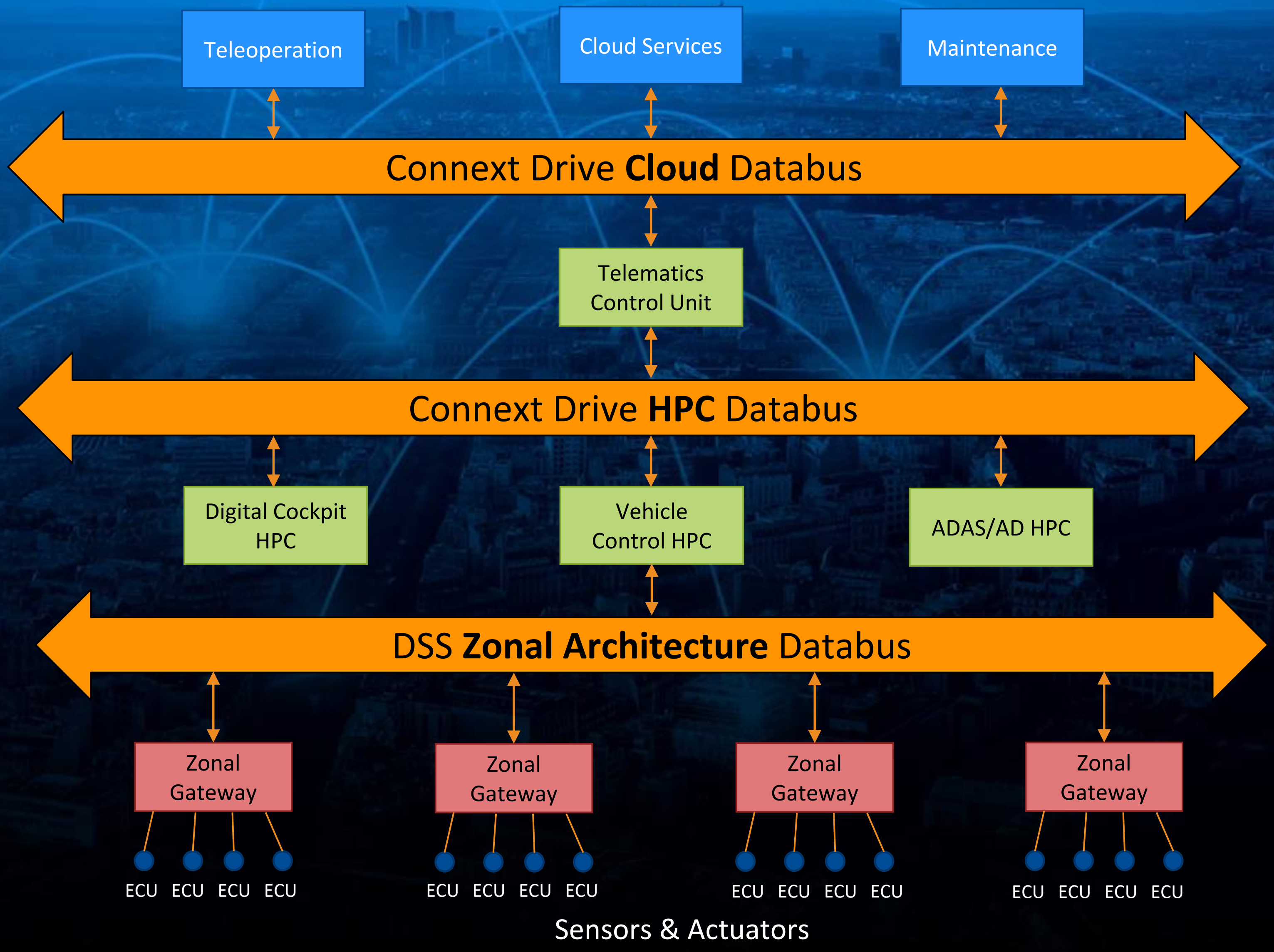
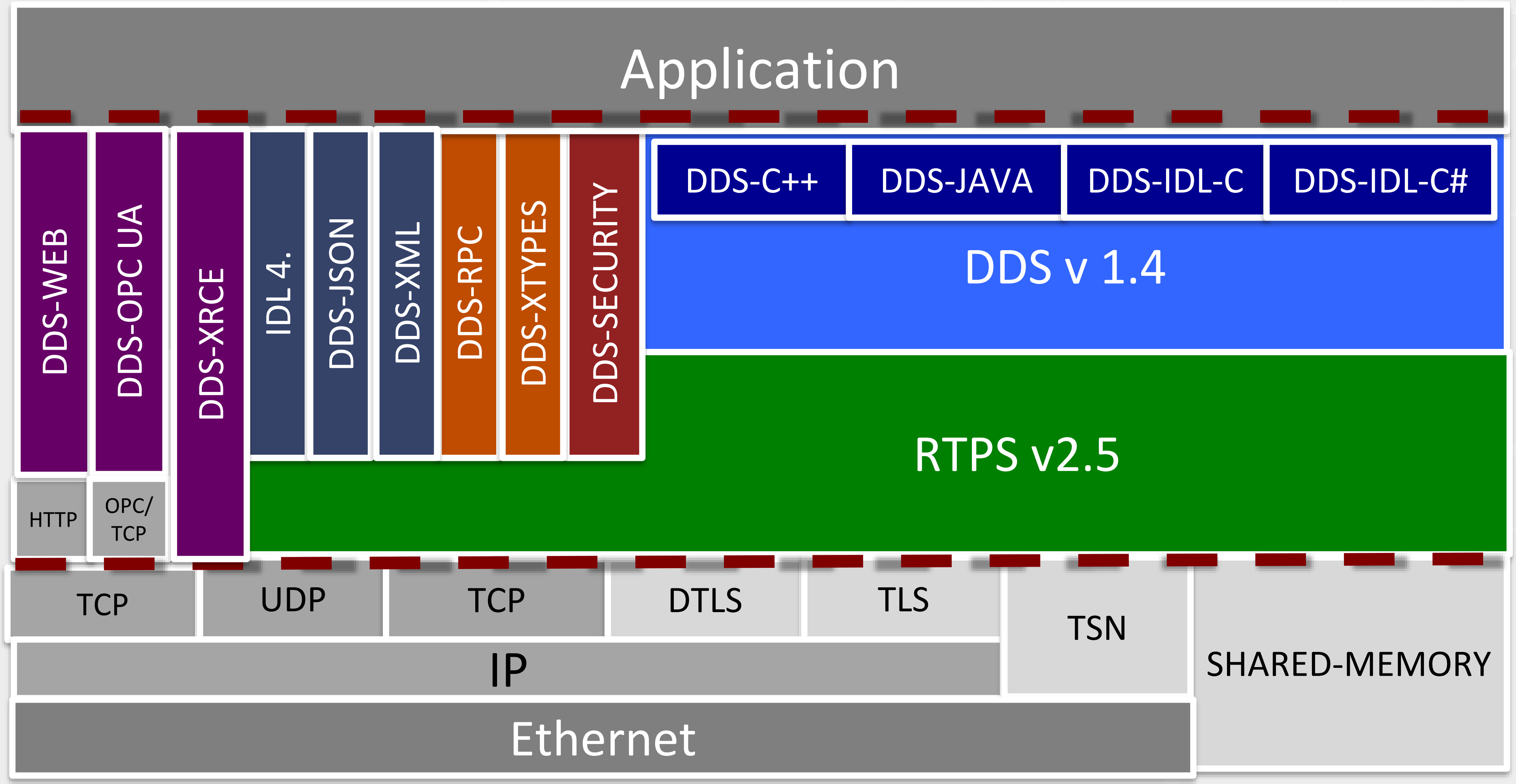
DDS over TSN: configuring TSN to meet DDS-level QoSes

