Analysis of Converged Network Traffic Using Time-Sensitive Networking (TSN)

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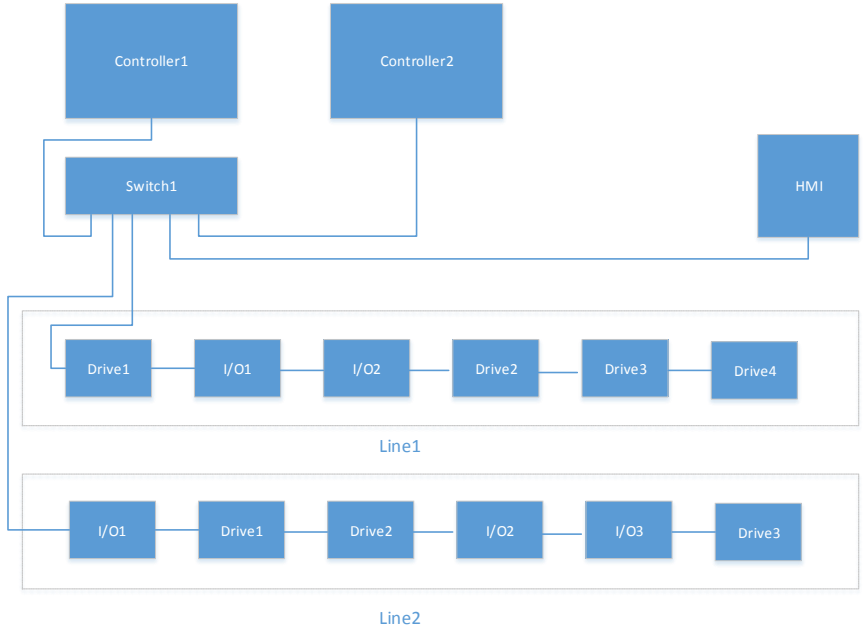
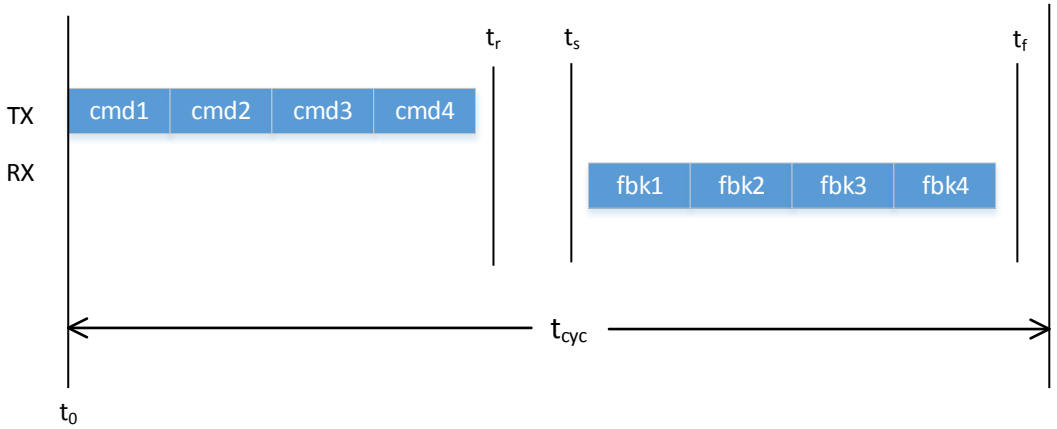
What is Convergence?

