Design and Evaluation of Future Ethernet-based ECU Networks

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Outline

- Motivation
- Ethernet and IP in automotive networks
- Ethernet AVB
  - Timing analysis
  - Timing simulation
- Use Case and Conclusions

Motivation

- Novel applications in the infotainment and driver assistance domain
  - Bird's eye view
  - Car-to-X
  - Rear seat entertainment

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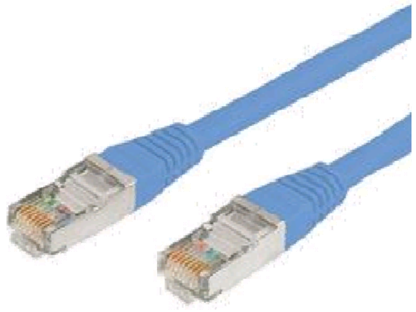
- Result: Heavily increasing bandwidth requirements
- Problem: Common field busses (FlexRay, CAN, …) overstrained

List of Wishes for a Novel Field Bus

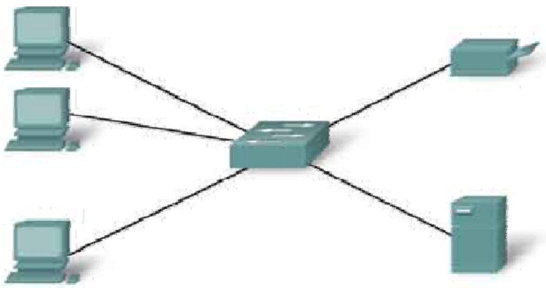
- Technical requirements
  - High bandwidth
  - Simplify current heterogeneous bus systems
  - Real-time capabilities
- Economical requirements
  - Low cost for communication controllers, wiring, …
  - Open standard

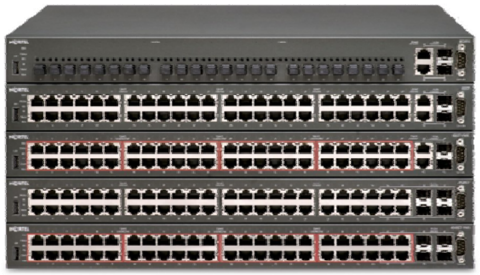
Candidate: IP over Ethernet

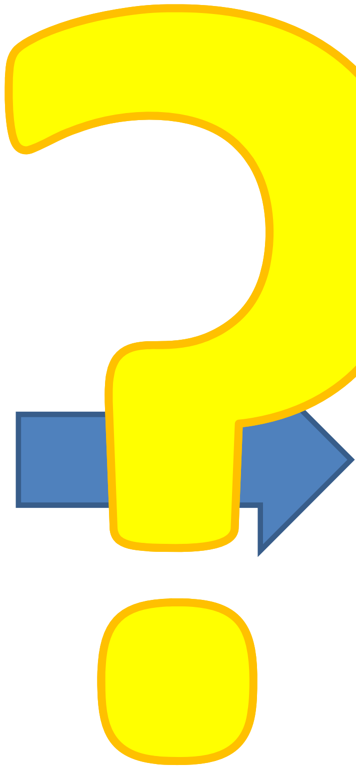


- Technical advantages
  - 10MBit/s up to 10GBit/s bandwidth
  - IP as common addressing scheme
  - Extensions for hard (PROFINET, EtherCAT, …) and soft (Ethernet AVB) real-time capabilities
- Economical advantages
  - Ethernet physical and MAC layer are a common standard in various areas
  - Unshielded twisted pair wires for 100MBit/s possible

Motivation







GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

SEIS – Security in IP based embedded Systems

Audi
VOLKSWAGEN AKTIENGESELLSCHAFT
BOSCH
DAIMLER
Continental
BMW Group
infineon
EADS
SEIS
Alcatel·Lucent
design

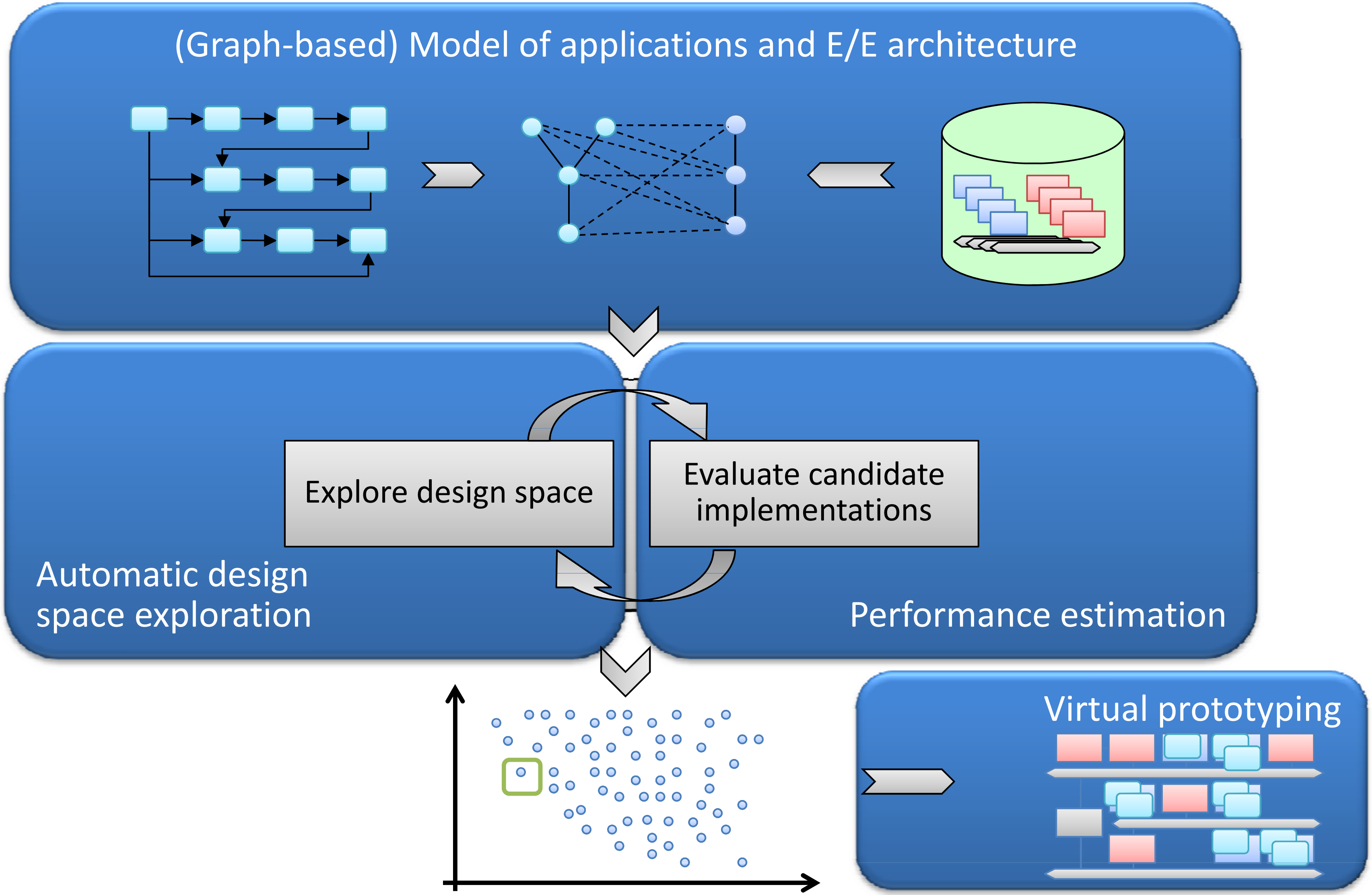
SIT
Fraunhofer Institut Sichere Informations-Technologie

