AN OVERVIEW ON A RISK-AVERSE INTRODUCTION OF TSN FEATURES IN AUTOMOTIVE NETWORKS

OCTOBER 12, 2021, ONLINE
802.1 TSN - P802.1DG CALL

October 12, 2021
K. Budweiser, BMW Group

BMW GROUP THE NEXT 100 YEARS

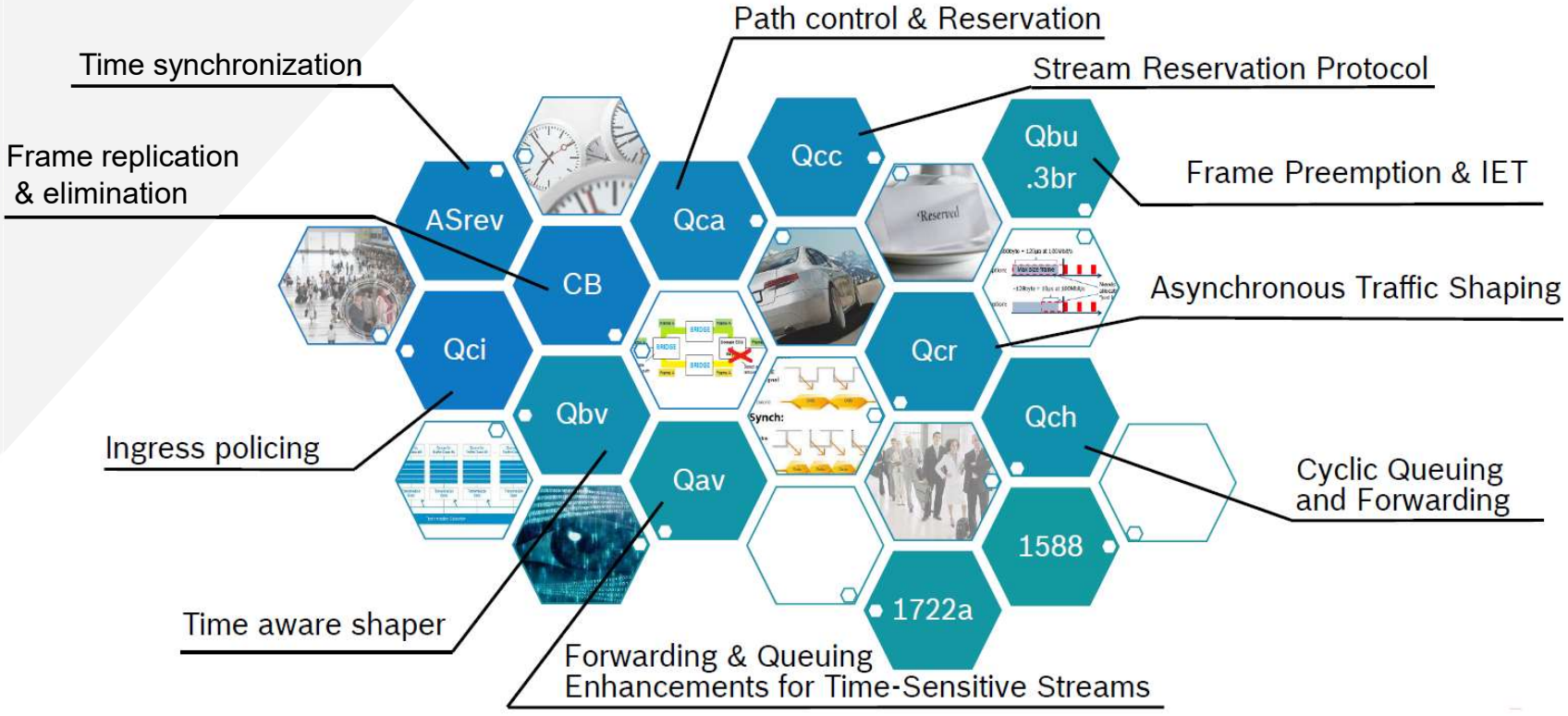
Rolls-Royce Motor Cars Limited

AGENDA.

- Introduction
- On Selected TSN Features
- Combination of TSN Features
- Best Practice
- Towards a Risk-Averse Introduction of TSN

OVERVIEW OF THE MOST FAMOUS TSN STANDARDS INTRODUCTION, DEFINITIONS AND FUNCTIONS.

The TSN Standards provide a tool-set that can be used to tackle various different problems.



AGENDA.

- Introduction
- **On Selected TSN Features**
- Combination of TSN Features
- Best Practice
- Towards a Risk-Averse Introduction of TSN

BASIC OPERATION OF THE MOST FAMOUS FEATURES. TIME SYNCHRONIZATION.

- Two messages: Sync- and FollowUp-message
- pOT (preciseOriginTimestamp: Instance in time when the time-grandmaster sent a Sync-message
- corr (correctionTime): accounts for the elapsed time between pOT and forwarding the Sync-message
- correctionTime calculation at TAS_k:

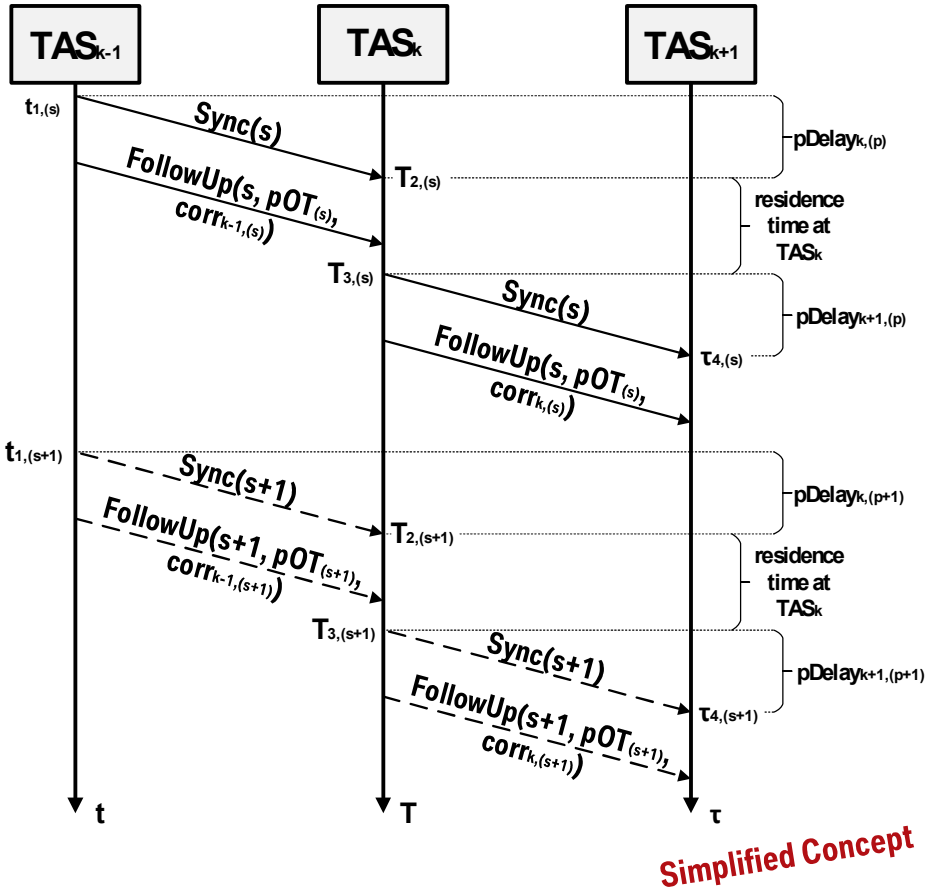
$$corr_{k,(s)} = \underbrace{corr_{k-1,(s)}}_{\text{previous correctionTime}} + pDelay_{k,(p)} + \underbrace{\left(T_{3,(s)} - T_{2,(s)}\right)}_{\text{residence time}}$$