- Merging of multiple traffic types on a single wire
- Operational Technology (OT)
- Isochronous (motion)
- Cyclic (I/O)
- Events (Control events and alarms)
- Information Technology (IT)
- Web
- Email
- database



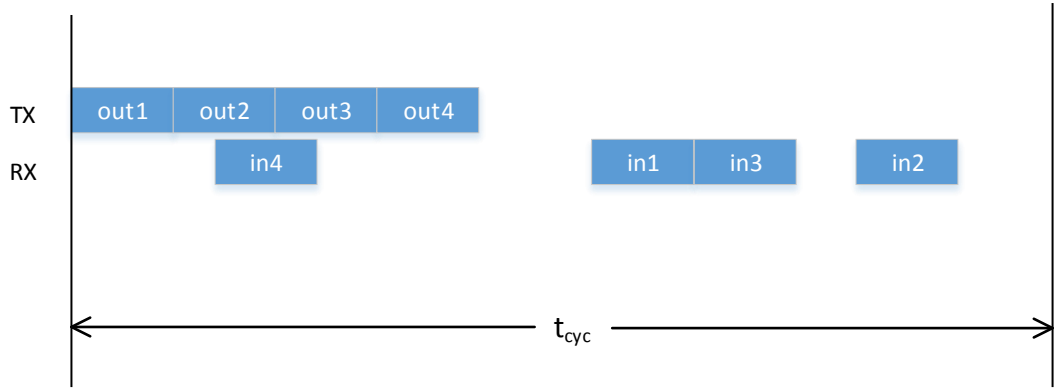
Isochronous Traffic Pattern (motion)

- Cyclic, often at high rates (<= 1 ms)
- Synchronized network and application time
- Low tolerance to interference
- Typically small payloads



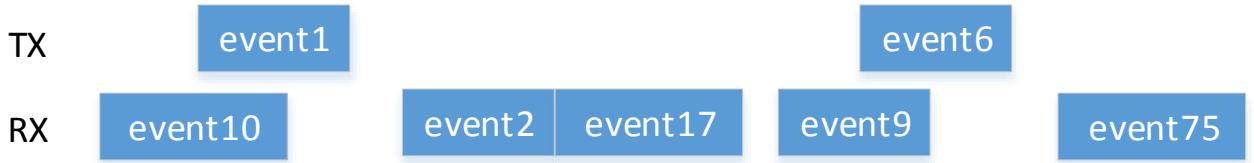
Cyclic Traffic Pattern (I/O)

- Application cycle times not synchronized with data transmission cycle times
- Interference needs to be controlled
- Client-Server (e.g. Modbus®)
- Pub-Sub (e.g. EtherNet/IP)



Event Traffic Pattern (Alarms and Control Events)

- Acyclic traffic
- Bandwidth guarantee required to handle bursts (e.g. alarm shower)
- Application retries for message loss during excessive message generation

