IEEE 802.1 Audio/Video Bridging and Time-Sensitive Networking

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Outline

- General Overview
- Basic Technology
- TSN/VB Protocol Services
- Applications
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What is Time-Sensitive Networking?

- **Time-Sensitive Networking (TSN)** is a set of standards developed by the *Time-Sensitive Networking Task Group (IEEE 802.1)*
- Formed at November 2012 by renaming the existing *Audio/video Bridging Task Group* and continuing its work.
- Renamed as a result of extension of the working area of the standardization group.
- Define mechanisms for the time-sensitive transmission of data over Ethernet.

Standard Architecture

- IEEE 802.3
  - PHY layer and MAC layer of Ethernet
- IEEE 802.1
  - 802 LAN/MAN architecture
  - Internetworking among 802 LANs, MANs and wide area networks
  - 802 Link Security
  - 802 overall network management
  - Protocol layers above the MAC layers

AVB Task Group

- AVB task group
  - Formerly a part of “residential Ethernet” study group
  - Standardize protocol and mechanisms to improve the real time behavior of video/audio system
- “IEEE Standard for Local and Metropolitan Area Networks- ” (in 2011)
  - 802.1AS Timing and Synchronization for Timing-Sensitive Applications
  - 802.1Qat Stream Reservation protocol(SRP)
  - 802.1Qav Forwarding and Queuing Enhancements
  - 802.1BA lists of standards and definition of profiles fro AVB systems

TSN Task Group

- Core standards (currently working)
  - 802.1ASbt Timing and Synchronization
  - 802.1Qcc Stream Reservation Protocol
  - 802.1Qbv Enhancements for scheduled traffic
  - 802.1Qbu Frame Preemption
  - 802.1Qca Path control and Reservation
  - 802.1CB Frame Replication and Elimination for reliability

- Recommends using no more than 6-7 switches/hops to low delay

Target Markets

- Traffic Type
  - Best-effort (BE) traffic, low-priority traffic without timing and delivery guarantees
  - Rate constrained (RC) traffic, each flow has a bandwidth limit defined by two parameters: minimum inter-frame intervals and maximal frame size
  - Time-trigger (TT) traffic, each flow has a accurate time to be sent
- Markets
  - Originally video/audio markets
  - New markets of time-sensitive applications such as industrial control and automotive applications

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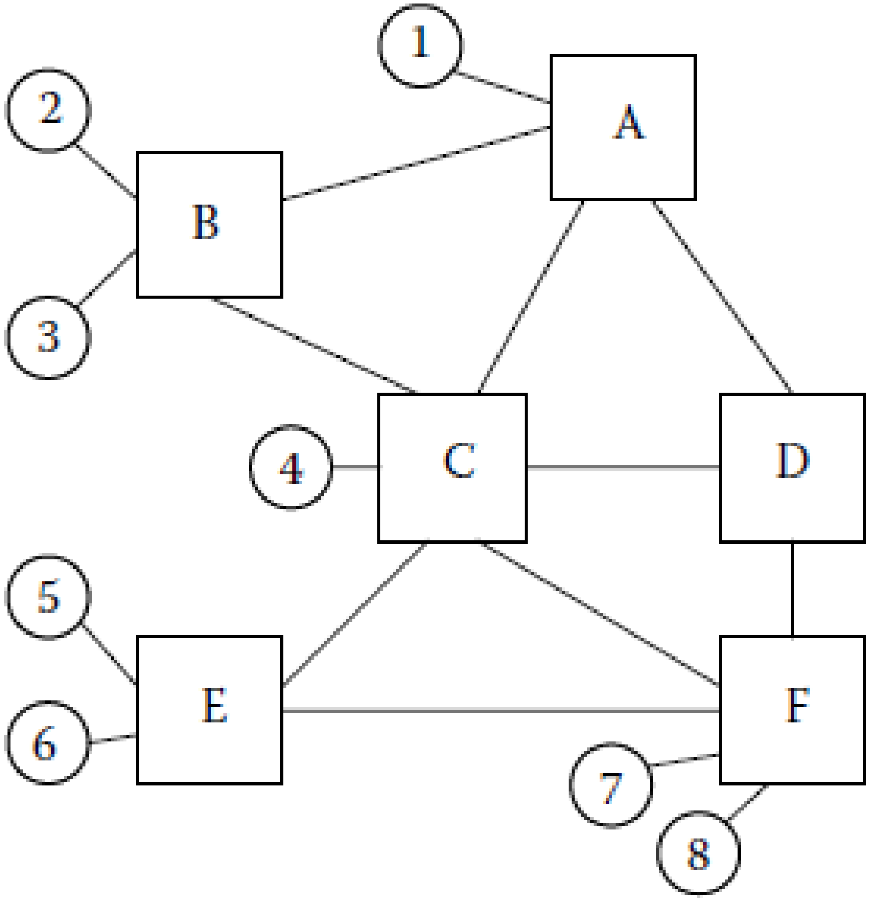
Physical Topology

- Switched Ethernet
  - End stations
  - Bridges (switch)
  - Physical ports
  - Ethernet Frame
- Bridge Functions
  - Switching: find a path from source to destination
  - Traffic shaping (traffic scheduling)



Ethernet Frame

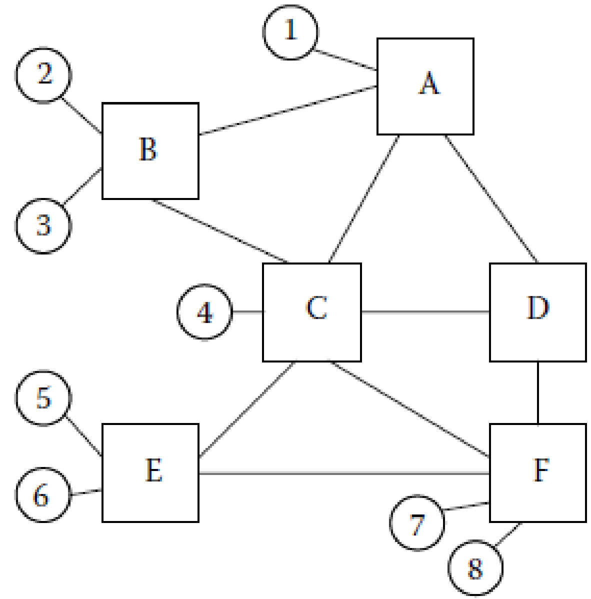
7B	1B	6B	6B	4B	2B	42B–1500B	4B	12B
Preamble	SOF	MAC destination	MAC source	802.1Q "VLAN" Tag	Ethertype/ length	Payload	FCS	IFG