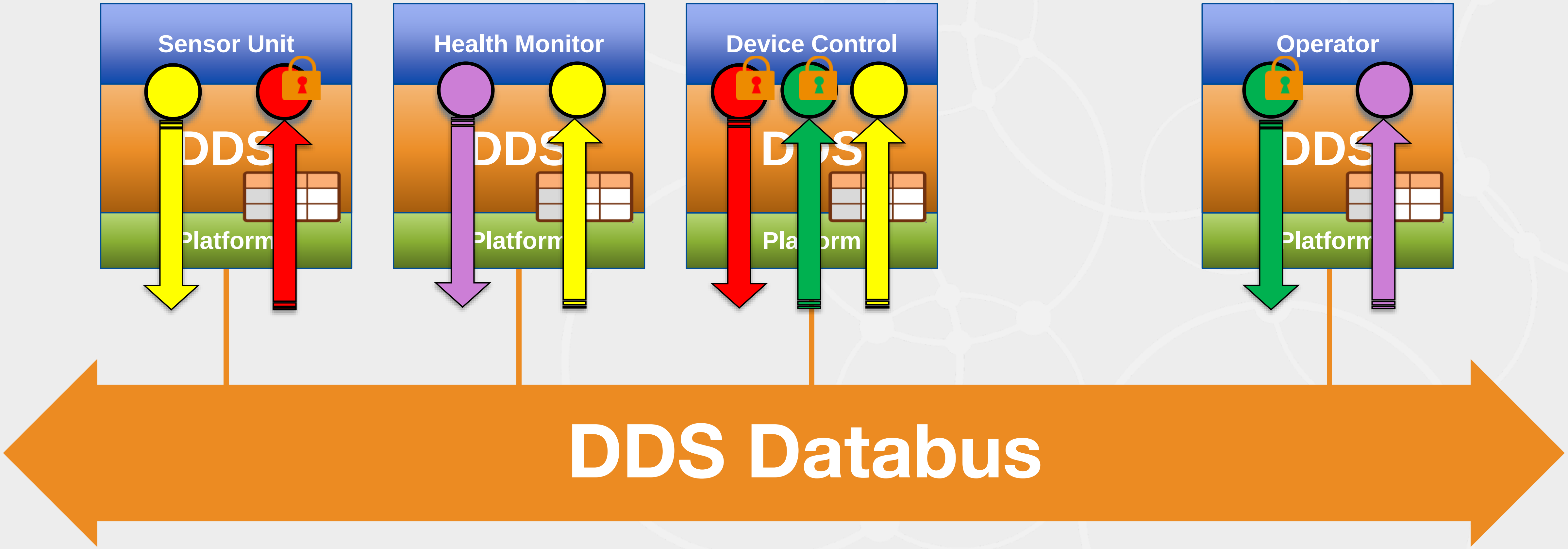
Software-defined vehicle Architecture



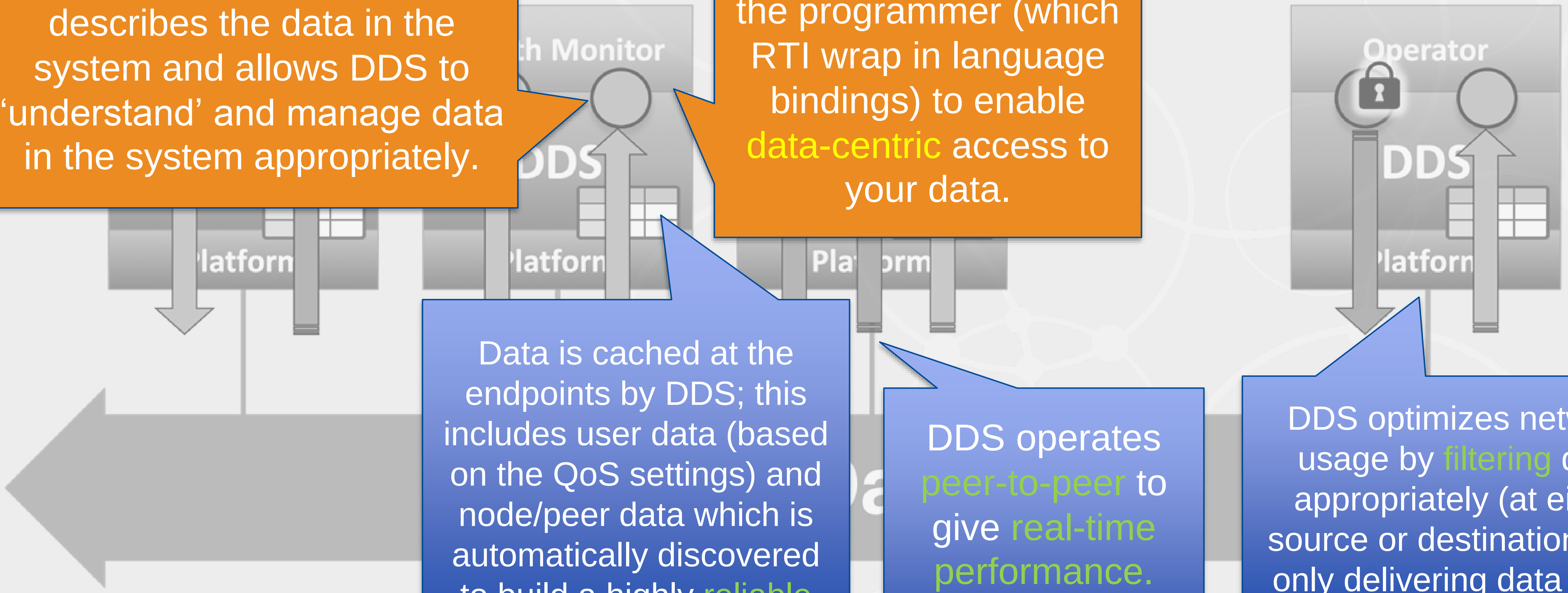
Communication framework based on DDS



Designing Distributed Systems with DDS



Designing Distributed Systems with DDS



A Data Model (written in IDL) describes the data in the system and allows DDS to ‘understand’ and manage data in the system appropriately.

DDS provides an API to the programmer (which RTI wrap in language bindings) to enable data-centric access to your data.

Data is cached at the endpoints by DDS; this includes user data (based on the QoS settings) and node/peer data which is automatically discovered to build a highly reliable and resilient network.

DDS operates peer-to-peer to give real-time performance. There is no central server.

DDS optimizes network usage by filtering data appropriately (at either source or destination) and only delivering data when and where it is needed.

