Experiments on IEEE 802.3cg 10BASE-T1L & Preemption in Process/Industrial Automation

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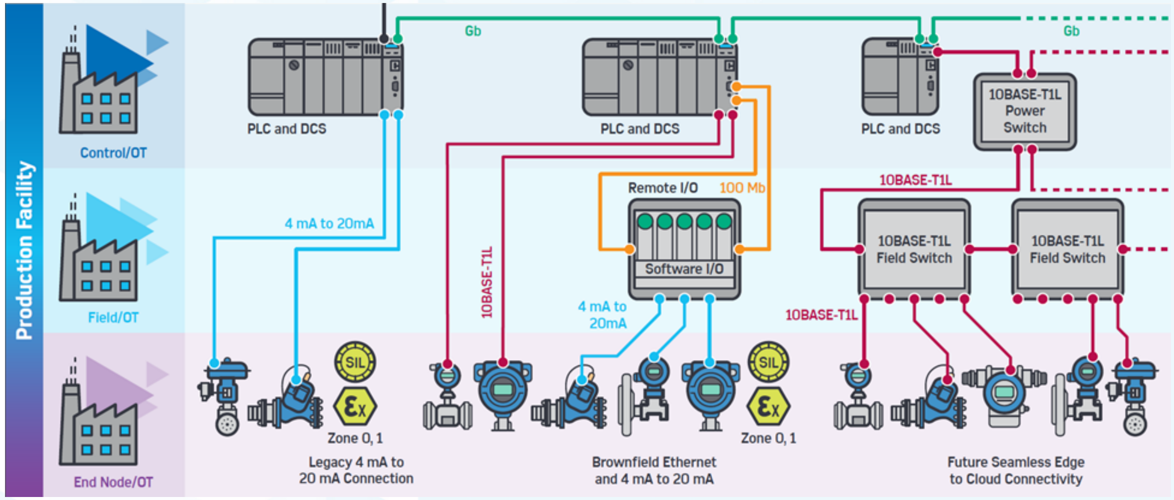
Process Automation (PA) Characteristics

- A PA system is used to control a process such as chemical, steel, oil refineries, petrochemical, paper or pulp factories.
  - Individual stations are spread over a large geographical area.
  - 10BASE-T1L is needed to provide connectivity over these distances.
- PA data consist of many analog values, such as temperature, pressure, flow, or level.
- Fast control cycle is NOT required (1 sec cycle is enough in many cases).
- A PA system operates 24x7x365 and requires procedures to stop safely.
- Hence, the extra high reliability and availability is required
- Topologies with multiple T1L links in series result in large worst-case latencies; Frame Preemption can help reduce these latencies



Communication Example (in a TSN domain)

- Application Scan Interval
  - HMI: 1000ms
  - Controller: **Basic 1000ms, Fast 100ms**
- Controllers to HMI (monitoring)
  - Data size: 1400 Bytes
  - Up to 3000 subscribed signals per scan interval
  - Scan interval: 1000ms
- IO control Data Size (PV or MV)
  - 4 Byte data + 1-4 Byte status per IO item
  - Up to 1024 Byte per IO-Station (which has up to 128 IO items)
  - Input vs Output = 2:1 (Typically)
- IO-Stations to Controllers (input)
  - Up to 2000 published signals per scan interval (typical 1500)
  - Scan interval: **100 – 1000ms (typical 1000ms)**
- Controllers to IO stations (output)
  - Up to 2000 published signals per scan interval (typical 750)
  - Scan interval: **100 – 1000ms (typical 1000ms)**
- Controllers to Controllers
  - Up to 1000 published signals per scan interval
  - Scan interval: **50 – 500ms (typical 500ms)**

Reference: https://www.ieee802.org/1/files/public/docs2018/60802-sato-pa-system-quantities-0718-v01.pdf

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Minimizing Latency for important traffic

- In the presence of so many traffic sources, congestion is inevitable
- The 60802 Profile defines seven traffic types to accommodate traffic
  - Due to the comparatively slow control loop cycles, the added complexity of scheduled traffic is often undesirable
  - However certain traffic types require minimized latency, making the MAC Merge sublayer desirable