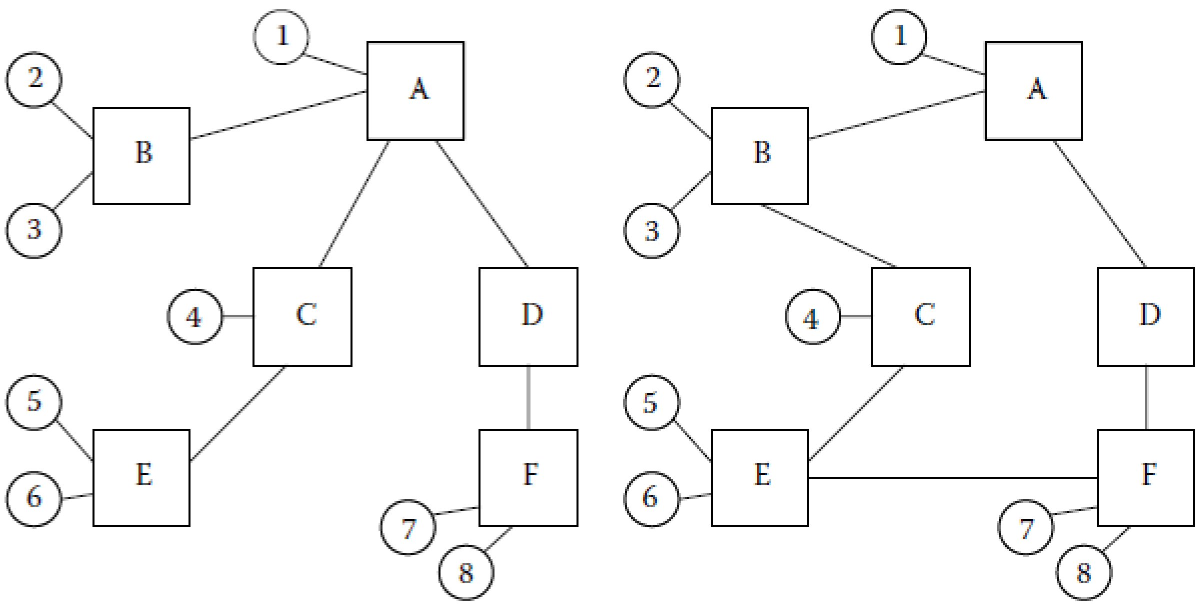
16 bits	3 bits	1 bit	12 bits
Tag protocol identifier	Priority code point	Drop eligible indicator	VLAN identifier

FIGURE 20.2 Structure of an Ethernet frame and detailed representation of the IEEE 802.1Q *VLAN* tag.

Switching

- Active topology
  - Spanning tree protocol
  - Shortest path bridging





(a) (b)

Traffic Shaping

- Traffic shaping
  - Each bridge decides how to schedule multiple packets serially

- Mechanisms
  - Best-effort traffic *“Priority Scheduling Algorithm”*
  - Rate Constraints traffic *“Credit based shaper”*
  - Time-trigger traffic “ Time aware shaper”

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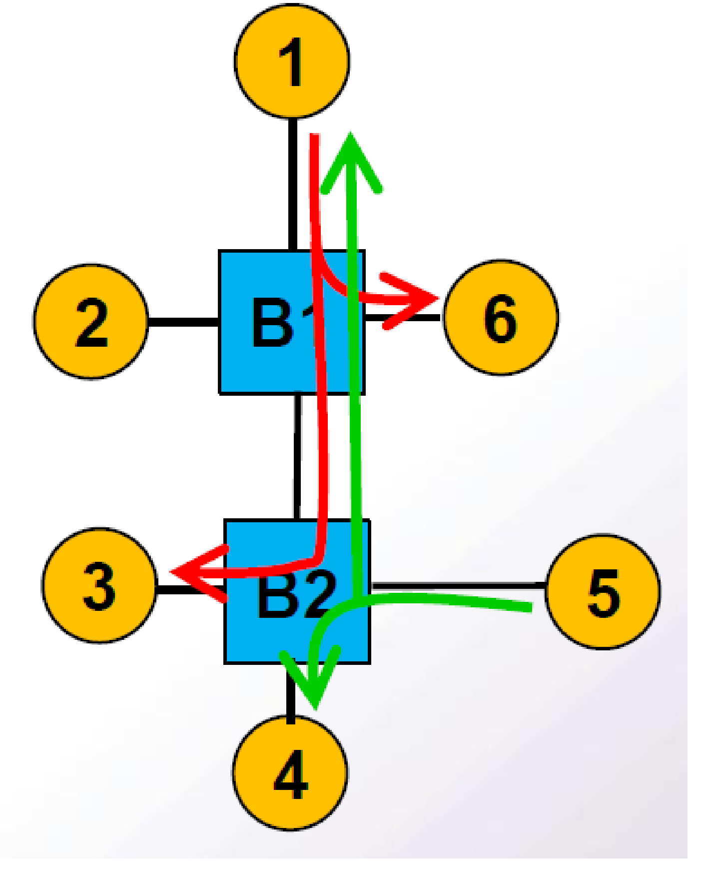
Time Sensitive Stream

- Examples
  - Node 1 is talker of a stream **X**
    received by listeners 6 and 3
  - Node 5 is talker of a stream **Y**
    received by listeners 1 and 4
- Strategies for time guarantee
  - reserve resource for each stream
  - Stream Reservation Protocol (SRP)
  - Traffic shaper (credit based shaper)