DDS QoS Policies

QoS Profiles

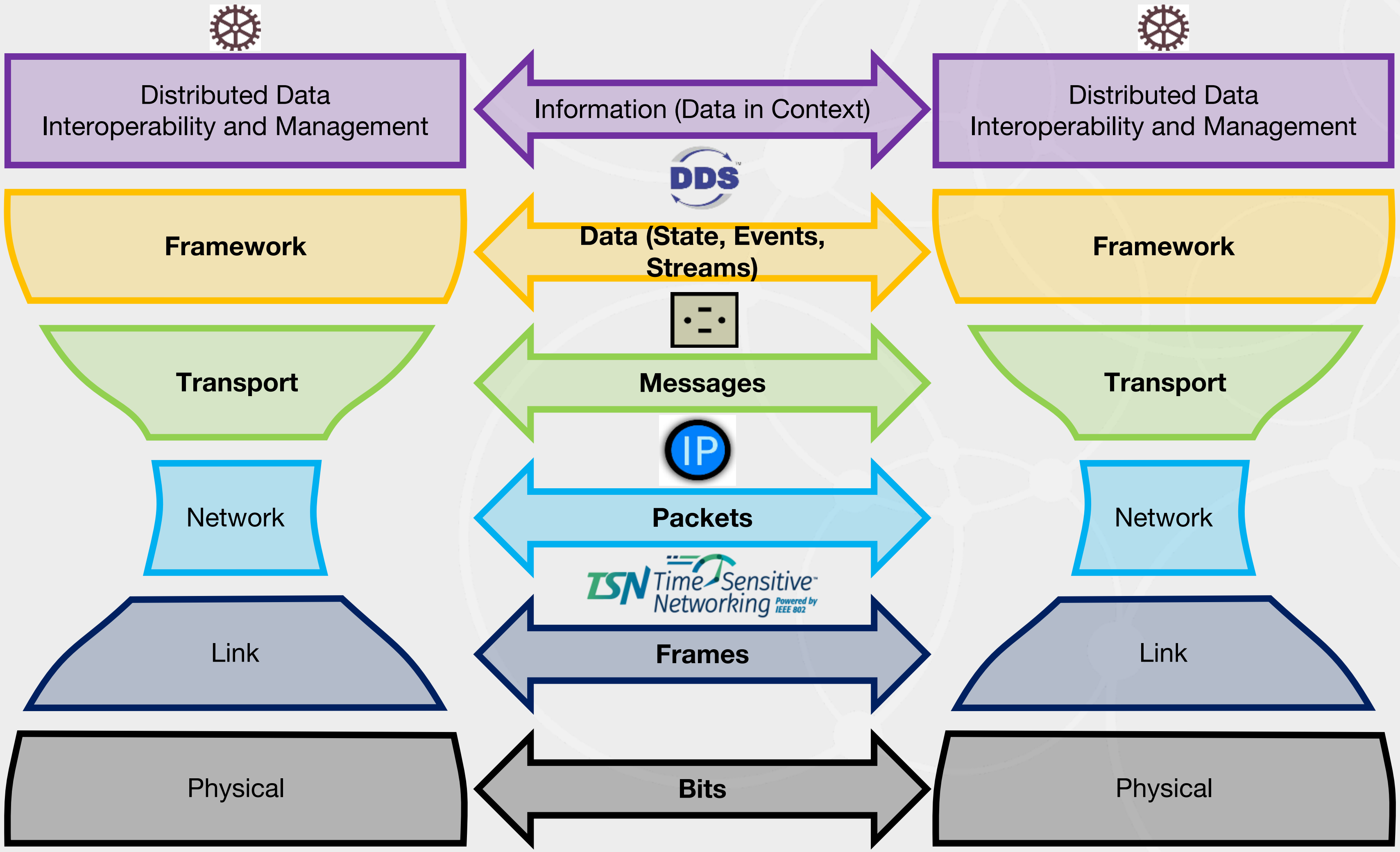
Streaming Sensor Data

Alarms & Events

Configuration Data (Last Value Cache)

Image or Video Frames (Large Data)

Extending DDS Communication via TSN



DDS + TSN Integration

Designing Distributed Systems with DDS

Configuring TSN Extensions for DDS

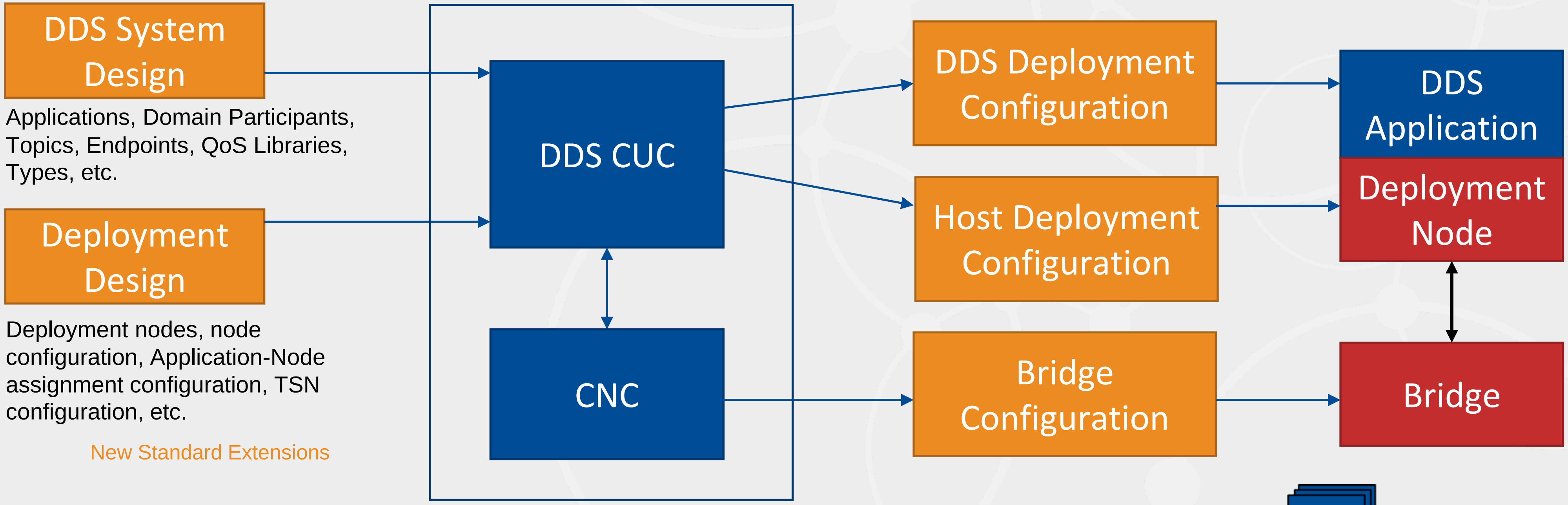
Deploying DDS over TSN

Data Modeling, QoS Policies, Communication Endpoints

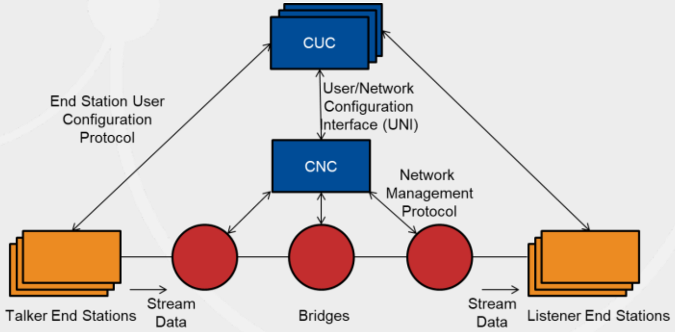
Deployment Configuration, Resource Allocation, Traffic Shaping

Identification and Translation of DDS DDS Streams

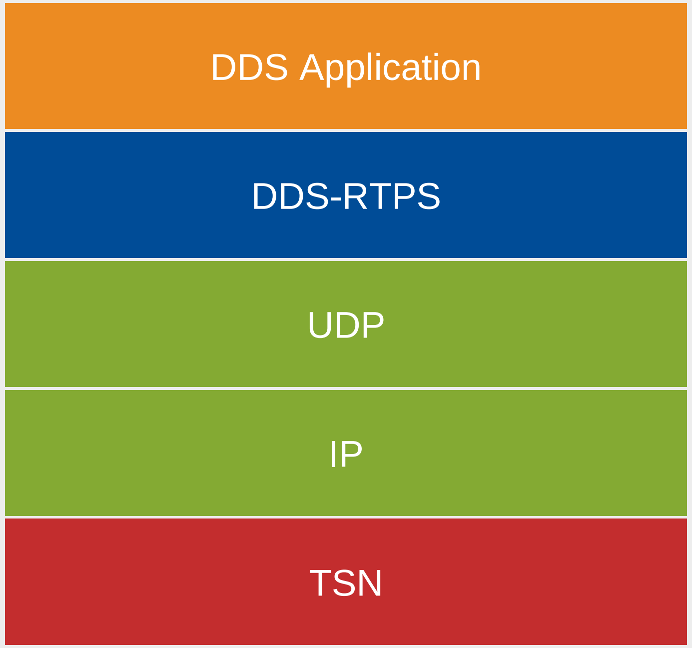
Configuring DDS Extensions for TSN



Logically speaking, CUC and CNC could be combined and even built with a toolchain that performs static configuration.