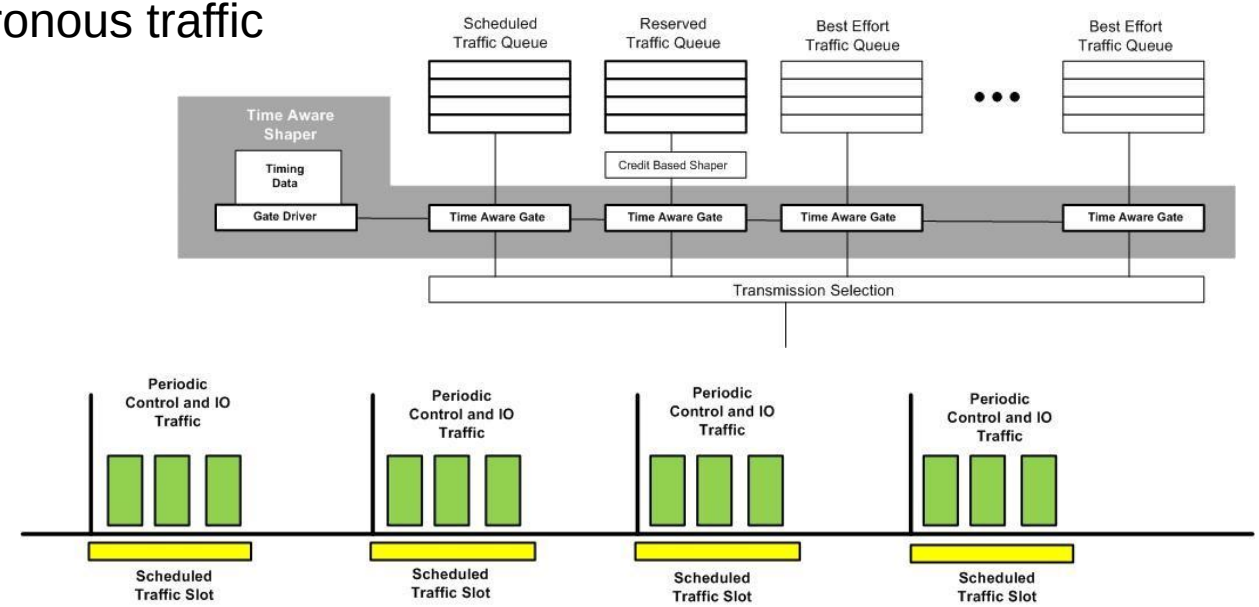


TSN Overview

- IEEE 802.1Qav - Forwarding and Queuing Enhancements for Time-Sensitive Streams
- IEEE 802.1AS-Rev - Timing and Synchronization for Time-Sensitive Applications
- IEEE 802.1Qbu & IEEE 802.3br - Frame preemption
- IEEE 802.1Qbv - Enhancements for Scheduled Traffic
- IEEE 802.1Qca - Path Control and Reservation
- IEEE 802.1Qcc - Stream Reservation Protocol (SRP) Enhancements and Performance Improvements
- IEEE 802.1Qci - Per-Stream Filtering and Policing
- IEEE 802.1CB - Frame Replication & Elimination for Reliability

Time-Aware Traffic Shaping

- Scheduled traffic
- Queuing offers guarantee of exclusive network access
- Ideal for Isochronous traffic



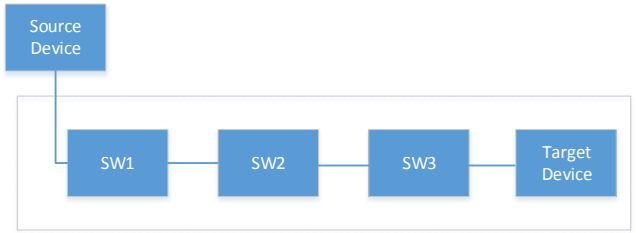
QoS Strict Priority

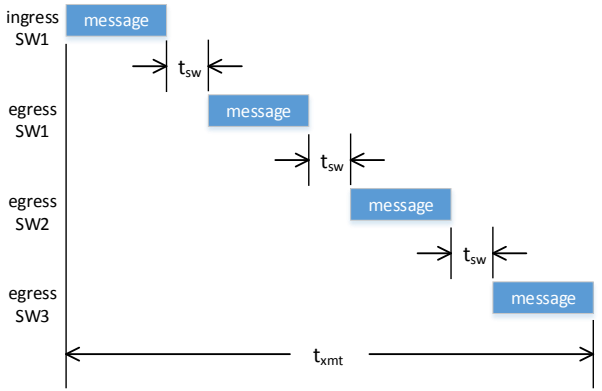
- Default queuing mechanism for Ethernet bridges (switches)
- Higher numbered queues have priority over lower numbered queues
- In general, highest numbered queue with message is transmitted next
- Shaping mechanisms can affect priority queuing

Cut-through Switching

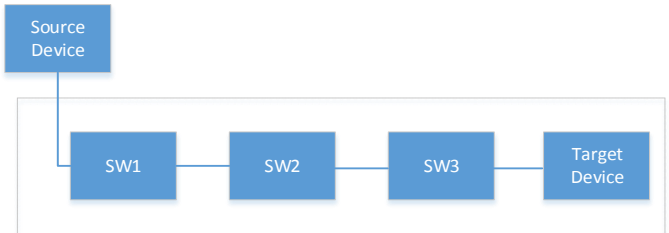
- Advantages
  - Switch begins forwarding before fully receiving messages
  - Offers lower latencies over store-and-forward switching
- Caveats
  - Behavior not specified in standards
  - Propagates corrupted messages
- Congestion and port speed differences cause fallback to store-and-forward behavior

