Latency requirements for automotive camera systems

IEEE 802.3dm

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Motivation

- During the July 24 plenary a number of perceived requirements concerning automotive camera applications were presented in https://www.ieee802.org/3/dm/public/0724/houck_fuller_3dm_01_0724.pdf.
- This presentation discusses the requirements presented in the above presentation and puts them in perspective.
- This presentation thereby distinguishes between
  - Core requirements coming from the application and
  - Requirements that are the result of a selected technical solution.
- It (once more) shows that latency is not the issue.

Agenda

- Functional safety basics
- Comparing SerDes P2P scenarios with networked Ethernet for
  - Decision path
  - Synchronization path
  - Camera control path
- Putting timing in perspective
- Summary and conclusion

Functional Safety (1)

Functional safety targets at systematically protecting car users from an unacceptable risk of injury because of malfunctioning electronics (TÜV Süd, 2022. *About Functional Safety.* https://www.tuvsud.com/en-us/services/functional-safety/about)

Automotive Safety Integrity Level (ASIL) classification (ISO 26262:2018 – Road Vehicles – Functional Safety)

Severity	Exposure	Controllability		
		C1 (simple)	C2 (normal)	C3 (difficult, uncontrollable)
S1 (light and moderate injuries)	E1 (very low)	QM*	QM	QM
	E2 (low)	QM	QM	QM
	E3 (medium)	QM	QM	A
	E4 (high)	QM	A	B
S2 (severe and life threatening injuries, survival probable)	E1 (very low)	QM	QM	QM
	E2 (low)	QM	QM	A
	E3 (medium)	QM	A	B
	E4 (high)	A	B	C
S3 (life threatening and fatal injuries)	E1 (very low)	QM	QM	A
	E2 (low)	QM	A	B
	E3 (medium)	A	B	C
	E4 (high)	B	C	D

*QM = Quality Management

Functional Safety (2)

The ASIL classification and functional safety protection is considered end-to-end, which is assessed for every use case and application individually.

Communication technologies are not a use case in itself, but a means to an end for the various applications. In ISO 26262 they are considered as “Safety Elements out of Context”.

Following ISO 26262, a communication system should be able to identify

- loss of communication peer
- corrupted messages
- messages unacceptably delayed
- lost messages
- unintended message repetitions
- incorrect message sequences
- inserted messages
- masqueraded messages
- incorrectly addressed messages.

Functional Safety (3)

Examples for “Message unacceptably delayed”:

- Delay/latency is significantly longer than “normal” → Safety Element out of Context

  This is independent of the use case and might indicate that something is wrong.

  Possible to notice per hop:

  - If the latency is normally exactly the same and then is not (might work P2P, difficult in an Ethernet network)
  - In a system with synchronized clocks and timestamps (recommended in an Automotive Ethernet network)

- Delay/latency is so long that the application has a problem → End-to-End validation

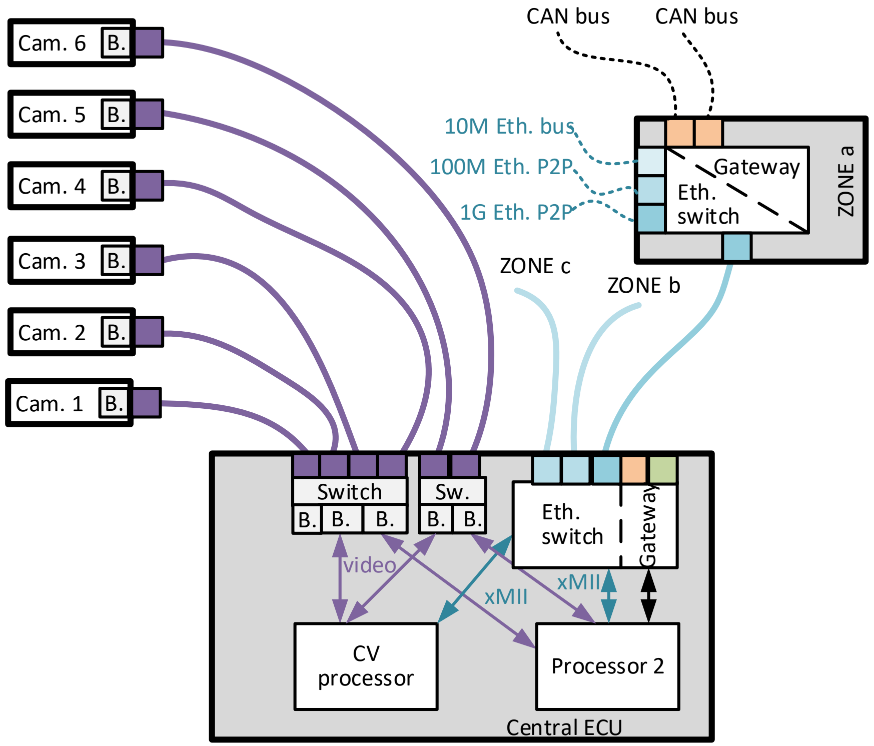
  Needs to consider the exact realization of the application.

