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Holistic analysis of task scheduling and message scheduling in automotive centralised E/E architecture

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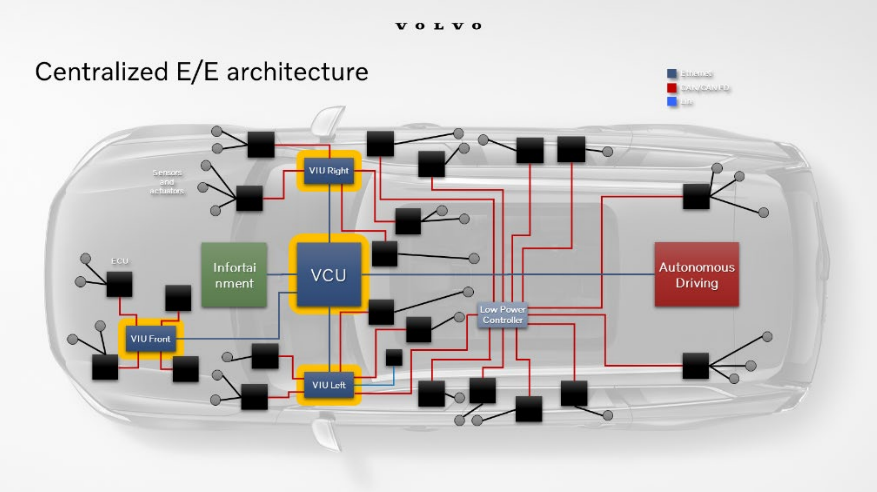
Using Ethernet as Core Network in Centralized E/E Architecture

Challenges

1. How to guarantee fulfillment of real-time requirements of different application domains across the network
2. How to minimize the interference on real-time traffic from non real-time traffic in the network
3. CAN-Ethernet bridge strategy for the gateway



Recap from last year presentation (IEEE/SA Ethernet/IP@Automotive Technology Day 2019) [1]

Lessons Learnt

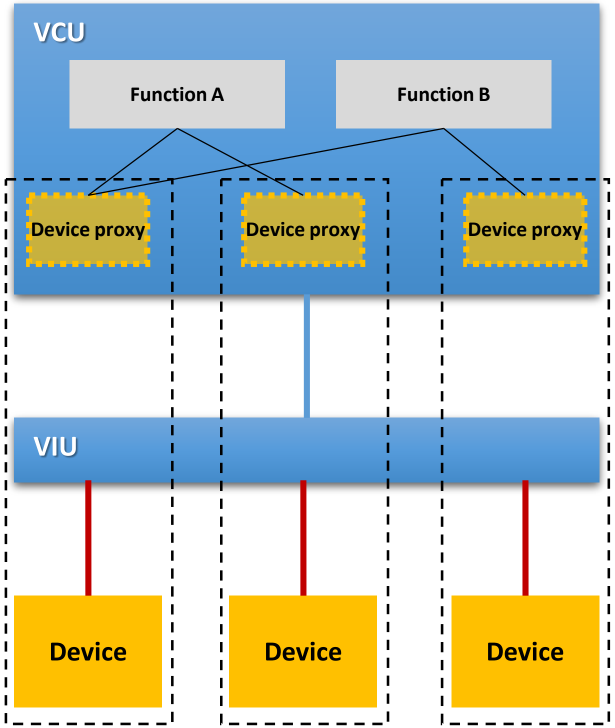
Using Time Sensitive Networking (TSN) Ethernet with suitable traffic shaping/ scheduling could:

- provide bounded network delay, and
- assert reservation of required bandwidth

But…

The centralized processing function, however, largely impacts the sense and act response times in the system

- The end-to-end response time of any message depend on multiple factors:
  - network delay,
  - processing time, and
  - process scheduling mechanisms.