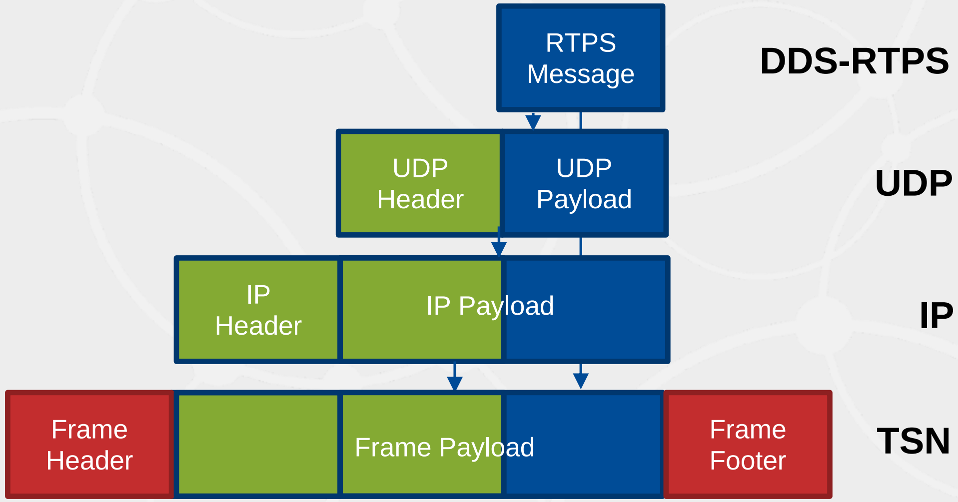


Deploying a DDS System Over TSN



DDS-RTPS traffic can be encapsulated either in:

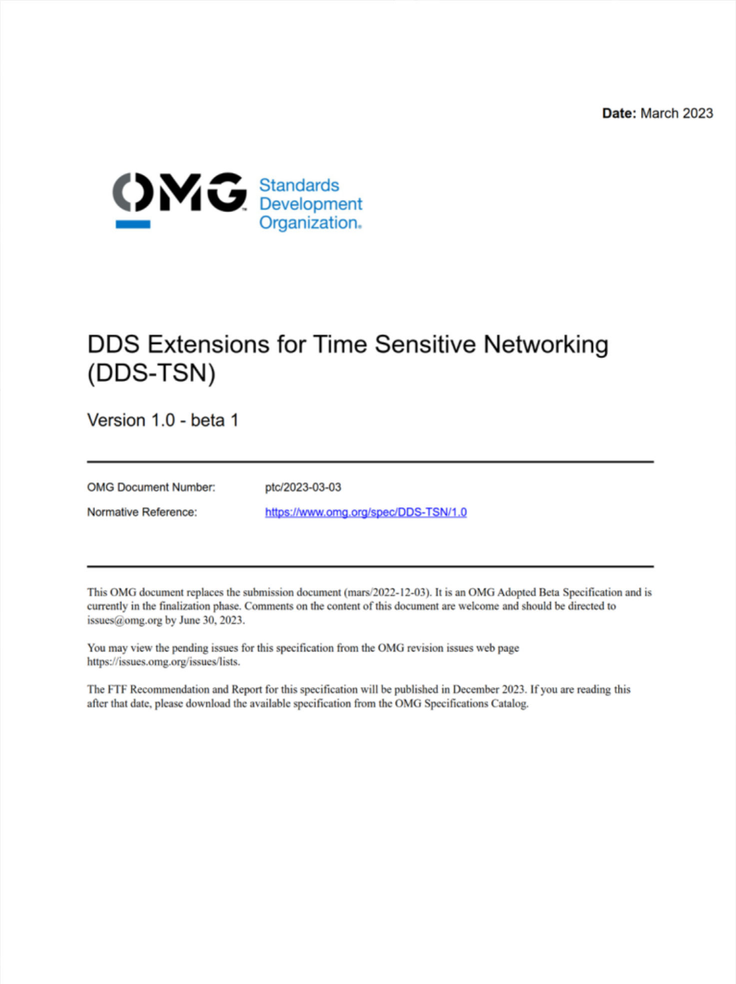
- UDP/IP datagrams
- Directly into Ethernet frames (new extensions)



DDS + TSN

- TSN is becoming important in different markets, especially in automotive, industrial automation, and avionics.
  - Customers requesting integration with DDS
- TSN opens new possible use cases for DDS
  - Helps guarantee QoS Policies, such as those that aim to ensure reliability and bounded latencies at the data-link layer
- OMG has recently published a standard that defines:

  "a set of mechanisms to allow DDS infrastructures to be deployed on, and leverage, TSN-enabled networks."



Date: March 2023

OMG Standards Development Organization.

DDS Extensions for Time Sensitive Networking (DDS-TSN)

Version 1.0 - beta 1

OMG Document Number: ptc/2023-03-03

Normative Reference: https://www.omg.org/spec/DDS-TSN/1.0

This OMG document replaces the submission document (mars/2022-12-03). It is an OMG Adopted Beta Specification and is currently in the finalization phase. Comments on the content of this document are welcome and should be directed to issues@omg.org by June 30, 2023.

You may view the pending issues for this specification from the OMG revision issues web page https://issues.omg.org/issues/lists.

The FTF Recommendation and Report for this specification will be published in December 2023. If you are reading this after that date, please download the available specification from the OMG Specifications Catalog.

https://www.omg.org/spec/DDS-TSN

DDS Quality of Service Properties

RTaW RealTime-at-Work

- The DDS middleware compares **required and offered QoS properties** to match data writers and data readers. Here we will focus on
  - Deadline QoS -> periodicity of sample updates
  - LatencyBudget QoS -> latency constraint on network traversal time
- The fulfillment of the QoS is monitored online and can be queried by the applications.
- **But if the underlying network resources are insufficient in certain circumstances**, the DDS middleware can detect QoS violations and call handlers to deal with the fault situation, but it can do little to prevent them.
- The network design **must guarantee upfront** that network resources are sufficient under all circumstances.
- **TSN and related scheduling mechanism can help** to achieve these guarantees, but **Worst-Case Analysis** is needed for **verification**.

TSN Scheduling mechanisms

RTaW RealTime-at-Work

Which are relevant (TSN-)Scheduling mechanisms and what do they allow to achieve?

