Determinism in White Rabbit Network

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Hardware and Timing Section, CERN

WR Tutorial Workshop at ICALEPCS2017
Barcelona, 7 October 2017
Agenda

• Determinism and Network Latency - defined
• Why Would You Need a Deterministic Network?
• Network Latency Contributors
• Latency in WR Switch
• Optional/advanced
  • Concept of VLANs
  • Details of WR Switch Operation
  • Fast Forward
  • Standard Priorities
  • High Priority (experimental)
• Latency Performance of WR Switch
• Demo
• Summary
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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.
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.

• **Network latency**

![Diagram showing network latency and timing](image)
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.

• **Network latency**

**Deterministic network** is a network in which we can calculate the maximum latency.
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Why would you need deterministic network?

• Scheduling events to happen in near future
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- Scheduling events to happen in near future

<table>
<thead>
<tr>
<th>Event ID</th>
<th>Hh:mm:ss:nanoseconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID = 1</td>
<td>00:00:10:0000000000</td>
</tr>
<tr>
<td>ID = 2</td>
<td>00:00:10:0000000010</td>
</tr>
<tr>
<td>ID = 3</td>
<td>00:00:10:000000100</td>
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</tbody>
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Why would you need deterministic network?

- Scheduling events to happen in near future

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</tr>
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<td>ID = 3</td>
<td>00:00:10:000000100</td>
</tr>
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</table>

Control Message (CM)
Why would you need deterministic network?

- Scheduling events to happen in near future
- Trigger distribution

Max latency
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Network latency contributors

(WR) Ethernet Local Area Network

Network latency: 

- $t_{tx}$
- $t_{rx_1}$
- $t_{rx_2}$

Time
Network latency contributors

Network latency:

\( t_{tx} \) \( t_{rx_1} \) \( t_{rx_2} \)

Network latency contributors
Network latency contributors

- Cables: 5us/km – we cannot do much about this
- Switch operation  
  \[ \text{We can do something about this} \]
- Other traffic

Network latency:

- Ethernet Frame
- Ethernet Frame
- Switch
- Switch
- Switch

$t_{tx}$  $t_{rx_1}$  $t_{rx_2}$

Time
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Switch in a nutshell (reminder)
Latency in WR Switch

• WR Switch is deterministic by design:
  • Open-source, each source of latency is verifiable
  • Designed with latency in mind
Latency in WR Switch

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  - Frames forwarded as soon as possible
  - Common optimization of latency in switches
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![Ethernet traffic](image-url)
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    - Any traffic with selected D-MAC addresses
    - Optimization of latency due to switch operation
    - Released feature
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  • High Priority (HP):
    • Fast Forward traffic with selected priorities
    • Optimization of latency due to non-HP traffic
    • Experimental
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- And what on Earth are priorities...?
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Concepts of Virtual LANs (VLANs)

Ethernet Frame:

- **D-MAC**: 00-1B-C5-00-00-02
- **S-MAC**: 00-1B-C5-00-00-01

PC 1
- **MAC**: 00-1B-C5-00-00-01

PC 2
- **MAC**: 00-1B-C5-00-00-02

PC 3
- **MAC**: 00-1B-C5-00-00-03
Concepts of Virtual LANs (VLANs)

Ethernet Switch

VLAN = 1

VID : 2
Prio : 1

VLAN = 2

VID : 1
Prio : 0

D: 00-1B-C5-00-00-02
S: 00-1B-C5-00-00-01

D: 00-1B-C5-00-00-01
S: 00-1B-C5-00-00-03

PC 1
MAC: 00-1B-C5-00-00-01

PC 2
MAC: 00-1B-C5-00-00-02

PC 3
MAC: 00-1B-C5-00-00-03

D-MAC S-MAC EType Payload CRC

Ethernet Frame with Q-tag:
D-MAC S-MAC Q-tag EType Payload CRC
Concepts of Virtual LANs (VLANs)

- Standard and optional extension of Ethernet Frame (IEEE802.1Q)
- Logical separation of network, no bridging between VLANs
Concepts of Virtual LANs (VLANs)
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Details of WR Switch Operation

MAC: 00-1B-C5-00-00-01
MAC: 00-1B-C5-00-00-02
MAC: 00-1B-C5-00-00-03
Details of WR Switch Operation

D: 00-1B-C5-00-00-02
S: 00-1B-C5-00-00-01

MAC: 00-1B-C5-00-00-01
MAC: 00-1B-C5-00-00-02
MAC: 00-1B-C5-00-00-03
Details of WR Switch Operation