TUM

ESK
Fraunhofer Einrichtung Systeme der Kommunikationstechnik

TELEMATICS
SSC

Our Focus in SEIS: Design Automation



Automotive Design Automation

- Modeling: Tool coupling with industrial CASE tool PREEvision (supports model-based design)

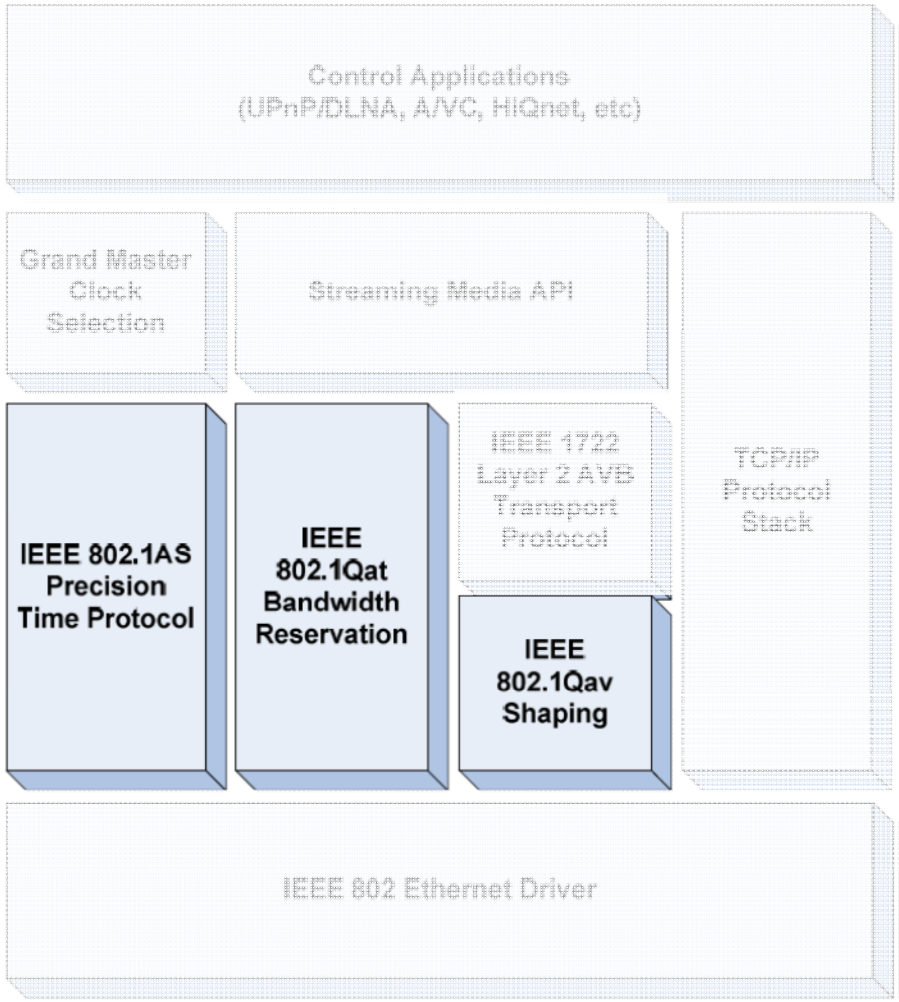
aquintos PREEvision®
www.aquintos.com

mycodesign.com/research/scd

- Automatic Design Space Exploration
  - See talk of M. Lukasiewycz: *Model-based Design of Distributed Automotive Systems*
- This talk: Performance estimation
  - Timing evaluation of an IP/Ethernet-based E/E architecture

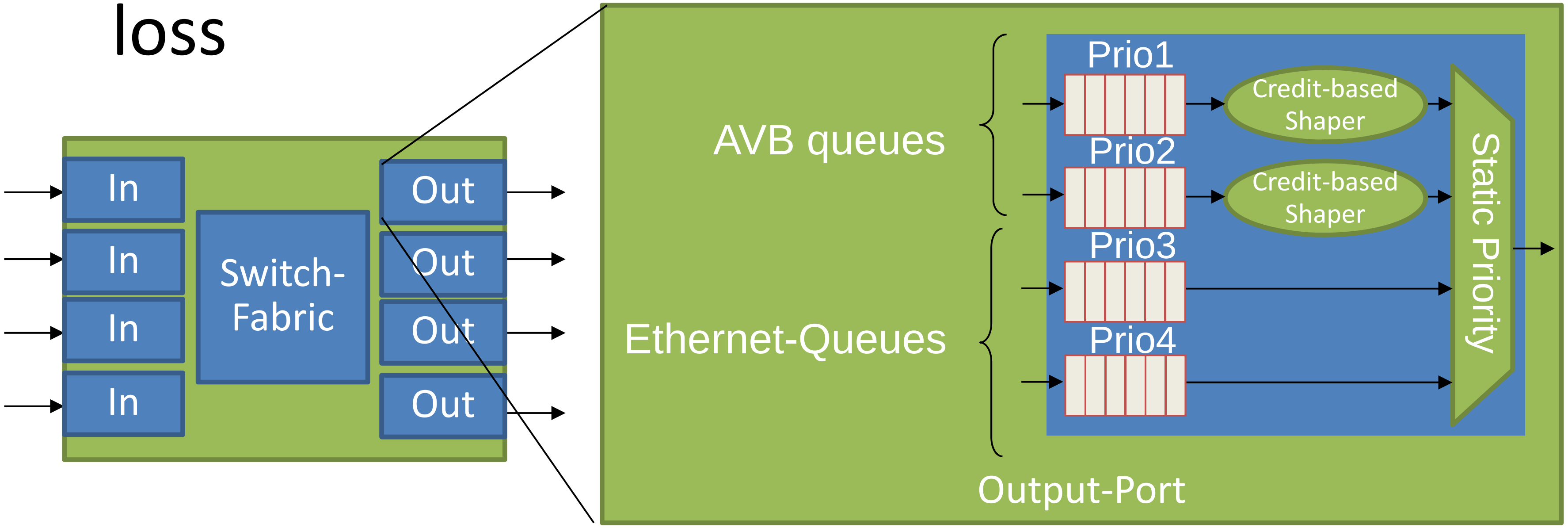
Ethernet/AVB (Audio/Video Bridging)