- Construction of reference time-tuple $\tau_{4,(s)}$ and $\tau'(\tau_{4,(s)})$ at TAS_{k+1}:

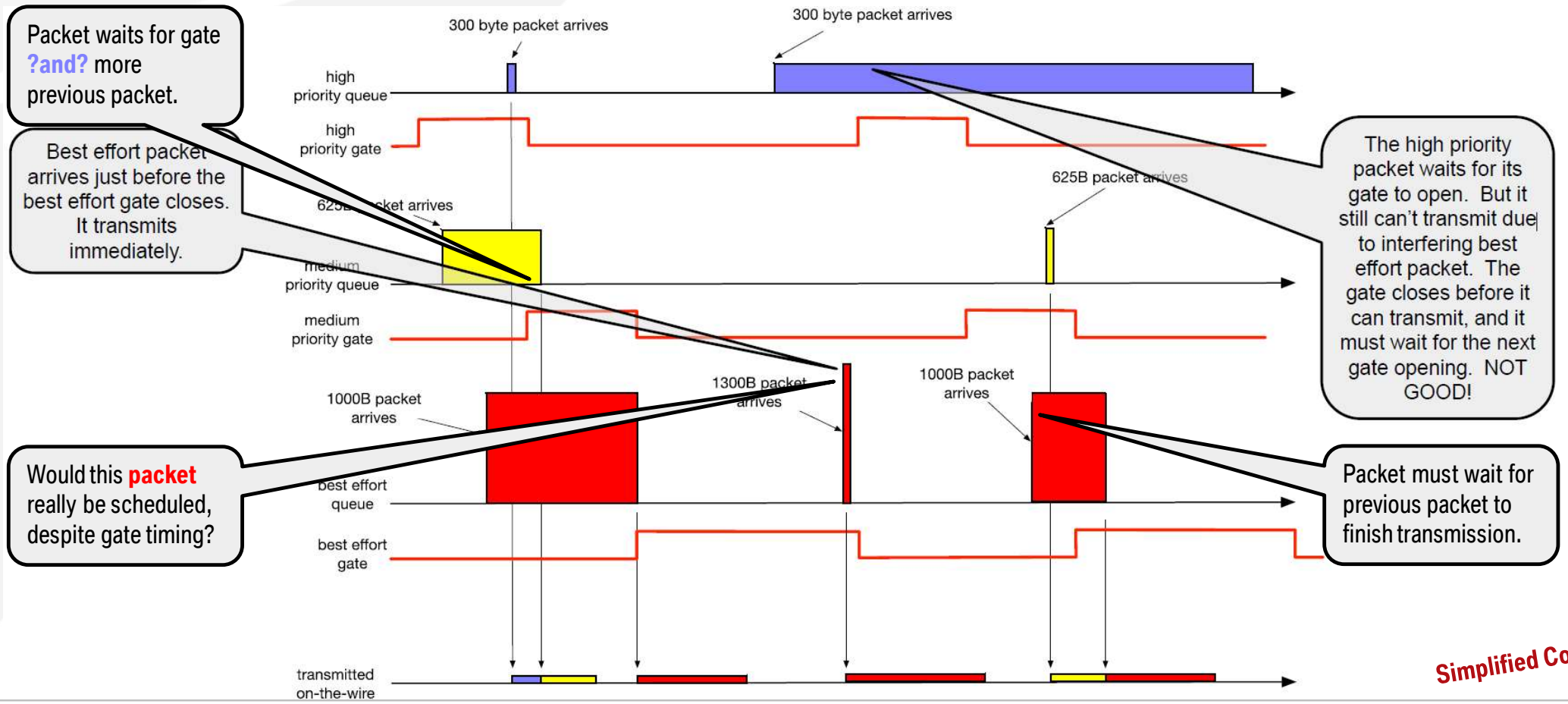
$$\left(\tau_{4,(s)}, \tau'\left(\tau_{4,(s)}\right) = pOT_{(s)} + corr_{k,(s)} + pDelay_{k+1,(p)}\right)$$

- Synchronized time $\tau'(\tau)$ at TAS_{k+1}:

$$\tau'(\tau) = \underbrace{\tau'\left(\tau_{4,(s)}\right)}_{\text{reference}} + \underbrace{\left(\tau - \tau_{4,(s)}\right)}_{\text{elapsed time}}$$