  In case of camera sensors a distinction is necessary between:

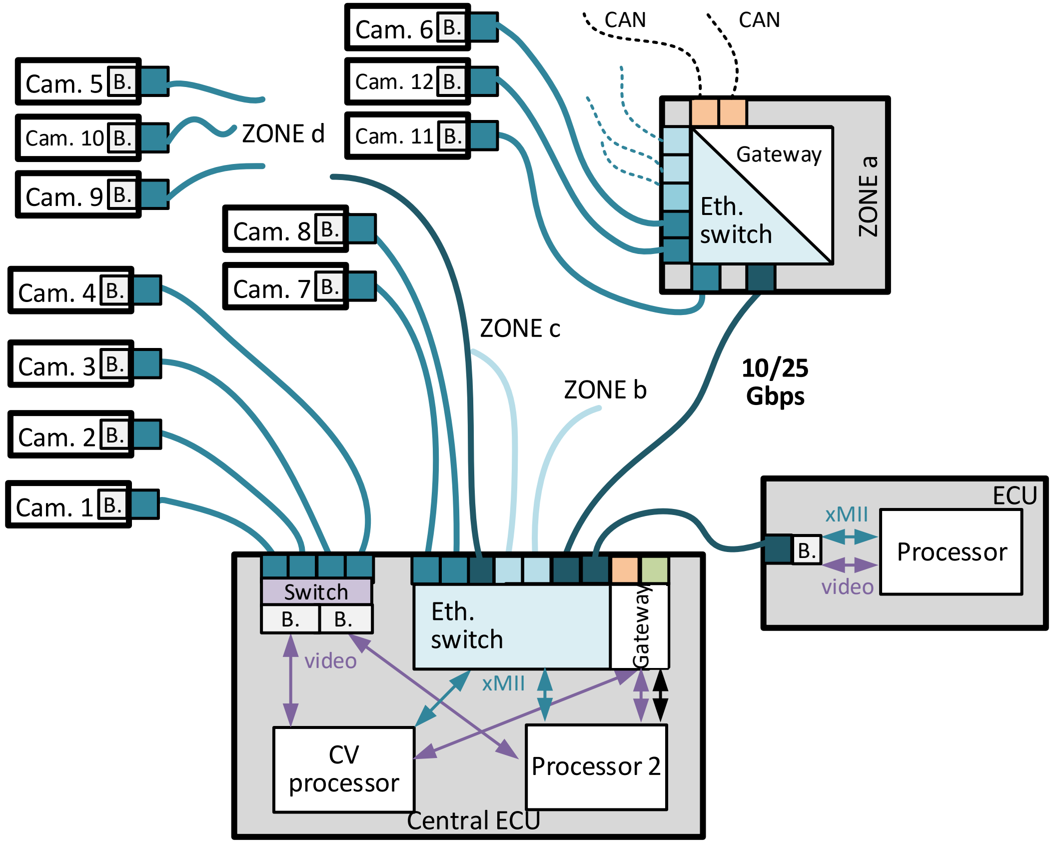
  - Decision loop
  - Camera control loop.