Traffic type name	Cyclic	Data delivery requirements	Time-triggered transmit	Traffic-type-category
Isochronous	Yes	Deadline	Yes	IA time-aware-stream
Cyclic-Synchronous	Yes	Latency	Yes	IA time-aware-stream
Cyclic-Asynchronous	Yes	Latency	No	IA stream
Alarms and Events	No	Latency	No	IA traffic engineered non-stream
Configuration & Diagnostics	No	Latency	No	IA traffic engineered non-stream
Network Control	Optional	Latency	No	IA traffic engineered non-stream
Best Effort	No	N/A	No	IA non-stream

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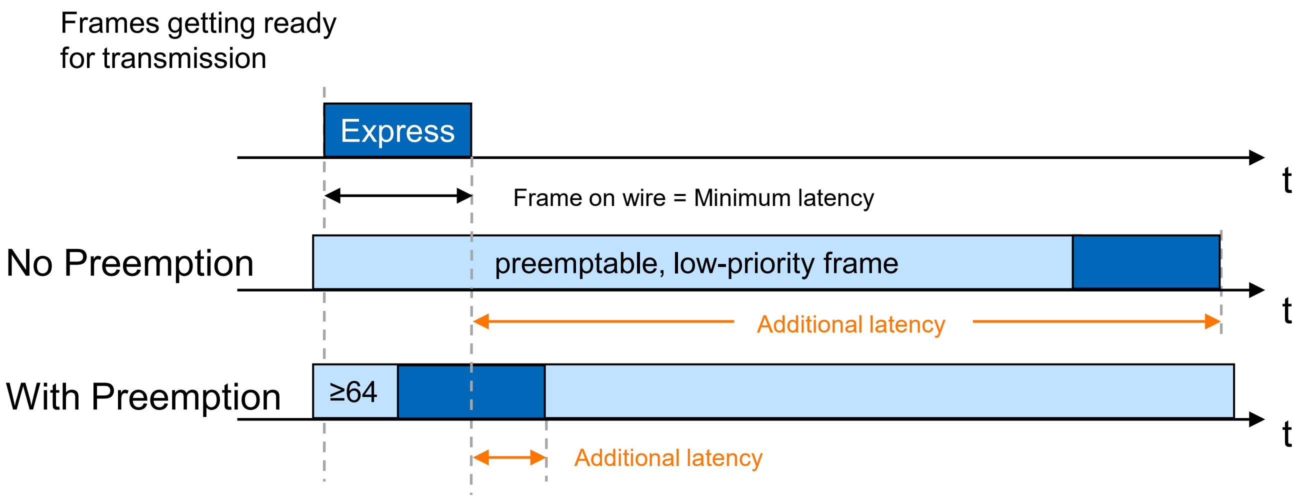
Frame Preemption Explained

- A method from the TSN "toolbox", standardized in 802.3br and 802.1Qbu
- Pauses transmission of a preemptable Ethernet frame to allow timely transmission of an express frame
- After the express frame is transmitted, transmission of the interrupted frame continues