- Ethernet defines physical and MAC-Layer
- AVB enhances MAC layer by:
  - Clock Synchronization (IEEE802.1AS)
  - Bandwidth Reservation (IEEE802.1Qat)
  - Traffic Shaping (IEEE802.1Qav)
- IEEE1722 is the transport protocol of AVB
- TCP/IP can be used in parallel to AVB/1722



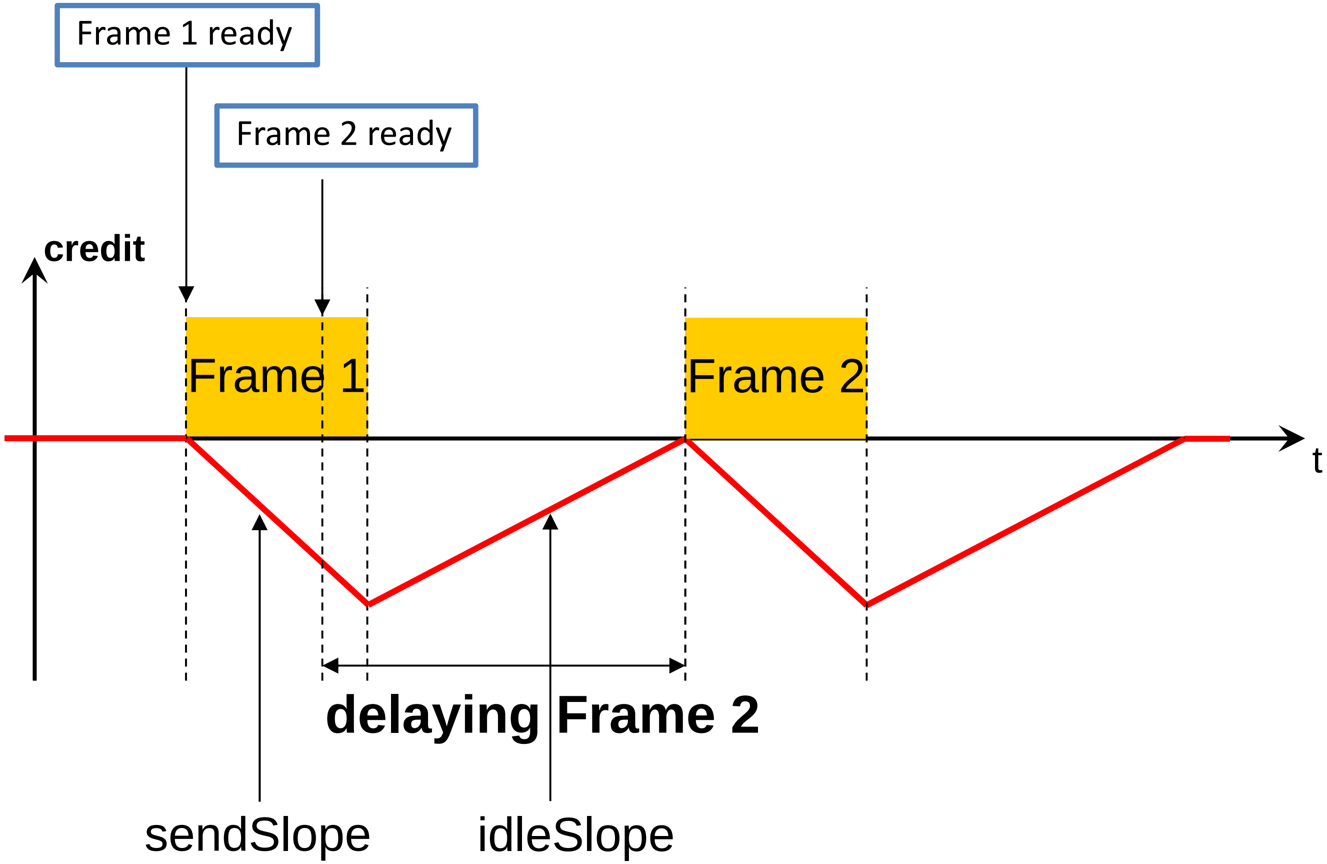
Credit Based Shaping of Ethernet AVB

- Traffic shaping at each output port
- CBS delays messages to avoid bursts
- Otherwise, bursts could lead to buffer overflows at switches and, thus, to message loss