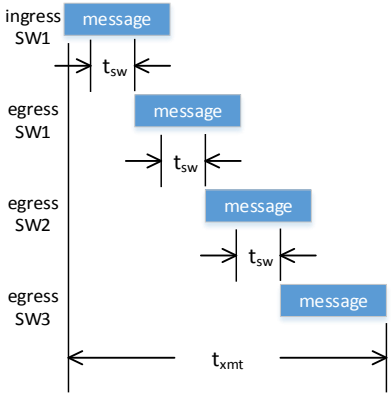
Store-and-forward vs. Cut-through switching





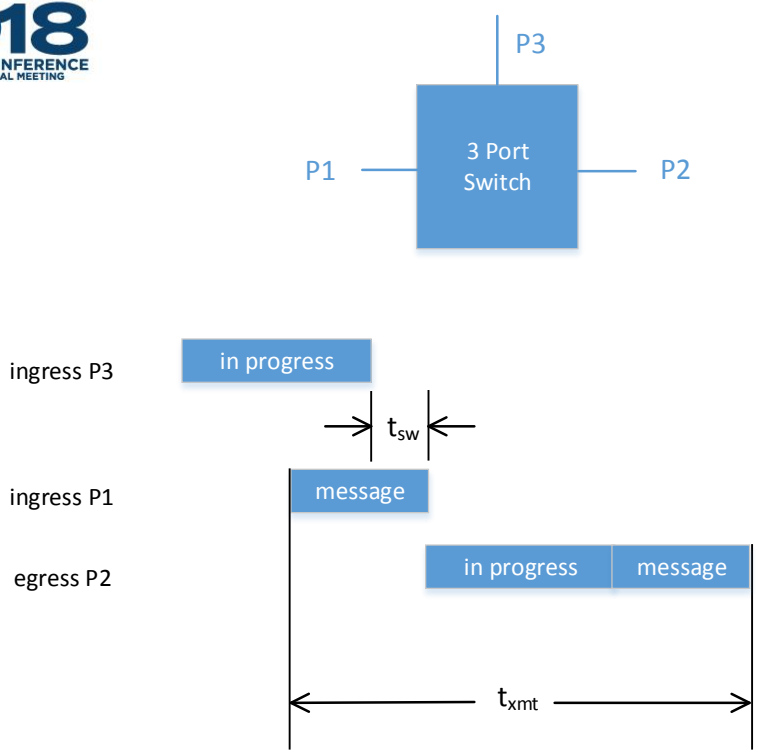
Store-and-forward



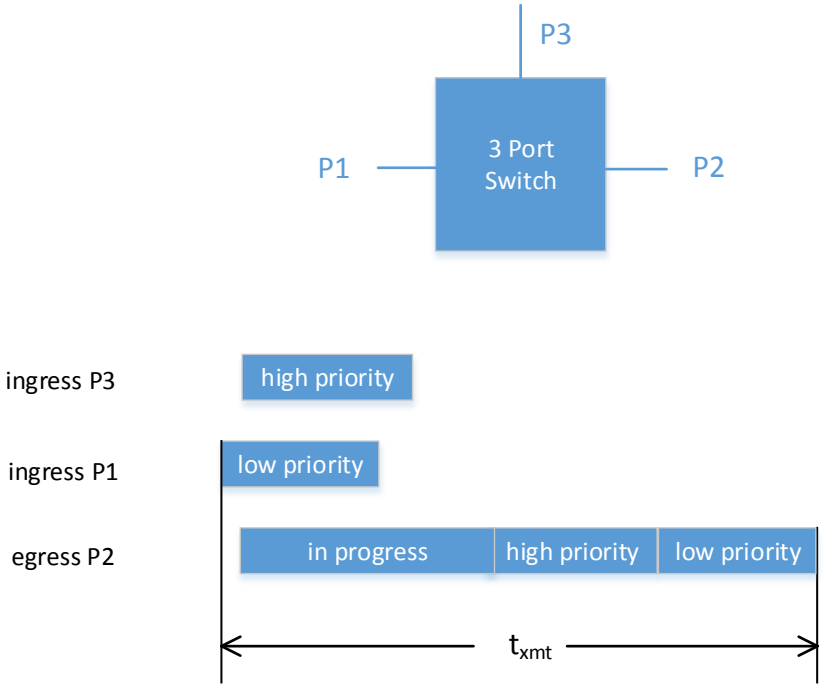


Cut-through

Interference

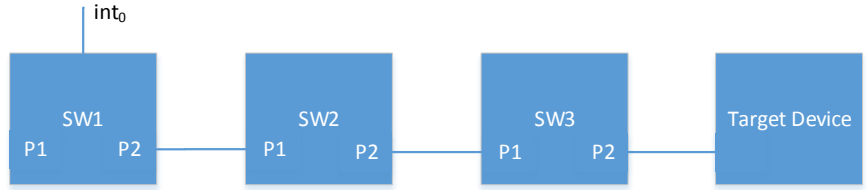