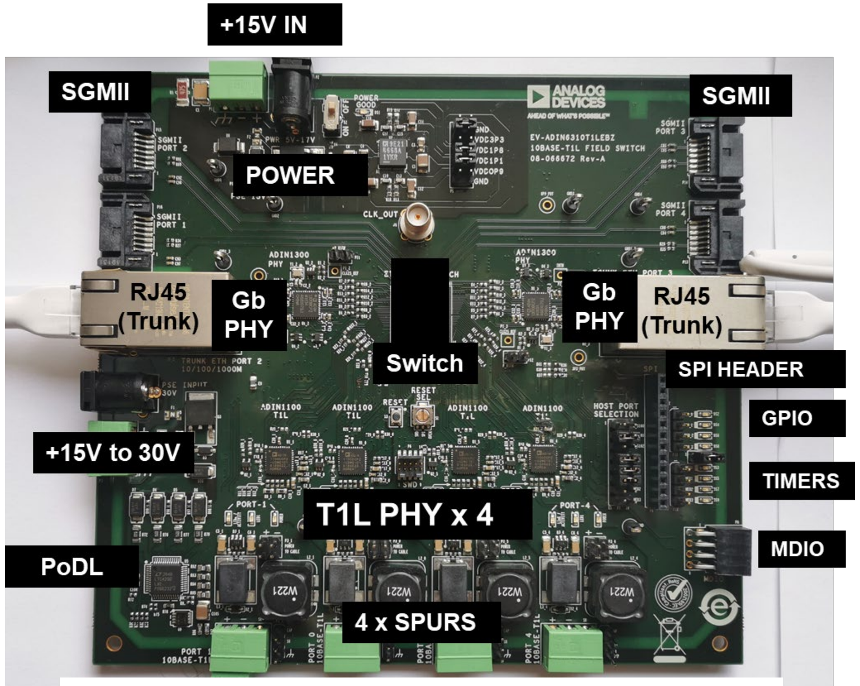


Note:
Each priority value is either mapped to express or preemptable.
Express frames can not preempt other express frames
Preemptable frames can not preempt any frames

- The SFD octet (between preamble and destination address) is modified to identify and re-assemble frames
  - This does NOT work with 10BASE-T, but
    it works with all more modern Ethernet variants such as 100 BASE-TX or 10BASE-T1L
- The lower the link speed, the higher the benefit in absolute figures

Frame Preemption & 10BASE-T1L

- **Purpose**:
  - Demonstrate how Frame Preemption can provide Bounded latency over 10Mb T1L Links
  - Demonstrate latency reduction achieved with Frame Preemption
    - From 1.3ms to <200us

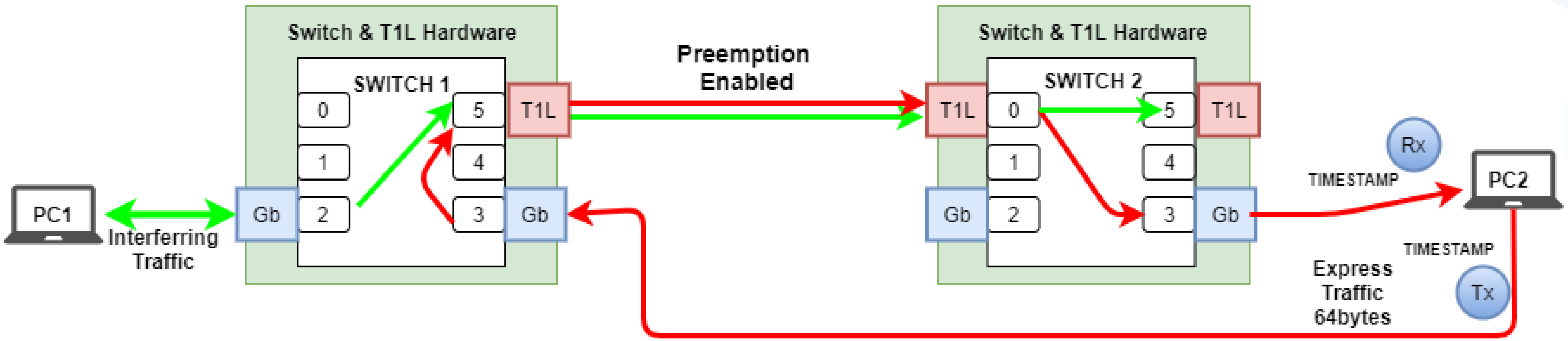


Switch & T1L Evaluation Board

- **Hardware used for this testing:**
  - 6-Port TSN Switch
  - 10/100/1000 Ethernet PHY
  - 10BASE-T1L Ethernet PHY
  - uModule for component power
- **6 Ports configured to support:**
  - 4x 10BASE-T1L Spurs
  - 2x Gb Trunks (RJ45 with integrated Magnetics)
  - SGMII interconnects for increased port count using SATA cables
- External Host Processer (SPI header access)

Test & Hardware Configuration

- PC1 configures Switches & provides Interfering Traffic
- PC2 provides Express traffic & Captures hardware timestamps
  - Tx Timestamp = time of express traffic transmitted to Switch 1
  - Rx Timestamp = time of express traffic received from Switch 2
  - Calculate Jitter/Latency = Rx – Tx. Time for the express packet to transit across two Switches, 2 Gb PHYs & 1 T1L Link in the presence of other interfering traffic
  - Compare with Frame Preemption disabled, enabled and differing Fragment sizes



