"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 644080."

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SAFety and secURity by dEsign for interconnected mixed-critical cyber-physical systems

Worst Case Analyses of Ethernet in SymTA/S

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OUTLINE

- **Introduction**
- **Overview – Usage of SymTA/S**
- **Modelling Ethernet in SymTA/S**
- **Worst Case Analyses in SymTA/S**
- **Live Demo – State of the Art of Customer Systems**

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INTRODUCTION

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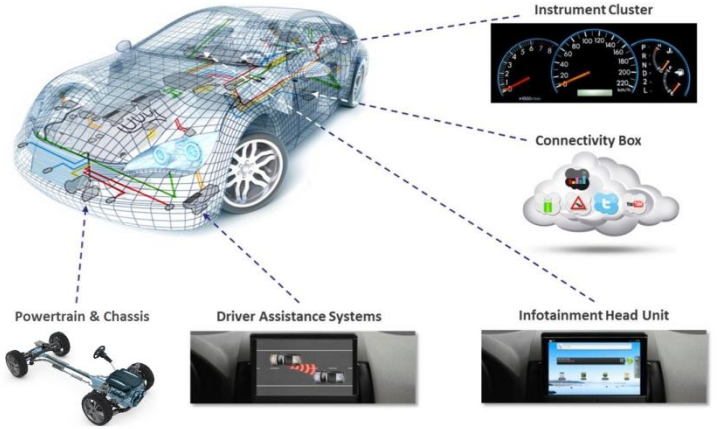
Trends in automotive networks

- **Ever-increasing requirements:**
  - more sophisticated infotainment applications
  - quickly growing sensor traffic
  - complex low-latency traffic
  - high reliability



- **Switched Ethernet is a viable approach**
  - bandwidth scalability (100Mb/s - 1Gb/s - 10Gb/s …)
  - highly configurable (adaptable performance & redundancy)
  - shared technology cost (huge engineering platform experience)

- **Conclusion**
  - a comprehensive timing model is key to success in the automotive market today.

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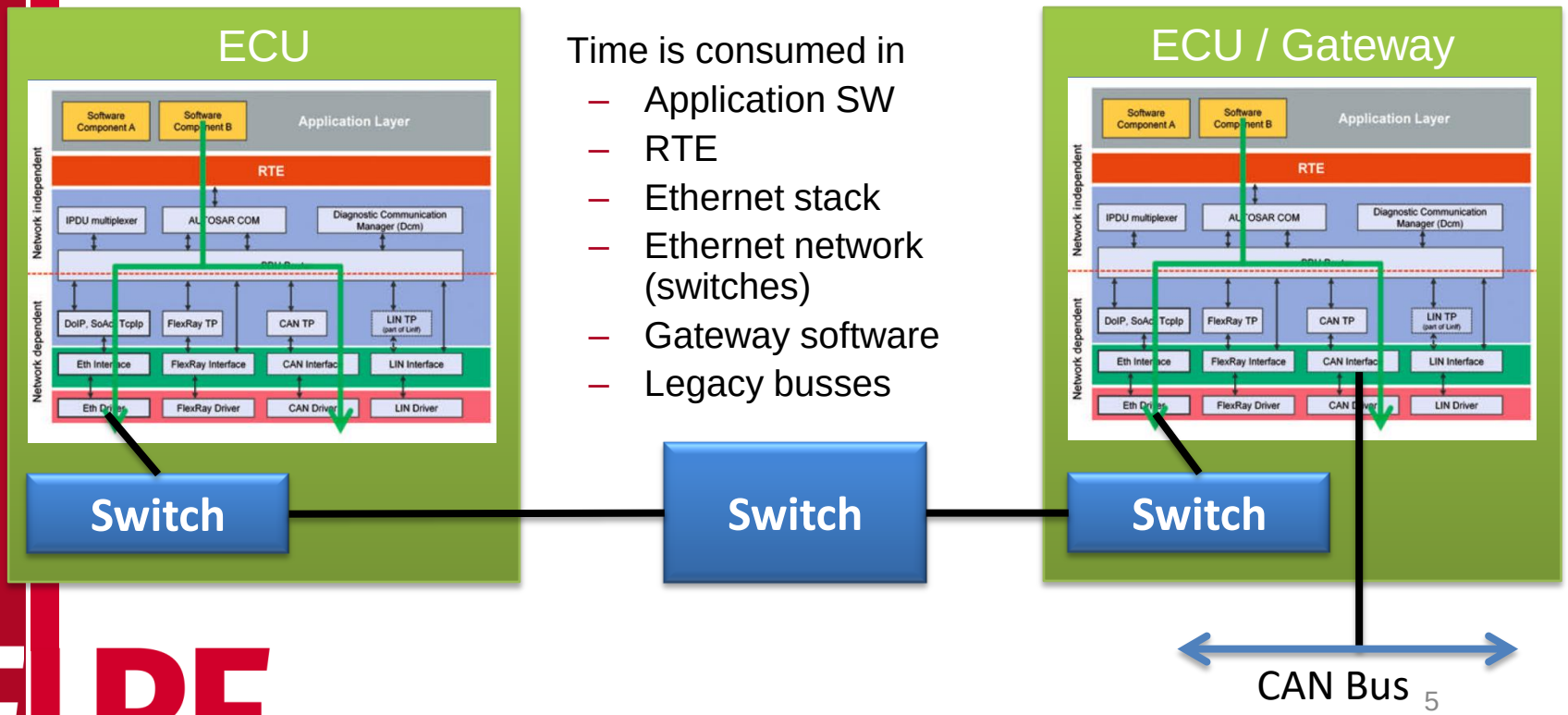
Timing Consumption in Ethernet