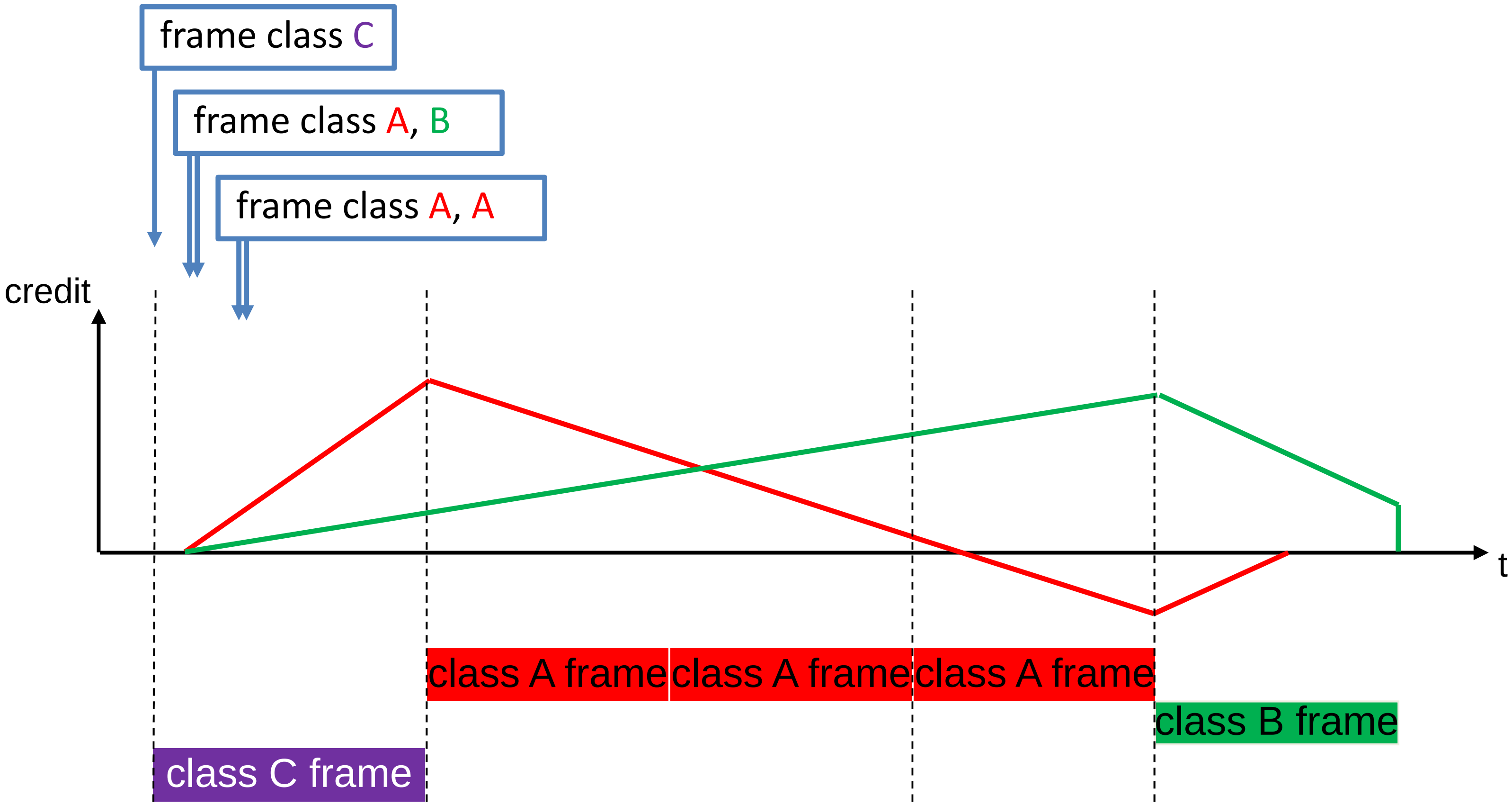
CBS – Example 1

- Two consecutive frames of same traffic class



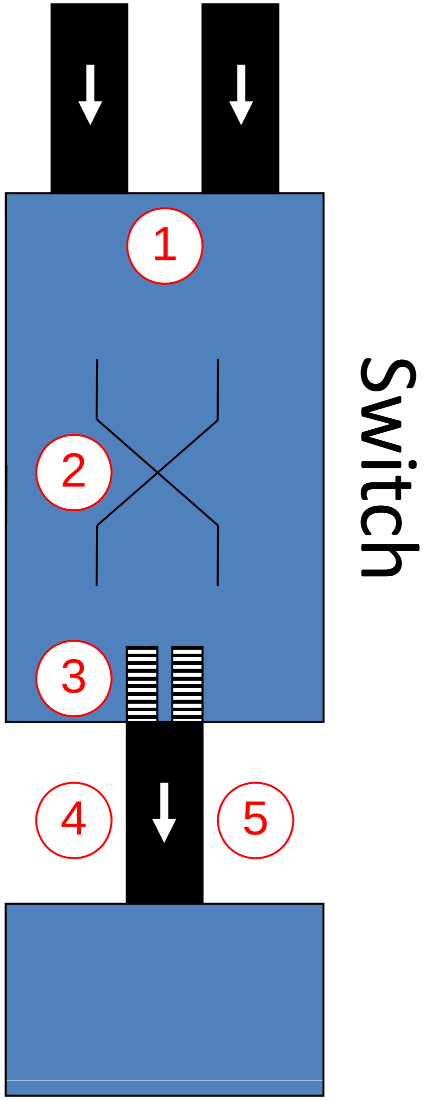
CBS – Example 2

- 3 queues; queue A and B with CBS



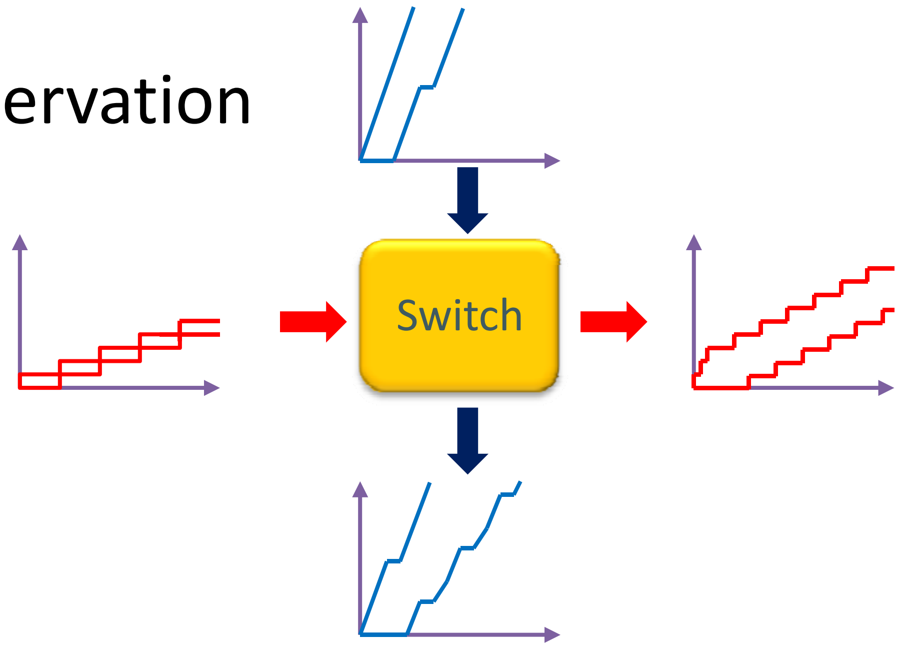
Delays in Ethernet-based Networks

1. Input Queuing Delay
   - *Typically negligible*
2. Store-and-forward Delay
   - *Crossbar operates at high bandwidth*
   - *Non-blocking switches typically used: bandwidth of crossbar >> bandwidth of input links*
3. Interference Delay
   - *Interference with traffic from other input ports*
   - *Best effort, priority-based, and CBS*
4. Frame Transmission Delay
   - *Depends on link bandwidth*
   - *10 MBit/s, 100MBit/s, 1GBit/s, 10GBit/s*
5. LAN Propagation Delay
   - *Signal propagation on medium at light speed*



Real-time analysis of Ethernet AVB

- Real-time calculus to evaluate end-to-end best and worst case delays
- All message streams are known at design time (in contrast to common Ethernet-based systems)
  - Dynamic bandwidth reservation IEEE802.1Qat unnecessary
  - Routing, priorities, and traffic queues fixed during runtime