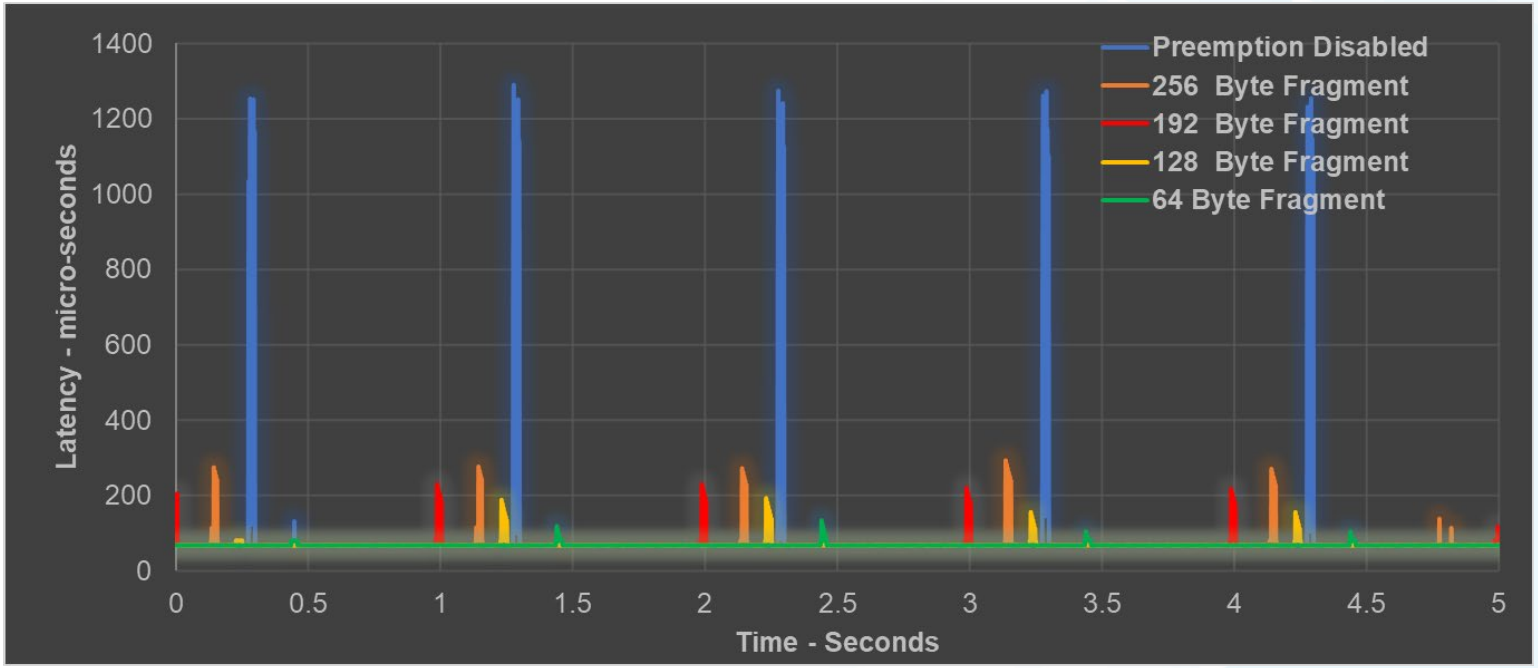
- **“Interfering” traffic**
  - Burst of 1500byte packets for 0.4s every 1s, Priority 2
- **“Express” traffic**
  - 64byte packet every 1ms, Priority 5

Frame Preemption, Bounded Latency with T1L

Measured Results

- Measurement of the time taken for the express traffic to transit in the presence of interfering traffic with Frame preemption disabled vs enabled

	Frame Preemption Disabled	Frame Preemption Enabled			
Minimum fragment size =	**-**	**64 bytes**	**128 bytes**	**192 bytes**	**256 bytes**
Expected Maximum Additional Latency	1.234ms	114.4us	165.6us	216us	268us