- To utilize Ethernet for
  - time-sensitive (e.g. ADAS) and
  - time-critical (e.g. control) communication,

  timing must be assessed



Major Ethernet Timing Challenges

1. Ethernet ports and Ethernet switches ➔ network architecture
   - blocking at shared resources (output ports) produces significant delays despite high bandwidth
   - ECU and switch buffers are limited resources (buffer overflows)
2. Signal-based communication ➔ communication configuration
   - cyclic transmission timeout produces sampling delays, which needs to be considered in grouping PDUs together
   - packing/un-packing leads to additional timing effects
3. ECU/Gateway load ➔ ECU SW architecture
   - Ethernet more demanding than legacy busses (CAN, FlexRay)
     - more processing, higher data rates
     - higher buffer requirements

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Ethernet Configuration Parameters

ECUs

Switches

Switch Configuration
(traffic classes, shaping)

Topology

Switching Technology (QoS, AVB, …)

Bandwidth (100Mbit/Gbit)

All Affect Timing!

Signals

Frames

Sender/Receiver
Payload Size

PDUs

Triggering of Ethernet Frames
(periodic, immediate, buffer fill)

Activation of Traffic
(periodic, sporadic, …)

Unpacking Strategy
(handling of priorities etc.)

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OVERVIEW - USAGE OF SYMTA/S

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Symtavision Timing Analysis Methodology

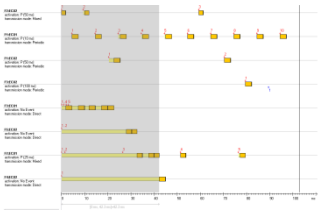
ECU, Network & E/E levels

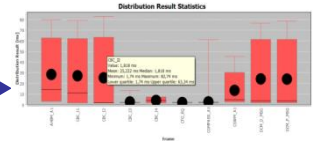
manual configuration & timing model

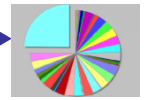
DBC, Fibex, AUTOSAR XML, OIL, XLS, XML, etc.

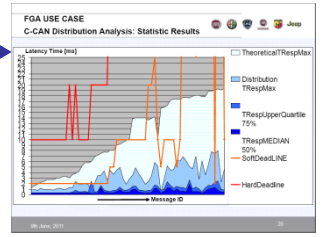
import configuration & timing model

optimized configuration & refined timing model









Network / ECU traces

import dynamic timing information

Visualization, Timing Analysis, Configuration Optimization & Reports

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ETHERNET MODELLING IN SYMTA/S