Camera use case

P2P SerDes

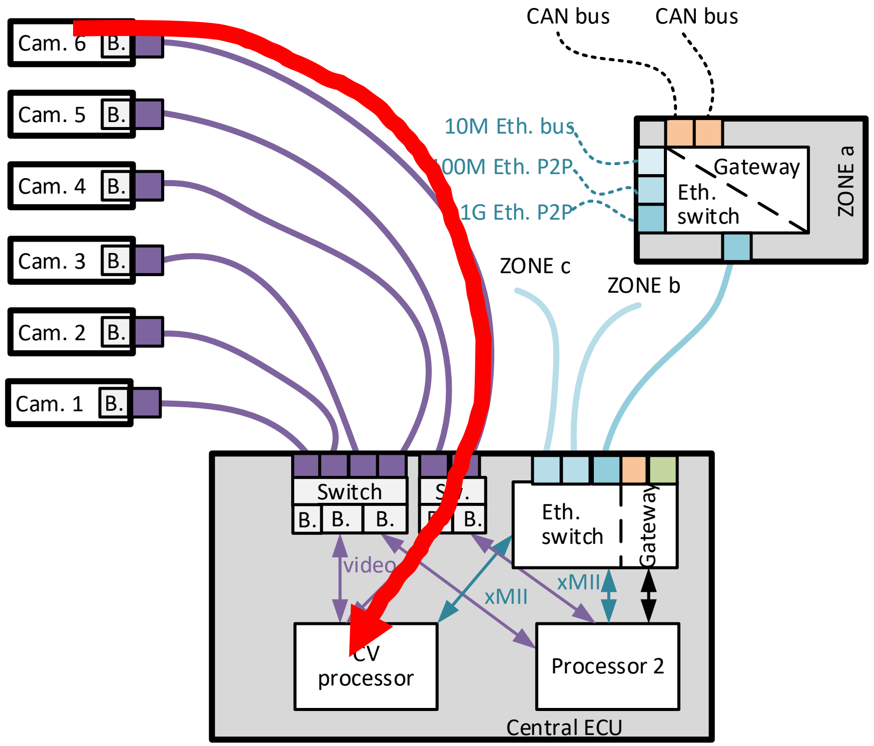


Networked Ethernet



(Uni-directional) decision latency

P2P SerDes

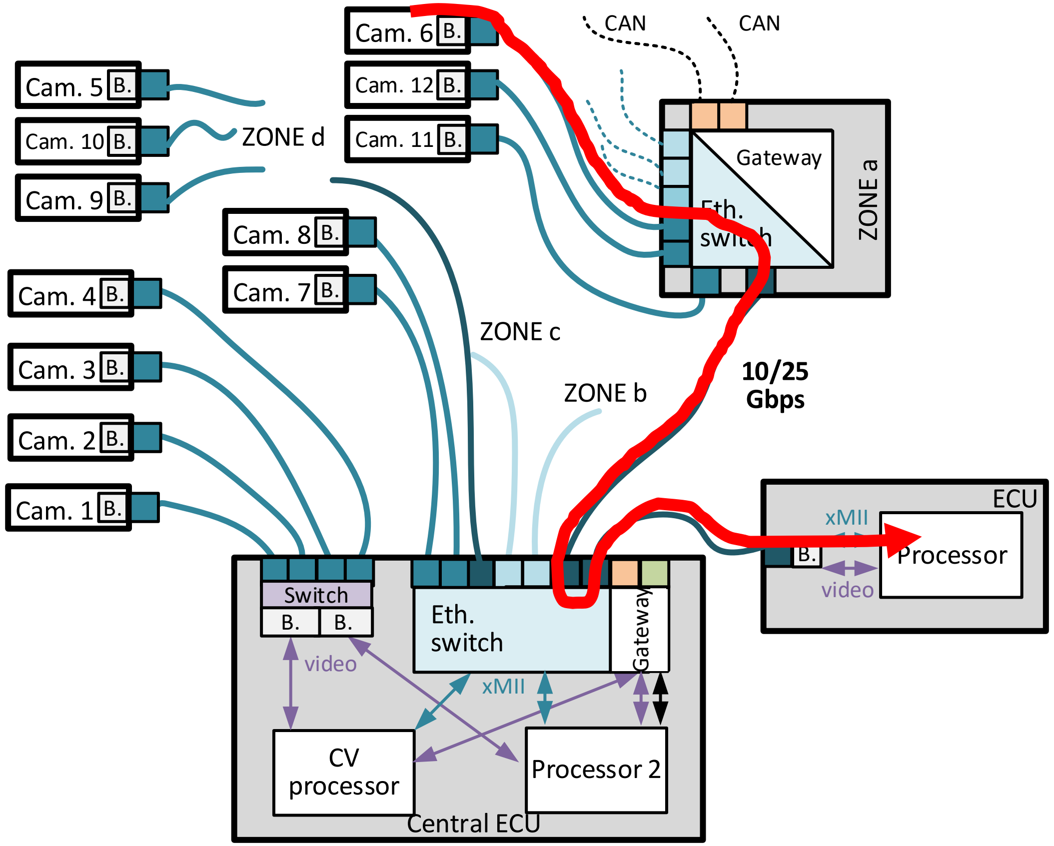


- E2E latency more or less controllable (exc. CSI-2 conversion).
- More or less same latency situation for all cameras.