D: 00-1B-C5-00-00-02
S: 00-1B-C5-00-00-01

D: 00-1B-C5-00-00-01
S: 00-1B-C5-00-00-03

MAC: 00-1B-C5-00-00-01
MAC: 00-1B-C5-00-00-02
MAC: 00-1B-C5-00-00-03
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D: 00-1B-C5-00-00-02
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PC 1
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S: 00-1B-C5-00-00-03

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MAC: 00-1B-C5-00-00-02

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MAC: 00-1B-C5-00-00-03
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For the traffic selected as **Fast Forward traffic**:
- The forwarding decision introduces no latency
- The forwarding decision is always “broadcast within VLAN”

The Fast Forward traffic configuration:
- By default: Broadcast, PTP & Link-Local Protocols
- Optionally configurable MAC addresses
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WR Switch Not Using Priorities

Min frame: 0.672us
Max frame: 12.336us

D: 00-1B-C5-00-00-02
S: 00-1B-C5-00-00-01

D: 00-1B-C5-00-00-02
S: 00-1B-C5-00-00-03

MAC: 00-1B-C5-00-00-02
WR Switch Using Standard Priorities

- Assignment of priorities – standard option

Min frame: 0.672us

Max frame: 12.336us
WR Switch Using Standard Priorities

- Assignment of priorities – standard option
- Two problems remain:
  - Memory resources
  - Frames being transmitted

Min frame: 0.672us
Max frame: 12.336us
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High Priority traffic in White Rabbit:
- Concerns priorities selected by configured
- By default: separate memory resources
High Priority

Traffic in White Rabbit:
- Concerns priorities selected by configured
- By default: separate memory resources
- Experimental option: drop non-HP frames

VID: 0  Prio: 5

VID: 0  Prio: 7

Min frame: 0.672us
Max frame: 12.336us
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WR Switch performance tests

WR Switch is tested with professional IT test equipment

- Generates and analyses traffic
- Used by CERN IT to verify any model of switch bought by CERN
- Used by manufacturers to verify performance and standard compline
# Latency of WR Switch for Fast Forward

<table>
<thead>
<tr>
<th>Intervening traffic</th>
<th>Latency [us]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One switch</td>
</tr>
<tr>
<td></td>
<td>Max</td>
</tr>
<tr>
<td>No</td>
<td>3.1</td>
</tr>
<tr>
<td>WR-PTP</td>
<td>5.6</td>
</tr>
<tr>
<td>Non-HP traffic</td>
<td>3.1</td>
</tr>
</tbody>
</table>

## Max latency over one and two WR switches (with PTP traffic)

- P1 → P4 (2 switches)
- P4 → P3 (2 switches)
- P4 → P1 (2 switches)
- P1 → P4 (2 switches, no PTP)
- P1 → P2 (1 switch)
- P1 → P2 (1 switch, no PTP)
Latency of WR Switch for High Priority

<table>
<thead>
<tr>
<th>Intervening traffic</th>
<th>Latency [us]</th>
<th>One switch</th>
<th>Two switches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max</td>
<td>Pk-pk</td>
<td>Max</td>
</tr>
<tr>
<td>No</td>
<td>3.1</td>
<td>0.3</td>
<td>5.8</td>
</tr>
<tr>
<td>WR-PTP</td>
<td>5.6</td>
<td>2.8</td>
<td>8.7</td>
</tr>
<tr>
<td>Non-HP traffic</td>
<td>3.1</td>
<td>0.2</td>
<td>N/A</td>
</tr>
</tbody>
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WR Switch
(High Priority traffic at prio=7, enabled dropping frames for non-HP)

<table>
<thead>
<tr>
<th>VLAN ID</th>
<th>Port 1</th>
<th>Port 2</th>
<th>Port 3</th>
<th>Port 4</th>
<th>Port 5</th>
<th>Port 6</th>
<th>Port 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Test stream</td>
<td>🟥</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>🟥</td>
</tr>
<tr>
<td>2: Background stream</td>
<td>🟢</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>🟢</td>
</tr>
</tbody>
</table>

VLAN ID: 1
Priority: 7
Frame size [bytes]: 64
Bandwidth [%]: 10

Xena traffic generator and analyser

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Port 1</th>
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<tbody>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Priority</td>
<td>0</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Frame size [bytes]</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>500</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td>Bandwidth [%]</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>

Maximum Latency [us] (over 1s)
A diagram of a WR Switch with VLAN ID and Priority settings is shown, with VLAN ID 1 representing a Test stream and VLAN ID 2 representing a Background stream. The diagram also includes parameters such as VLAN ID, Priority, Frame size, and Bandwidth, with values distributed across different ports for each parameter. A note indicates Maximum Latency [us] over 1s.
Demo