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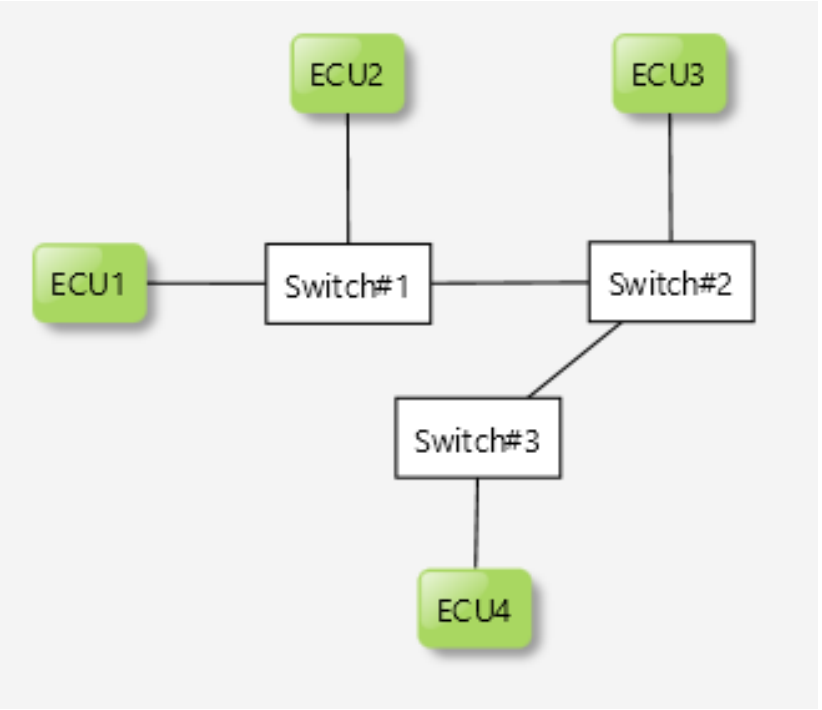
SymTA/S Ethernet Modelling

- Modelling topology via
  - ECUs (vehicle control units)
  - switches
  - ports and links in between
- Defining properties
  - link speed
  - switch delay



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SymTA/S Ethernet Modelling

- Modelling traffic via
  - Ethernet messages (streams)
- Defining properties
  - activation model
  - payload size
  - sender and receiver

*List of all Ethernet Messages

	Element		Ethernet Message					Internal	Payload
	Name	Parents	Sender	Receiver	Broadcast	Priority	Transport Protocol	Activation	Size [Byte]
1 EthernetMessage#1	Etherne...sage#1	Etherne...o-ECU2	ECU1	ECU2	false	1	UDP	P(50 ms)	[1472;1472]
2 EthernetMessage#2	Etherne...sage#2	Etherne...o-ECU3	ECU1	ECU2, ECU3	false	2	UDP	P(20 ms)	[1000;1000]
3 EthernetMessage#3	Etherne...sage#3	Etherne...o-ECU4	ECU1	<empty>	true	3	UDP	P(10 ms)	[500;500]

ETHERNET WORST CASE ANALYSES IN SYMTA/S

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Standards – State of the Art

State of the Art

- Standard Ethernet IEEE802.1
- Static Priority Non-Preemptive IEEE802.1Q
- AVB IEEE802.1Qas

Future

- TSN (in future)
  - Traffic Shaper IEEE802.1Qbv
  - Frame Preemption IEEE802.1Qbu
  - Frame Replication IEEE802.1CB
  - String Filtering IEEE802.1Qci

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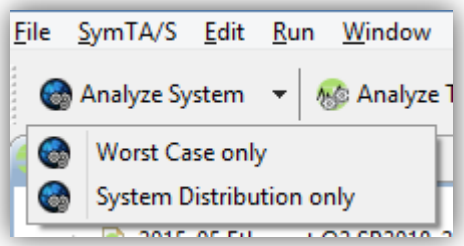
Worst Case Analyses

- Offers two different types of analyses
  - Worst Case Analysis
  - System Distribution (Simulation)
- **SAFURE Focus**: Worst Case Analyses
  - Main metrics (based on theory from TUBS):
    - Load (for ports and switches)
    - Data Rate (for Ethernet messages (streams))
    - Latency (for Ethernet messages (streams))
      - » including end-to-end latency
    - Buffer Fill Level (for ports and switches)



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Worst Case Analysis: Data Rate

- Data rates are provided for Ethernet messages
  - ratio between the message payload and distance of occurrences regarding the activation pattern

Element	Data Rate		
Name	Total	Execution	Scheduling Overhead
EthernetMessage#1	1233.6 kbit/s	1224 kbit/s	9.6 kbit/s
EthernetMessage#2	856 kbit/s	846.4 kbit/s	9.6 kbit/s
EthernetMessage#3	456 kbit/s	446.4 kbit/s	9.6 kbit/s