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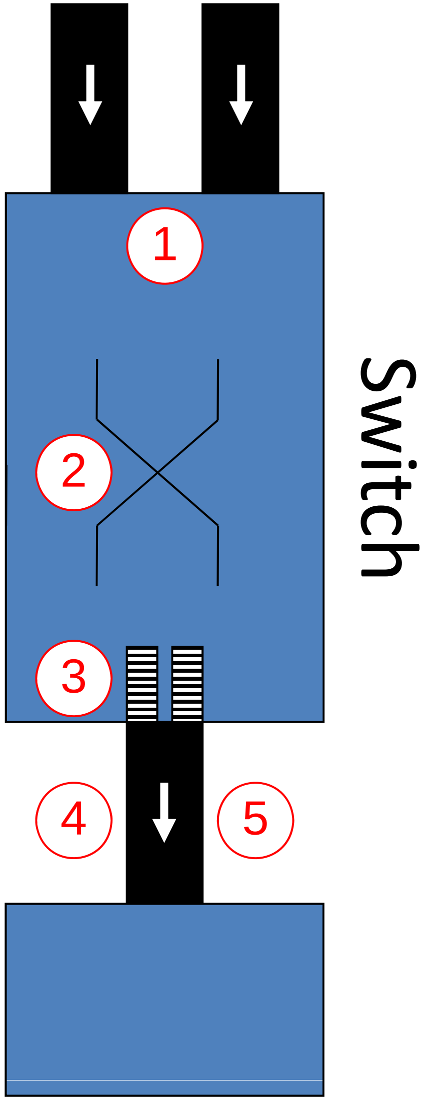
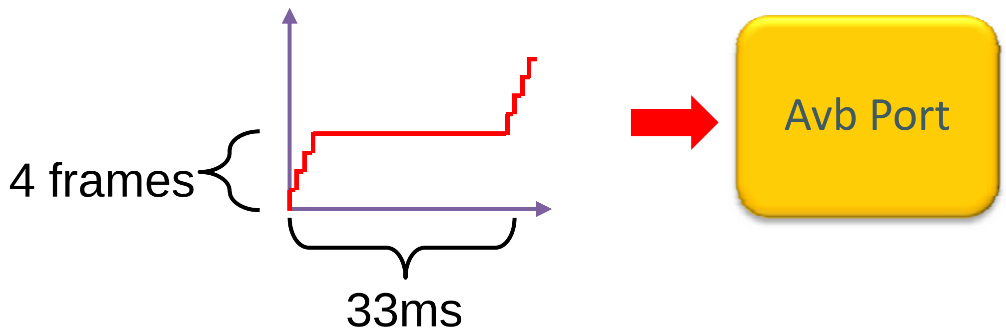


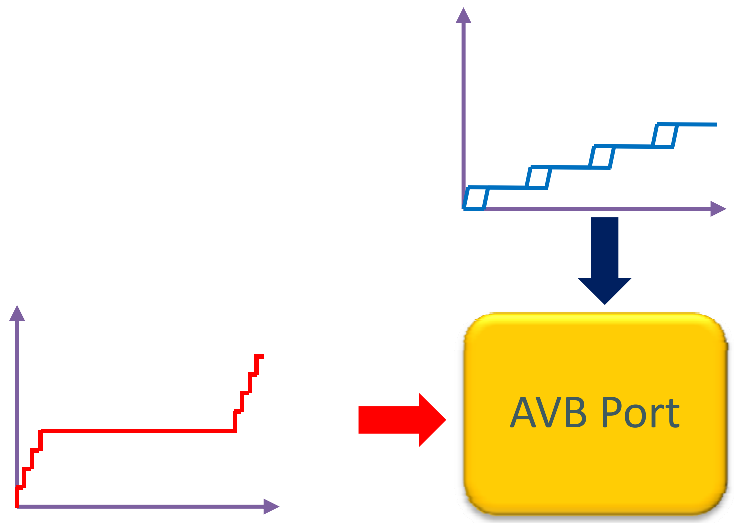
Credit-based Shaping and RTC

- Typical use case: Video stream
  - One image each 33ms
  - HD resolution -> about 1400 Ethernet frames
  - Significant burst
- Simplified use case for this talk: 6kByte every 33ms
  - Burst of 4 frames with 1500 Byte each
  - No interfering traffic



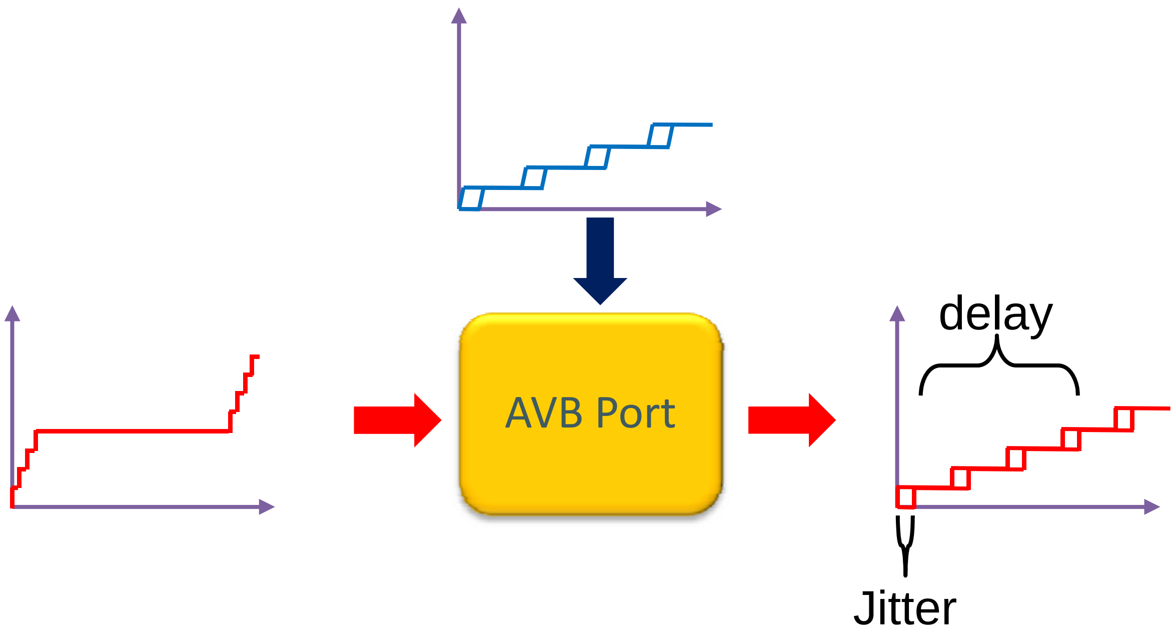
Credit-based Shaping and RTC

- Available service depends on reserved bandwidth of the queue
- Modells CBS by providing service in small chunks