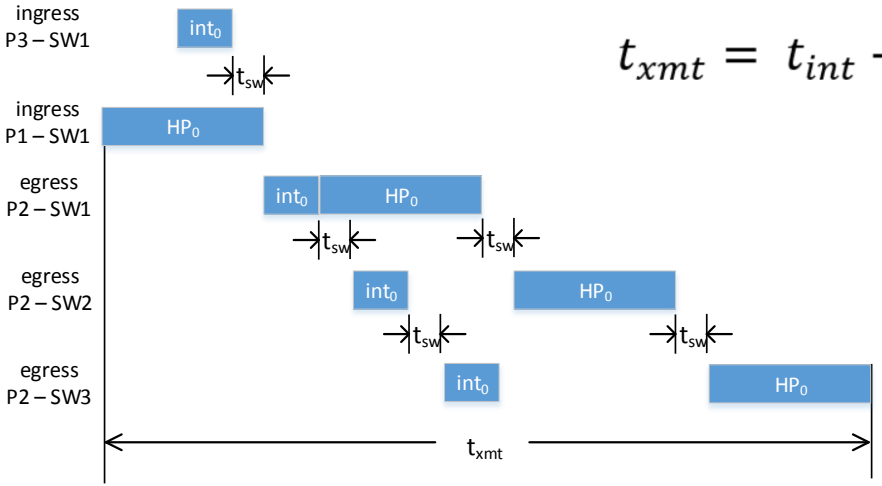
Interference due to in-progress message



High-priority Interference

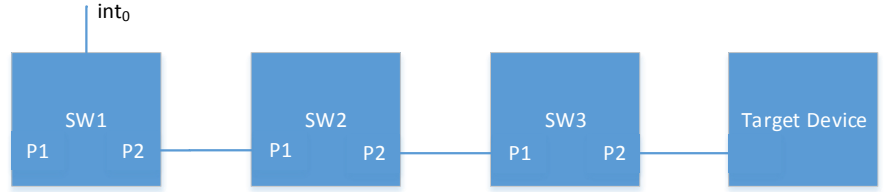
Small Interfering Message

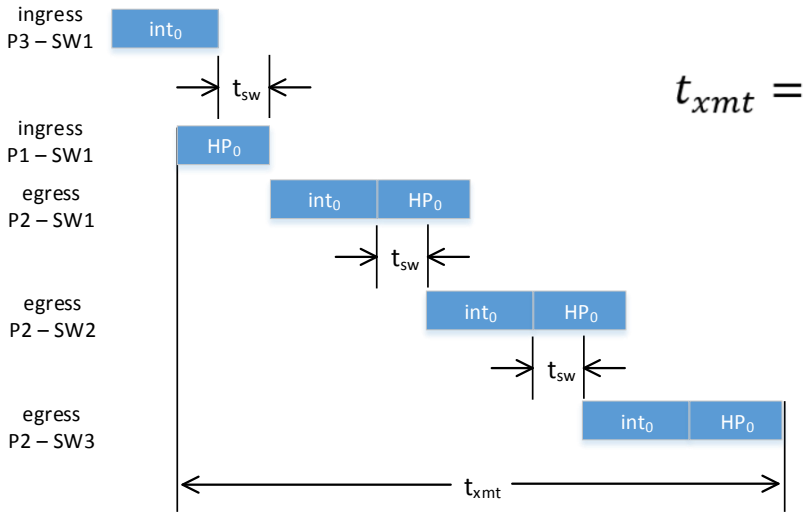




$$t_{xmt} = t_{int} + t_{msg} + n_{sw} * (t_{msg} + t_{sw})$$