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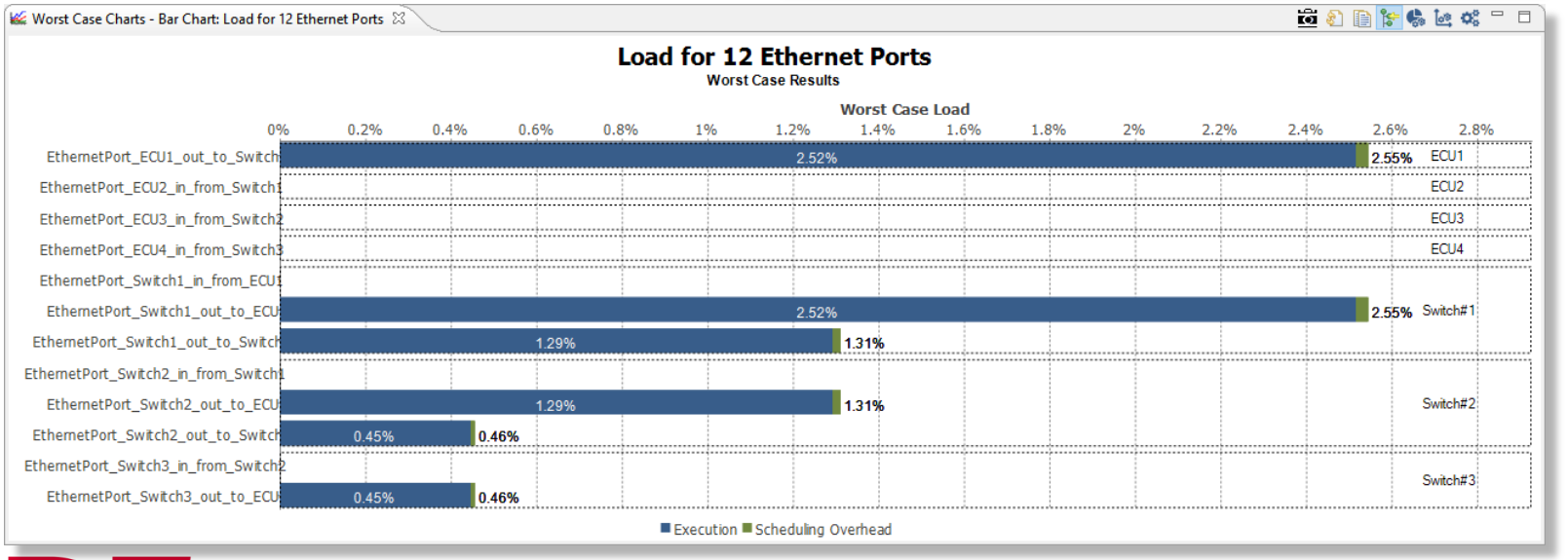
Worst Case Analysis: Load

- sending (TX) load is calculated on each port and for ECUs and switches
  - occupancy of the port regarding all transmitted Ethernet messages on this port
- additional bar charts for a better understanding

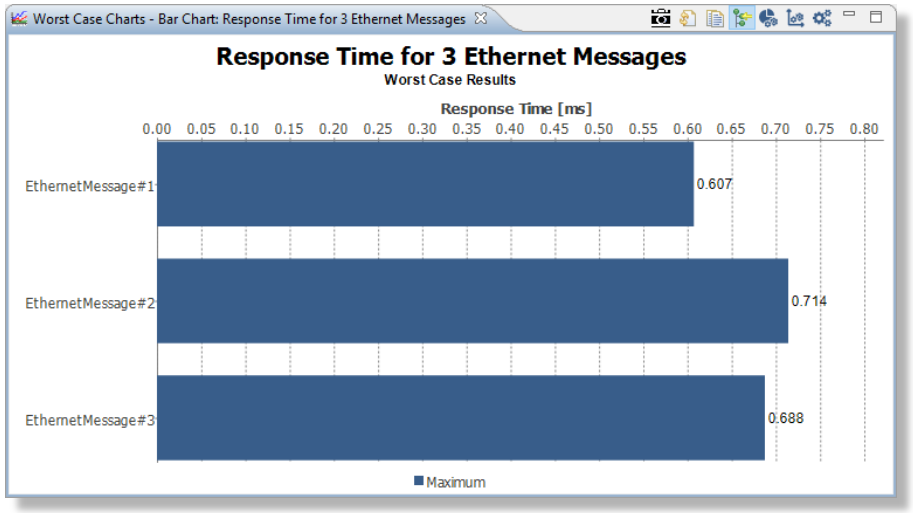
Element	Load		
Name	Total	Execution	Scheduling Overhead
EthernetPort_ECU1_out_to_Switch1	0.025456	0.025168	0.000288
EthernetPort_ECU2_in_from_Switch1	0	0	0
EthernetPort_Switch1_in_from_ECU1	0	0	0
EthernetPort_Switch1_out_to_ECU2	0.025456	0.025168	0.000288
EthernetPort_ECU3_in_from_Switch2	0	0	0
EthernetPort_Switch2_in_from_Switch1	0	0	0
EthernetPort_Switch2_out_to_ECU3	0.01312	0.012928	0.000192
EthernetPort_Switch1_out_to_Switch2	0.01312	0.012928	0.000192
EthernetPort_ECU4_in_from_Switch3	0	0	0
EthernetPort_Switch3_in_from_Switch2	0	0	0
EthernetPort_Switch3_out_to_ECU4	0.00456	0.004464	0.000096
EthernetPort_Switch2_out_to_Switch3	0.00456	0.004464	0.000096