Credit-based Shaping and RTC

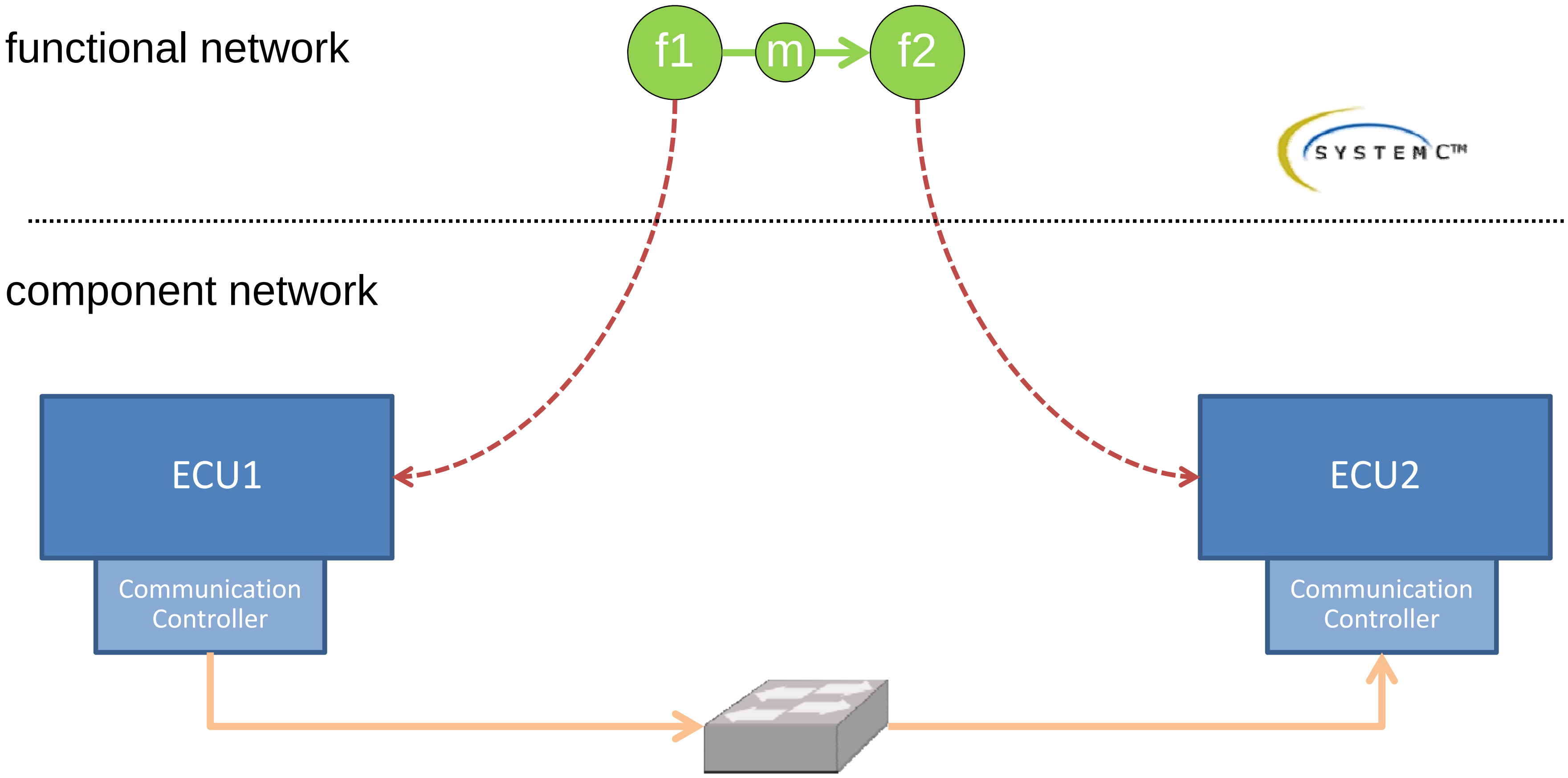
- Resulting arrival curve shows equally shaped messages
- Bigger delay but much less jitter as with standard Ethernet



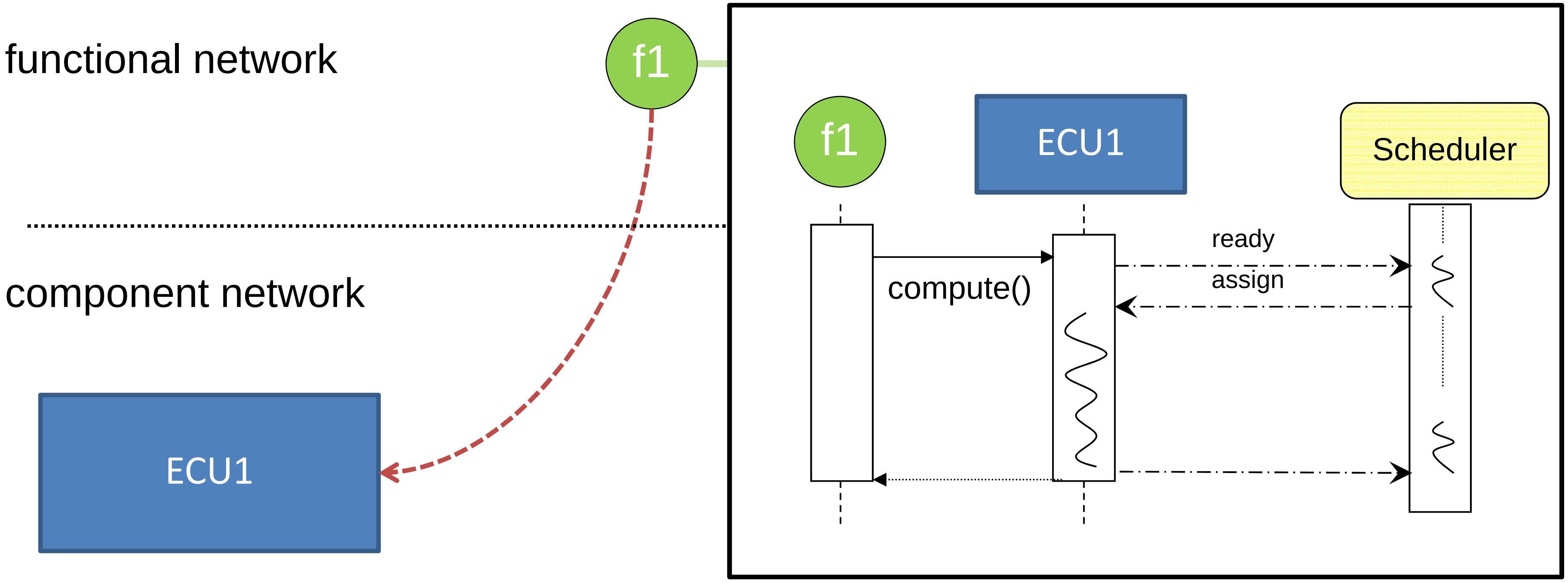
Credit-based Shaping and RTC

- Analysis has to consider additionally:
  - Interfering traffic of higher traffic classes
  - Traffic in same traffic class
    - Either already shaped or
    - New, unshaped input
  - Head of line blocking of best effort traffic from lower priority queues