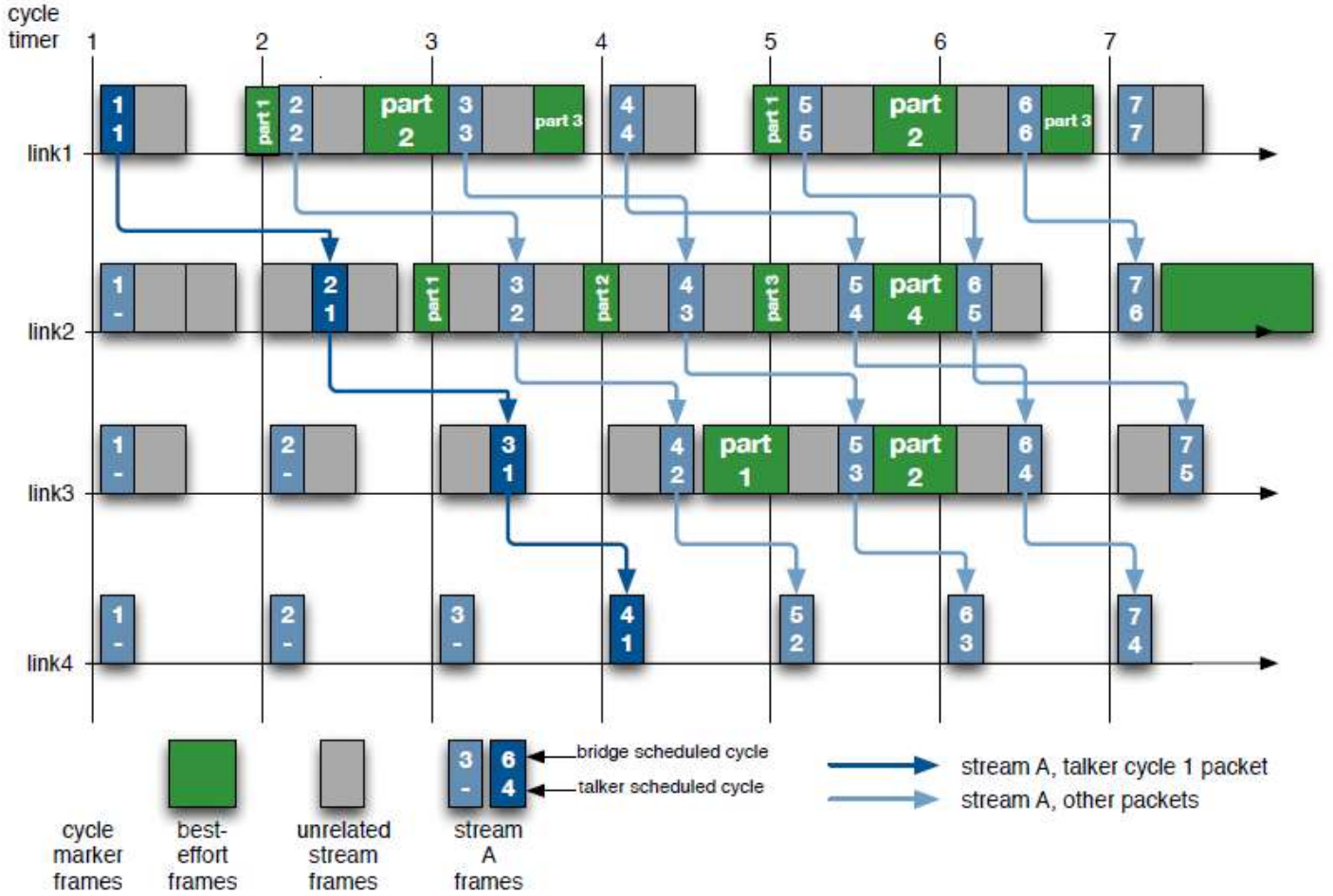


BASIC OPERATION OF THE MOST FAMOUS SHAPERS. THE TIME-AWARE SHAPER IEEE802.1QBV.



Simplified Concept

BASIC OPERATION OF THE MOST FAMOUS SHAPERS. CYCLIC QUEUING IEEE802.1QCH (1).



Simplified Concept

https://www.ieee802.org/1/files/public/docs2014/new-tsn-mjt-peristaltic-shaper-0114.pdf

BASIC OPERATION OF THE MOST FAMOUS SHAPERS. CYCLIC QUEUING IEEE802.1QCH (2).

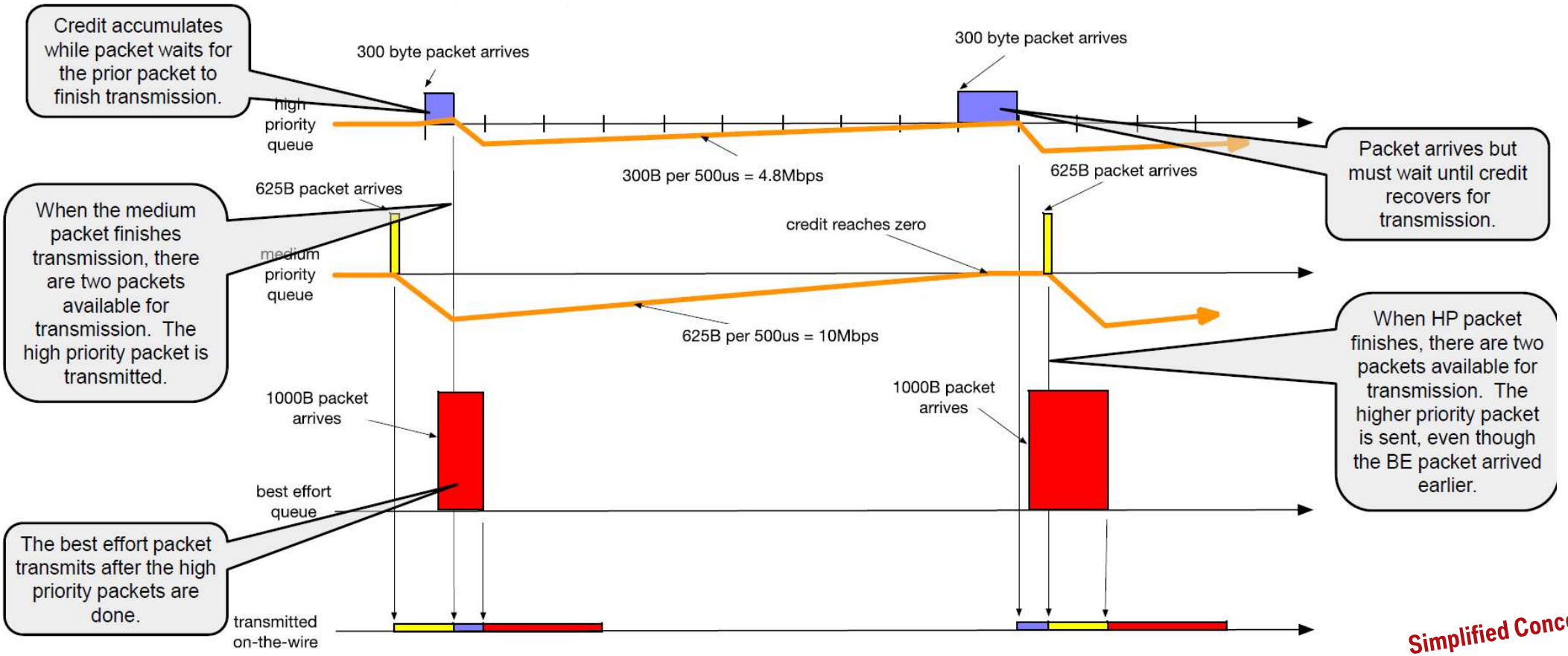
What is needed?

- IEEE 802.1AS (for a common notion of time in the network)
- EEE 802.1Qbv (to install time gates & and enforce cycle times)
- IEEE 802.1Qci (for redirection of incoming frames to certain gates)

What is not included in the Standard?