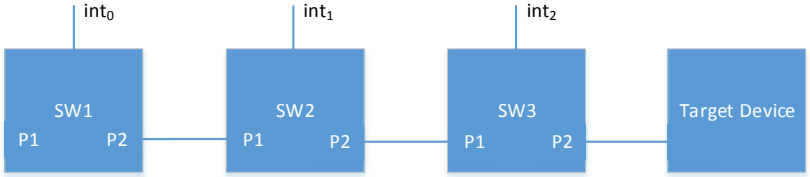
Large Interfering Message

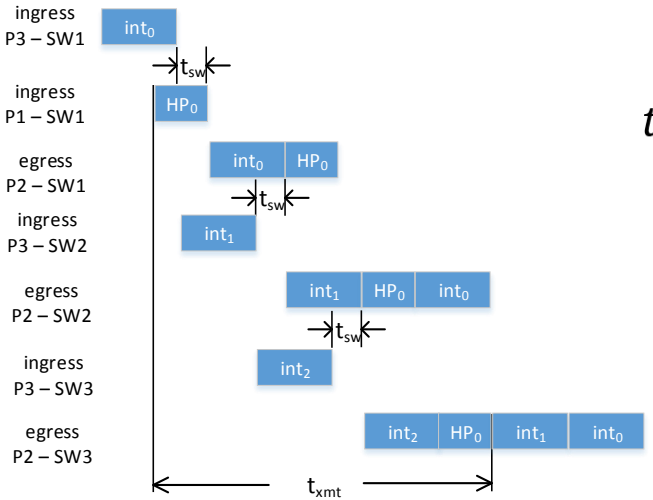




$$t_{xmt} = t_{int} + n_{sw} * (t_{int} + t_{sw}) + t_{msg}$$

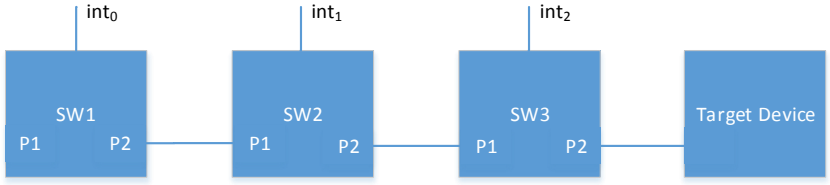
Subsequent Interference – Large Low Priority Messages

