2018-02-27 11:28:37										
2018-02-27 11:28:25										
2018-02-27 11:25:00		ctdwa-ccr-cttmaster								
V White Rabbit Switches Status										
ctdwa-193-cttad ctdwa-354-cttmaster1	ctdwa-355-cwrsps	ctdwa-ccr-clist1	ctdwa-ccr-ctnallm1	ctdwa-ccr-cttmaster						
OK Warning	ОК	ОК	ОК	ОК						
ctdwa-sm18-ctts1 ctdwa-sr4-clist1				k						

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 BE-CO services:
 Configuration with CCDE



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BE-CO services: Configuration with CCDE

Controls Configuration	Switch Configura	tion		2
Dashboard Hardware	Switch browser Switch Name	Version [HW / FW]	Basic Advanced Ports Vlans	
NXCals	Switch Name	Version [HW / FW] ~	Host name ctdwa-774-cinm1 Generate	
ー う History	ctdwa-864-clabs1	3.4 / 5.0		
III Data Browser	ctdwa-ccr-cdevallm1 ctdwa-ccr-ctnallm1	3.4/5.0.1		
62 Expert •	Cidwa-cr2-cgpnallm1 Cidwa-774-chs2 Cidwa-774-ch51 Cidwa-774-cb1 Cidwa-774-cb1 Cidwa-774-cb1 Version browser Haroware Version	34/5.0.1 34/5.0.1 34/5.0.1 34/5.0.1 4/5.0.1 4/5.0.1 4/5.0.1 Firmsare Version	Hadhalas Velsion Himalas Velsion 3.4 •) 50.1	•
	Hardware Version		ip-time-1.cem.ch be-co-tracing	
_	3.4	5.0		
jpalluel	3.4	5.0.1		
E Keyboard shortcuts	3.3	5.0.1	Additional details Computer Name Location Responsible Operational Support	
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Support			HCP Image Path HCP Server OS Operatic Diamon Layout MTF /white_rabb//config-H CS-CCR-FELAB.CE LINUX EMB () A Q Q	
C> Logout			Description	
<		v	waster test swi	*
0.3.23		+ Add new version	🗎 Remove switch 🗙 Discard changes 📑 Save sw	vitch

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BE-CO services: Configuration with CCDE

62			WR Nemo		Start	typing a name	C	2
	Data E		WR Nemo Servers Search Provide search otheria Basic DSL Ø Basic search Ø Q	WR Nodes WR Nemo Serv Computer Name CS-CCT-CWNemo	Responsible Ig1 Julien Pallu		T NETWORK M	10
	🔒 Hardware		Nemo Server 🔺 🗸 Responsible 🗸 🗸 Rack 🗸 Description 🗮	Building	Room	Rack		
			CONTROL WHITE RABBIT NETWORK MC	Provide search criter	ria			
	RBAC Edit		Cs-ccr-cwnemog2 Julien Palluel SERVER FOR CS-CCR-CWNEMOG2	Basic DSL	Basic search		0	Q
	FESA Edit					MAC Ad ~ IP Addr ~ Comput ~ M		
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	History			0		22:33:03:DF 192.168.5.1 cfc-774-cbt 55		
	 III Data Brov			0		22:33:03:6C 192:168:5.1 cfc-774-cbt 55		
				0	OASIS.TRIG	22:33:05:0E 192:168:5:1 cfv-774-cac 72	125 /	0
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			Senerate DHCPD			× Delete all selected nodes		
1			Generate DHCPD			X Delete all selected nodes	+ Add new	node

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WR applications in science and beyond

- Time & frequency transfer
- Time-based control
- Precise timestamping
- Trigger distribution
- Fixed-latency data transfer
- Radio-frequency transfer

WR applications in science and beyond

Management

Applications

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Standardisation

• Time & frequency transfer

Equipment

Time-based control

Technology

Introduction

- Precise timestamping
- Trigger distribution
- Fixed-latency data transfer
- Radio-frequency transfer

NOTE

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Summary

Selected WR applications at CERN will be detailed next week



Time & frequency transfer

• Widely used/evaluated by National Time Labs (5 countries)

