Time-Sensitive Networking (TSN) – How the additional value will meet your requirements

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How the additional value will meet your requirements

- **Scalability**
  - Choose the right traffic class for your application

- **Timing Guarantees**
  - Attach to each traffic class the expected latency and priority

- **Reliability**
  - Give for each traffic class a bandwidth guarantee
  - Consider redundancy if needed
  - Ensure stable traffic by policing
It began with the IEEE standardization out of the Audio/Video Bridging Task Group, specifying the basis for low latency transmission on Ethernet:
- IEEE 802.1BA: "Audio Video Bridging (AVB) Systems"
- IEEE 802.1AS: "Timing and Synchronization for Time-Sensitive Applications (gPTP)"
- IEEE 802.1Qav: "Forwarding and Queuing for Time-Sensitive Streams (FQTSS)"
- IEEE 802.1Qat: "Stream Reservation Protocol (SRP)"

and standards for time sensitive applications:
- IEEE 1722: "Layer 2 Transport Protocol (AVTP)"
- IEEE 1733: "Layer 3 Transport Protocol (RTP)"

What is TSN – It began with AVB ...

Time-Sensitive Networking (TSN)

Tx

Credit Based Shaper

Rx

Credit Based Shaper

Time Sensitive Data

Presentation Time

Best Effort Data

Send Slope

Idle Slope

T1 T2 T3

T1 T2 T3

T1 T2 T3
The IEEE Time-Sensitive Networking Task Group as the successor of the AVB Task Group

- specifies the basis for **deterministic** transmission on Ethernet
  - IEEE 802.1Qbv "Enhancements for Scheduled Traffic"
- and standards for **latency reduction**
  - IEEE 802.1Qbu "Frame Preemption"
  - IEEE 802.3br "Specification and Management Parameters for Interspersing Express Traffic"
- and standards for **Safety and Security**
  - IEEE 802.1CB "Frame Replication and Elimination for Reliability"
  - IEEE 802.1Qci "Per-Stream Filtering and Policing"

**Time-Sensitive Networking (TSN)**

**What is TSN – ... and has been extended to TSN**

- **Deterministic Data**
- **Non Deterministic Data**

**Tx**

**Time Aware Shaper**

**Rx**

**Gate Control List**

**Gate**

**Time Slot**

**S1**

**S2**

**S3**
Time-Sensitive Networking (TSN)

Bricks of TSN

- Bandwidth management
- Latency
- Redundancy & Policing
- Time synchronization
- Priority
**Time synchronization**

- The Grand Master distributes the Global Time to all nodes within a time aware system.
  - **Sync and Follow_Up message**

- Time Slave Ports measure the path delay and add it to the received Global Time.
  - **Pdelay_Req, Pdelay_Resp and Pdelay_Resp_Follow_Up message**

- Endpoints and Switches are time synchronized to the Grand Master with a jitter $\leq 1\mu s$. 
Categorization of traffic classes depending on their latency

- **Best Effort traffic class**
  - Latency definition on protocol level

- **Worst case based latency traffic classes**
  - AVB traffic class A – 2ms end to end latency
  - AVB traffic class B – 50ms end to end latency

- **Deterministic traffic**
  - Latency = \( f(\text{CycleTime}, \text{MaxTxPacketLengthPerPort}, \text{GuardBand}) \)
  - GuardBand =
    - Without Preemption: \( \text{MaxFrameLengthPerLink} + 20 \text{ Byte} \) (for Preamble, SOF, Interpacket Gap)
    - With Preemption: \( 64 \text{ Byte} + \text{Max}[\text{FrameLengthPerLink mod 64}] + 20 \text{ Byte} \) (for Preamble, SOF, Interpacket Gap)
    - An Ethernet frame could be preempted by a higher prior frame and resumed afterwards at the preempted position, whereat each fragment must have at least 64 Byte.

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**Earliest Preemption Point (Frame with 128 Byte)**

<table>
<thead>
<tr>
<th>Byte</th>
<th>Ethernet Frame</th>
<th>Frame Length</th>
<th>Time[μs] @ 100MBit</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>8 + 64</td>
<td>8 + 1522 + 12</td>
<td>0,64 + 5,12 + 0,96</td>
</tr>
<tr>
<td>64</td>
<td>Ethernet Frame</td>
<td></td>
<td>0,64 + 121,76 + 0,96</td>
</tr>
</tbody>
</table>
Bricks of TSN

Categorization of messages depending on their priority

- As defined in
  - IEEE 802.1Q "Bridges and Bridged Networks":

<table>
<thead>
<tr>
<th>Low Priority</th>
<th>Medium Priority</th>
<th>High Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>Best Effort</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Excellent Effort</td>
<td>Critical Applications</td>
<td>5</td>
</tr>
<tr>
<td>Audio latency</td>
<td>Internetwork Control</td>
<td>6</td>
</tr>
<tr>
<td>Video latency</td>
<td>Network Control</td>
<td>7</td>
</tr>
</tbody>
</table>

- Priority-Queue assignment in hardware (depending on availability)
  - Shaped queues having a higher priority than unshaped queues
The Stream Reservation Protocol ensures bandwidth guaranties
- Registration of streams by Talker/Listeners
- De-Registration of streams by Talker/Listeners
- Maintaining stream reservation information by Bridges

⇒ Unregistered streams will not pass the Bridge.
Redundancy and Policing

**Redundancy**
- Packet replication for redundant transmission
  - Ethernet frame extension by a Redundancy Tag (R-TAG = 0xF1C1)
  - Shortest path transmission
- Detection and elimination of duplicated packets
Redundancy and Policing

- **Filtering and Policing**
  - Avoids, that queues in Bridges could be captured by unexpected traffic
    - Ingress, frame and egress filtering
    - Flow classification and metering for dedicated Gates (priorities) and streams
    - Implementation of an Ingress Policing Function
The IEEE Time-Sensitive Networking Task Group focuses actually on 16 projects.

Approx. 50% of them are automotive relevant.

- Already published are:
  - IEEE 802.1Qbv "Enhancements for Scheduled Traffic"
  - IEEE 802.1Qbu "Frame Preemption"

- Work group stable are:
  - IEEE 802.1CB "Frame Replication and Elimination for Reliability"
  - IEEE 802.1Qci "Per-Stream Filtering and Policing"

TSN extensions require mostly HW extensions as well.

- HW support for IEEE 802.1Qbv is already available.
- HW support for IEEE 802.1Qbu is rarely available.
Time-Sensitive Networking (TSN)

Summary

- TSN is a set of IEEE specifications specifying mechanisms and protocols to scale and control an Ethernet network regarding latency and reliability.

- Using these additional values, Ethernet networks will be designed to meet your requirements.

- TSN provides a solution for a smooth coexistence of all Ethernet traffic classes.
I wish you an exiting day!

Time-Sensitive Networking (TSN)

How the additional value will meet your requirements
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