Deterministic Ethernet: Standardization in Progress and Beyond
RATE Workshop, Vancouver, Dec 3\textsuperscript{rd}, 2013

Wilfried Steiner, Corporate Scientist
wilfried.steiner@tttech.com

Norman Finn, CISCO Fellow
nfinn@cisco.com
Overview

- Deterministic Ethernet Goals
- Background on IEEE 802.1
- Background on IEEE 802.1 (Audio/Video Bridging)
- Standardization in Progress (Time-Sensitive Networking)
- IEEE 802.1 and Fault-Tolerant Clock Synchronization
- Conclusions
Deterministic Ethernet Goals

The goal of Deterministic Ethernet is to make Ethernet better suitable for real-time and fault-tolerant applications.

To meet this goal, Deterministic Ethernet needs, upon others, to be **real-time analyzable**, which is:

*a Boolean property of a communication system that is satisfied when there exists a reasonable model of the communication system in which it is always possible to calculate real numbers for the worst-case latency and communication jitter of messages of interest.*

A model is **reasonable**, when it sufficiently represents reality for all use cases of the communication system.

There are many different interpretations of the term “determinism.” I am not touching this, Kopetz is the expert in this field, see, e.g.:

Background on IEEE 802.1

IEEE 802.1 is standardizing general architectures for local area networks (LANs) and metropolitan area architectures (MANs). Together with IEEE 802.3 they are the main working groups working standards for Ethernet switches.

Efficient utilization of the communication bandwidth and plug-and-play capabilities are topmost requirements in IEEE 802.1. With AVB, IEEE 802.1 moved into the area of real-time communication. With TSN, IEEE 802.1 moves into the area of hard real-time and reliable communication.

Upcoming mainstream IT equipment aims to provide real-time and dependable communication features (to a significant higher degree than today).
AVB – Audio/Video Bridging

802.1AS Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks: a protocol and technique to synchronize local clocks in the network to each other.

802.1Qat Stream Reservation Protocol (SRP): a protocol that allows applications to dynamically reserve bandwidth in the network.

802.1Qav Forwarding and Queuing Enhancements for Time-Sensitive Streams: an enhancement over strict priority based forwarding and queueing mechanisms that establishes fairness properties for lower priority traffic in the network.

802.1BA: definition of profiles for AVB systems.

→ AVB is incorporated in the IEEE 802.1 standards documents since 2011.
802.1Qav: Credit-Based Shaping

Class A Queue
Queue with lower priority
high credit
Class A credit
 idle slope
send slope
Class A queued frames
Class A Queue transmit allowed
Class A Queue transmit
output port

Copyright © TTTech Computertechnik AG. All rights reserved.
Credit-based shaping is realized in the IEEE 802.1Q Audio/Video Bridging Standard.

The aim is to guarantee 2ms network latency for SR Class A traffic over seven hops (=six bridges), considering several assumptions, e.g.,

- 100 Mbit/sec network
- SR Class A is sent with a period of 125us
- Limited number of AVB streams
  - Sum of AVB traffic may not exceed 75% of the port transmit rate.
  - 75% of 125us = 93.75us
  - Minimum Ethernet frame size is 6.72us
  \[ \text{int}(93.75us/6.72us) = 13 \text{ frames max. per port} \]

The credit-based shaper operates on one or many outgoing queues per port in the bridge.

It guarantees “fairness” properties wrt. lower priority traffic than AVB traffic, i.e., it is guaranteed that bursts of AVB traffic will be interrupted and low priority non-AVB (standard Ethernet) traffic will be served.
TSN – Time-Sensitive Networking

802.1ASbt Timing and Synchronization: Enhancements and Performance Improvements

802.1Qbv Enhancements for Scheduled Traffic: a basic form of time-triggered communication

802.1Qbu Frame Preemption: a mechanism that allows to preempt a frame in transmit to intersperse another frame.

802.1Qca Path Control and Reservation: protocols and mechanisms to set up and manage the redundant communication paths in the network.

802.1CB Frame Replication and Elimination for Reliability: to eliminate redundant copies of frames transmitted over the redundant paths setup in 802.1Qca.

802.1Qcc – enhancements and improvements for stream reservation
TSN – Time-Sensitive Networking

802.1ASbt Timing and Synchronization: *Enhancements and Performance Improvements*

802.1Qbv Enhancements for Scheduled Traffic: a basic form of *time-triggered communication*

802.1Qbu Frame Preemption: a mechanism that allows to preempt a frame in transmit to intersperse another frame.

802.1Qca Path Control and Reservation: protocols and mechanisms to set up and *manage the redundant communication paths* in the network.

802.1CB Frame Replication and Elimination for Reliability: to *eliminate redundant copies of frames* transmitted over the redundant paths setup in 802.1Qca.