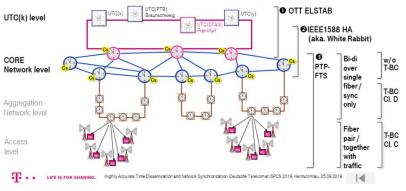


Time & frequency transfer

- Widely used/evaluated by National Time Labs (5 countries)
- Evaluated by Deutsche Telecom

High Accuracy Time Dissemination

4. Application of Time Transfer Methods and Network Sync Level

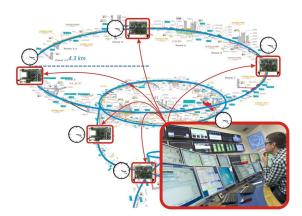


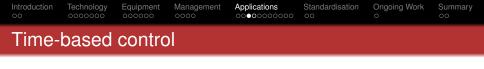
ISPCS keynote Highly Accurate Time Dissemination & Network Synchronisation, Helmut Imlau, Deutsche Telekom

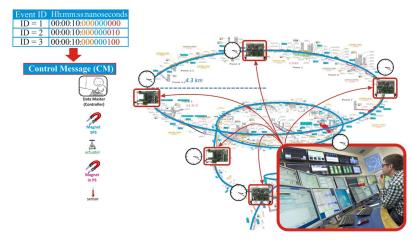
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Introduction to White Rabbit

Introduction Technology Equipment Management oco Standardisation Ongoing Work Summary oco Time-based control

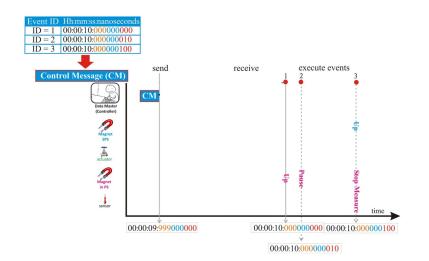




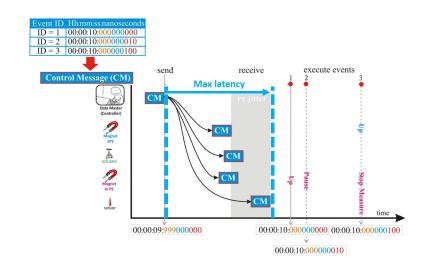


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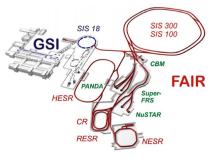




Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary 00000000000

Time-based control - example application

GSI Helmholtz Centre for Heavy Ion Research in Germany



Time-based control - example application

Applications

Standardisation

Management

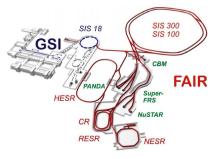
 GSI Helmholtz Centre for Heavy Ion Research in Germany

Equipment

Introduction

Technology

1-5 ns accuracy and 10 ps precision



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Time-based control - example application

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Applications

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Standardisation

 GSI Helmholtz Centre for Heavy Ion Research in Germany

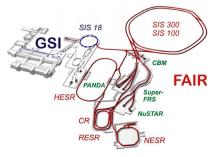
Equipment

- 1-5 ns accuracy and 10 ps precision
- WR network at GSI:

Technology

Introduction

- Operational since June 2018: 134 nodes & 32 switches
- Final: 2000 WR nodes & 300 switches in 5 layers



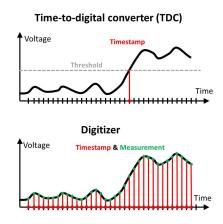
Ongoing Work

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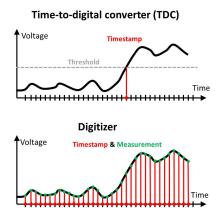
Association of time with

- an event
- a sample (measured value)





- Association of time with
 - an event
 - a sample (measured value)
- The most widely used WR application



Introduction	Technology	Equipment	Management	Applications		Ongoing Work	Summary 00			
Precis	Precise timestamping									

Association of time with

- an event
- a sample (measured value)