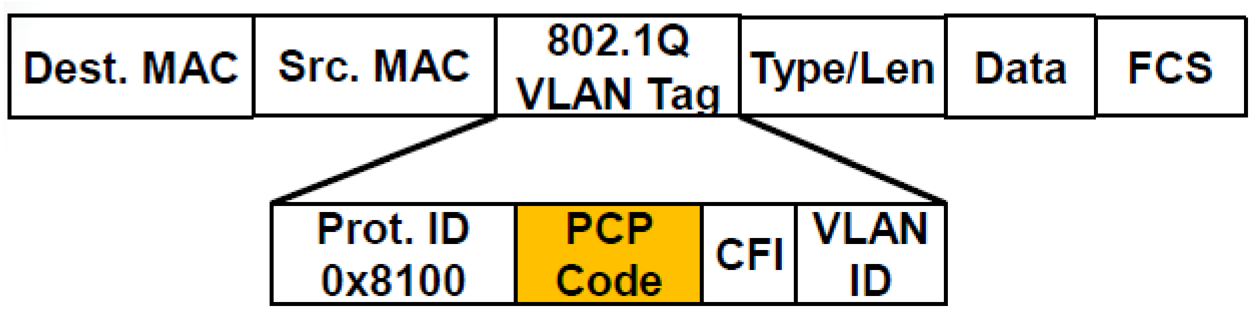


TSN/AVB Protocol Services

- Traffic shaper
  - Strict Priority algorithm
  - Credit based shaper
  - Time aware shaper
- Stream Reservation Protocol (SRP)
  - Register streams / reserve bandwidth
- Clock Synchronization Protocol
- Redundancy Management: proactive transmission of multiple copies without having to use retransmission for ensuring reliability and real-time

Strict Priority Algorithm

- No resource reservation between flow transmission
- Frames tagged with a 3 bit Priority Code Point value



- Bridge ports have between 1 and 8 outbound queues (1:1 mapping)
- Each outbound queue of a port has a traffic class number assigned (1:1 mapping)
- Traffic classes numbers range from 0 to N-1. (N = number of the ports outbound queues).

Strict Priority Algorithm (cont.)

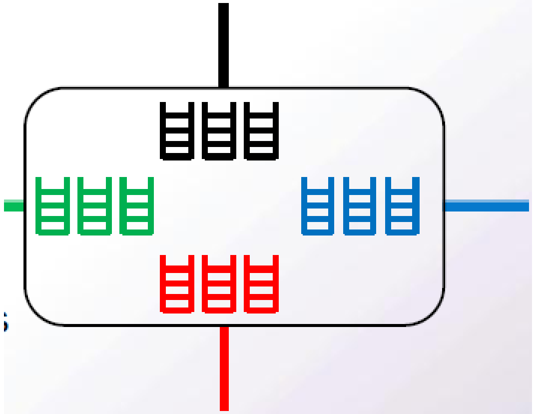
- Port is configured with a mapping: “PCP codes” to “Traffic Classes (queues)”.

Example:

PCP Code in Frame	0	1	2	3	4	5	6	7
Traffic class number	0	0	0	0	1	1	2	2

(Recommended mapping for 3 queues in cases where only strict priority scheduling is used)

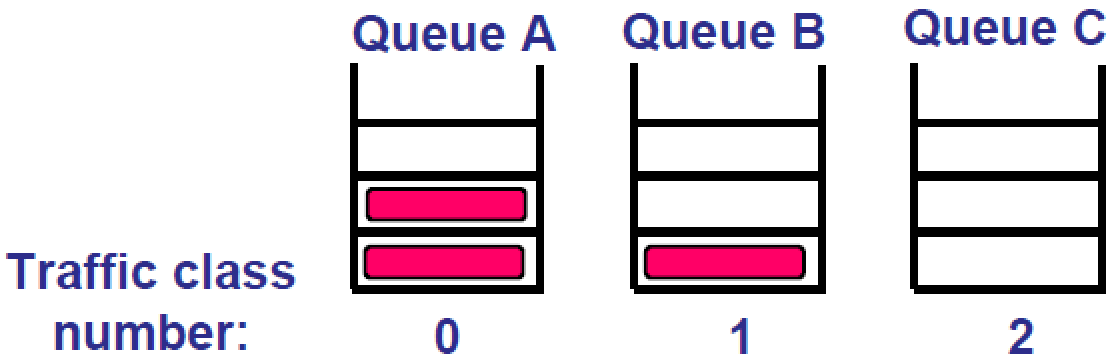
- The PCP values of a frame and the mapping will determine the traffic class (= queue into which frame will be placed).



4 Port Bridge with 3 out-bound queues per port

Strict Priority Algorithm (cont.)

- Strict Priority Algorithm:
  - Available for transmission = Queue contains one or more frames
- Next frame for transmission:
  - From queue with the highest traffic class number that has a frame available for transmission.



- Note: For other algorithms, the fact that a queue contains a frame does not automatically imply that the frame is available for transmission.

Credit Based Shaper

- To improve fairness between flows
- Rules
  - Separate queue for Class A and Class B
  - Separate credit variable for Class A queue and Class B queue
  - When no frame in the queue, credit is set to 0
  - A queue is available to transmit when credit is nonnegative
  - Credit increased by *idleSlope* when there is a least a frame in the queue
  - Credit decreased by sendSlope when a frame is transmitted

Credit Based Shaper (cont.)