802.1Qcc – enhancements and improvements for stream reservation
802.1Qbv
Time-Aware Shaper

• The time-aware shaper defines a time-triggered paradigm on a per-class level (opposed to on a per-flow level).
  • Background:
    • The class of a frame is determined by the priority of the VLAN tag.
    • The field is three bits long, hence there are eight priorities.
    • Thus, it is typical that switches implement eight “logical queues” per output port of a switch.
  • It is planned that the time-aware shaper will allow to enable and to disable each of the queues based on a communication schedule.
  • The execution of the communication schedules in the switches (and potentially also end systems) is synchronized using IEEE 802.1AS.
TSN – Time-Sensitive Networks

802.1ASbt Timing and Synchronization: **Enhancements and Performance Improvements**

802.1Qbv Enhancements for Scheduled Traffic: a basic form of **time-triggered communication**

802.1Qbu Frame Preemption: a mechanism that allows to preempt a frame in transmit to intersperse another frame.

802.1Qca Path Control and Reservation: protocols and mechanisms to set up and **manage the redundant communication paths** in the network.

802.1CB Frame Replication and Elimination for Reliability: to **eliminate redundant copies of frames** transmitted over the redundant paths setup in 802.1Qca.

802.1Qcc – enhancements and improvements for stream reservation
The clock synchronization protocol is a classical master-slave protocol. The master is called the “grandmaster”. When the grandmaster fails, then a new grandmaster is elected. Issues with this mechanism have been reported by industry.
### Background: Industrial Need for FT Clock-Sync

#### Toolbox of Mechanisms

Comprehensive Toolbox of Mechanisms for Implementing Time and Safety Critical Communication systems

<table>
<thead>
<tr>
<th>Scheduled Traffic</th>
<th>Ultra low latency, Highly deterministic, QoS, Planning &amp; Flexibility issues, Adequate for most challenging applications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible Automotive / Industrial Control Traffic Class</td>
<td>Low latency, QoS, Flexible, Goal Adequate for the majority of control applications. Ongoing discussion in 802.1TSN: BLS? Peristaltic? Urgency based? Per ingress shaping?</td>
</tr>
<tr>
<td>Seamless Redundancy</td>
<td>Safety critical control.</td>
</tr>
<tr>
<td>Ingress Policing</td>
<td>Safety critical, Fault containment, Single point of failure.</td>
</tr>
<tr>
<td>Fault Tolerant Clock Sync</td>
<td>Safety critical, Fault containment.</td>
</tr>
<tr>
<td>Adequate support for reservations</td>
<td>Automotive requirements currently under discussion (=&gt; AAA2C)</td>
</tr>
</tbody>
</table>

---

Markus Jochim, General Motors Research IEEE 802.1 Plenary Session July 14 - 19, 2013 – Geneva, Switzerland

802.1ASbt Clock Synchronization
Proposals for Improvements

Primary Clock Source, e.g. GPS

Grand Master Clock (Primary)

Grand Master Clock (Backup)

Active Case: sends its own Sync (bSync).
Passive Case: detects Primary Sync (pSync) msg and only upon timeout, sends its own bSync. Often shorter hold-over time than Ethernet Stations.

Ethernet or other IEEE 802 Time Sensitive Networks (TSN)

"Architecture Design is Interface Design" [Kopetz]

Red Interface specifies the behavior of the FT Clock Generator as observed by the connecting bridges of the IEEE 802.1 network.

Internal behavior of the FT Clock Generator may (and most likely will) be much more complex than as observed at the interface.

Blue Interface specifies the behavior of the FT Clock Generator as observed by the FT Clock Consumers.
The red interface is different from the blue interfaces, because there is additional behavior introduced by the IEEE 802.1 network connecting the FT Clock Generator to the FT Clock Consumers.

Both, red and blue, interfaces need to be specified to enable the usage of a fault-tolerant timebase.
Example Realization

SAE AS6802 (“Time-Triggered Ethernet”) standardizes a fault-tolerant clock generator as depicted above.

It does so by combining the timing information of several “Synchronization Masters” in the switches, who implement a “Compression Master” functionality.

For the steady state operation mode, it looks a bit like in the following animations.
Mandatory elements of the interface description of a FT Clock Generator

*failure model*: description of failure mode, number, frequency, etc.

*precision*: worst-case difference of any two non-faulty clocks in the system

*accuracy*: worst-case difference of the clocks in the system relative to an external time reference

*startup time*: worst-case time after startup of the time sources until the system is synchronized (with given precision and/or accuracy)

*integration time*: worst-case time for a non-synchronized component in the system to become synchronized

*changeover time*: worst-case time for the components in the system to change from one time source to another one (e.g., in the case that the original time source fails)

*recovery time*: worst-case time for the synchronized timebase to recover after global synchronization loss
Conclusion

There is a native standardization body for Ethernet and it is the IEEE. In particular, IEEE 802.3 develops and maintains the Ethernet PHY and MAC standards, IEEE 802.1 develops and maintains bridging (aka switching) standards.

With AVB, the IEEE has moved Ethernet into the real-time applications domain.

With TSN, the IEEE moves Ethernet into the hard real-time applications domain and improves Ethernet’s robustness.

With the growing competences in the IEEE standards, products built on these standards increase their market potential.

Well-defined interfaces allow to re-use existing fault-tolerant clock-synchronization protocols.