• The most widely used WR application

• Time-of-flight measurement

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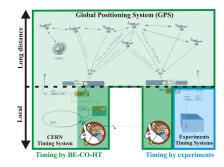
Precise timestamping

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 - Speed of neutrinos CNGS



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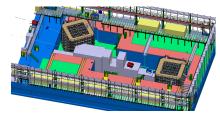
Precise timestamping

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 - Types of particles ProtoDUNE



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Association of time with

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- Time-of-flight measurement
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 - Types of particles ProtoDUNE
- Cosmic ray and neutrino detection

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 - Large High Altitude Air Shower Observatory



Technology

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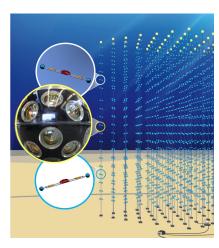
Standardisation

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Precise timestamping

- Association of time with
 - an event
 - a sample (measured value)
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 - Cubic Kilometre Neutrino Telescope



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Precise timestamping

Association of time with

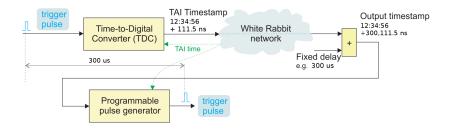
- an event
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- Time-of-flight measurement
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 - Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy
- High Frequency Trade monitoring
 - German Stock Exchange



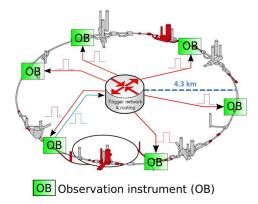
Introduction Technology Equipment Management OCOCO Standardisation Ongoing Work Summary OCOCO Trigger distribution



Introduction Technology Equipment Management OCON Standardisation Ongoing Work Summary

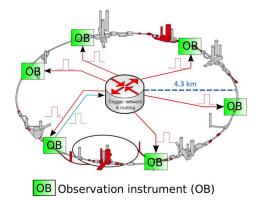
Trigger distribution - example applications

LHC trigger distribution to measure beam instabilities - since 2016



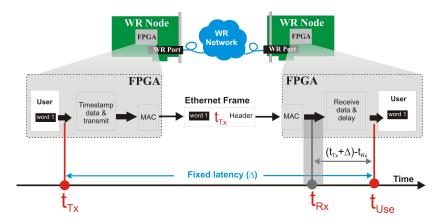
Trigger distribution - example applications

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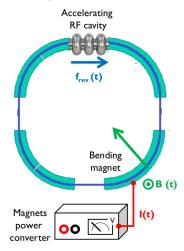
WRTD - White Rabbit Trigger Distribution- to be used for CERN's Open Analog Signals Information System (OASIS) Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary

Fixed-latency data transfer



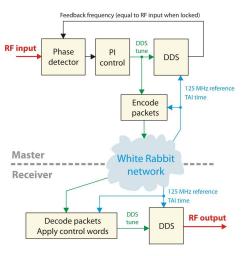


Distribution of magnetic field in CERN accelerators



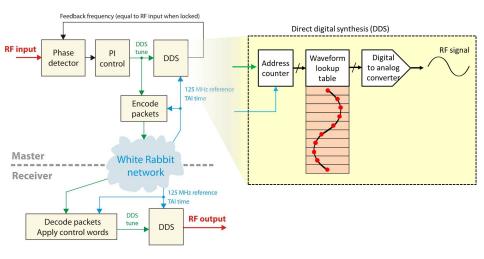


Radio-frequency transfer



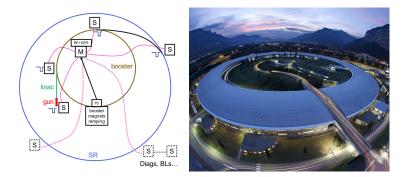


Radio-frequency transfer



Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary

Radio-frequency transfer - example application



- RF over WR at European Synchrotron Radiation Facility (ESRF)
 - A prototype tested in operation: <10 ps jitter</p>
- RF over WR at CERN
 - A prototype: <100 fs jitter and <10 ps reproducibility over reboots

Introduction	Technology	Equipment	Management	Applications	Standardisation	Ongoing Work	Summary 00
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 WR standardisation in IEEE 1588 (1)