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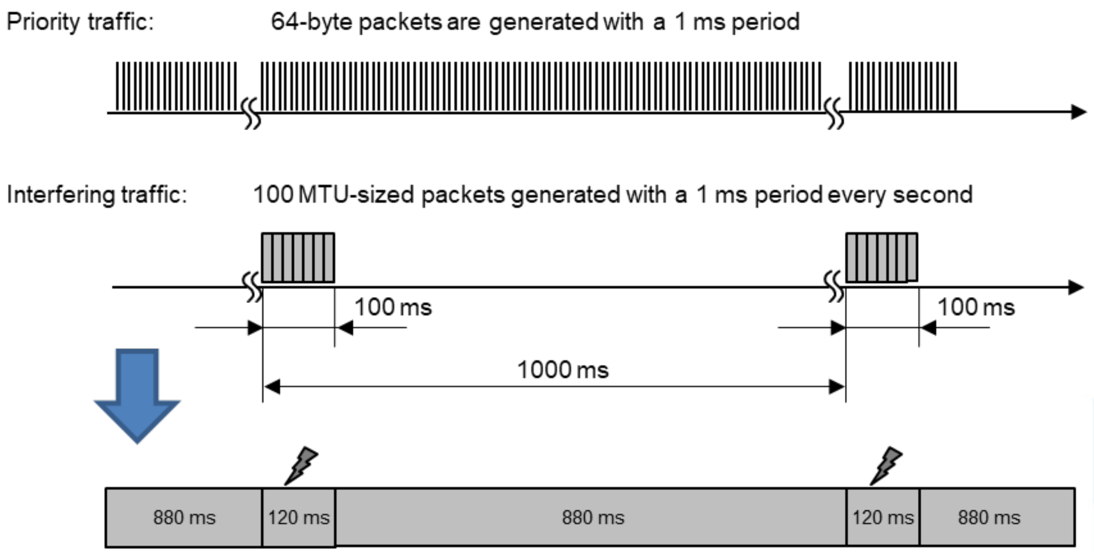
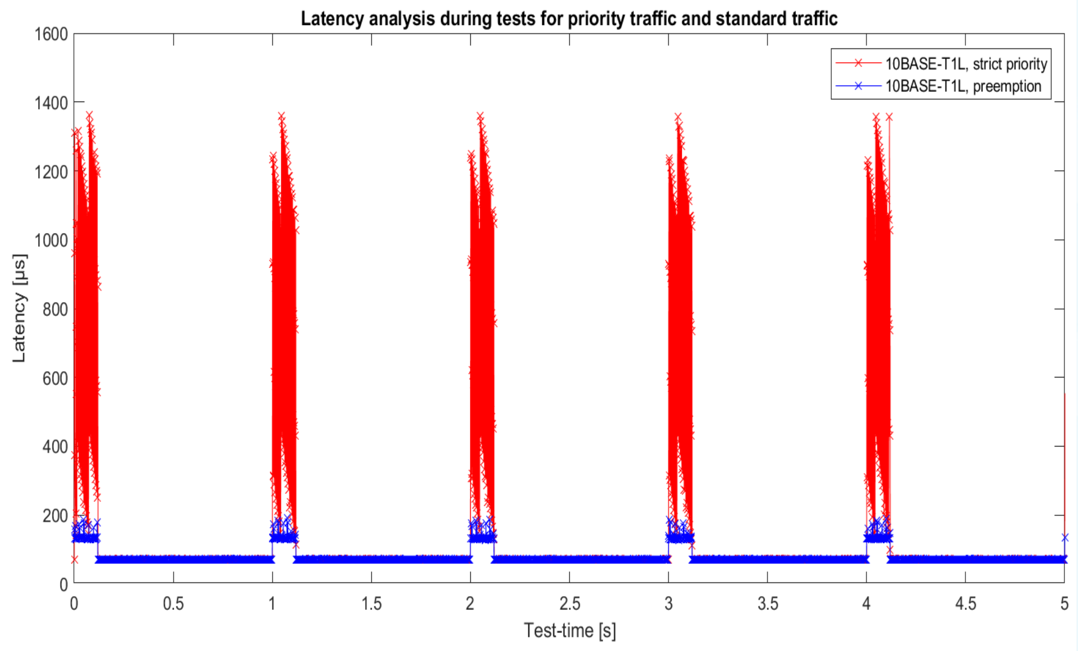
Tests at ZHAW in mixed-vendor setup