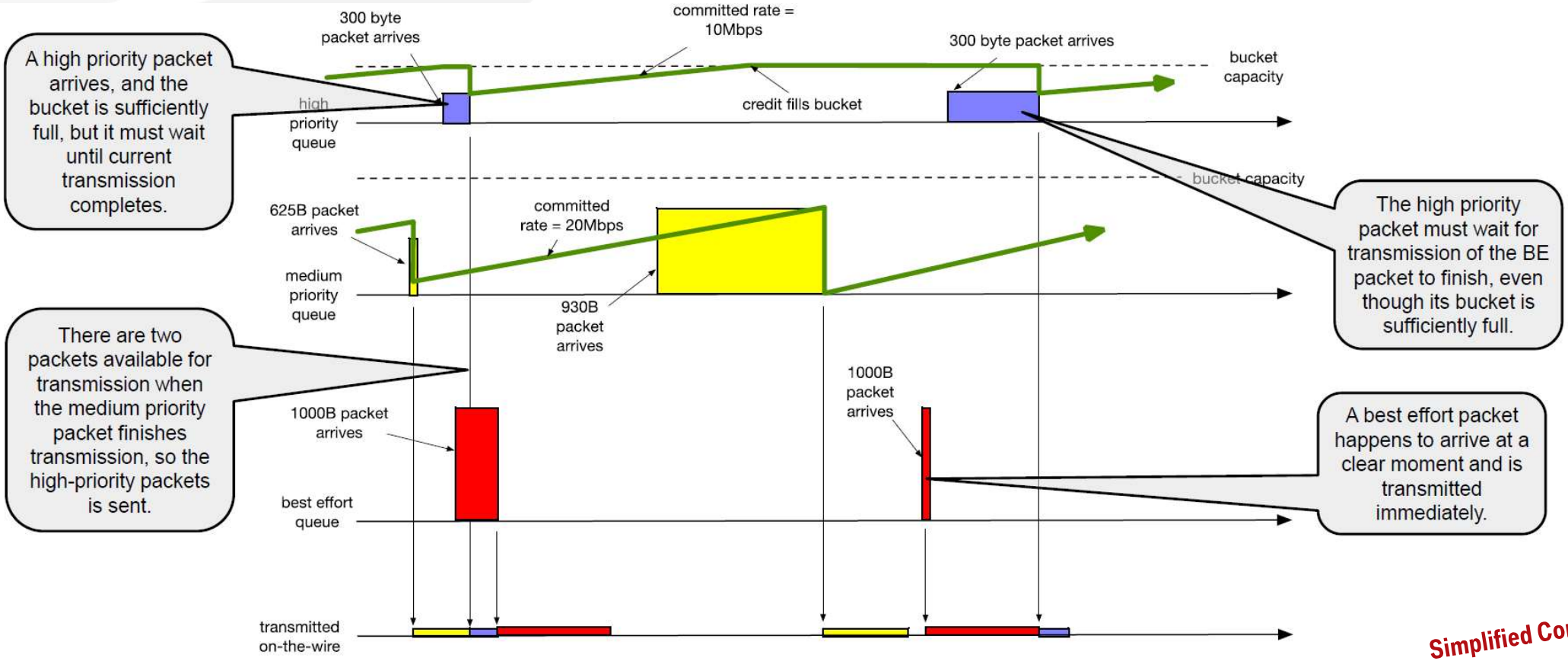
- Generation/Consumption of data in the application layers synchronized to the cyclic queuing and forwarding process
  - this demands **time-synchronized applications** and **potentially realtime-capable operating systems**

BASIC OPERATION OF THE MOST FAMOUS SHAPERS. THE CREDIT-BASED SHAPER IEEE802.1QAV.



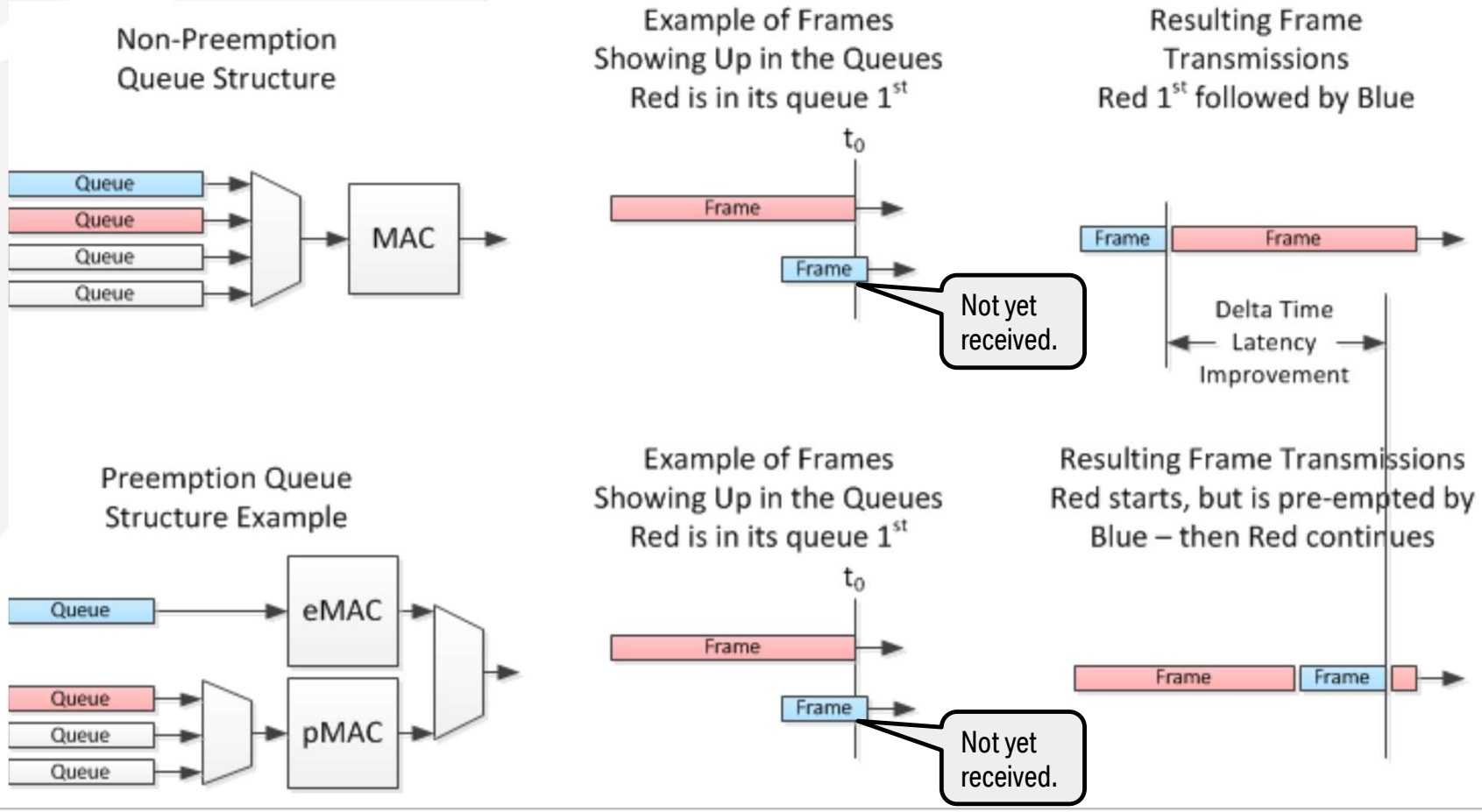
Simplified Concept

BASIC OPERATION OF THE MOST FAMOUS SHAPERS. THE ASYNCHRONOUS SHAPER IEEE802.1QCR.



Simplified Concept

BASIC OPERATION OF THE MOST FAMOUS FEATURES. PREEMPTION & INTERSPERSING EXPRESS TRAFFIC IEEE802.1QBU & 3.BR.