WR Switch

(High Priority traffic at prio=7, enabled dropping frames for non-HP)

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<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
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<td>0</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Frame size [bytes]</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>500</td>
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<td>1500</td>
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<td>10</td>
<td>10</td>
<td>10</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
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</table>

Background stream of 64 bytes size

64 bytes adds 0.7us

Maximum Latency [us]
(over 1s)
WR Switch
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<tr>
<td>1: Test stream</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2: Background stream</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Background stream of 500 bytes size**

**Xena traffic generator and analyser**

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<tbody>
<tr>
<td>VLAN ID</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Priority</td>
<td>0</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Frame size [bytes]</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>500</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td>Bandwidth [%]</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
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Maximum Latency [us]
(over 1s)

500 bytes adds 4.2us
WR Switch

(High Priority traffic at prio=7, enabled dropping frames for non-HP)

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<th>Port 1</th>
<th>Port 2</th>
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<th>Port 5</th>
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<th>Port 7</th>
</tr>
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<tbody>
<tr>
<td>1: Test stream</td>
<td>✔️</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2: Background stream</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✔️</td>
</tr>
</tbody>
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Parameter name | Port 1 | Port 2 | Port 3 | Port 4 | Port 5 | Port 6 | Port 7 |
<table>
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<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Priority</td>
<td>0</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Frame size [bytes]</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>500</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td>Bandwidth [%]</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Maximum Latency [us] (over 1s)

1000 bytes adds 8.2us
Demo

WR Switch
(High Priority traffic at prio=7, enabled dropping frames for non-HP)

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<th>Port 2</th>
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<th>Port 4</th>
<th>Port 5</th>
<th>Port 6</th>
<th>Port 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Test stream</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
</tr>
<tr>
<td>2: Background stream</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
<td>✋</td>
</tr>
</tbody>
</table>

Background stream of 1500 bytes size

Xena traffic generator and analyser

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Port 1</th>
<th>Port 2</th>
<th>Port 3</th>
<th>Port 4</th>
<th>Port 5</th>
<th>Port 6</th>
<th>Port 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLAN ID</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Priority</td>
<td>0</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Frame size [bytes]</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>64</td>
<td>500</td>
<td>1000</td>
<td>1500</td>
</tr>
<tr>
<td>Bandwidth [%]</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>

Maximum Latency [us] (over 1s)

1500 bytes adds 12.2us
Demo

WR Switch

(High Priority traffic at prio=7, enabled dropping frames for non-HP)

<table>
<thead>
<tr>
<th>VLAN ID</th>
<th>Port 1</th>
<th>Port 2</th>
<th>Port 3</th>
<th>Port 4</th>
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<th>Port 6</th>
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</thead>
<tbody>
<tr>
<td>1: Test stream</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

2\textsuperscript{nd} background stream of 1500 bytes size

<table>
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<tr>
<th>Parameter name</th>
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<td>64</td>
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<td>10</td>
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<td>70</td>
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<td>70</td>
</tr>
</tbody>
</table>

Maximum Latency [us] (over 1s) Two frames of 1500 bytes adds 24.3us
<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Port 1</th>
<th>Port 2</th>
<th>Port 3</th>
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<td>70</td>
<td>70</td>
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<td>70</td>
</tr>
</tbody>
</table>

**Test Stream with higher priority**

- **Test stream** with higher priority
- **Xena traffic generator and analyser**
- **Maximum Latency [us]** (over 1s): 1500 bytes adds 12.2us time
### VLAN ID

<table>
<thead>
<tr>
<th>VLAN ID</th>
<th>Port 1</th>
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<td></td>
<td></td>
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### Parameter details

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<th>Parameter name</th>
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### Maximum Latency [us]

(over 1s)
Agenda

• Determinism and Network Latency - defined
• Why Would You Need a Deterministic Network?
• Network Latency Contributors
• Latency in WR Switch
• Optional/advanced
  • Concept of VLANs
  • Details of WR Switch Operation
  • Fast Forward
  • Standard Priorities
  • High Priority (experimental)
• Latency Performance of WR Switch
• Demo
• Summary
Summary

- WR Switch and so WR Network
  - is deterministic by (open) design
  - is latency-optimized for selected traffic
  - is tested with professional IT equipment

- WR Switch provides optional features to optimize network latency:
  - Fast Forward
  - Priorities
  - High Priority (HP)

- WR Switch worst-case latency
  - Without WR-PTP traffic: 3.1us
  - With WR-PTP traffic: 5.6us
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Thank you