IEEE standards are revised periodically



Introduction Technology Equipment Management OCON Standardisation Ongoing Work Summary

- IEEE standards are revised periodically
- IEEE 1588 revision started in 2013 & targeted "...support for synchronisation to better than 1 nanosecond"



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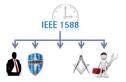
IEEE standards are revised periodically

Equipment

Introduction

Technology

- IEEE 1588 revision started in 2013 & targeted "...support for synchronisation to better than 1 nanosecond"
- Working Group with 5 sub-committees



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IEEE standards are revised periodically

Equipment

- IEEE 1588 revision started in 2013 & targeted "...support for synchronisation to better than 1 nanosecond"
- Working Group with 5 sub-committees
- High Accuracy sub-committee
 - Focus on White Rabbit

Introduction

Technology

- Experts from industry and academia
- Division of WR into self-contained parts
- Definition of Optional Features and PTP Profile that allow WR-like implementation and WR performance



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IEEE standards are revised periodically

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Introduction

Technology

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- Division of WR into self-contained parts
- Definition of Optional Features and PTP Profile that allow WR-like implementation and WR performance
- Revised IEEE 1588 approved on 7 Nov 2019



Ongoing Work

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WR standardisation in IEEE 1588 (2)



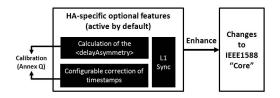
White Rabbit integration into IEEE 1588 as High Accuracy: https://www.ohwr.org/projects/wr-std/wiki/wrin1588 Introduction Technology Equipment Management Operations Standardisation Ongoing Work Summary Operations Standardisation in IEEE 1588 (2)



White Rabbit integration into IEEE 1588 as High Accuracy:

Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary oo

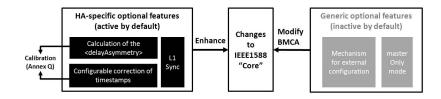
WR standardisation in IEEE 1588 (2)



White Rabbit integration into IEEE 1588 as High Accuracy:

Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary oo

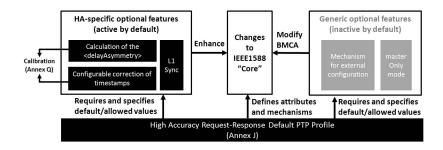
WR standardisation in IEEE 1588 (2)



White Rabbit integration into IEEE 1588 as High Accuracy:

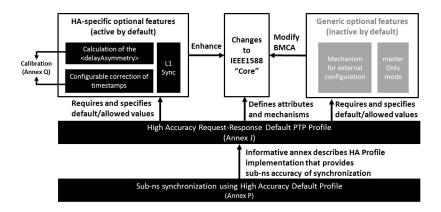
Introduction Technology Equipment Management Applications Standardisation Ongoing Work Summary of

WR standardisation in IEEE 1588 (2)



White Rabbit integration into IEEE 1588 as High Accuracy:

WR standardisation in IEEE 1588 (2)



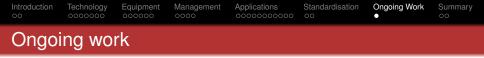
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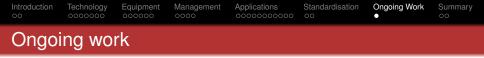
Greg Daniluk, Maciej Lipiński Introduction to White Rabbit

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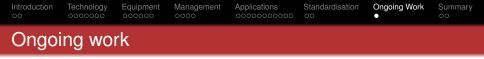
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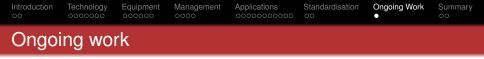
• Improve accuracy (<10 ps) and jitter (<100 fs)



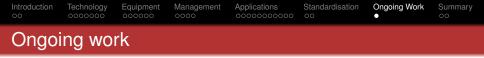
- Improve accuracy (<10 ps) and jitter (<100 fs)
- White Rabbit over 10 Gb Ethernet



- Improve accuracy (<10 ps) and jitter (<100 fs)
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- New WR Switch hardware