Simplified Concept

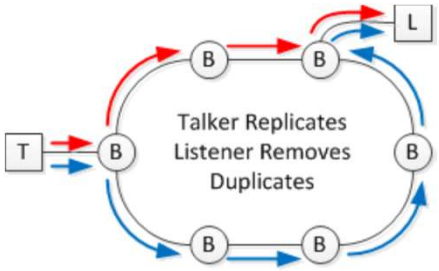
https://standards.ieee.org/content/dam/ieee-standards/standards/web/documents/presentations/d2-08_avnu_ieee-802.1-tsn_standards_overview_and_update_v2.pdf

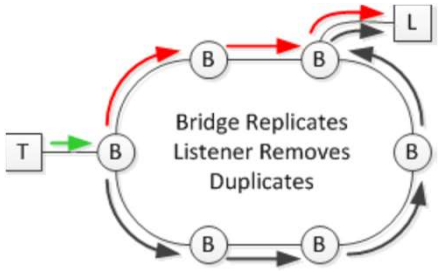
BASIC OPERATION OF THE MOST FAMOUS FEATURES. FRAME REPLICATION AND ELIMINATION IEEE802.1CB.

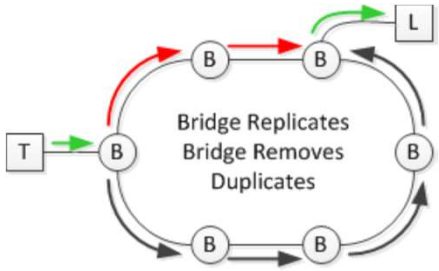
IEEE 802.1CB is the TSN standard for **Seamless Redundancy**, supporting zero recovery time from lost frames or hard errors.

Lessons Learned:

- IEEE 802.1CB provides **no safety metric** that can be used by functional safety engineers.
- Sending twice is almost as efficient as IEEE 802.1CB to prevent soft errors.
  (see https://www.ieee802.org/1/files/public/docs2020/dg-pannell-PracticalUseCasesForEthernetRedundancy-0920-v2.pdf).
- To mitigate hard errors **true redundancy** is required. True redundancy is, however, very expensive and most likely a total over-kill. A **fallback plane is way more favorable than CB**.







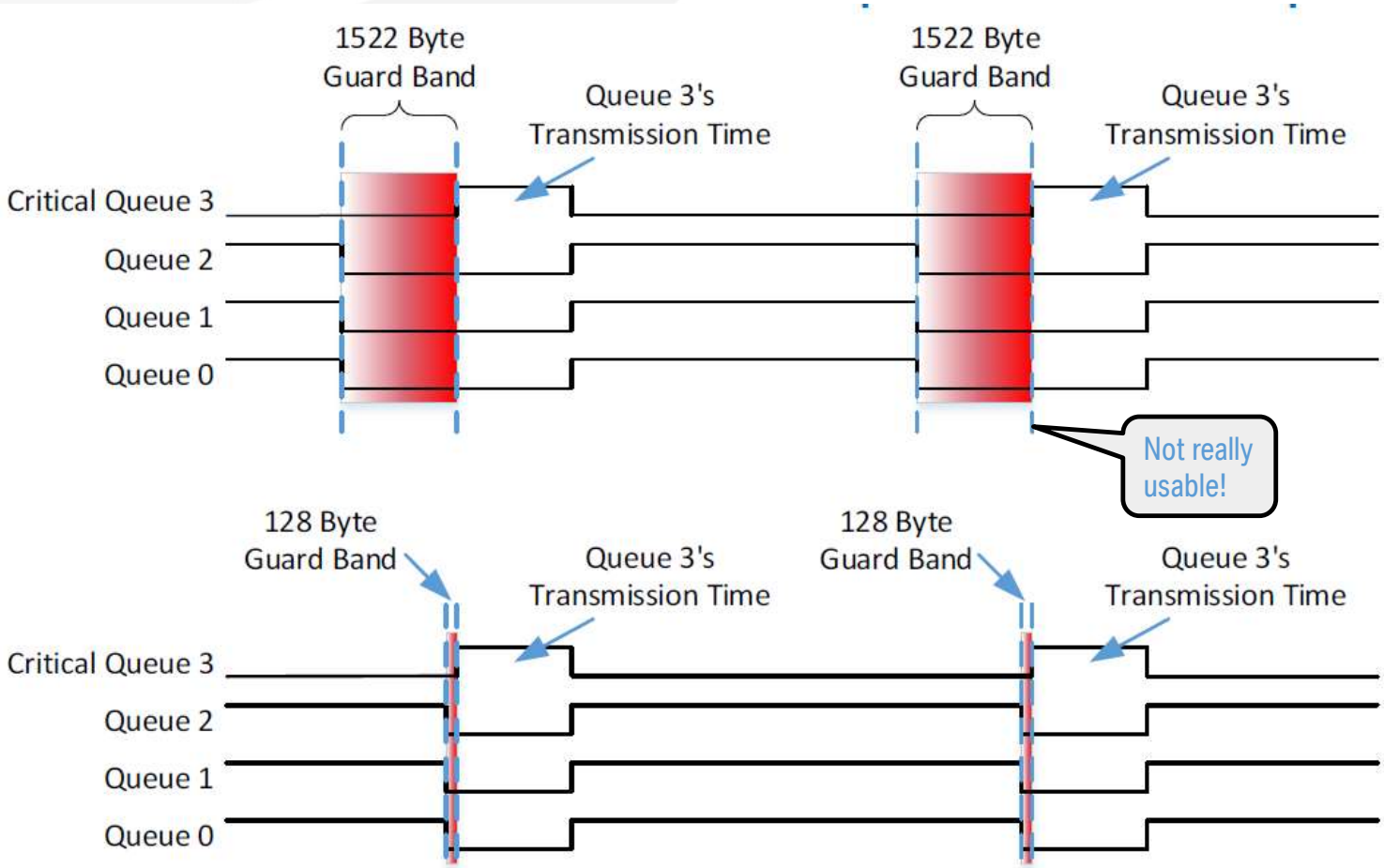
Simplified Concept

https://standards.ieee.org/content/dam/ieee-standards/standards/web/documents/presentations/d2-08_avnu_ieee-802.1-tsn_standards_overview_and_update_v2.pdf

AGENDA.

- Introduction
- On Selected TSN Features
- **Combination of TSN Features**
- Best Practice
- Towards a Risk-Averse Introduction of TSN

BASIC OPERATION OF THE MOST FAMOUS FEATURES. COMBINATION OF PREEMPTION & TAS FOR HIGHER UTILIZATION.



The Qbv Standard allows non-critical frames to be transmitted in the Guard Band, but only if they complete before the end of the Guard Band. This greatly limits utility of this time.

With Preemption ALL the time up to the start of the Guard Band can be used by non-critical frames. A preempted frame then continues after it's Queue re-opens.

Simplified Concept

https://standards.ieee.org/content/dam/ieee-standards/standards/web/documents/other/d2-03_pannell_increasing_network_efficiency_by_combining_ethernet_tsn_standards.pdf

AGENDA.