Scheduling mechanism	Useful effects
Priorities	lower delays for critical frames, by assigning them to traffic classes with a higher priority
TAS, Preemption	reduced “head-of-line” blocking ⇒ even lower delays for critical frames
CBS, ATS	spreading out transmission of bursty traffic ⇒ reduced delays of lower priority traffic ⇒ reduced memory requirement in switches
Pre-shaping	spreading out of queuing of bursty traffic at network ingress, as for example with Tspec / CMI rules ⇒ reduced memory requirement in ingress queues

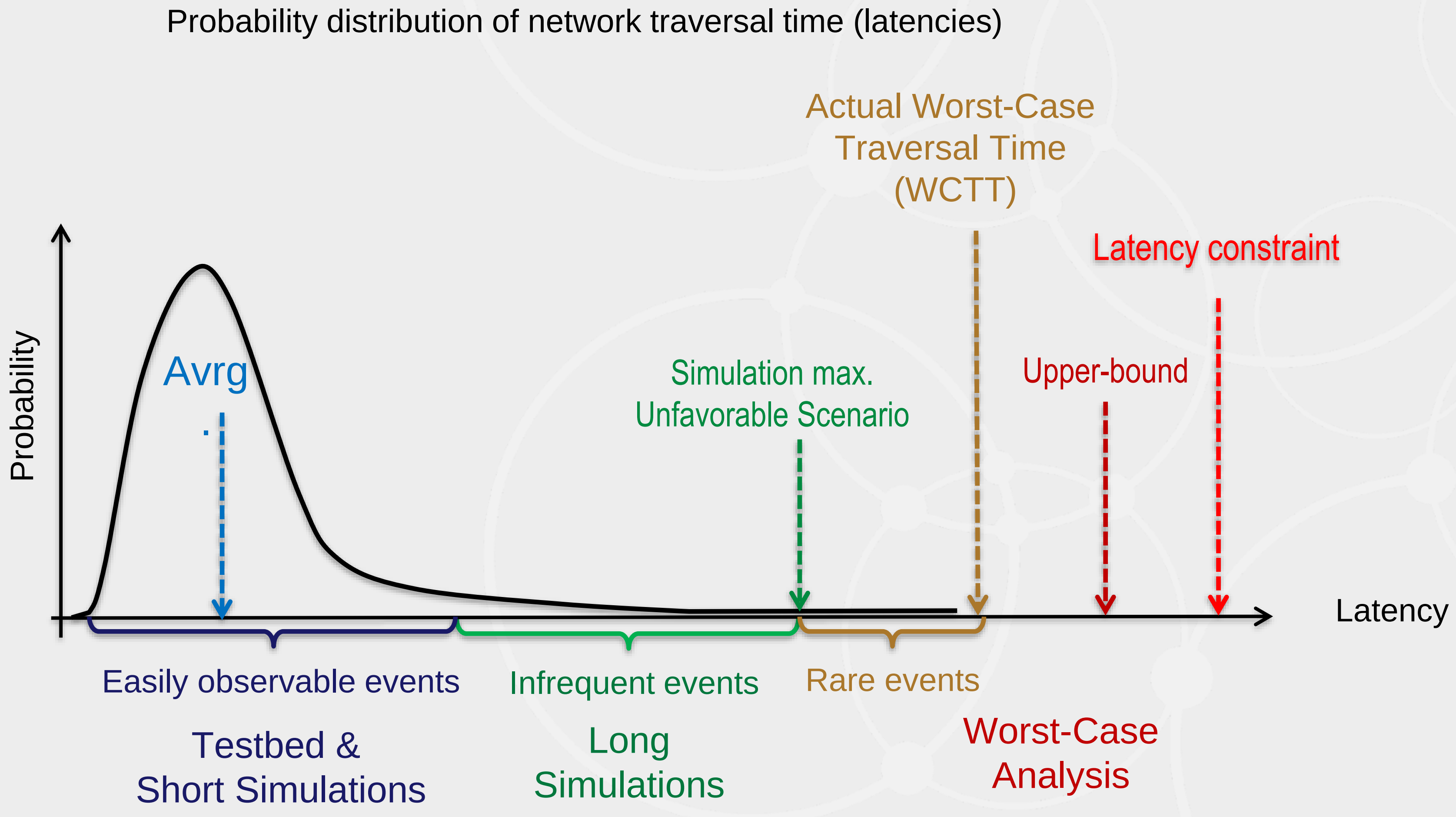
Note1:
TAS can also be used for bandwidth partitioning

Note 2:
Pre-shaping is useful for CBS shaping of streams with same source but different destinations (not needed with ATS)

But how do we verify that a TSN network configuration meets all timing related QoS?

Simulation & Worst-Case Analysis

RTaW
RealTime-at-Work



Remarks:

- Upper bound and statistics are complementary
- Simulation does not allow to find the worst-case,
- But simulation can provide useful insights through observed unfavorable scenarios, which worst-case analysis cannot provide

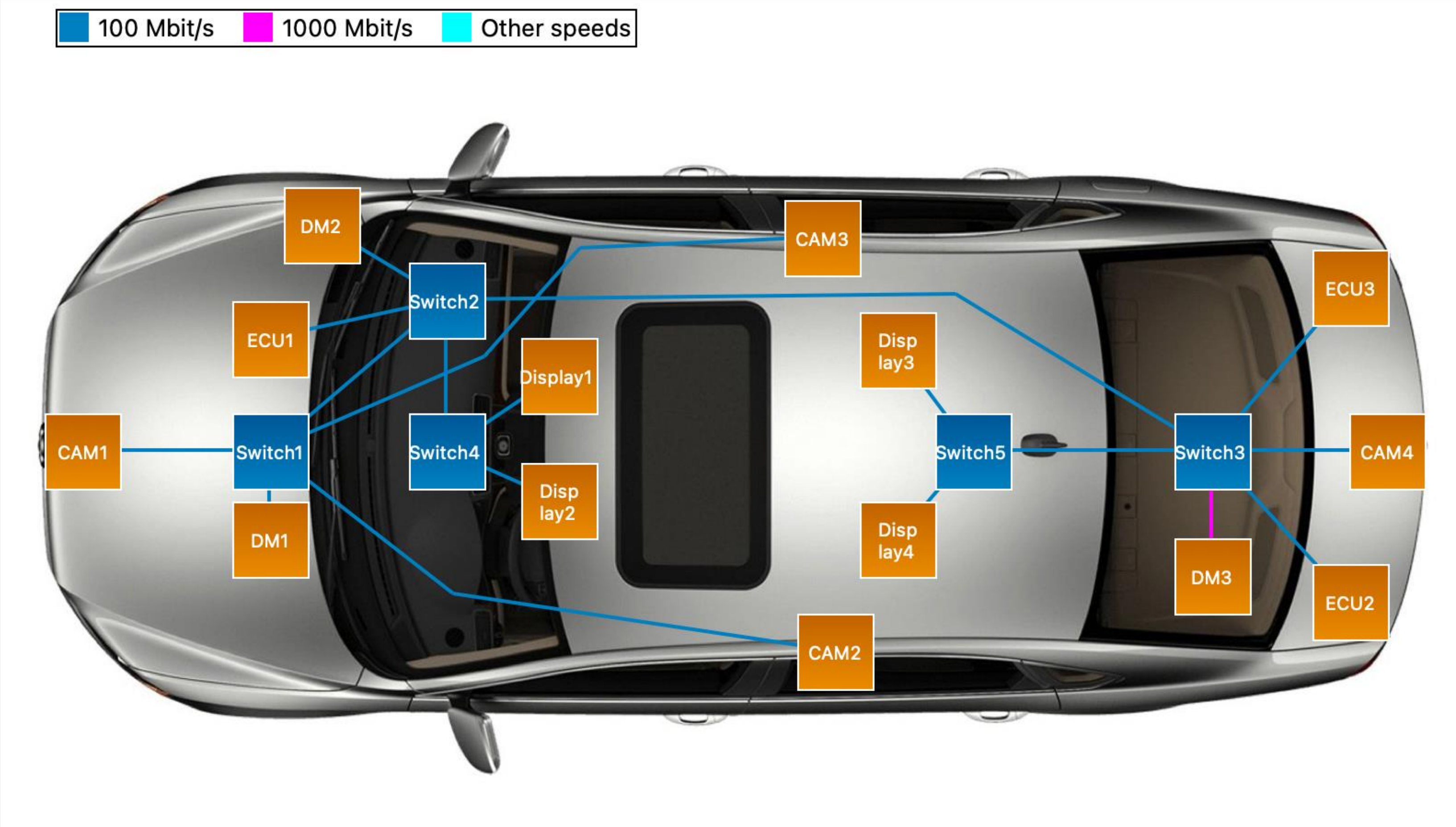
Worst-Case Analysis

RTaW
RealTime-at-Work

- TSN and related scheduling mechanisms are helpful, but alone, they do not allow to **guarantee** the fulfillment of **QoS requirements**.
- **Simulations** provide **insights** about typical delays
  - If an observed delay is larger than the LatencyBudget
    ⇒ we can conclude that the design is insufficient
  - If all delays are smaller than the LatencyBudgets
    ⇒ inconclusive: there could exist a worse scenario