Simulation-based evaluation

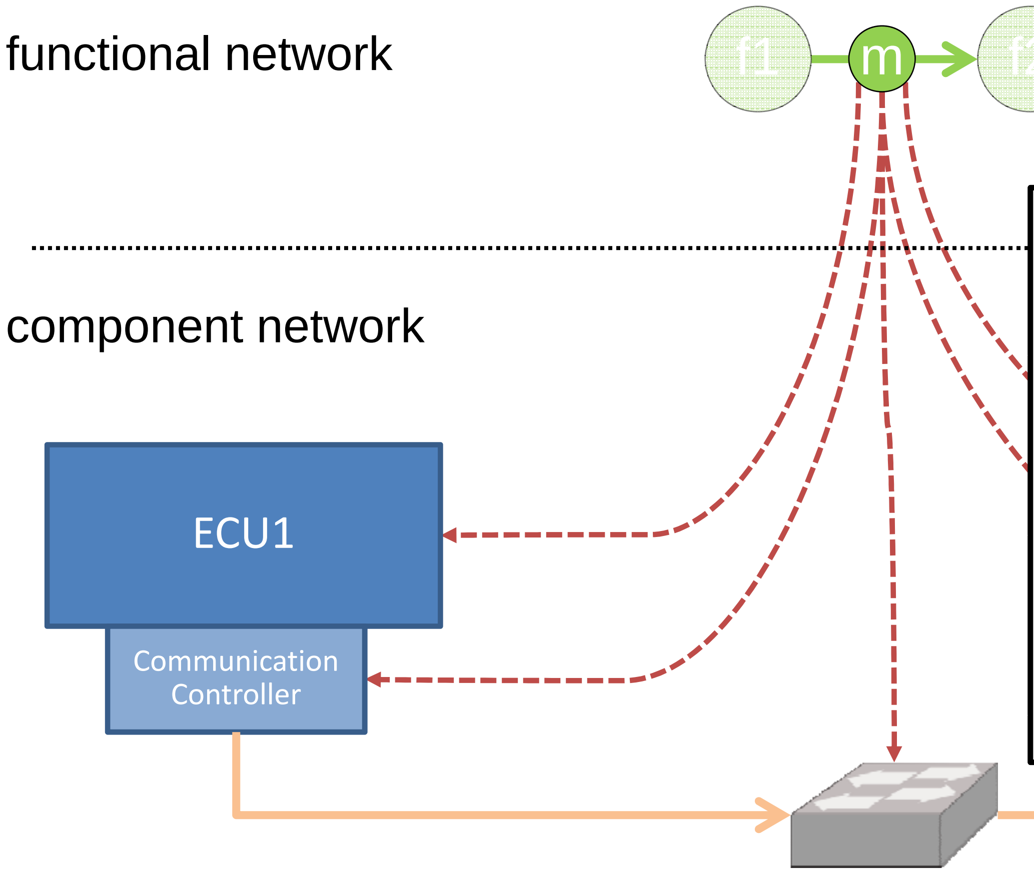


Simulation-based evaluation



- Function performs an action instantaneous and calls *compute()* for timing simulation
- Component determines additional delays due to
  - Scheduling
  - Resource contention
- Delay of an action is assumed to be specified for each mapping edge

Simulation-based evaluation

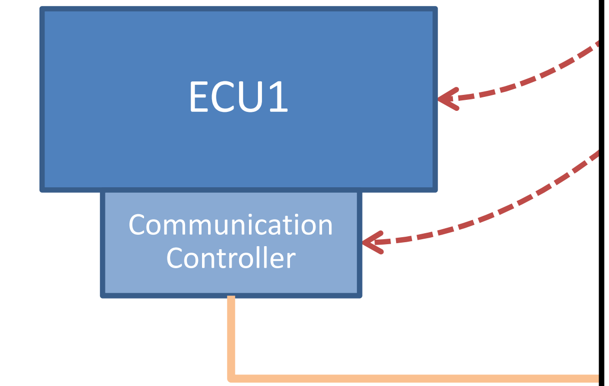


- Each message is routed statically
- Each resource adds corres-ponding transfer delay
- Ethernet and Ethernet AVB with credit-based traffic shaping are integrated as dedicated scheduler

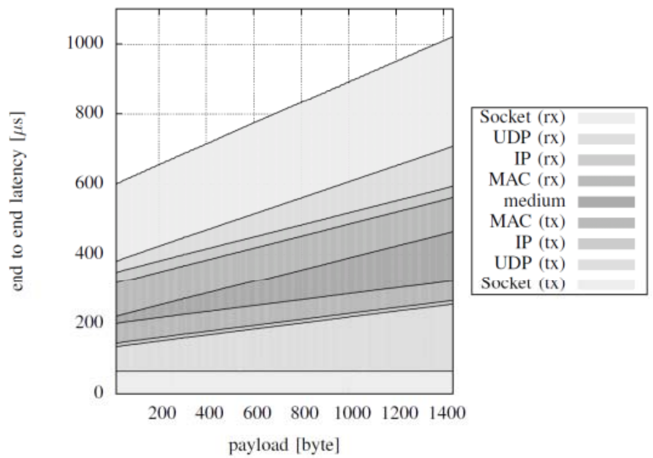
Simulation-based evaluation

functional network

component network



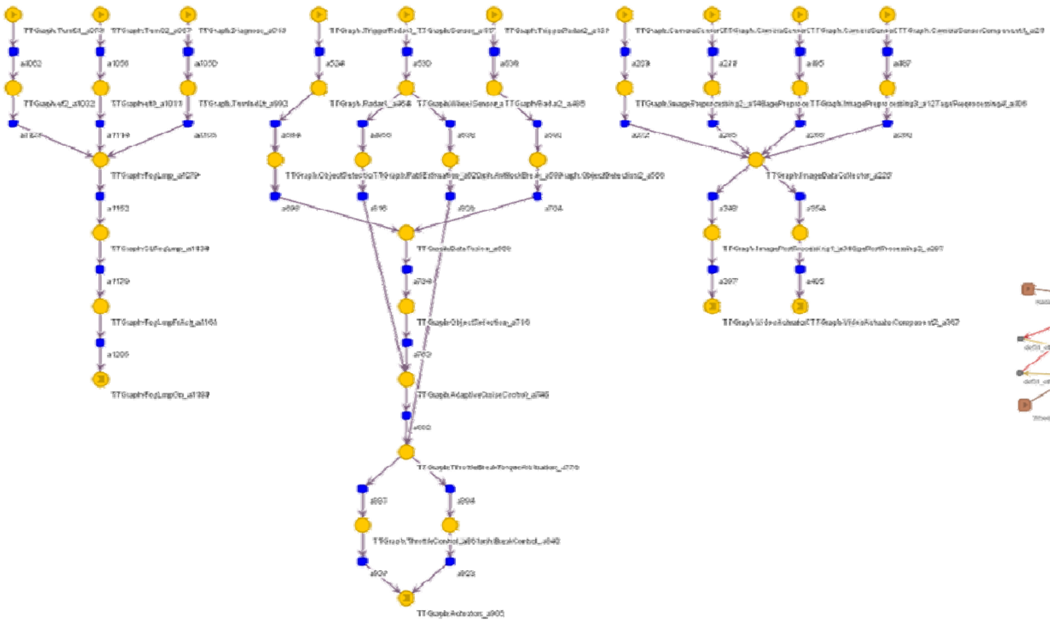
- Acceleration of simulation speed:
  - Extract all <u>static</u> delays in IP/Ethernet stack (most are indep. on message size)
  - Only compute <u>dynamic</u> delays (dep. on message size) during simulation:
    - CRC calculation in UDP
    - delay on physical medium