- Improve accuracy (<10 ps) and jitter (<100 fs)
- White Rabbit over 10 Gb Ethernet
- New WR Switch hardware
- WR PTP Core support for new FPGA families



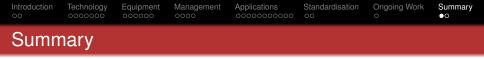
- Improve accuracy (<10 ps) and jitter (<100 fs)
- White Rabbit over 10 Gb Ethernet
- New WR Switch hardware
- WR PTP Core support for new FPGA families
- Support for building WR applications (next week BE seminar)

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Introduction	Technology	Equipment	Management	Applications	Standardisation	Ongoing Work o	Summary ●○
Summ	nary						

Ethernet-based synchronization



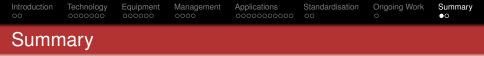
- Ethernet-based synchronization
- <1 ns accuracy and <10 ps precision out-of-the-box



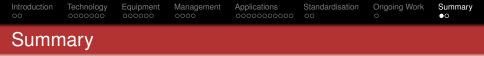
- Ethernet-based synchronization
- <1 ns accuracy and <10 ps precision out-of-the-box
- Sub-10 ps accuracy and sub-100 fs precision achievable



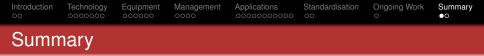
- Ethernet-based synchronization
- I ns accuracy and <10 ps precision out-of-the-box</p>
- Sub-10 ps accuracy and sub-100 fs precision achievable
- Open with commercial support



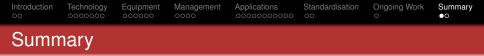
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- Standard-based and standard-extending



- Ethernet-based synchronization
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- Included in the revised IEEE 1588



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- Open with commercial support
- Standard-based and standard-extending
- Included in the revised IEEE 1588
- A versatile solution for general control and data acquisition



- Ethernet-based synchronization
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- Sub-10 ps accuracy and sub-100 fs precision achievable
- Open with commercial support
- Standard-based and standard-extending
- Included in the revised IEEE 1588
- A versatile solution for general control and data acquisition
- Showcase of technology transfer

Introduction	Technology	Equipment	Management	Applications	Ongoing Work	Summary ○●	
084							



Questions?

WR Project page: http://www.ohwr.org/projects/white-rabbit/wiki

WR Performance in Long Chain o	WR Performance Improvements	WR networks at CERN O	Determinism in WR
Backup slides			

Backup slides

WR Performance	in Long Chain	

WR networks at CERN

Determinism in WR

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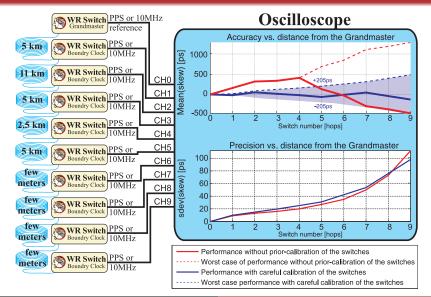
10 WR Performance Improvements





WR networks at CERN o Determinism in WR

WR performance in a long chain



WR networks at CERN o Determinism in WR

Outline









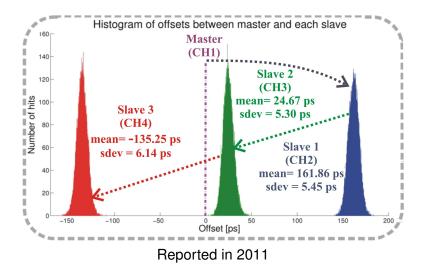
WR Performance in Long Chain \circ

WR Performance Improvements

WR networks at CERN

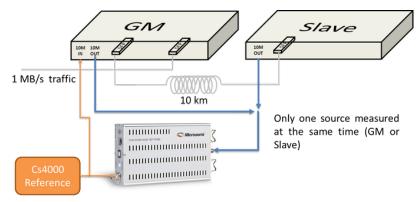
Determinism in WR

Time transfer: out-of-the-box



WR Performance in Long Chain o	WR Performance Improvements	WR networks at CERN $^{\circ}$	Determinism in WR