- Introduction
- On Selected TSN Features
- Combination of TSN Features
- **Best Practice**
- Towards a Risk-Averse Introduction of TSN

BEST PRACTICE.
PANNELL'S DISCUSSION ON TSN.

The Choice of the right TSN features is a delicate issue. Some sound practices can be found here:

Don Pannell, NXP:

– https://www.ieee802.org/1/files/public/docs2020/dg-pannell-ChoosingTheRightTSNToolsToMeetABoundedLatency-0920-v2.pdf

– https://www.allaboutcircuits.com/industry-articles/choosing-the-right-tsn-tools-to-meet-a-bounded-latency/

However, note that the goal is not to use all TSN Features!

AGENDA.

- Introduction
- On Selected TSN Features
- Combination of TSN Features
- Best Practice
- **Towards a Risk-Averse Introduction of TSN**

SOME TSN FACTS AND IMPLICATION OF CARELESS USAGE. STATE OF THE UNION.

- Many TSN features (.1CB, Qbu &.3br, Qbv,…) require **E2E-support of all network elements**
  - TSN has the **potential to limit the number of available semiconductors**
  - TSN requires strict **coordination of semiconductor selection** of every ECU
- Some **TSN features have dependencies** to others, the standards need to address to resolve them
  (see https://www.ieee802.org/802_tutorials/2015-03)
- Many TSN features are **not yet supported in AUTOSAR**
  - Currently, AR supports prioritization, some shaping and an “optimized” time synch
- New **data models** with **binding/reasonable timings** are needed to **derive TSN configurations,** otherwise **automatic configuration is impossible**
- New **TSN features must be qualified** beforehand
  - AVnu test specs currently covers 1 “TSN” features (Qbv), TC11 started to look at TSN
- TSN **with dynamic network configuration** à la **YANG** requires a very different holistic **testing approach,** as small communication changes may cause vast TSN re-configurations
  - TSN configuration should be **static** or provide some **over-provision** to avoid **”total re-tests”**
- Some TSN Feature are easier to implement, maintain and test than others
  - Gen. 1 TSN features (often referred to as AVB) are **mature, testable** and **do not have dependencies** to other 802.1 IEEE Standards like MACsec
  - Simulation shows that **AVB features** seem to be **sufficient** to meet harsh timing requirements (< ms)

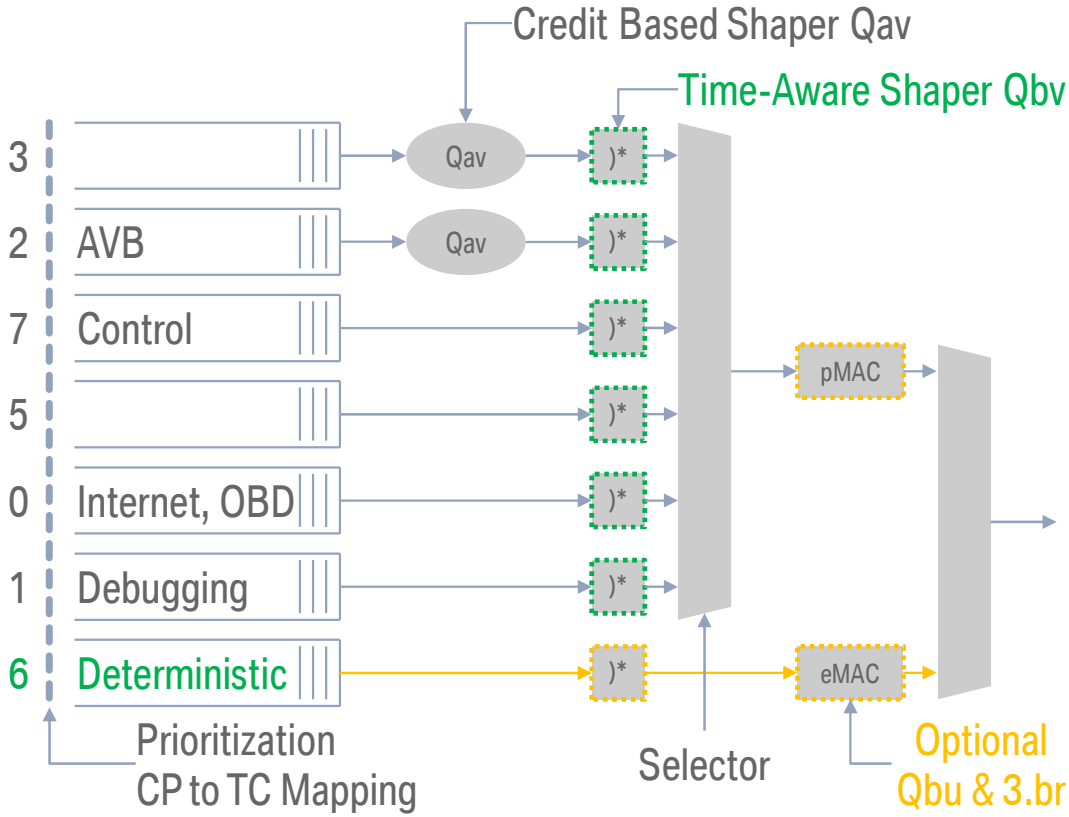
TSN PROPOSAL FOR REAL-TIME CRITICAL DISTRIBUTED CONTROL LOOPS. RISK-AVERSE PATH TOWARDS MORE TSN. (PROFILE 1)

1. **Marking of real-time critical traffic** by mapping these aggregates to “express/deterministic” sockets*
2. **Enabling of Time-Aware Shaping** by introduction of Qbv on <u>all</u> switches and all end nodes implementing a real-time critical distributed control loops to provide for deterministic low-latency communication on Ethernet*
3. **Implementation of AUTOSAR support for Qbv’s network schedule at dedicated end nodes,** so that time-critical applications can be scheduled deterministically **(Eth becomes a “partial-FlexRay”)***

4. **Elimination of inefficiencies caused by Qbv** through introduction of Frame Preemption (Qbu) and Qci to allow for smaller Guard Bands and prevent resource drainage
5. **Introduction of 3.br to mitigate packet losses** caused by preempting un-scheduled traffic (see 4.)