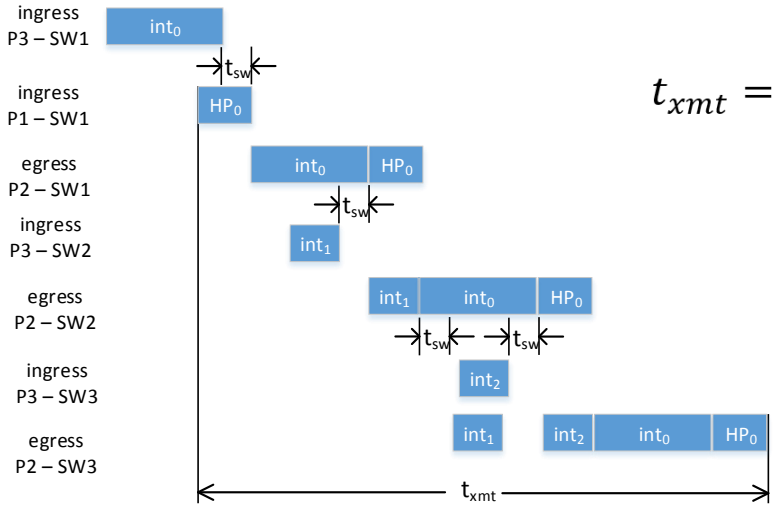




$$t_{xmt} = t_{int_0} + \sum_{n=1}^{n_{sw}} \left(t_{int_n} + t_{sw}\right) + t_{msg}$$

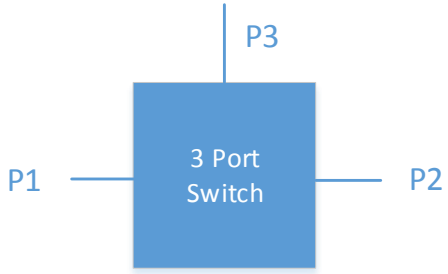
Subsequent Interference – Small Low Priority Messages

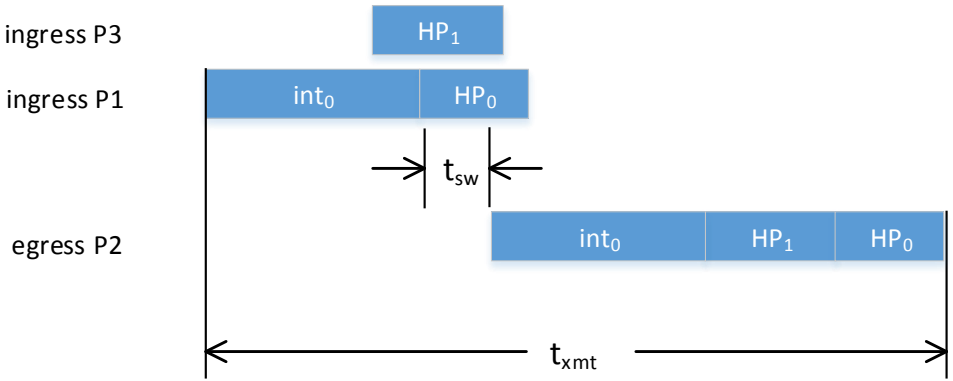




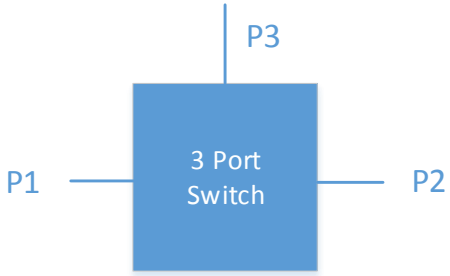
$$t_{xmt} = t_{int_0} + \sum_{n=1}^{n_{sw}} \left(t_{int_0} + t_{int_n} + t_{sw} \right) + t_{msg}$$