Frequency transfer: out-of-the-box and improved

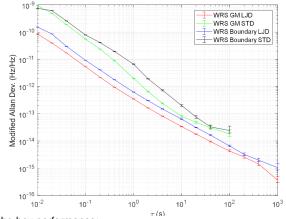


Measurement device: Microsemi/Microchip 3120A Phase Noise Test Probe

WR networks at CERN

Determinism in WR

Frequency transfer: out-of-the-box and improved

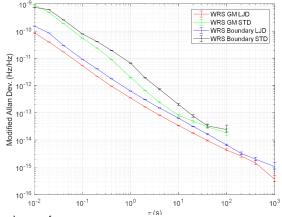


- Out-of-the-box performance:
 - GM-in to GM-out: jitter of 9 ps RMS 1 Hz–100 kHz and MDEV of 2E-12 τ =1 s ENBW 50 Hz
 - GM-in to Slave-out: jitter of 11 ps RMS 1 Hz–100 kHz and MDEV of 4E-12 τ=1 s ENBW 50 Hz

WR networks at CERN

Determinism in WR

Frequency transfer: out-of-the-box and improved

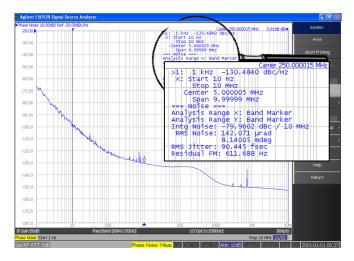


- Out-of-the-box performance:
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 - GM-in to Slave-out: jitter of 11 ps RMS 1 Hz–100 kHz and MDEV of 4E-12 τ=1 s ENBW 50 Hz
- WR Switches improved with Low Jitter Daughterboard (LJD):
 - GM-in to GM-out: jitter of 1 ps RMS 1 Hz-100 kHz and MDEV of <5E-13 τ=1 s ENBW 50 Hz</p>
 - **GM-in to Slave-out**: jitter of <**2 ps** RMS 1 Hz–100 kHz and MDEV of <**7E-13** τ =1 s ENBW 50 Hz

WR networks at CERN

Determinism in WR

WR time & frequency tranfser: state of the art



- GM-out to end-node-out: accuracy of <10 ps
- GM-out to end-node-out: jitter of <100 fs RMS 10 Hz-10 MHz

WR networks at CERN

Determinism in WR

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WR Performance Improvements

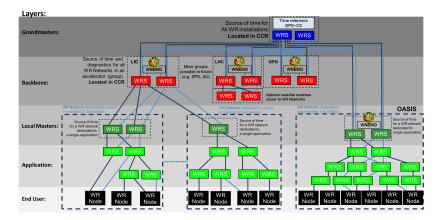




WR networks at CERN

Determinism in WR

Global WR network at CERN





WR Switch

Active fiber Ethernet link

Backup fiber Ethernet link

Copper Ethernet link

Greg Daniluk, Maciej Lipiński

Introduction to White Rabbit

WR networks at CERN o Determinism in WR

Outline



WR Performance Improvements



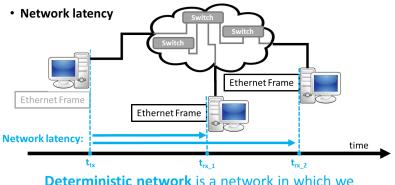


WR networks at CERN o Determinism in WR ●○○○○○

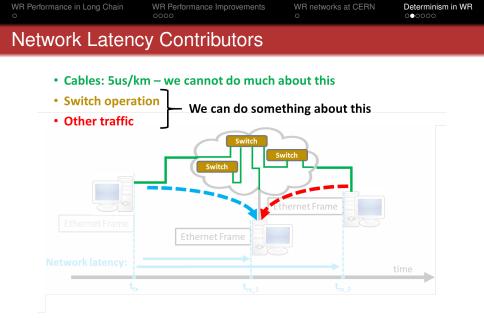
Determinism and Network Latency

• Determinism

A deterministic system is predictable: it provides calculable and consistent characteristics of operation that are required by the application, e.g. **network latency** of data transmission.



