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**

- Source Device
  - SW1
  - SW2
  - SW3
  - Target Device

  - Ingress SW1: message $t_{sw}$
  - Egress SW2: message $t_{sw}$
  - Egress SW3: message $t_{sw}$

  - $t_{xmt}$

**Cut-through**

- Source Device
  - SW1
  - SW2
  - SW3
  - Target Device

  - Ingress SW1: message $t_{sw}$
  - Egress SW2: message $t_{sw}$
  - Egress SW3: message $t_{sw}$

  - $t_{xmt}$
Interference due to in-progress message

High-priority Interference

Interference
Small Interfering Message

\[
t_{txmt} = t_{int} + t_{msg} + n_{sw} \times (t_{msg} + t_{sw})
\]
Large Interfering Message

\[ t_{xmt} = t_{int} + n_{sw} \times (t_{int} + t_{sw}) + t_{msg} \]
Subsequent Interference – Large Low Priority Messages

\[
t_{xmt} = t_{int_0} + \sum_{n=1}^{n_{sw}} (t_{int_n} + t_{sw}) + t_{msg}
\]
Subsequent Interference – Small Low Priority Messages

\[ t_{xmt} = t_{int_0} + \sum_{n=1}^{n_{SW}} (t_{int_0} + t_{int_n} + t_{sw}) + t_{msg} \]
Equal Priority Interference

3 Port Switch

ingress P3

HP_1

HP_0

int_0

t_sw

egress P2

HP_1

HP_0

int_0

t_xmt
Higher Priority Interference

\[ t_{xmt} = t_{int_0} + n_{sw} \times (t_{int} + t_{int_0} + t_{sw}) + t_{msg} \]
Scheduled Traffic Interference

Multiple Blocked Messages

\[ t_{xmt} = t_{msg} + n_{sw} \times (t_{msg} + t_{sw}) + t_{sch} \]

In-Progress Message
Putting It All Together

**Motion Traffic**

**I/O Traffic**

**Event Traffic**

**Converged Traffic**
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