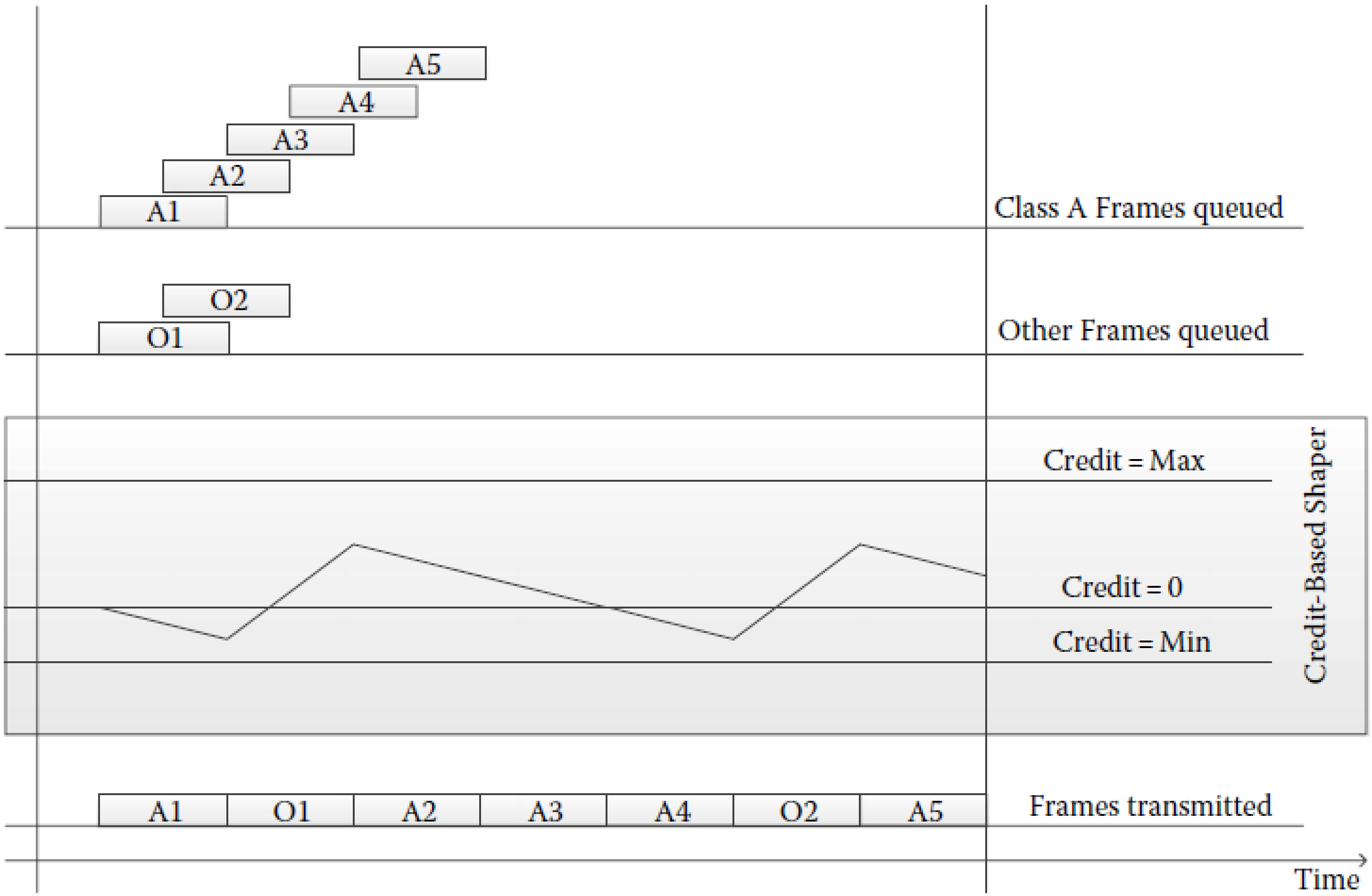


FIGURE 20.7 Example execution trace of traffic shaped according to the credit-based shaper.

Credit Based Shaper (cont.)

- Advantages
  - Fairer scheduling to low-priority packets
  - Smooths out the traffic flow to greatly reduce the possibility of dropped packets due to congestion
- Disadvantages
  - Average delay is actually increased
  - Delay can be up to 250us per hop
  - Delay too high for control applications

Time Aware Shaper

- Control system applications
  - Typically closed-loop, fixed cycle
  - 30 us to several ms, typical 125 us
- Rules (in discussion)
  - One option is to reserve bandwidth during the fixed time periodically
  - Use Time-aware signal
  - When TA is enabled, time-aware frames transmitted; when TA is disabled, frames from other queues may transmit

Time Aware Shaper (cont.)