- Through **upper bounds**, **Worst-Case Analysis** can provide **guarantees**
- Worst-Case analysis = mathematical model based on
  1. characteristics of network resources: topology, link speed, …
  2. characteristics of the streams: topic sizes, period, …
- If all upper bounds < LatencyBudget ⇒ OK

Automotive inspired sample



Priority	Traffic Class
6	C&C
5	Video
4	Vehicle
3	BE

Note: topologies with redundant paths could also be supported

DDS driven frames

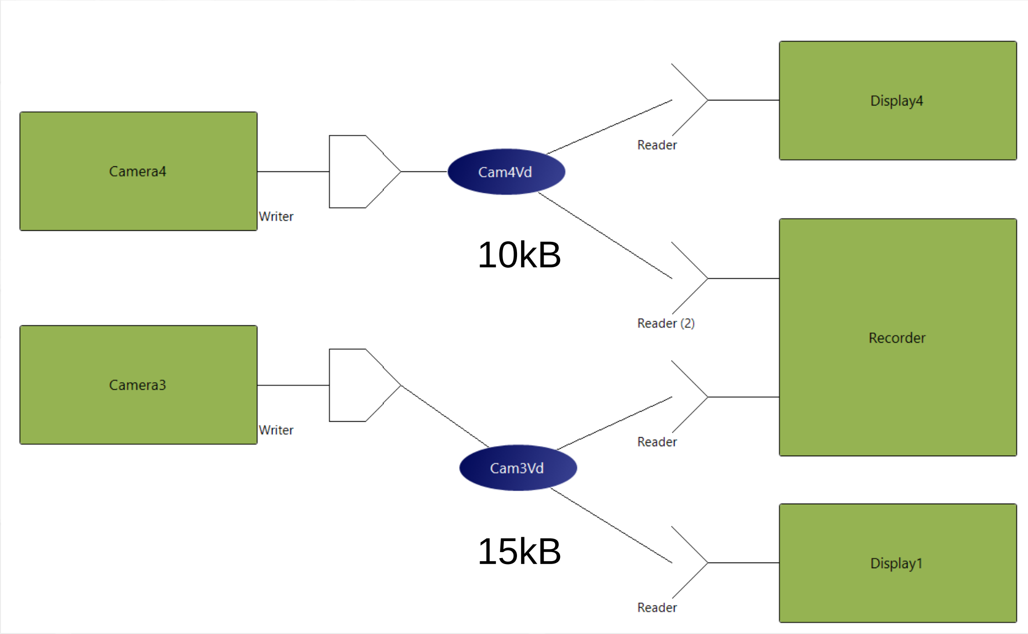
DCPS (classical topics)

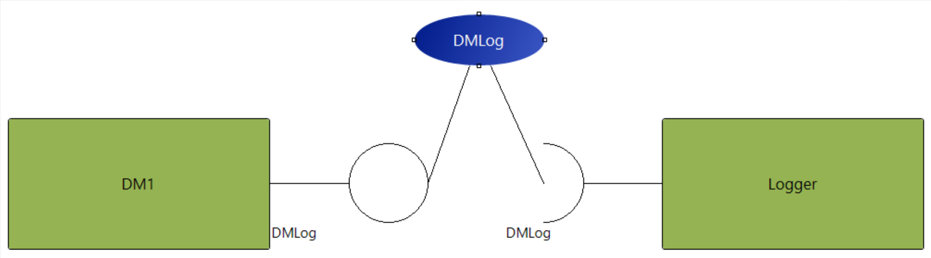
- Periodic Command and Control (C&C) topic with very tight latency constraints
- Video stream topic, with latency constraint, requiring fragmentation

RPC (services)

- Status service with hard latency constraint
- Best-Effort log service

Domain	Writer Participant	Writer Node	Topic	Reader Node	Reader Participant	Bound	Constraint
C&C	Camera3-CC	CAM3	Cam3Ctr	ECU1	ImageProcessing	0,607 ms	0,6 ms
C&C	Camera3-CC	CAM3	Cam3Ctr	Display3	Display3	0,975 ms	0,55 ms
Video	Camera3	CAM3	Cam3Vd	Display1	Display1	8,317 ms	15 ms
Video	Camera4	CAM4	Cam4Vd	Display4	Display4	7,005 ms	20 ms
Video	Camera4	CAM4	Cam4Vd	ECU1	Recorder	4,348 ms	20 ms

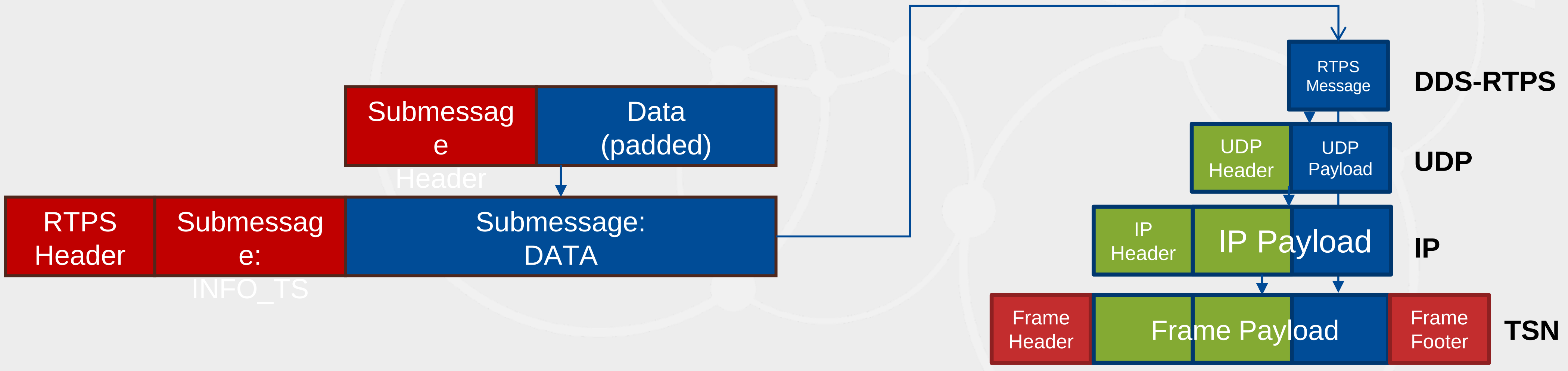




DDS frame mapping

Mapping of topics to frames

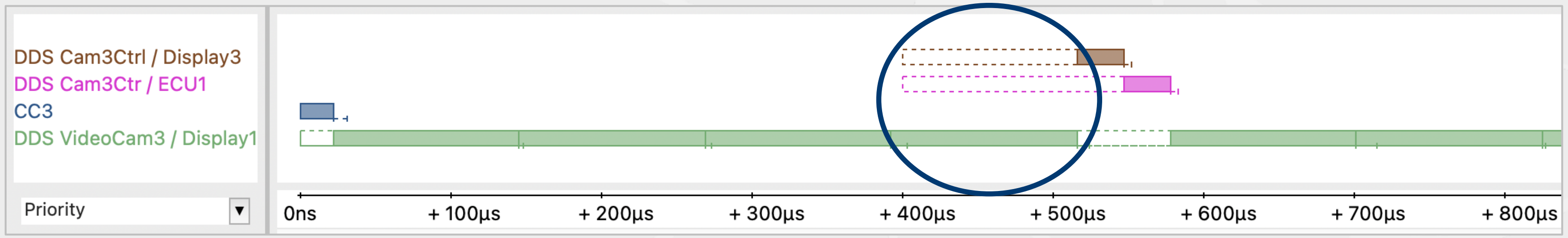
- Every topic update triggers the transmission of a separate frame
- uni-cast, multi-cast, multi-unicast
- DDS max message size can be configured to avoid IP fragmentation