Items marked with* are mandatory to allow for deterministic communication.
Add on: Introduction of Per Stream Filtering (Qci) to allow for HW-Firewalling & more flexible mapping of streams to TCs

6 existing Traffic Classes **+ 1 new scheduled queue/TC**

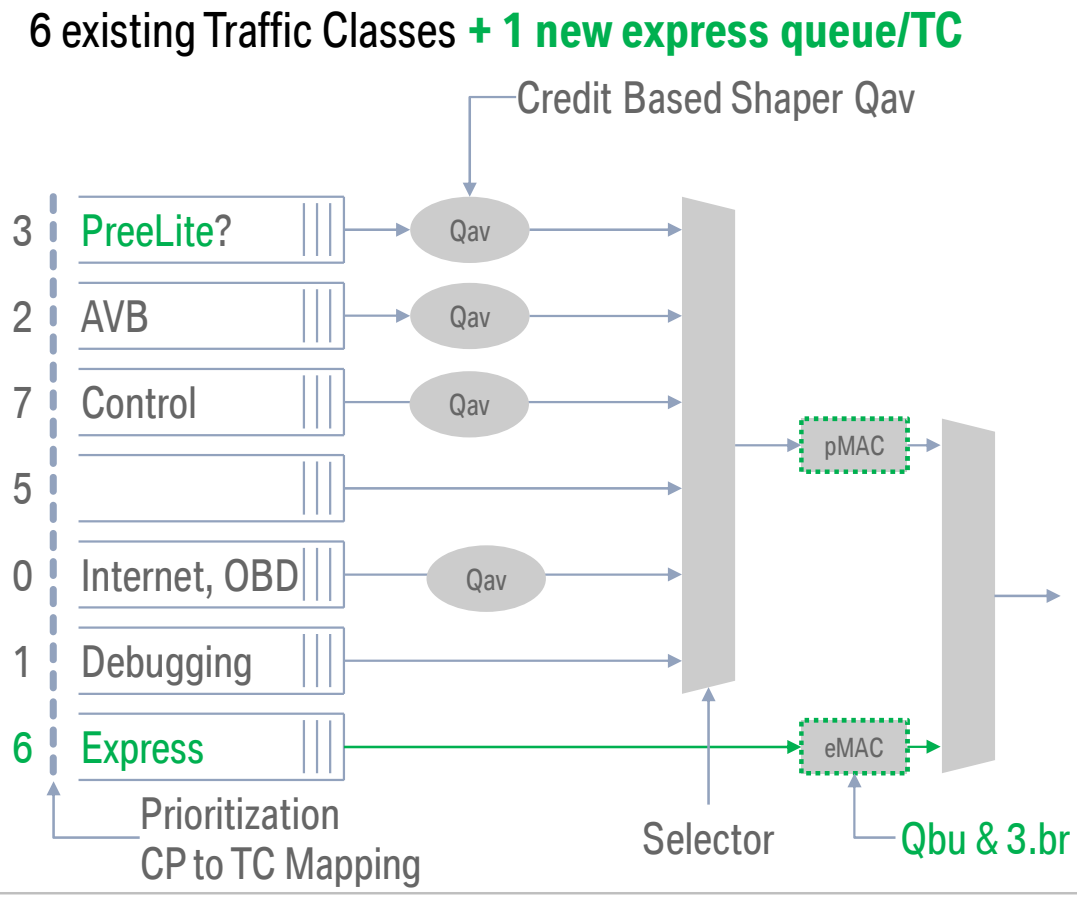


TSN PROPOSAL FOR MOST REAL-TIME CRITICAL TRAFFIC. RISK-AVERSE PATH TOWARDS MORE TSN. (PROFILE 2)

1. **Marking of real-time critical traffic** by mapping these aggregates to “express/deterministic” sockets*
2. **Enabling of one “Express Lane”** by introduction of **Frame Preemption (Qbu)** on all switches and all end nodes handling **real-time critical traffic** to provide for **lowest latency/jitter** communication on Ethernet*
3. **Mitigation of packet losses** caused by preempting non-express traffic through **IET (3.br)**
4. **Implementation of rule set** that
   1) Decides **which traffic is most real-time critical**
   2) Administrates the **amount of feasible critical traffic**

→Pre-conditioning of traffic through sending-side TSN Traffic Shaping
→Sanctioning of missing conditioning by TSN-Policing (Qci)
→ Isolation of error and mitigation of error propagation
→ **Interfering frame wird um #eMAC-frames/CMI länger!**

Items marked with* are mandatory to allow for deterministic communication.
Add on: Introduction of “Per Stream Filtering” (Qci) to allow for HW-Storm Protection & potentially more flexible mapping of streams to TCs



COMPLEXITY OF SELECTED TSN FEATURES. COSTS OF USE.

Topology
Overprovisioning

IEEE 802.1p (SP)
IEEE 802.1 Qav (CBS)

IEEE 802.1Qbu (Preemption)
IEEE 802.3br (IET)

IEEE 802.1CB (Seamless Redundancy)

IEEE 802.1Qci (Filtering) & Qcr (ATS)

IEEE 802.1Qbv (TAS)

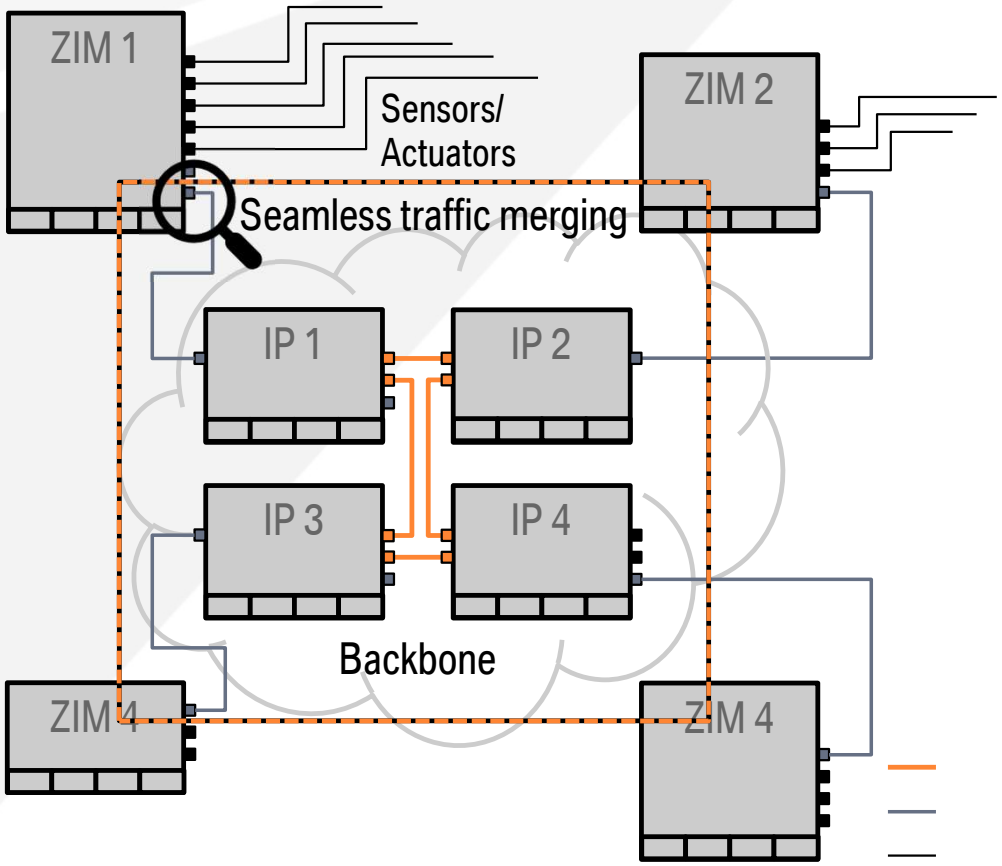
Scalability & Extensibility

Bounded Latency

Highly time sensitive traffic

Requires coordination!