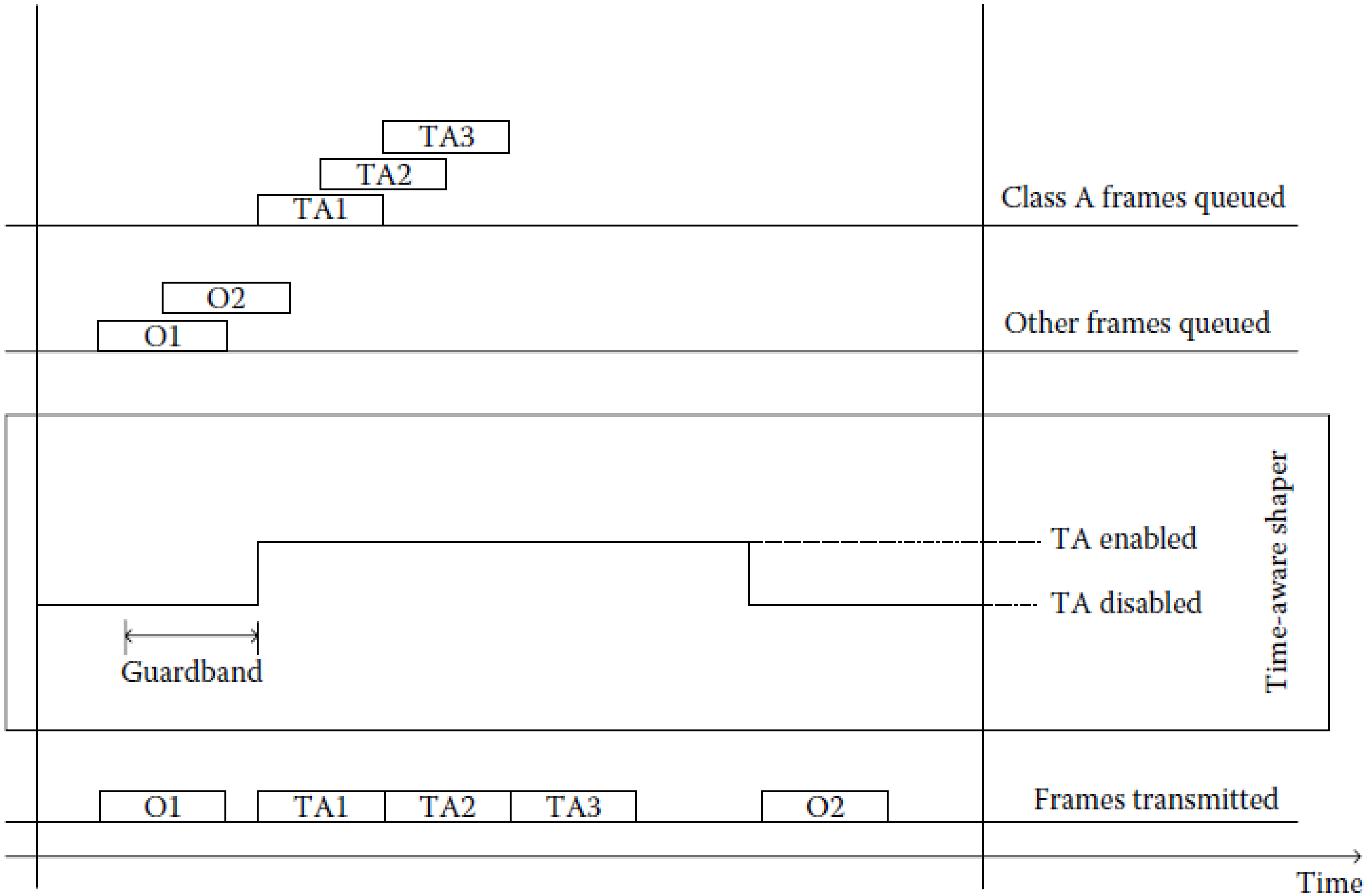
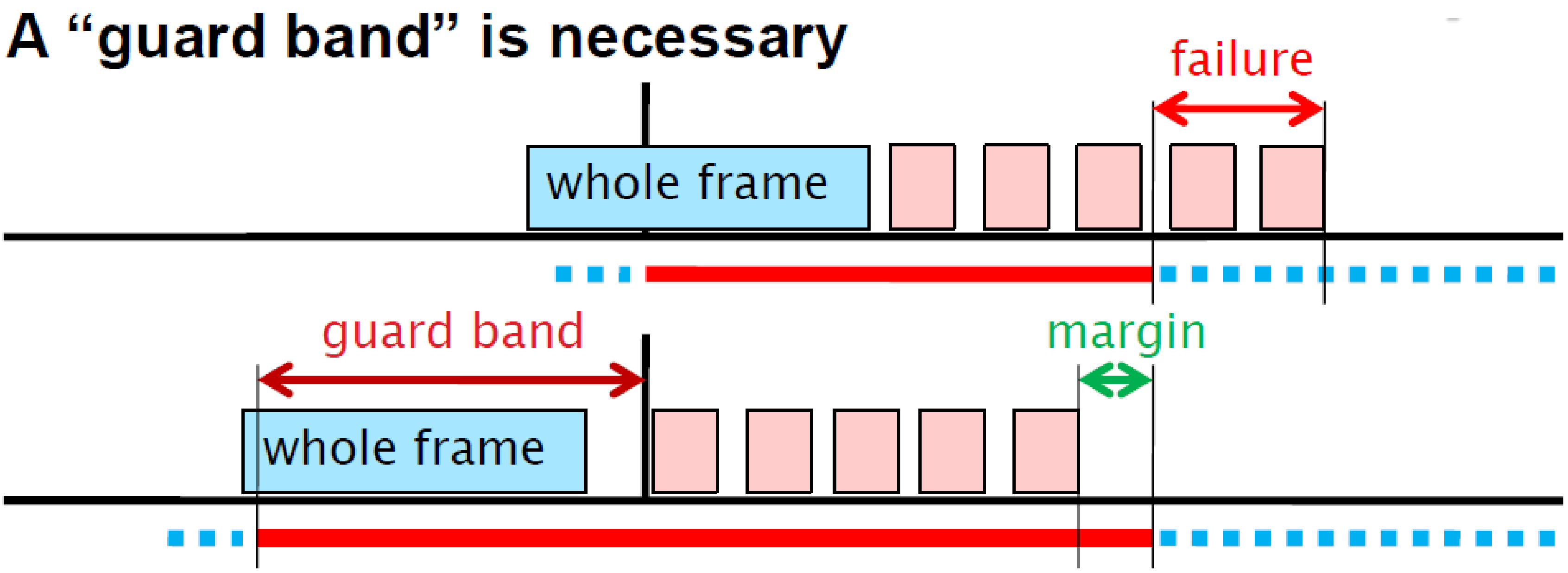


