

FEC in Deterministic Control Systems over GbE

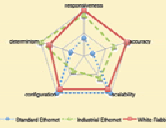
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DETERMINISTIC CONTROL SYSTEM

Control systems have distributed nodes that need to be synchronized. Synchronization is necessary in a system to establish a global ordering of events and tasks. The system may have a single central clock and communications equipment to exchange messages between the nodes and the central clock. White Rabbit is a novel field bus for data and time distribution. Although its initial scope is mainly targeted at Control System for experimental physics facilities, it could be embraced by the industry as well. GSI participates actively in the development of WR, and foresees the use of WR in the new FAIR facility.



White Rabbit Ethernet Field Bus

Generic Solution for Transfer Data:

- Fast
- Deterministic
- Safe

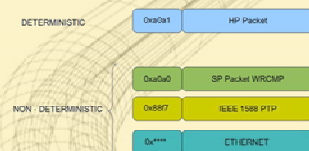
It is a GbE extension that provides:

- Synchronous Mode, 1ns and 20 ps jitter
- Deterministic Routing, max 64 byte-clock cycle

Deterministic Traffic

To distinguish between WR and other possible Ethernet traffic in the network, two different type of frames are defined:

- SP Standard Priority frame, non-deterministic
- HP High Priority frame, deterministic.



HP frames:

- Frames for time-critical control data.
- Frames routed with the lowest latency as possible.
- HP forcing fragmentation of SP

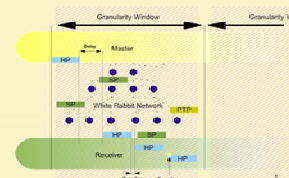
Preemption mechanism

When a HP packet arrives at the switch, and SP packet currently is being routed, it is fragmented allowing the HP packet to be sent out with minimal latency. The remaining part of the fragmented SP packet is sent later.



Granularity Window

Determinism is used to guarantee the execution of events in a certain period of time, it is possible to create a slice of time in which everything is perceived as deterministic, what its called in WR jargon, Granularity Window.

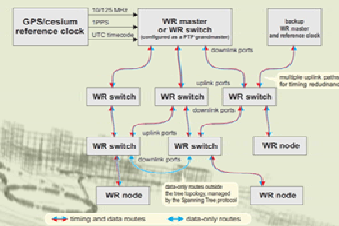
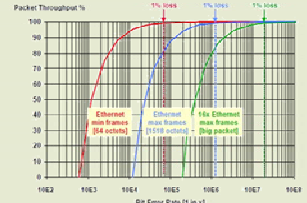


Once we define the span of determinism, the size of the GW, WRP provides the means to the transportation of the HP frames and the execution of the events in the very same GW.

GbE AND SWITCHING NETWORK

Gigabit Ethernet

- Physical medium optical fiber or twisted-pair cable.
- The Bit Error Rate = No. Bit Errors / No. Bits
- Fiber Optic BER, 10^{-9}
- Twisted-Pair BER, 10^{-12}
- Bit errors are equally distributed.



Network Topology

- Star or Tree Topology
- WR Master in top of the network
- 2000 stations WR Nodes
- Fixed transmission delay between WR Switches
- Implementation of CRC

Broadcast & BER

- Broadcast communication is a non thrifty method to convey information in a switched network.
- Terrible effective for simple communication networks.
- HP frames are broadcasted to all WR Receivers.
- The downside is a global BER.

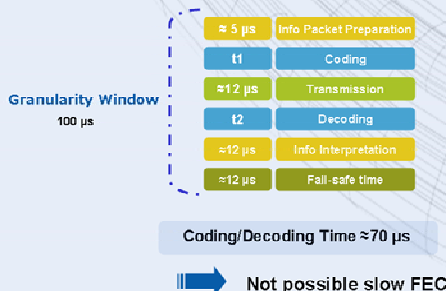
Since the events defined by the BEP are not mutually exclusive, the union of their probabilities is:

$$P(Pe_1 \cup \dots \cup Pe_n) = P(Pe_1) + \dots + P(Pe_n) - \sum_{i < j} P(Pe_i \cup Pe_j) + \sum_{i < j < k} P(Pe_i \cap Pe_j \cap Pe_k) + \dots + (-1)^{n+1} P(Pe_1 \cap \dots \cap Pe_n)$$

The transport medium that physically consists of a number N of wires, can be considered as an equivalent single cable with a higher BER, as many times as wires are. The BEP of the system as a whole, is the union of all the probabilities of every single medium path.

FORWARD ERROR CORRECTION

Granularity Window



Limited Upstream Traffic

Not possibility of positive/negative feedbacks from the receiver to sender and the retransmission of a lost or flawed frame.

Not possible TCP

Cyclic Redundancy Check

Cyclic Redundancy Check algorithm is calculated and introduced into the HP frames. This field allows early detection of header corruption during HP frame routing. If the header is corrupted, it will be detected and this frame is immediately dropped.

Frames lost

Requirements

- Time constrain due to GranularityWindow.
- No feedback channel and no retransmission.
- Stream of HP events within a GranularityWindow.
- Recovery of lost and flawed frames.
- Small length of the frame.
- Fully Ethernet compliant.
- One lost frame per year.
- Code Hardware Implementation.

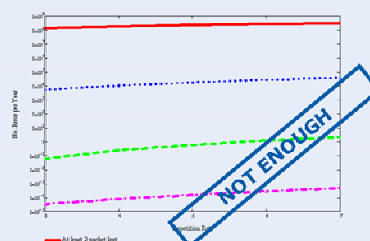
Test Case

- 2000 WR Receivers 144 WR Switches
- Fiber optic BER of 10⁻¹², CAT-5 BER of 10⁻¹⁰.
- Frame 23 bytes header, Payload 1000 bytes
- Granularity Window 100µs

No. Errors in one year

	P(error)	Frame Lost
Fiber Optic	3.91 · 10 ⁻⁷	12.4 · 10 ⁴
FO & CAT-5	3.67 · 10 ⁻⁵	11.5 · 10 ⁶

Repetition Code?



Clever Repetition Code

Low-Density Parity-Check Code

- Close performance to the channel of the channel.
- Linear time complex algorithms for decoding.
- Heavy use of parallelism.

LDPC Coding

$$H_{1,8} = \begin{pmatrix} 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$X_8 = x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8$$

$$Y_n = H_{m,n} \cdot X_m$$

Repetition

$$Y_4 = x_1 + x_5, x_1 + x_4, x_4 + x_5 + x_6 + x_3, x_2 + x_3$$

$$Y_4 = x_1 + x_5, x_1 + x_4, x_4 + x_5 + x_6 + x_3, x_2 + x_3$$

$$Y_4 = x_1 + x_5, x_1 + x_4, x_4 + x_5 + x_6 + x_3, x_2 + x_3$$

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$$Y_4 = x_1 + x_5, x_1 + x_4, x_4 + x_5 + x_6 + x_3, x_2 + x_3$$

Belief Propagation Decoding

$$p_{y_i}(y_i) = \sum_{y_1, \dots, y_n} p(Y)$$

$$X_8 = x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8$$