→ **Might work with fixed, low latencies. Low jitter.**

→ **Also works with synched clocks and timestamps.**

Networked Ethernet



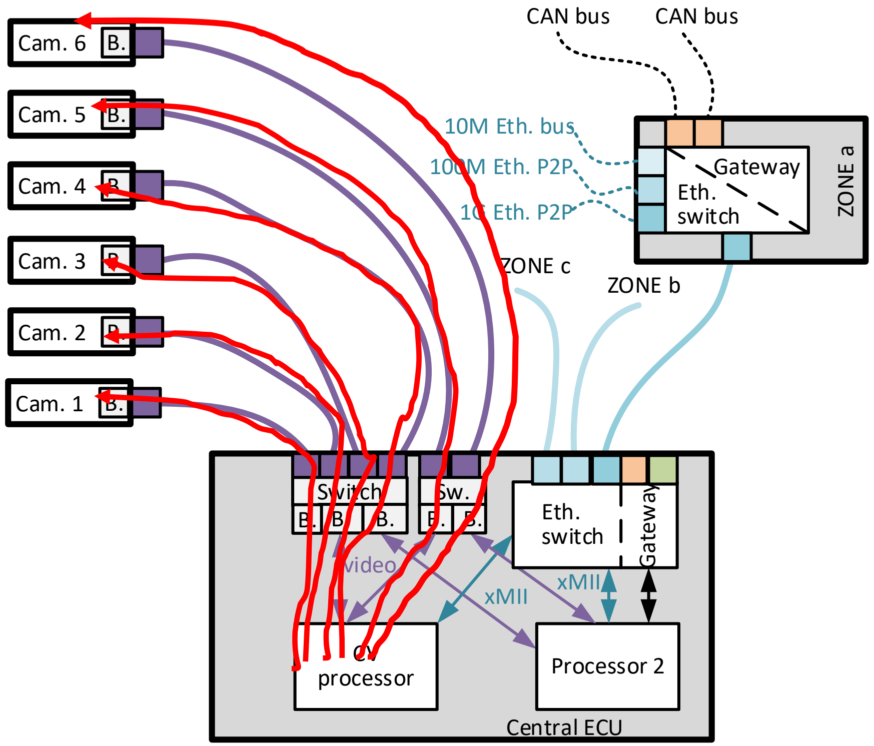
- E2E goes through a (much) less controllable network.
- Different latency situation for different cameras.

→ **Cannot be based on fixed, low latencies. Jitter present.**

→ **Works with synched clocks and timestamps.**

(Uni-directional) sensor synch latency

P2P SerDes

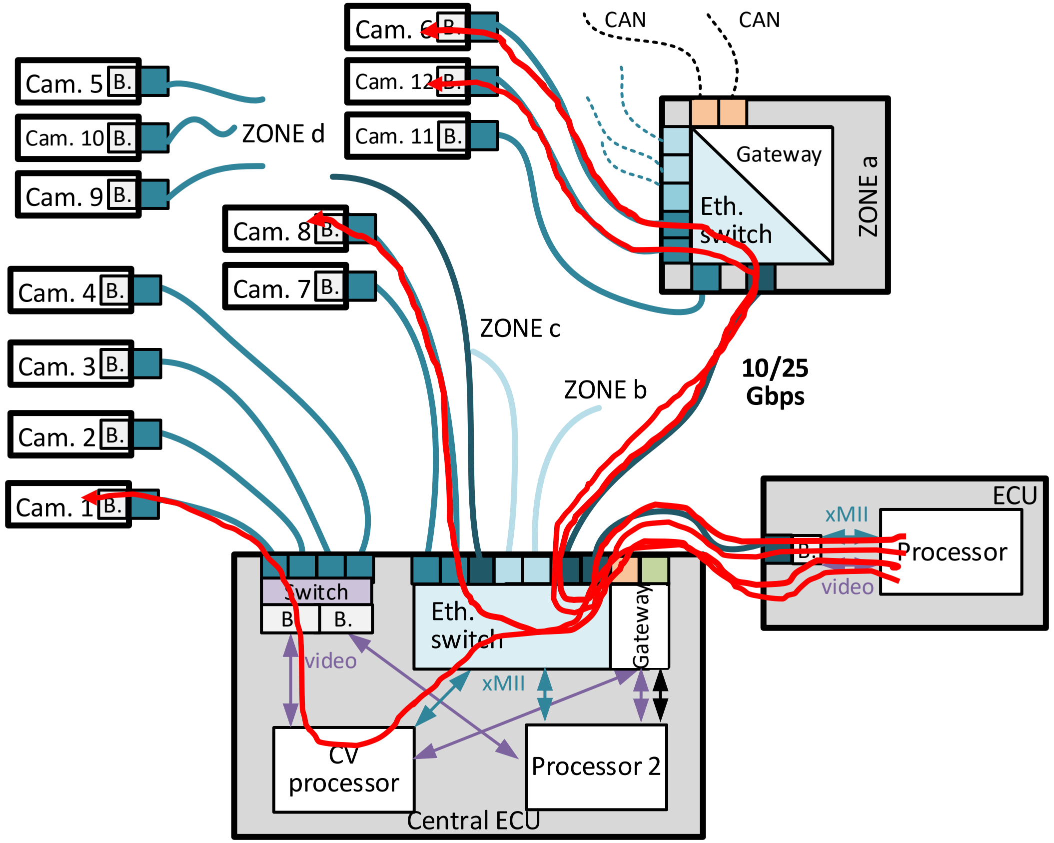


- E2E latency more or less controllable (exc. CSI-2 conversion).
- More or less same latency situation for all cameras.