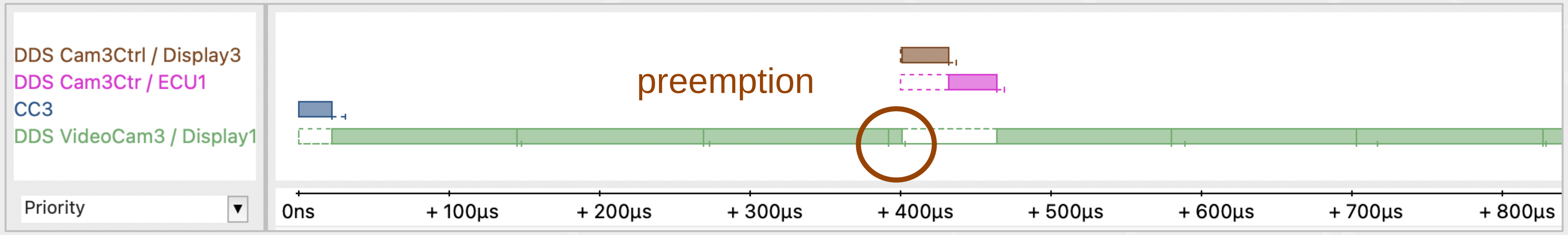
TAS / Preemption: reduced “head-of-line” blocking

Cam3Crtl = critical message

head-of-line blocking

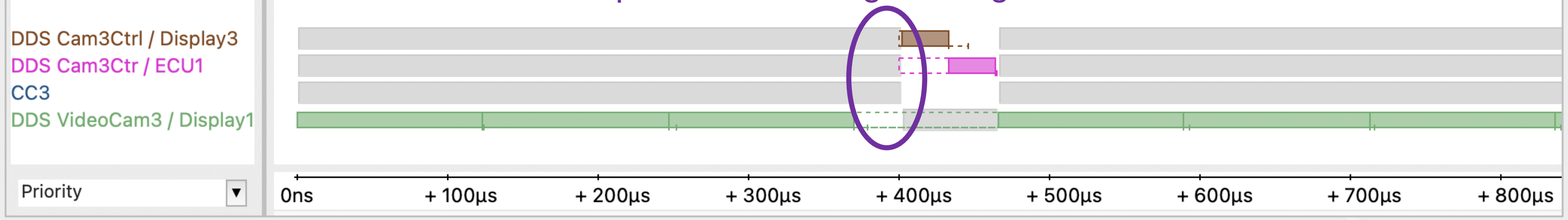


Writer Node	Topic	Reader Node	Reader Participant	Bound	Constraint
CAM3	Cam3Ctr	ECU1	ImageProcessing	0,607 ms	0,6 ms
CAM3	Cam3Ctr	Display3	Display3	0,975 ms	0,55 ms



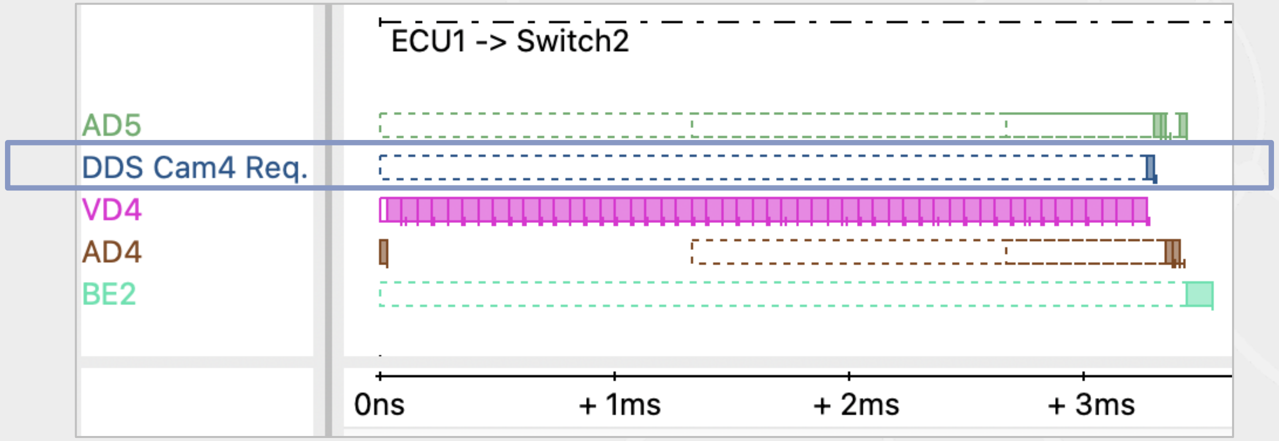
Writer Node	Topic	Reader Node	Reader Participant	Bound	Constraint
CAM3	Cam3Ctr	ECU1	ImageProcessing	0,271 ms	0,6 ms
CAM3	Cam3Ctr	Display3	Display3	0,475 ms	0,55 ms