Worst Case Analysis: Latency

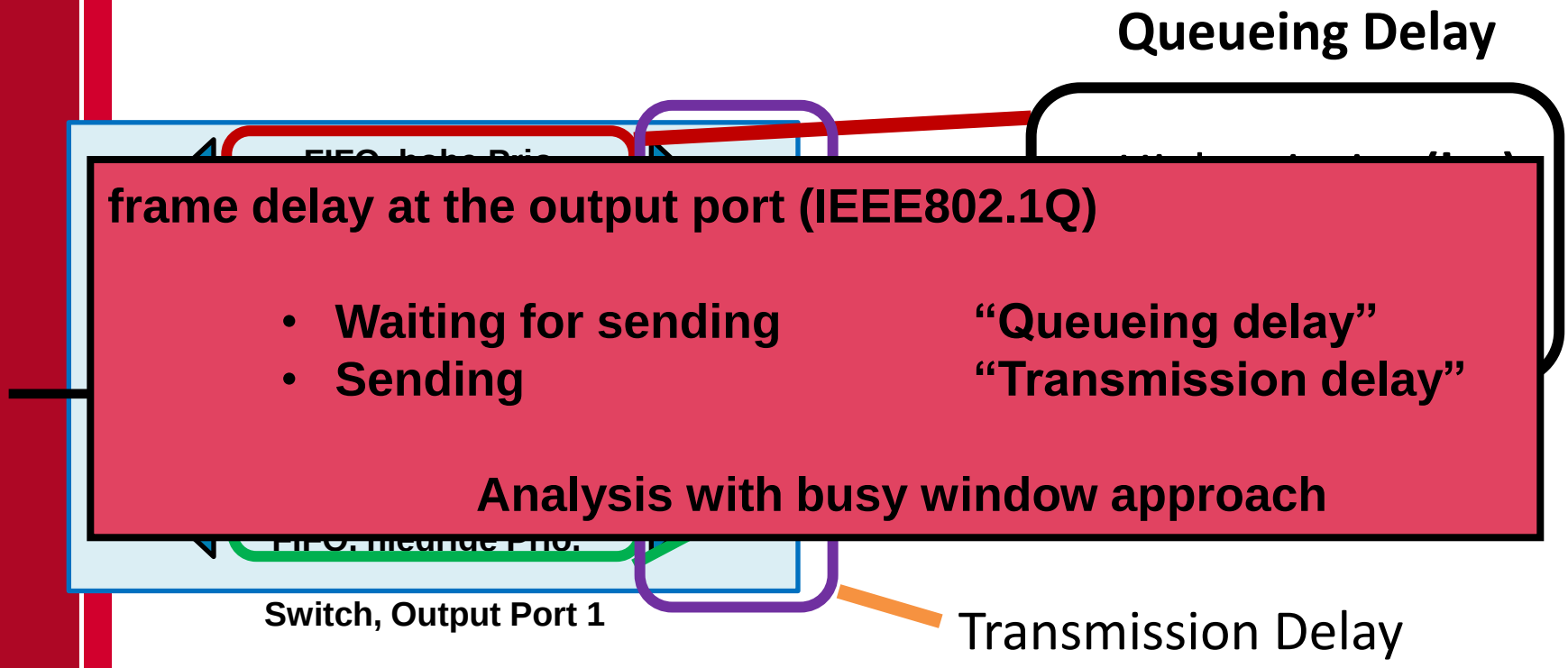
– latency (worst case response time) is provided for Ethernet messages including bar charts