- Setup similar, but with PHY evaluation boards and FPGA-based switch
- Bursts of interfering traffic for 120 ms every second

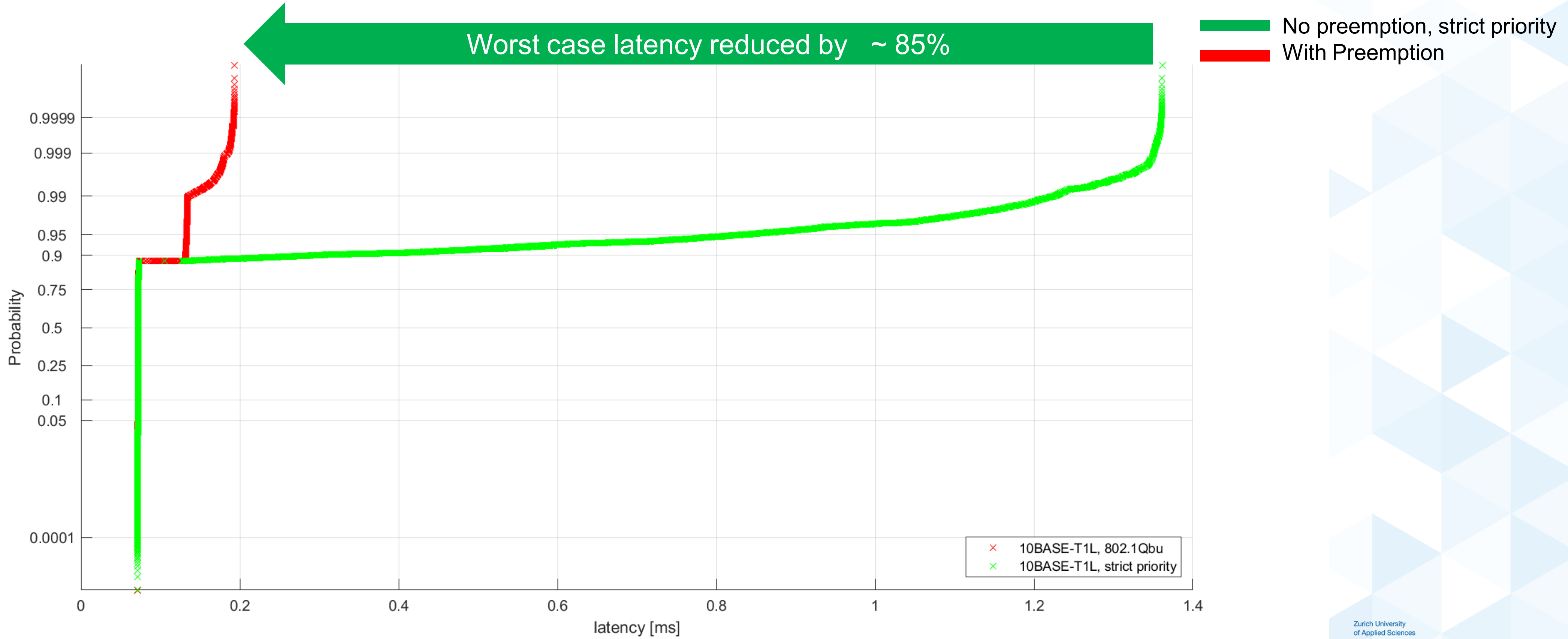




Probability Plot highlights outliers

Measurements done with existing PHYs in a mixed-vendor setup, 64 Byte min fragment size.

Bursts of interfering traffic (1500 Bytes packets) for 120 ms every second (12%)



Reference: https://www.ieee802.org/3/SPEP2P/public/ostertag_3SPEP2P_01_04142021.pdf

Conclusions

- Frame Preemption provides a means to address congestion by giving high priority traffic an express path through the network
- The experimental data presented herein quantifies the performance benefits of preemption and demonstrates the feasibility of its use on 10BASE-T1L links
- The specification of preemption on 10BASE-T1L links represents no new technology investment or backwards compatibility issues. It simply documents what already works