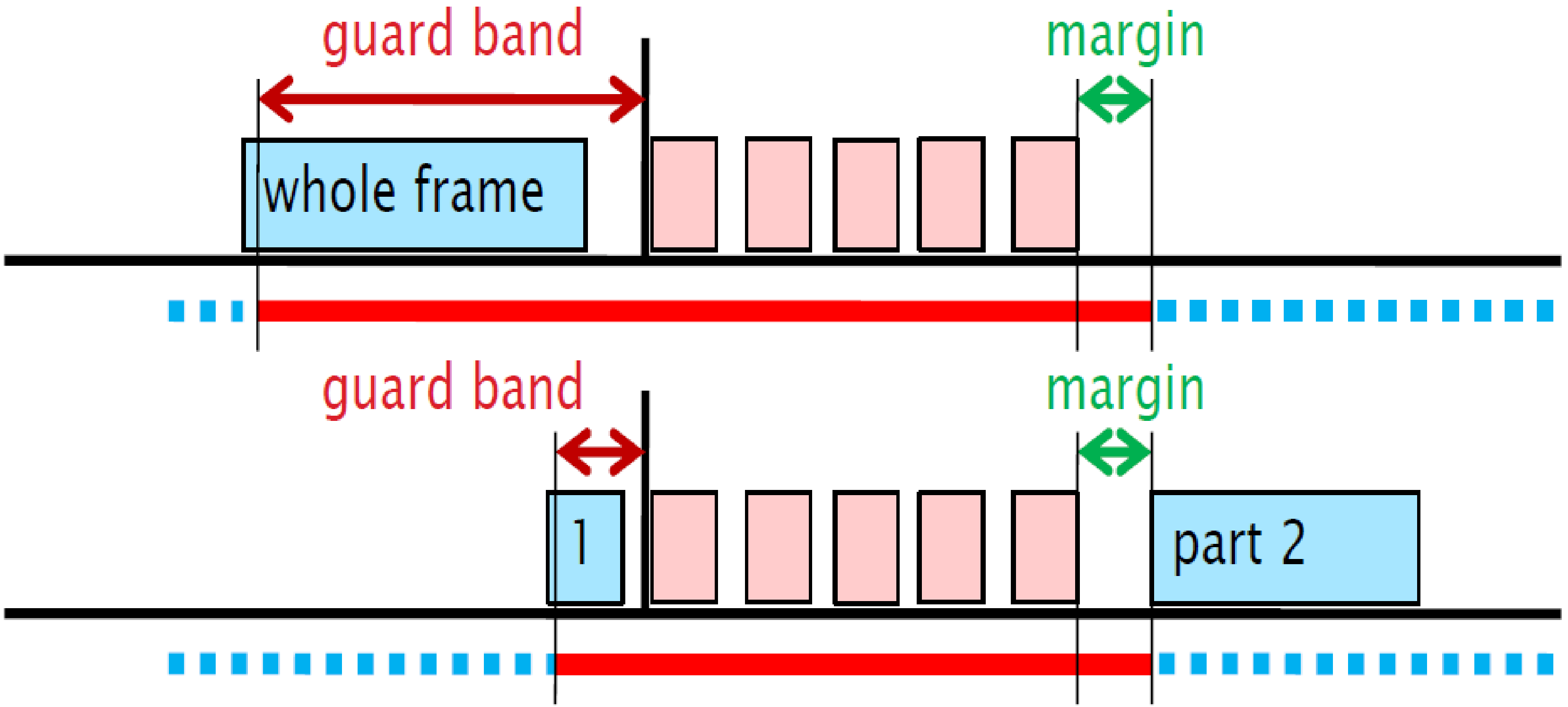
FIGURE 20.8 Example execution trace of traffic shaped according to the time-aware shaper.

Time Aware Shaper Issue



- A non-TA frame must end before TS starts
- Bring resource waste if the guard band is idle

Time Aware Shaper Premption



- A frame is divided into fragment; resume transmission after TA frames transmit
- Guard band can be narrower with TA preemption

Stream Reservation Protocol (SRP)

- Priorities and Shaping must work with SRP together
- AVB SRP use existing MRP
- Multiple registration protocol (MRP)
  - Defined in 802.1Q
  - General framework for stream registration
  - Used for switch/bridge/other devices to register and de-register attribute values
  - Applications: MSRP, MVRP, MMRP (S – reservation, V – VLAN, M – multicast)

Register A Stream

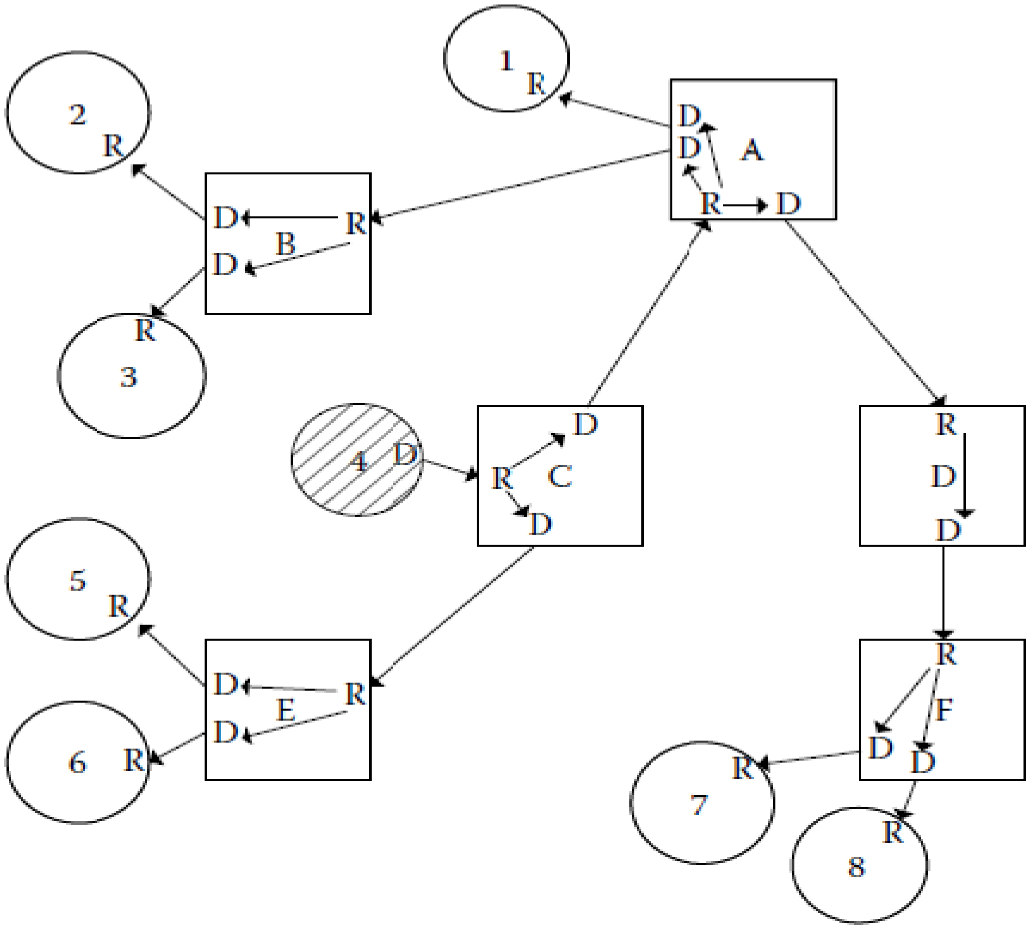


FIGURE 20.4 Example of MRP declaration/registrations as they propagate through the network.