→ **Might work by sending a “synch signal”.**

→ **Also works with synched clocks and time-based control.**

Networked Ethernet



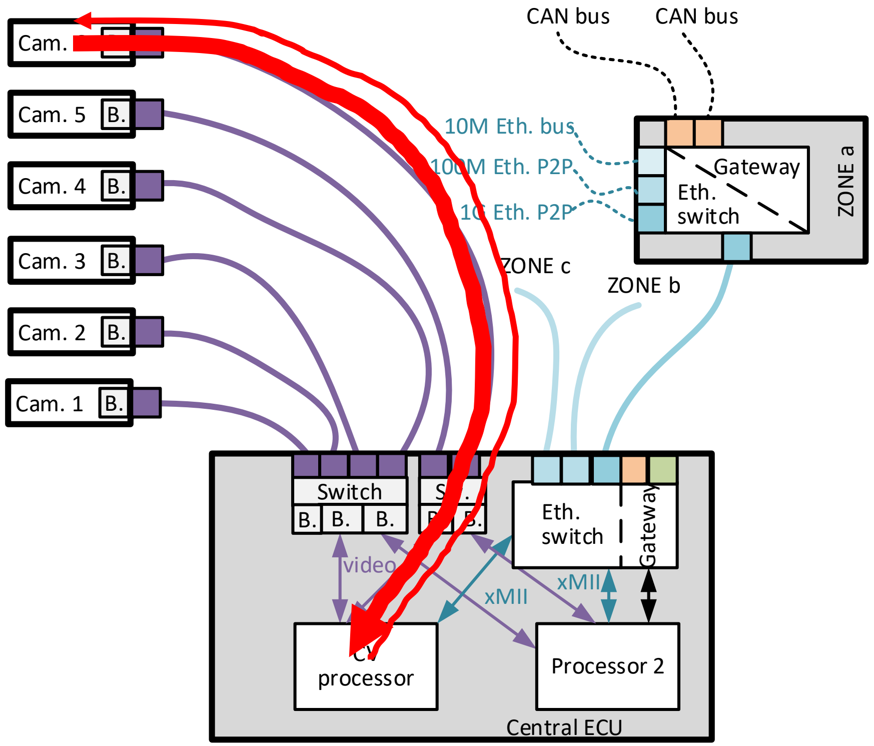
- E2E goes through a (much) less controlled network.
- Different situation for different cameras.

→ **Jitter in the “Synch signal” arrival likely. Not reliable.**

→ **Works with synched clocks and time-based control.**

(Bi-directional) control latency (1)

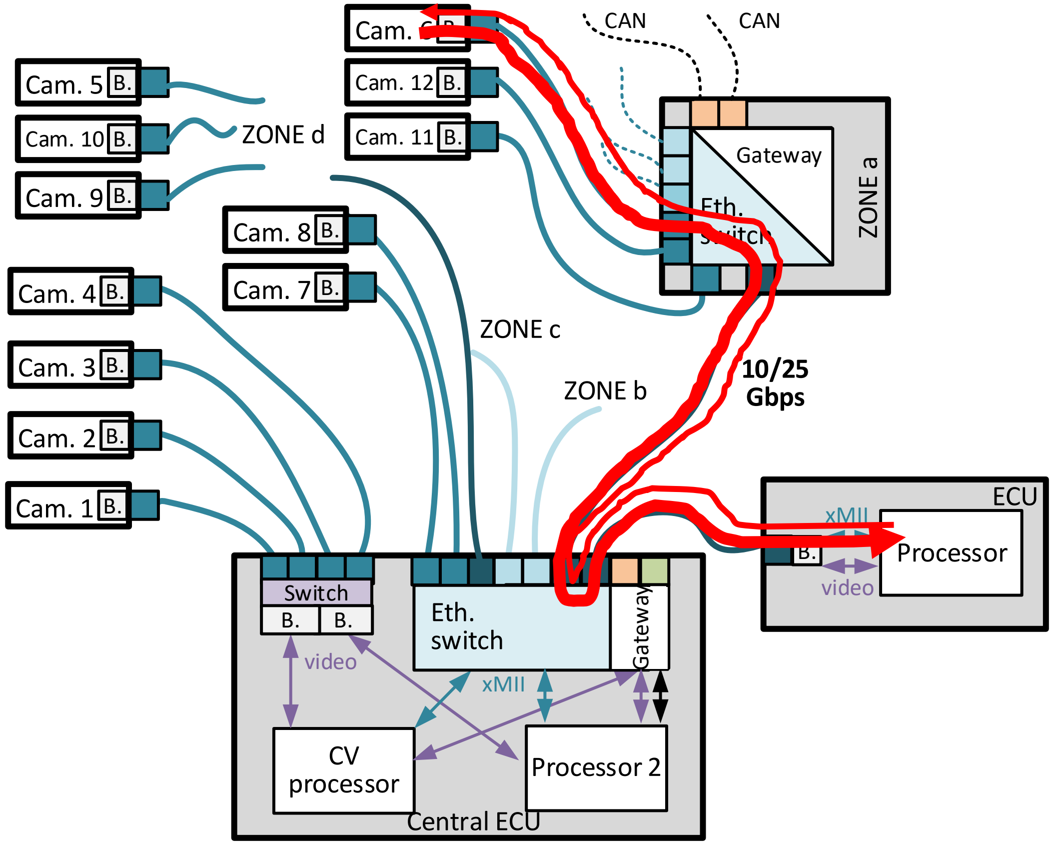
P2P SerDes



- E2E latency more or less controllable (exc. CSI-2 conversion).
- More or less same latency situation for all cameras.