Use Case AVB: Streaming and Control

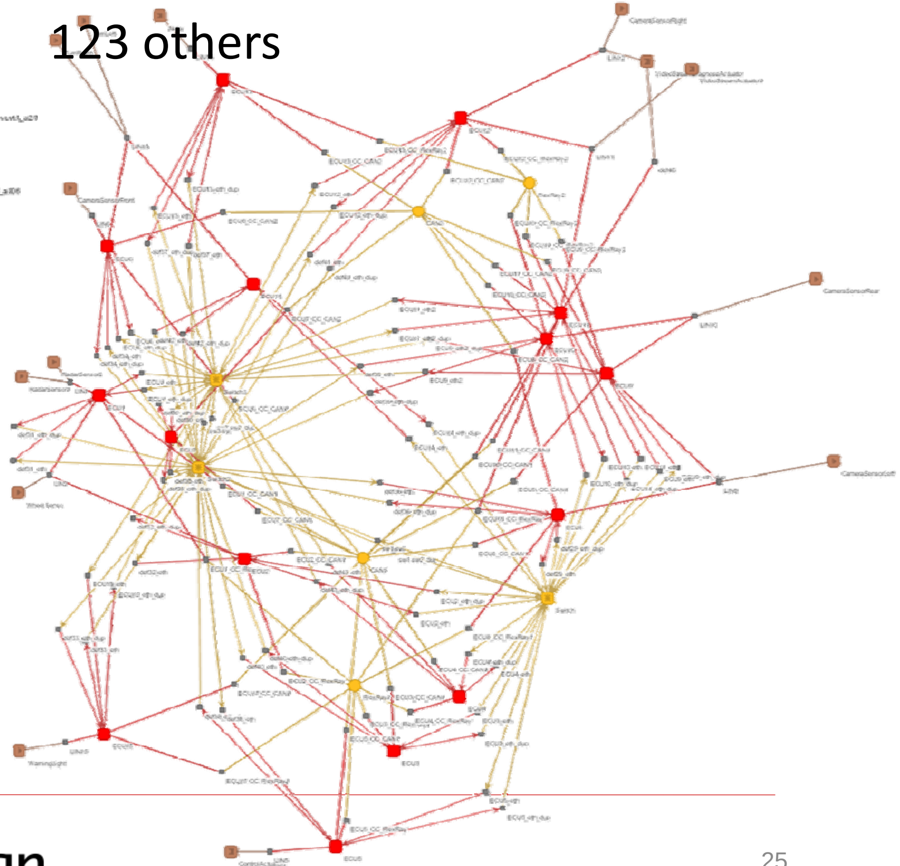
Application

- 40 tasks to map
- 39 messages to route



Architecture

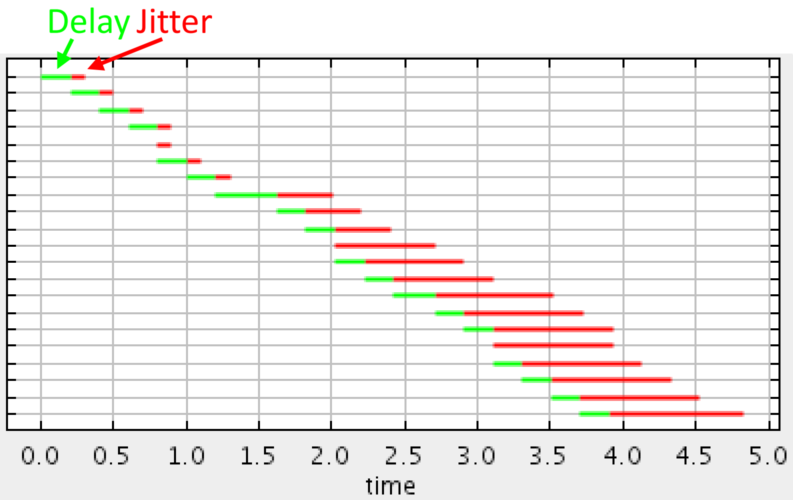
- 15 ECUs
- 4 CANs
- 3 Switches
- 123 others

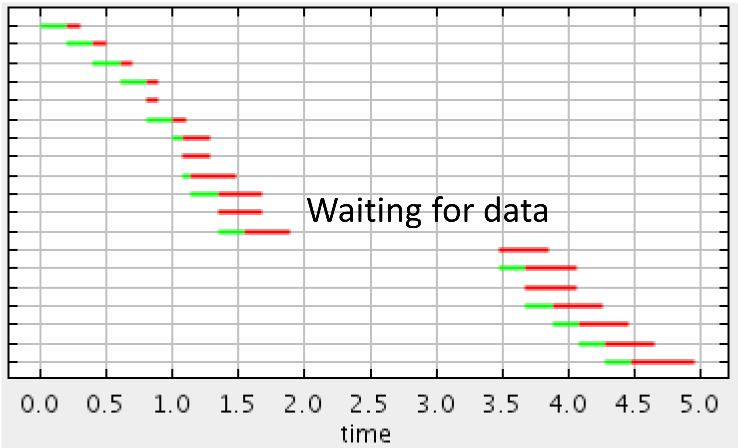


Use Case AVB Preliminary Results

Source to Sink delay	Best case [ms]	Worst case [ms]	Relative difference
Actuator 1	3,51	4,98	42%
Actuator 2	3,46	4,78	38%
Actuator 3	3,76	4,65	24%
Actuator 4	3,1	4,39	42%

Average case [ms]	Sim. Vs RTC
3,82	TBD
3,79	TBD
4,13	TBD
3,55	TBD





Lessons learnt from timing analysis

- Most important: Interference delay at output ports
- Traffic shaping reduces jitter
  - But: Best case delay higher as with best effort
- Jitter depends mainly on output port, i.e., messages with same direction

Conclusion

- Ethernet will be part of future cars!

- Successful integration of IP/Ethernet requires a holistic design flow
  - Consider specific features during modeling, optimization, and analysis
- This talk: Analytical and simulative timing evaluation for functional validation of Ethernet AVB-based E/E architectures

Thank you for your attention.

Questions?