Fields of Talker Advertise Message (i.e., registration message)

- Stream ID
  - talker MAC address + 16 stream id
- Data Frame Parameters
  - Destination MAC address + VLAN id
- Traffic Specification (Tspec)
  - MaxFrameSize
  - MaxIntervalFrame: max. number of frames in a measurement interval (e.g., 125 us, 250 us)
- Priority And Rank
- Accumulated Latency

Stream Bandwidth Preservation

- Two stream reservation classes: Class A & Class B
  - Measurement intervals CMI (measurement interval): Class A 125 us: Class B 250 us
- Required Bandwidth

$$BW = \frac{Tspec_{MaxIntervalFrames}}{CMI} \times 8 \times (Tspec_{MaxFrameSize} + Overhead_{mediaSpecific})$$

- During stream registration SRP checks

Sufficient resources? for a stream of desired class/ listeners?

Yes? = Stream is OK'd. NO? = Stream Preservation is not accepted.

Talker Advertise and Listener Ready

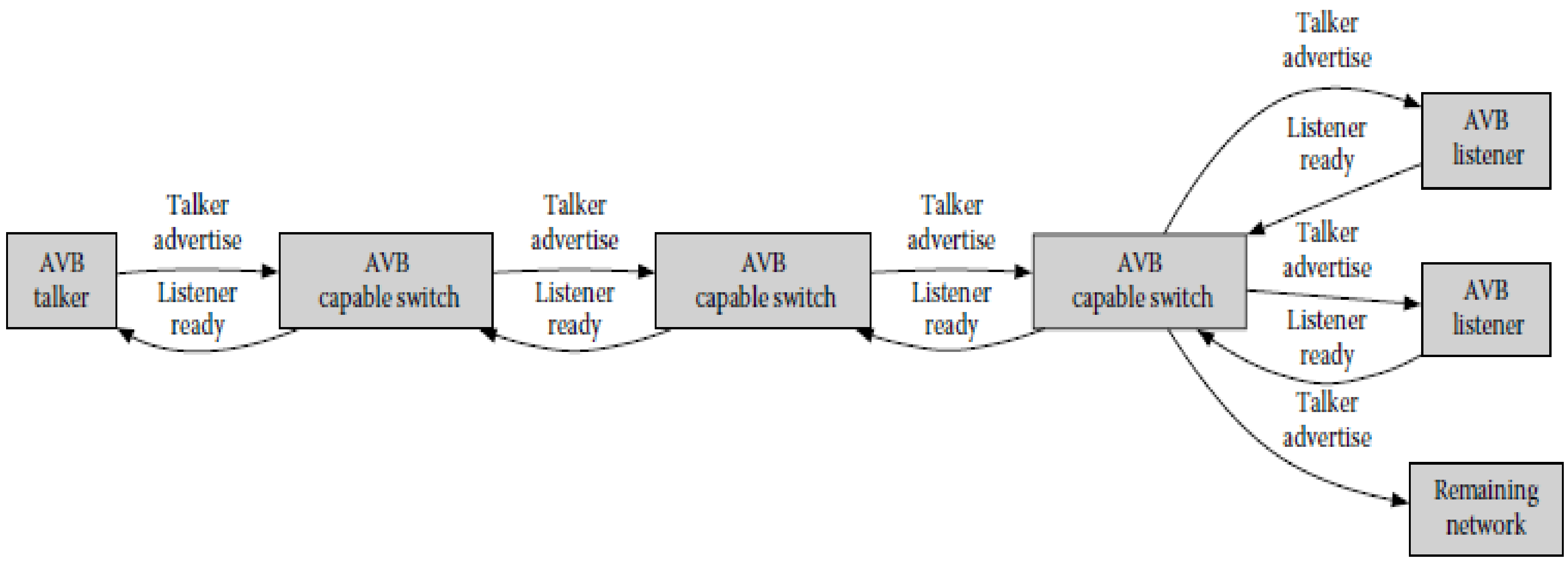


FIGURE 20.6 Example of talker advertise and listener ready propagation through an AVB network.

Clock Synchronization Protocol

- Select a grandmaster from multiple grandmasters
  - Receivers compare by “announce message”
- Periodically synchronize to the grandmaster clock
  - Distribute local time” preciseOrigininTimeStamp”
  - “Sync message” and “Follow up message”
- Measure the forwarding delays in the bridges
  - Bridge delay (Transmission time - Reception time)
- Measure the communication delays
  - Bridge A: t1-→ C: t2; C: t3--→A:t4
  - Communication delay [(t4-t1)-(t3-t2)]/2

Redundancy Management

- Retransmission unacceptable in real-time networks
- Redundancy management (in discussion)
  - Redundant communication paths
  - Multiple copies with the same sequence number
  - Eliminate redundant copies by sequence number