→ **Latency requirement depends on application.**

Networked Ethernet



- E2E goes through a (much) less controlled network.
- Different latency situation for different cameras.

→ **Latency requirement depends on application.**

(Bi-directional) control latency (2)

Example: Cameras have a number of adjustable parameters (see also email TJ Houck on STDS-802-3-ISAAC@LISTSERV.IEEE.ORG Monday August 12, 2024 22:50 CET). Distinction necessary between parameters that are defined during development and parameters that are changed during runtime. Only the latter results in traffic in the network.

Set parameters

- HDR functions
- Focus adjustment/control (no auto focus support in modern auto cameras)
- Gamma correction (predef., managed internally)
- Lens/dark/pixel shading compensation (predef., managed internally)
- Noise reduction (predef., managed internally)
- Color correction (predef., managed internally)
- Image resolution, digital cropping, pixel binning changes (predef., managed internally)
- Region of Interest (today predef.).

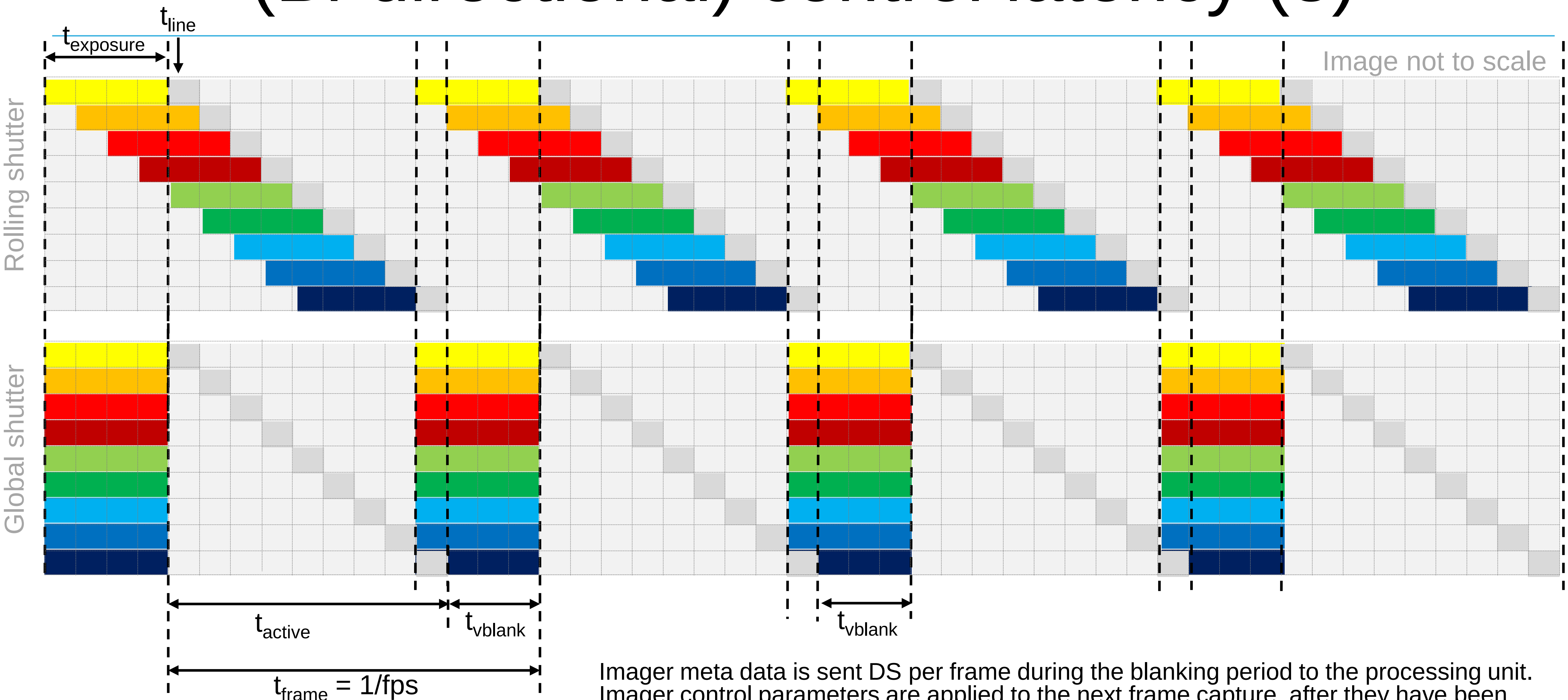
Parameters changed during runtime

Parameter	Approx. frequency	Approx. size	
Exposure*	Once per frame	3-5 registers	Depend on light
Gain*	Once per frame	8-10 registers	
White balancing*	Once per frame	8-10 registers	
Frame rate (rare use case)	Change of vertical blanking	2 registers	Depend on use case
Region of Interest	Maybe for future interior cameras	Tbd.	