A PURISTIC TSN NETWORK CONFIGURATION. THE HYPER SWITCH.



Advantages:

- Converged network with simplistic data model
- Exploitation of synergies
- Reduction of network complexity & development costs
  - No need for nPDU/Zug concept
  - No need for Traffic Shaping on switches and sensors/actuators
- Higher re-use rates and development continuity,…

Disadvantages:

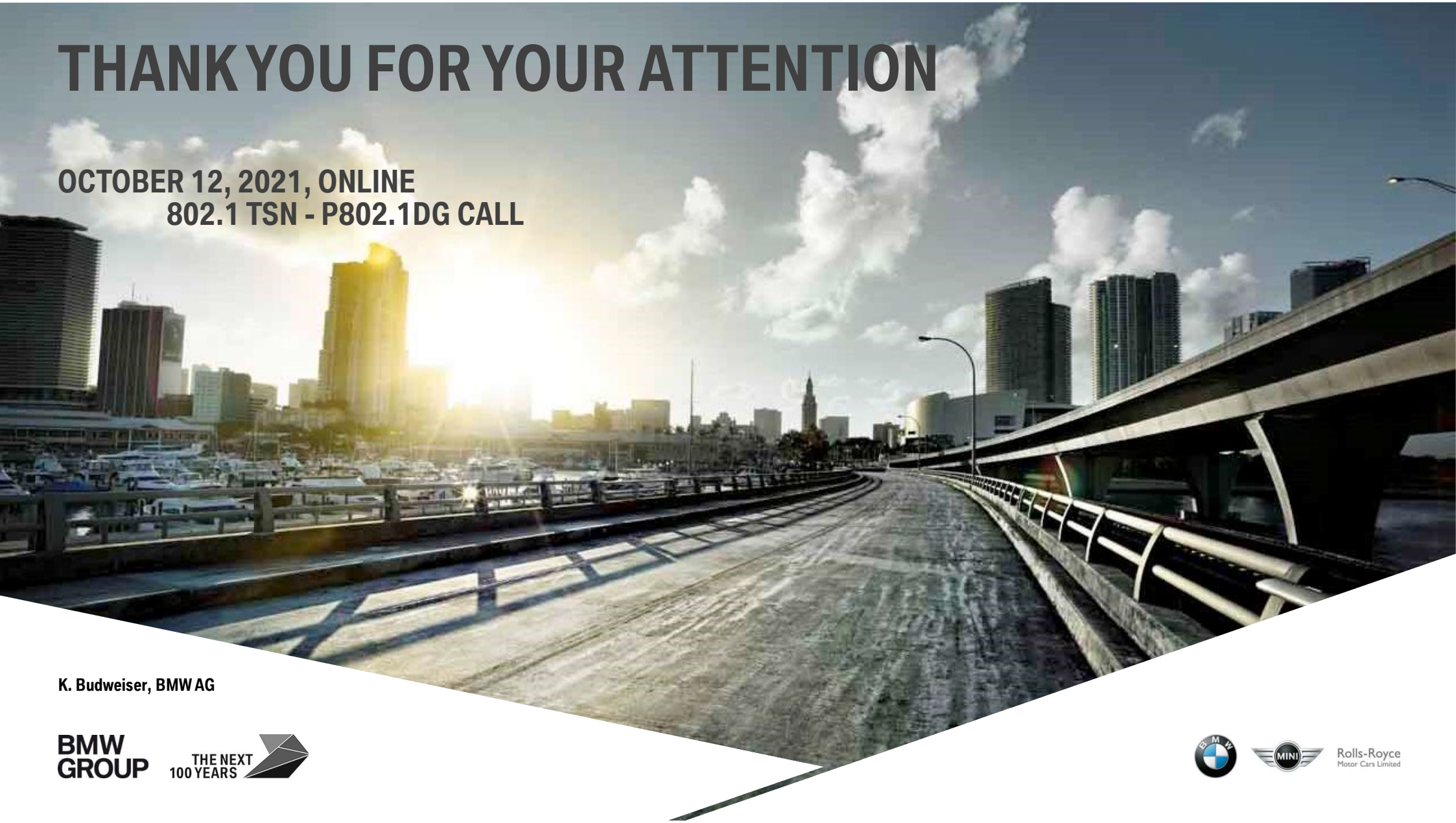
- Requires complete architectural commitment & rethink
- Requires new holistic cost model (to evaluate cost trade-off)
- Potential higher energy consumption

RISK-AVERSE INTRODUCTION OF TSN. SUMMARY.

- TSN is a tool-set that can be used to tackle various different problems
- The introduction of TSN is a delicate issue and **must be well-coordinated**
  - Some TSN features are easier to handle than others
  - **Dependencies of TSN features** to other functionalities must be resolved
- The **TSN testing eco-system** has still to evolve
- The only “TSN features” that ensure **upgradability** are Topology and Overprovisioning
- A real **Zonal Architecture** simplifies networking and provides both development continuity and high re-use rates

Recommendation: Use those TSN features that are easier to handle (Frame Preemtion) before those feature more complicated to deal with.

THANK YOU FOR YOUR ATTENTION



OCTOBER 12, 2021, ONLINE
802.1 TSN - P802.1DG CALL

K. Budweiser, BMW AG

BMW GROUP THE NEXT 100 YEARS

Rolls-Royce Motor Cars Limited

REFINEMENT AND RE-CLASSIFICATION OF TRAFFIC TYPES. PRIORITIZATION OF TRAFFIC AND TRAFFIC CLASSES.

Traffic Class	PCP	Different Types	Criticality of Types
~~AudioVideo with SR Class A~~ TC replaced by A2B	2	Warnings over CAN	Periodic, Very Critical
		Noise Cancelling	Periodic, Critical
		Entertainment-like (e.g. Deezer)	Conditional-Periodic, Low Criticality
AudioVideo/Video/MediaPlay AVB	3	Computer Vision & Critical Assist	Periodic, Critical
		Regular Assist (SVS, …) with tight WatchDogs	??? Drops cannot be accepted
		Entertainment-like (e.g. CarPlay)	Conditional-Periodic, Low Criticality
Command & Control via SOME/IP ➔ Repartitioning of TCP to best effort ➔ Higher QoS for Control Loops, etc.	7	Control/Alarms	Periodic, Very Critical
		Sensor	Periodic, Critical
		miscellaneous	Event-triggered, Low Criticality
~~VoIP VLAN~~ ➔ Integrate to AVB ➔ Mutual exclusiveness / BW-reservation must be considered	5	Emergency Call	Conditional-Periodic, Very Critical
		Telephony	??? Drops cannot be accepted
Internet, CE, EntertainmentCore ➔ Binding worst case limits	0	Map data, HMI-Control, SOTA	??? Drops can be accepted to a certain degree
		Web, Streaming, **+ OBD**	Quasi-Conditional-Periodic Low Criticality
Diagnostics ➔ Only DLT w/o BW-Garantie	1	~~OBD,~~ DLT~~,…~~	OBD use case mutual exclusive or background; Tradeoff between DLT and customer functionality