Element	Ethernet Message			Ethernet Message Result	Response Time	
Name	Sender	Receiver	Broadcast	Taken Route	Value	Jitter
EthernetMessage#1	ECU1	ECU2	false	[ECU1, Switch#1, ECU2]	[0.3448 ms;0.6072 ms]	0.2624 ms
EthernetMessage#2	ECU1	ECU2, ECU3	false	[ECU1, Switch#1, ECU2], [ECU1, Switch#1, Switch#2, ECU3]	[0.26928 ms;0.71408 ms]	0.4448 ms
EthernetMessage#3	ECU1	<empty>	true	<n/a>	[0.18928 ms;0.68752 ms]	0.49824 ms



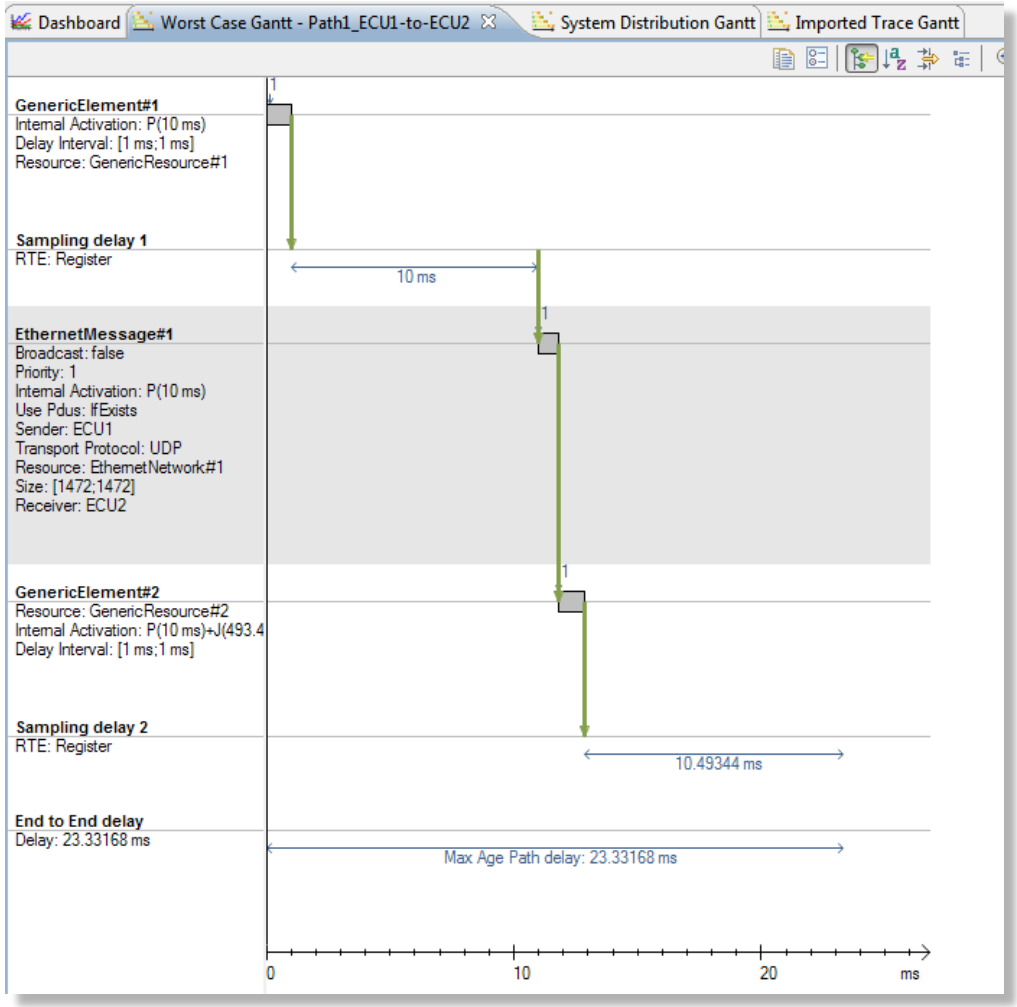
Worst Case Analysis: Latency Theory

- Ethernet supports 8 priorities
  - message streams have to share priorities
  - 1 queue per priority per port
  - priorities cause different delays