* Esp. human vision applications.

„Status“ is sent with image as meta data or indicated on error pin.

(Bi-directional) control latency (3)



Imager meta data is sent DS per frame during the blanking period to the processing unit. Imager control parameters are applied to the next frame capture, after they have been received US and processed.

Speed of change.

	10 km/h ~6.2 mph	30 km/h ~20 mph	50 km/h ~30 mph	80 km/h ~50 mph	110 km/h ~70 mph	130 km/h ~80 mph
1 us	2.7 um	8.3 um	13.8 um	22.1 um	30.5 um	36 um
10 us	27 um	83 um	138 um	221 um	305 um	360 um
100 us	270 um	830 um	1.38 mm	2.21 mm	3.05 mm	3.6 mm
1 ms	2.7 mm	8.3 mm	1.38 cm	2.21 cm	3.05 cm	3.6 cm
10 ms	2.7 cm	8.3 cm	13.8 cm	22.1 cm	30.5 cm	36 cm
100 ms	27 cm	83 cm	1.38 m	2.21 m	3.05 m	3.6 m
1 s	2.7 m	8.3 m	13.8 m	22.1 m	30.5 m	36 m
10 s	27 m	83 m	138 m	221 m	305 m	360 m
100 s	277 m	831 m	1.385 km	2.21 km	3.05 km	3.6 km

How much may light conditions change within one or two image captures (e.g. 33.3ms, 66.6ms)?
How off must imager parameters be such that the correct function of the application is at risk?
Object recognition is possible several 100m ahead.