can calculate the maximum latency



WR Performance in Long Chain	WR Performance Improvements	WR networks at CERN	Determinism in WR				
o		o	○○●○○○				
Determinism in WR							

- "White Box" design of WR switch allows thorough analysis
- Backward-compatible extension of the IEEE 802.1Q std

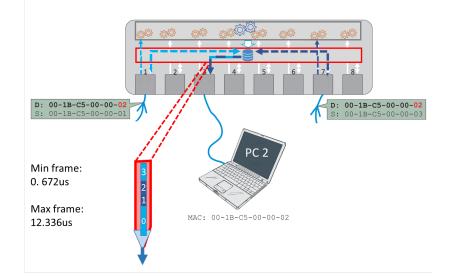
WR Performance in Long Chain $_{\rm O}$

WR Performance Improvements

WR networks at CERN

Determinism in WR

Priorities

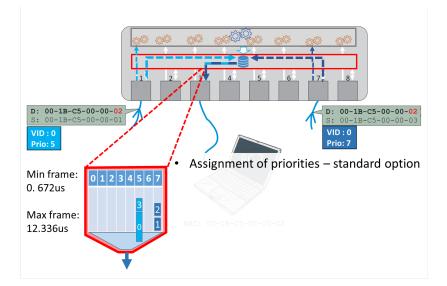


WR	Performance	Long	Chain	

WR networks at CERN

Determinism in WR

Priorities

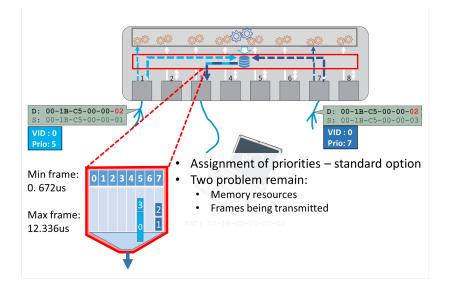


WR	Performance	Long	Chain

WR networks at CERN

Determinism in WR

Priorities



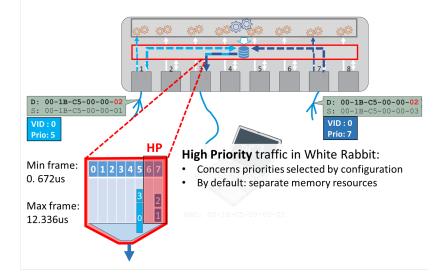
WR Performance in Long Chain o

WR Performance Improvements

WR networks at CERN

Determinism in WR

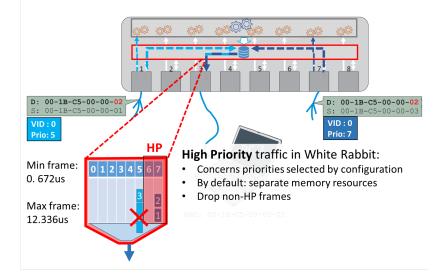
High Priority



WR networks at CERN

Determinism in WR

High Priority



--- P17 -> P11

bytes

Determinism in WR 000000

WR Switch Latency

	Center			Latend	รงโมรไ	
Fiber (5m)		Intervening traffic	One switch		Two switches	
0 1121314 516171819101	1213141151617	traffic	Max	Pk-pk	Max	Pk-pk
Deterministic stream		No	3.1	0.3	5.8	0.5
Best effort	·>	WR-PTP	5.6	2.8	8.7	3.9
stream Best effort	▶	Non-HP traffic	3.1	0.2	N/A	N/A
stream		cy for 10 streams between 4	ports			
1000		(no PTP traffic)	-	P0 -> P11 (deterministic))	
		1		P5 -> P0 P5 -> P11		
100 E	1		1	P5 -> P17 P11 -> P0		
[ratency [us]	$-/\Gamma$	N	2/1	P11 -> P5 P11 -> P17		
		/	P17 -> P0			
3.04 3.04 3.05 3.04 3 2.88 2.89 3.04 3.04 2.9 2.88						

50

256 512

10 20 30 40 50

128

10 20 30 40 50 %

1024