Worst Case Analysis: Latency for data paths

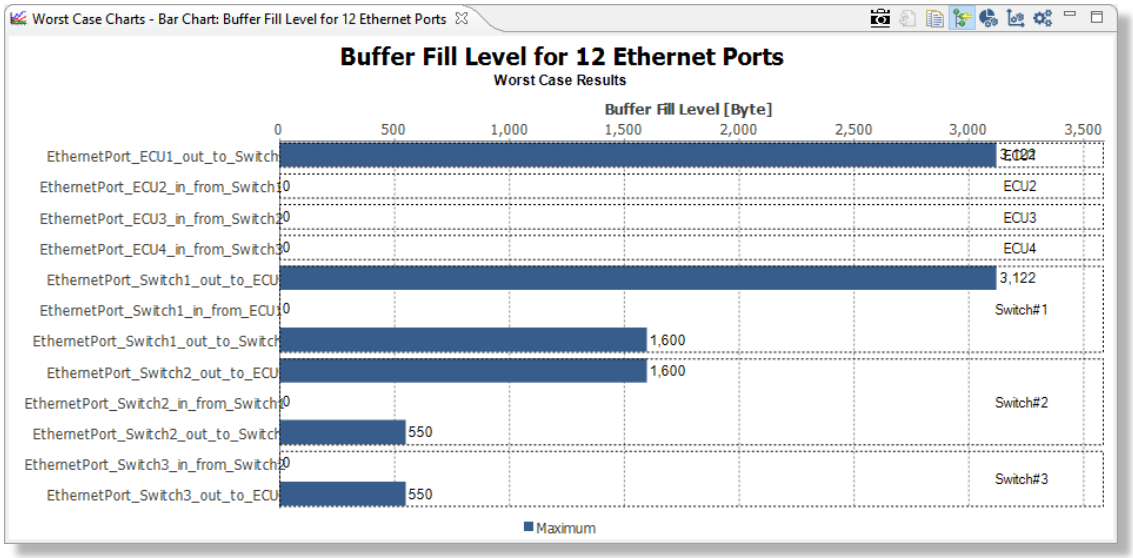
- Worst case latency for end-to-end paths, which include the Ethernet messages
- Latency information of data flow from sender to receiver including sending and receiving task operations



Worst Case Analysis: Buffer Fill Level

- Buffer fill levels are provided for each port and for each switch including bar charts

Element	Buffer Fill Level	
Name	Minimal [Bytes]	Maximal [Bytes]
EthernetPort_ECU1_out_to_Switch1	0	3122
EthernetPort_ECU2_in_from_Switch1	0	0
EthernetPort_Switch1_in_from_ECU1	0	0
EthernetPort_Switch1_out_to_ECU2	0	3122
EthernetPort_ECU3_in_from_Switch2	0	0
EthernetPort_Switch2_in_from_Switch1	0	0
EthernetPort_Switch2_out_to_ECU3	0	1600
EthernetPort_Switch1_out_to_Switch2	0	1600
EthernetPort_ECU4_in_from_Switch3	0	0
EthernetPort_Switch3_in_from_Switch2	0	0
EthernetPort_Switch3_out_to_ECU4	0	550
EthernetPort_Switch2_out_to_Switch3	0	550