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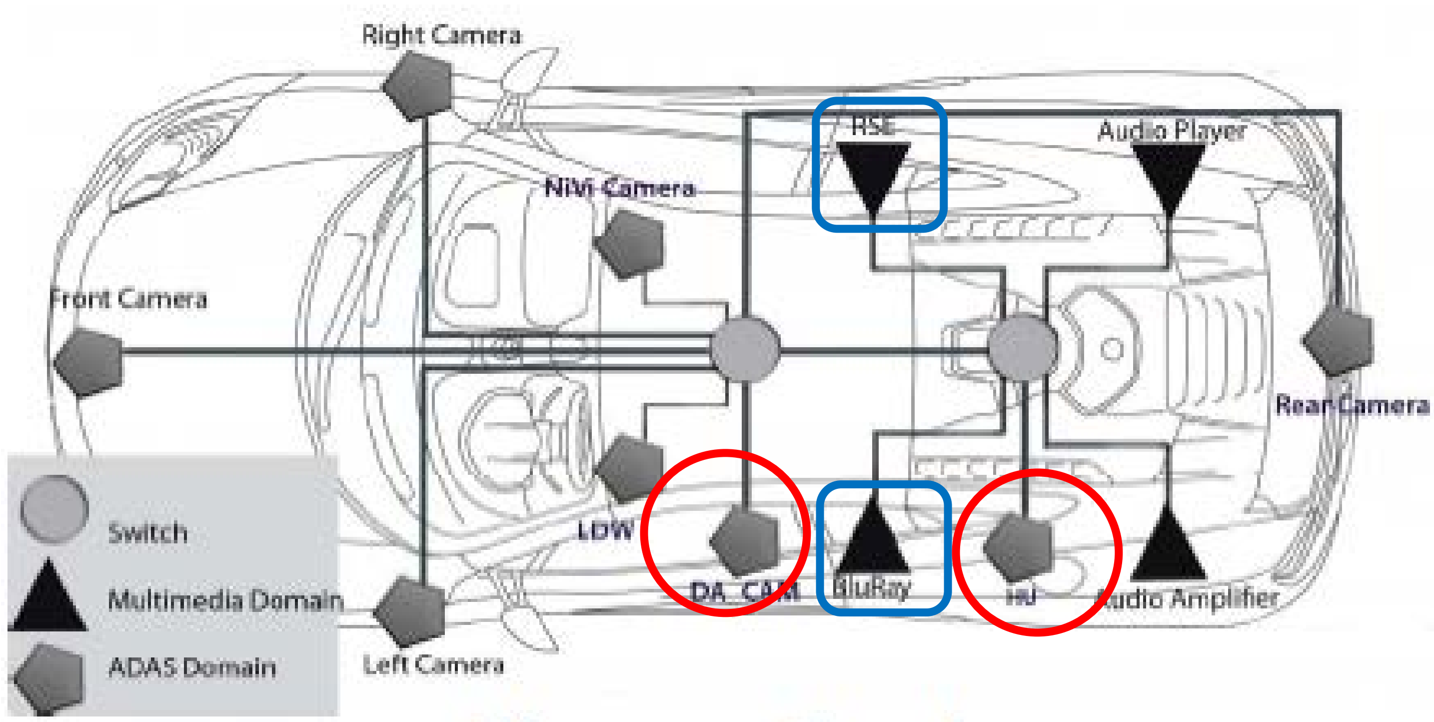
AVB in Advanced Driver Assistance System



G. Alderisi, G. Iannizzotto, and L. Lo Bello. Towards IEEE 802.1 Ethernet AVB for advanced driver assistance systems: A preliminary assessment. *IEEE Conference on Emerging Technologies and Factory Automation (ETFA)*, Krakow, Poland, September 2012.

Traffic model / AVB priority

Type	Bandwidth [Mbps]	Appl.Payload [Byte]	Service rate [ms]	AVB Priority
Cameras	32.75	910	1.11	AVB SR Class A
LDW/TSR camera	13.10	910	0.555	AVB SR Class A
DA-Cam Video traffic				
Single flow (Case A)	6.55	910	1.11	AVB SR Class A
Aggregated flow (Case B)	32.76	910	0.22	
DA-Cam Warning traffic	0.016	100	50	AVB SR Class A
BluRay	40	1400	0.28	AVB SR Class B
Audio	8	1400	1.4	AVB SR Class B

Table 1 – Characteristics of Traffic Model and configured traffic/priority classes

Simulation Results

Traffic type	Latency [ms]				Jitter [μs]			
	Case A		Case B		Case A		Case B	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Cameras	0.321	0.487	0.333	0.487	1.45	54	6.02	81
LDW/TSR camera	0.365	0.569	0.385	0.569	555	881	555	960
DA-Cam	0.238	0.238	0.242	0.242	0	0	0	0
Navigation warnings	0.098	0.170	0.105	0.180	0.52	6.2	0.62	7.8
BluRay	0.239	0.239	0.239	0.239	0	0	0	0
Audio	0.239	0.239	0.239	0.239	0	0	0	0

Table 3: Mean and maximum latency and jitter of the Ethernet frames for every traffic class.

Traffic type	Latency [ms]				Jitter [μs]			
	Case A		Case B		Case A		Case B	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Cameras	32.68	32.68	32.43	32.43	2.80	81	2.86	135
LDW/TSR camera	16.50	16.50	16.51	16.51	6.24	78	7.6	118
DA-Cam	32.41	32.41	32.43	32.43	0	0	0	0

Table 2: Mean and maximum latency and jitter values for the ADAS video frames

	Workload (Mbps)		Throughput (Mbps)	
	Case A	Case B	Case A	Case B
Switch 1	57.64	87.78	57.64	87.78
Switch2	58.27	87.49	58.27	87.49

Table 4: Switch workload and throughput

Simulation Results Analysis

- Warning messages latency is less than standardization (0.5 ms)
- Camera traffic less than 33ms (45ms)
- LDW/TSR delay less than 16.55ms (22.5ms)
- No packet loss

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- TSN history
  - Extend to wider application area
- TSN protocols
  - Based on AVB/Under standardization
  - Extend from reserving bandwidth to minumize latency
  - Extend from credit based shaper to time aware shaper
- Potential Applications
  - Industrial automation
  - Automotive applications

Credit

- AAA2C Discussion Topic: Type of Traffic in AVB 2, Michael Johas Teener, Markus Jochim