protection through TAS gates

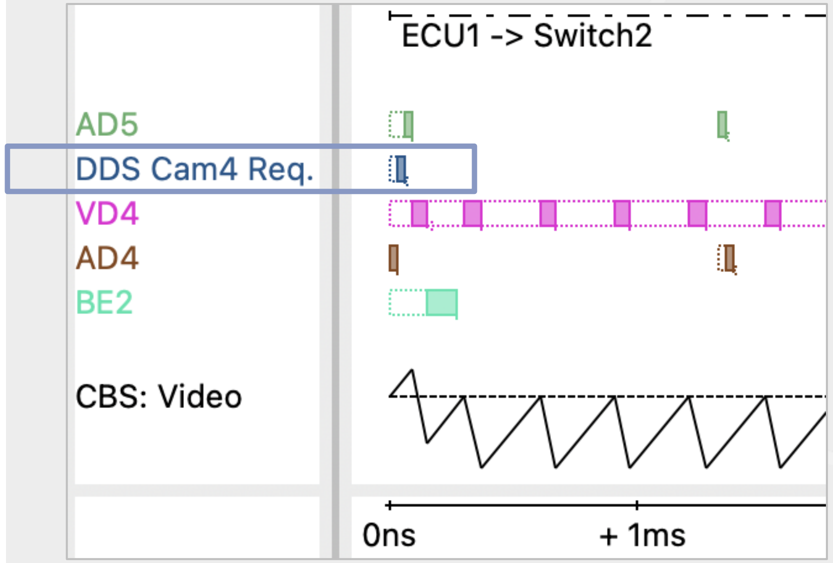


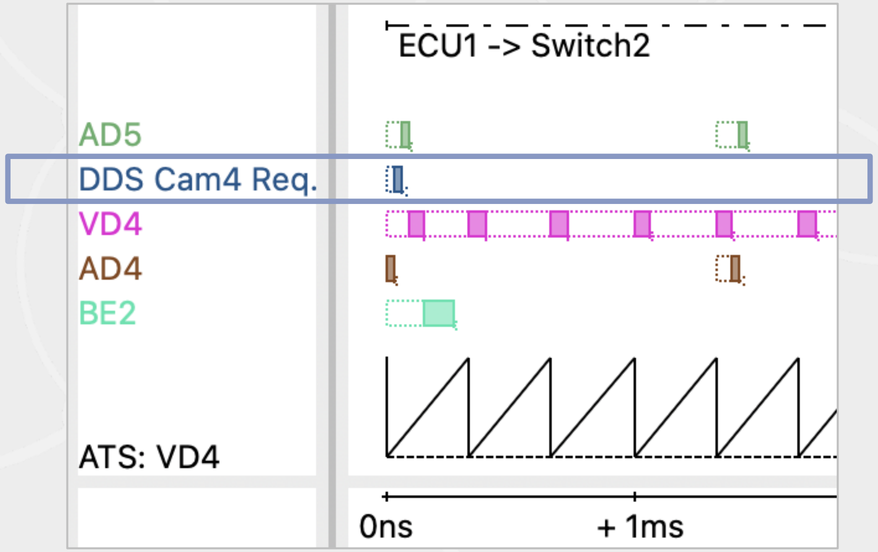
Writer Node	Topic	Reader Node	Reader Participant	Bound	Constraint
CAM3	Cam3Ctr	ECU1	ImageProcessing	0,195 ms	0,6 ms
CAM3	Cam3Ctr	Display3	Display3	0,291 ms	0,55 ms

CBS, ATS: reduced delays at lower priorities



Long delay because of video bursts with higher priority

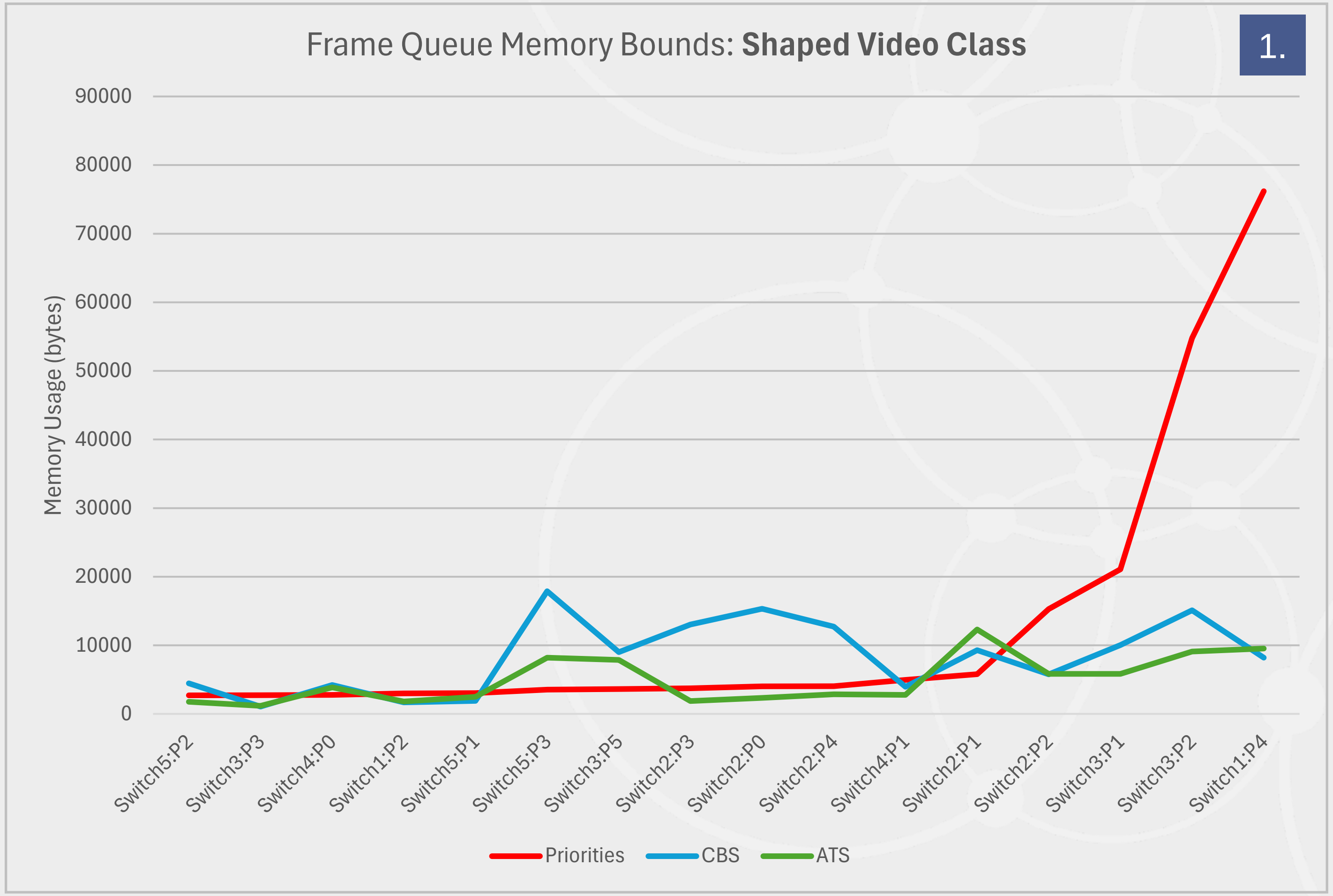




Shorter delay because of CBS or ATS shaping of bursts

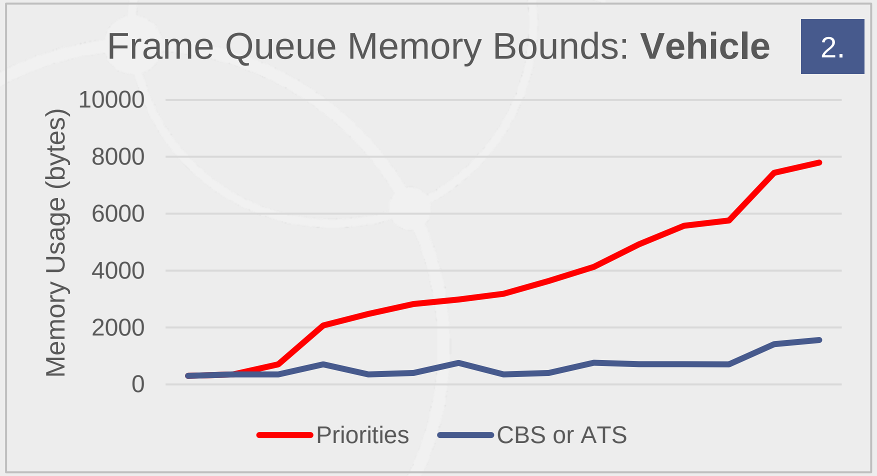
CBS, ATS: reduced memory usage in switches

RealTime-at-Work



Shaping reduces memory requirements for

1. shaped traffic class
2. lower priority traffic classes



Conclusions

RTaW RealTime-at-Work

- TSN scheduling mechanisms can help
  - meeting time-related QoS requirements
  - optimize the usage of network resources
- If the configuration of TSN scheduling mechanisms is combined with worst-case analysis for verification, then QoS requirements can be guaranteed

Q&A

For more information:
www.rti.com/tsn
www.realtimeatwork.com

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