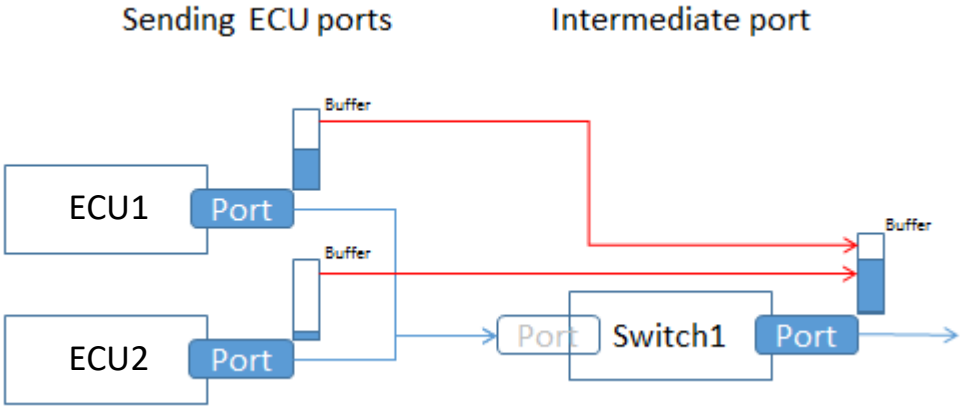


Worst Case Analysis: Buffer Fill Level Theory

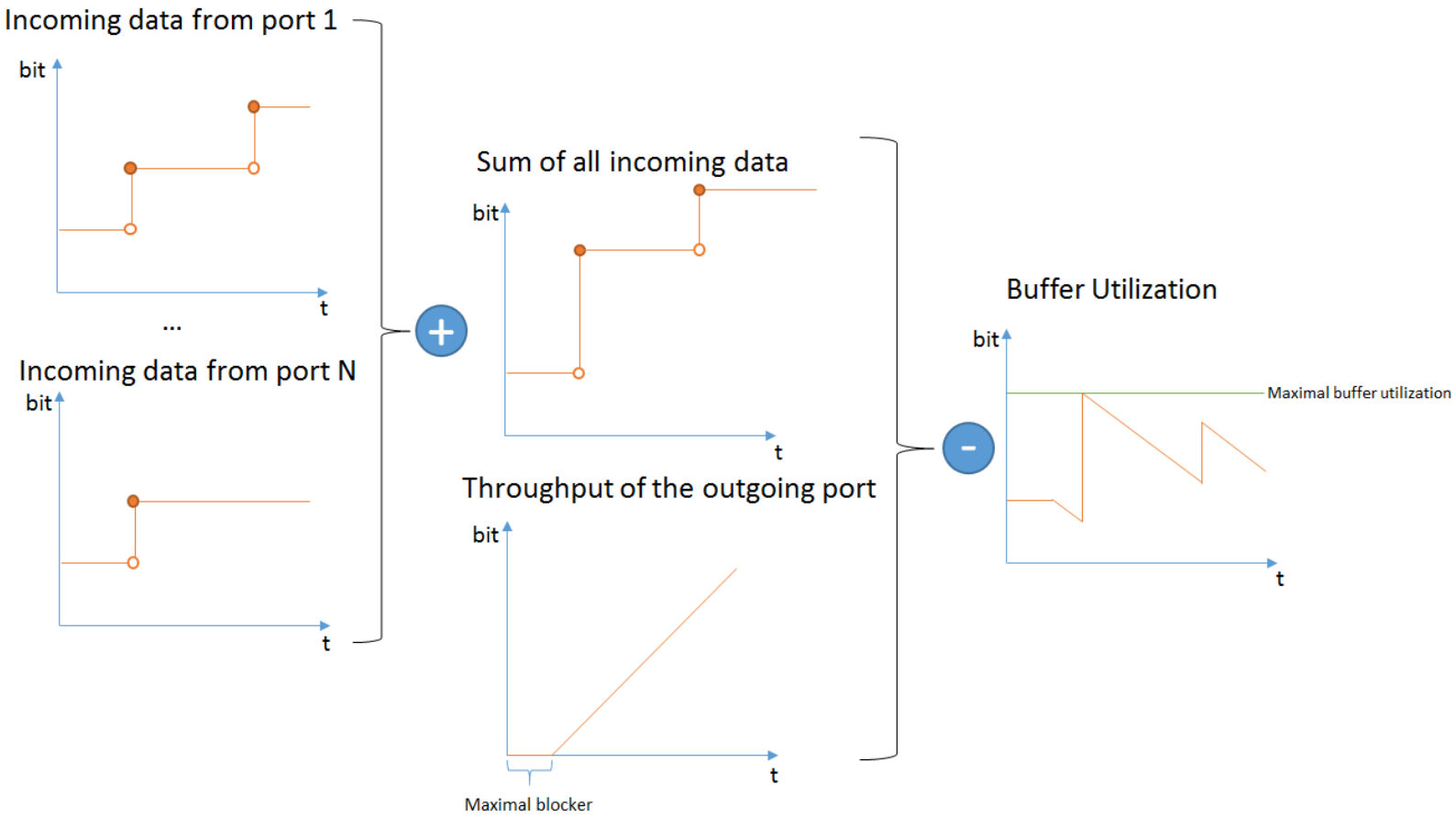
- Compute max. incoming data (requested service/inflow) over any time interval
- Compute min. outgoing data over time for this port,
- Subtract the incoming data from the outgoing data to get the maximal buffer utilization.

Incoming data can originate from two sources:

- In case of the outgoing port of a sending ECU it is assumed that the ECU produces the data with the given Event Model of the Ethernet message
- In case of the outgoing port of an intermediate switch the incoming data comes from the outgoing ports of the predecessor resources on the route of the Ethernet messages



Worst Case Analysis: Buffer Fill Level Theory



LIVE DEMO

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THANK YOU

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SAFURE Grant Agreement No. 644080

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 644080."

"This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 15.0025. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the Swiss Government."

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