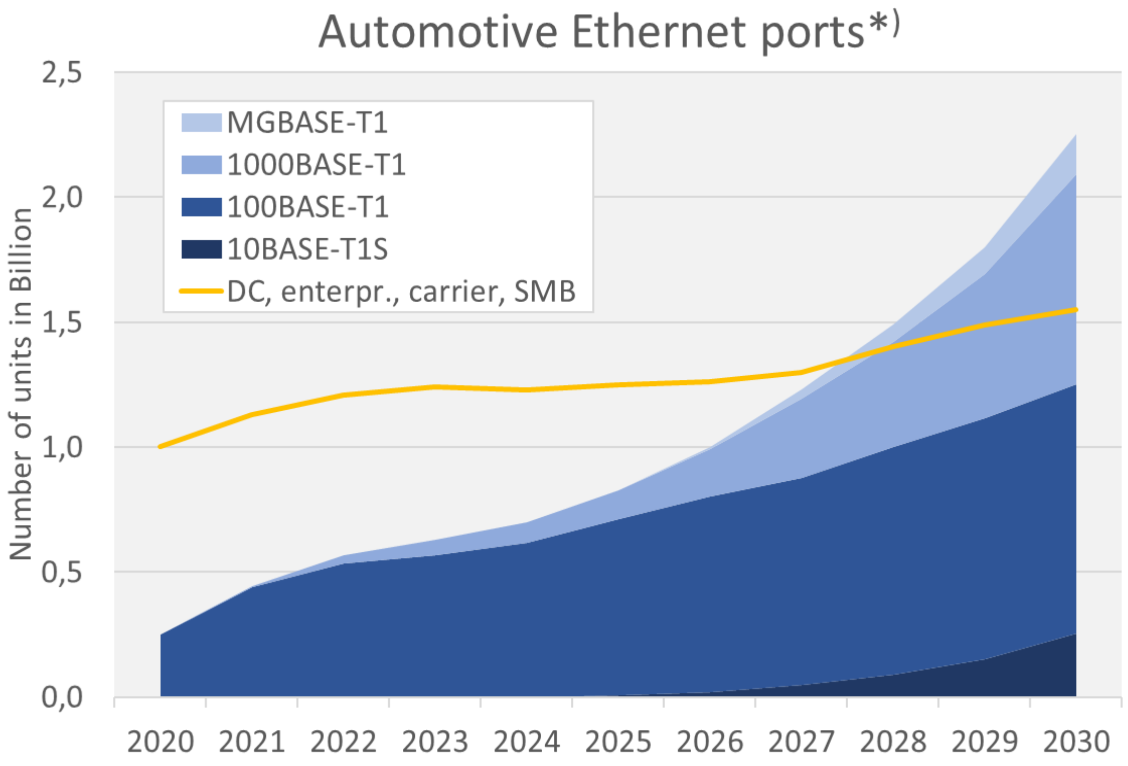
Summary and conclusion

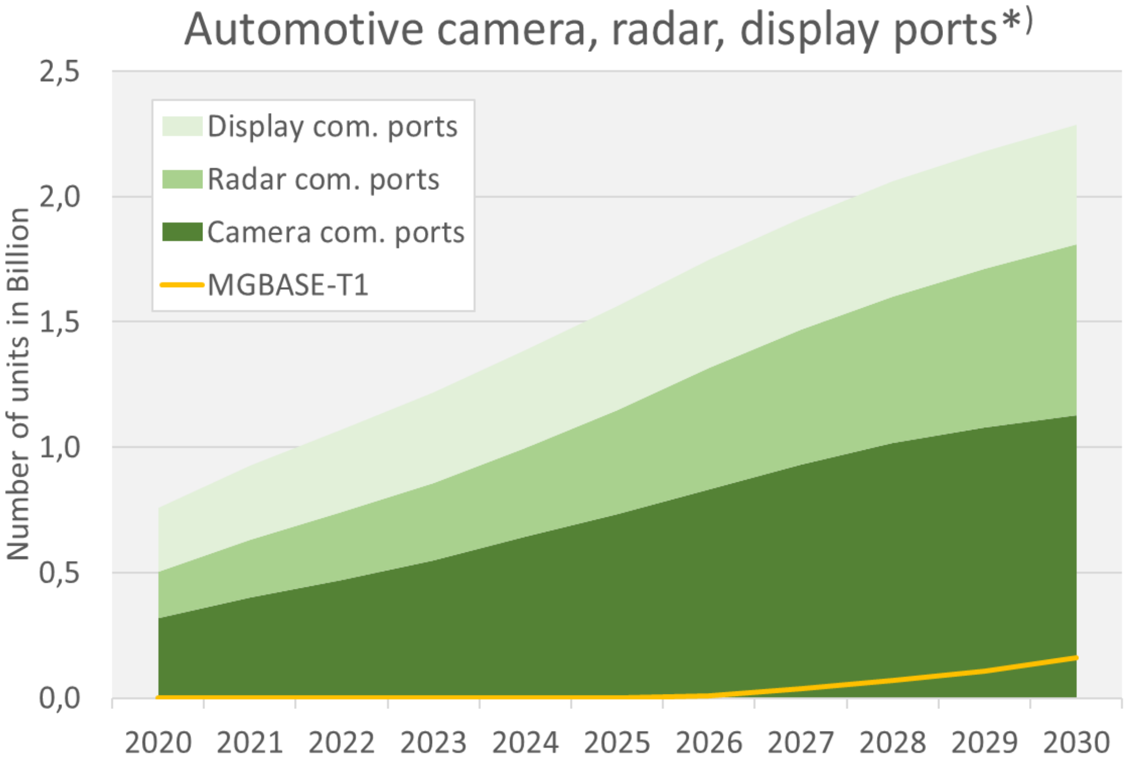
- Cameras, Radars, and Lidars operate in cycles of tens of milliseconds, far exceeding any potential delays in the proposed 802.3dm duplexing schemes.
- Therefore latency is not a critical factor in choosing between duplexing schemes.
- Low latency and jitter-free traffic may work for coordinated point-to-point SerDes links but are not universally applicable.
- Applying low-latency requirements to Ethernet networks adds unnecessary complexity.
- Ethernet can meet sensor timing needs using synchronized clocks, timestamps, and time-based control, without imposing extreme latency demands.

Thank You!

Back up

Market size justifies to target the camera use case.





*) Sources: R&S, TSR, mobility foresights, TechInsight, OLED org, semiconductor vendors.

Note, that there is some overlap between the charts, as some radars, cameras, or displays might be connected with Automotive Ethernet. However, it is assumed that the vast majority of the market data depicted, does NOT come from camera and radar use cases.

Wants and needs

Wants: Shortest latency possible (this is like: highest bandwidth, largest storage, …). “est”s are costly and justified only in very few cases.

Needs:

- To know when data was generated (accurate timestamps)
- To know it was all generated at the same time (synchronization of sensors with low jitter)
- To ensure a control loop closes within a certain time (max latencies)
- Shortest latency possible ???

Know your requirements

	Latency < max. value	**Latency always the same*)**	**Minimum possible latency**	**Knowing when data was generated**
Ethernet/TSN protocols	802.1Qav 802.1Qcr	802.1Qbv 802.1Qch	Cut through switching, preemption 802.1Qbu & 802.3br	802.1AS
Solutions in legacy networks	Possible with a partially loaded CAN	FlexRay, MOST, designed for cyclic data	Possible for the CAN packet with highest priority identifier	