Equal Priority Interference

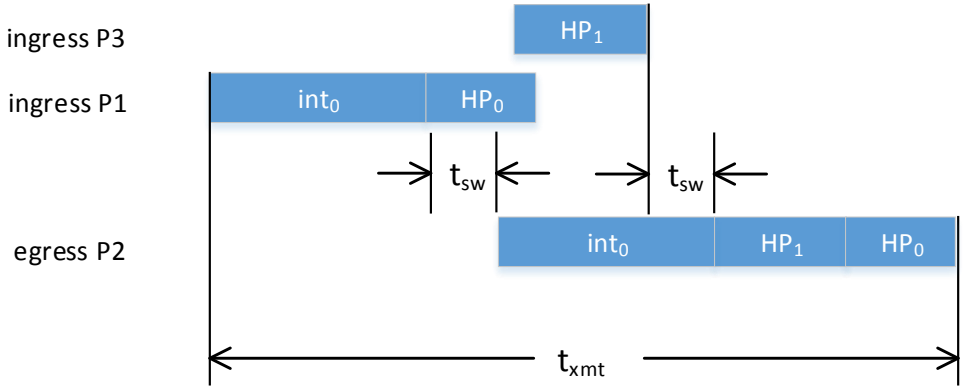




Higher Priority Interference

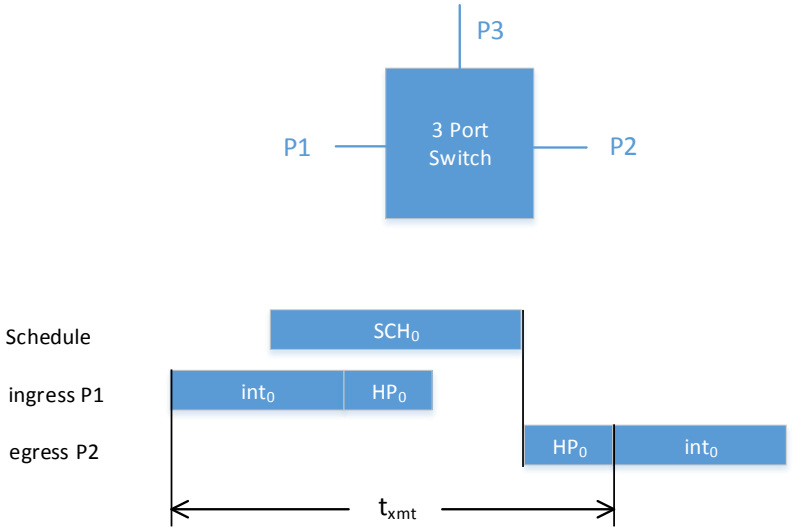


$$t_{xmt} = t_{int_0} + n_{sw} * \left(t_{int} + t_{int_0} + t_{sw}\right) + t_{msg}$$

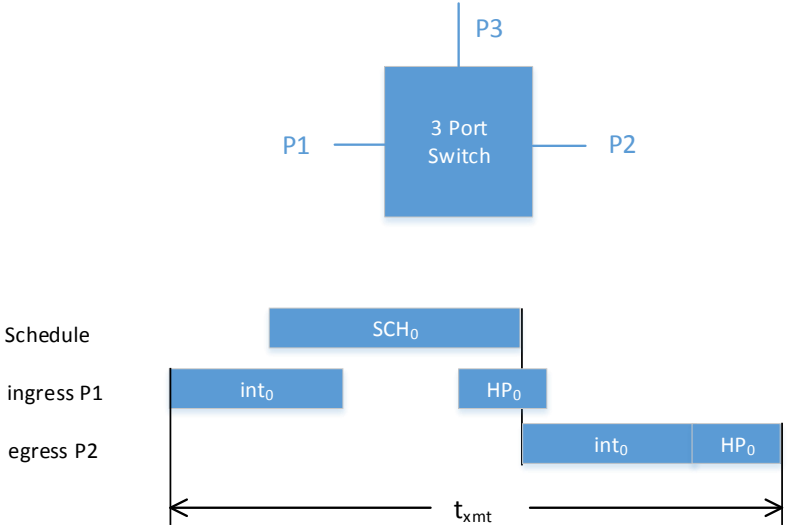


Scheduled Traffic Interference

Multiple Blocked Messages



In-Progress Message



$$t_{xmt} = t_{msg} + n_{sw} * (t_{msg} + t_{sw}) + t_{sch}$$

Putting It All Together

Summary & Conclusions

- Simple system used to demonstrate convergence
- Three traffic types (motion, I/O & event)
- Different interference scenarios analyzed
- Convergence can affect latencies, but TSN provides mechanisms to determine if in acceptable range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