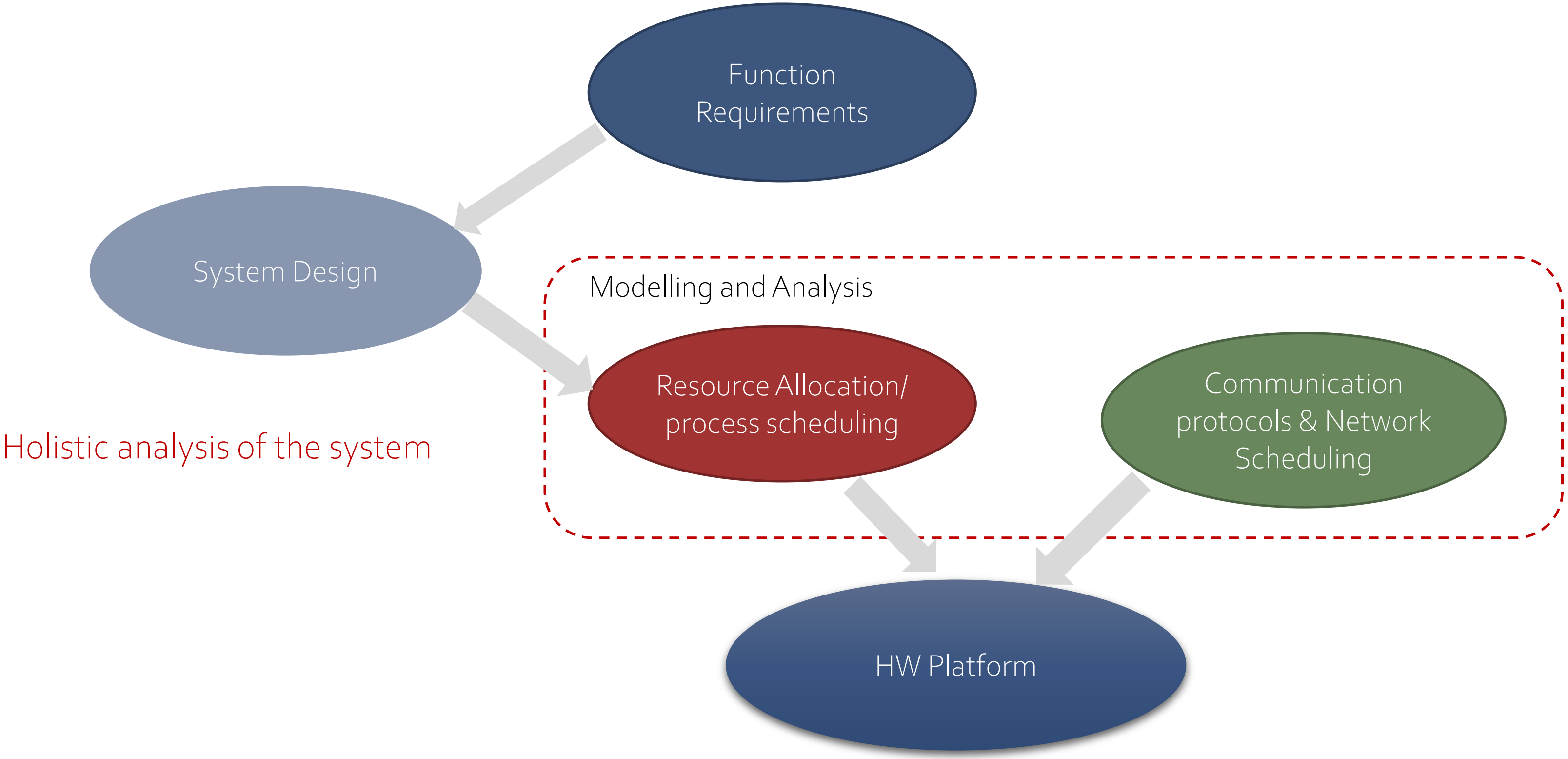


Contribution of this work

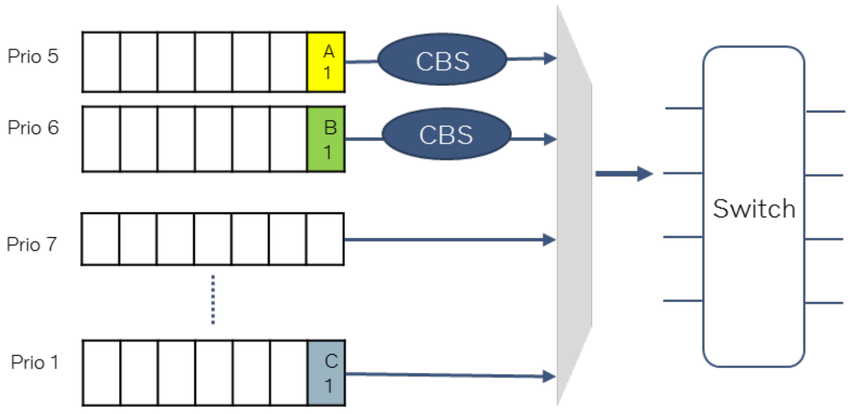
We have extended the network simulator developed in [1] with processor scheduling. The tool can be used to:

- provide end-to-end delay analysis, including network delay and task response time in the processor,
- suggest scheduling strategy to guarantee real-time performance of automotive applications, and
- increase predictability in early design of a system

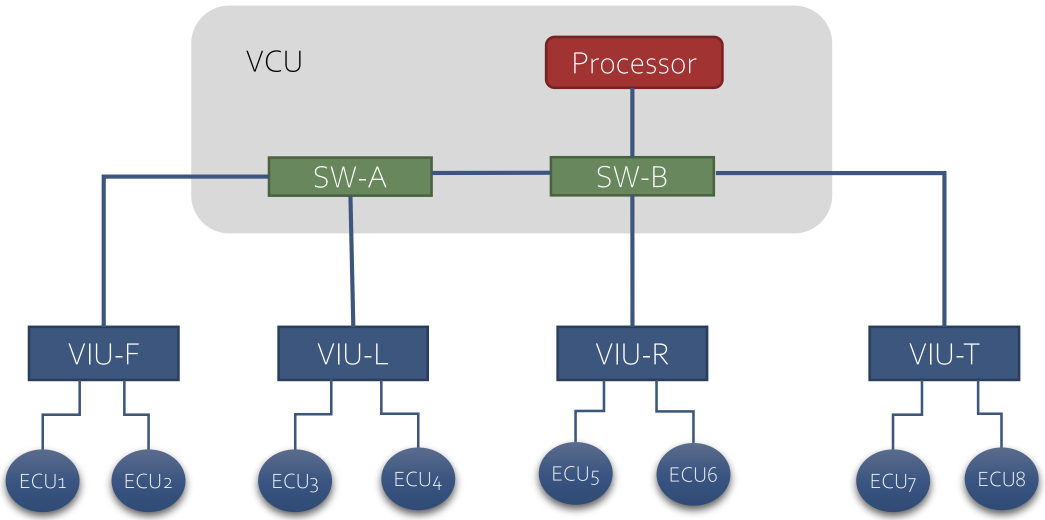
Design Approach



Communication Protocols and Network Scheduling



- Control traffic from ECUx → VIU→VCU: UDP protocol has highest priority (7)
- Infotainment traffic use AVB with priority 5 and 6
- Dianogstic traffic uses DoIP and has lowest priority
- Messages are sorted in priority queues at each port of the switch



Resource Allocation and Process Scheduling

Moving from a domain architecture to a centralized architecture in automotive naturally means that

- system central compute unit (VCU) must handle much higher work load
- the VCU must handle different applications with different timing constraints

The choice of scheduling policy makes a dramatic difference in

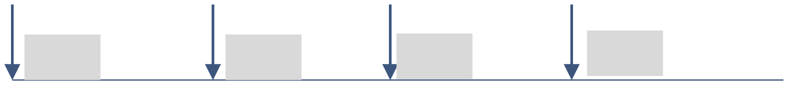
- how the system behaves (in particular at overload),
- and determines whether a designer can predict characteristics of the system at overload

Static vs. Dynamic scheduling

- In the dynamic scheduling approach, task priority is assigned on the fly. Thus, the system designers cannot predict which specific threads will miss their deadlines during overload conditions → not suitable for time-critical applications
- In the static scheduling approach, schedulability analysis can be performed to assure that the deadlines of critical threads will be satisfied even during overload.
- Employing a predictable scheduling policy is especially important for safety-critical systems

Periodic vs. Sporadic

Periodic events: An event with an arrival pattern that has a bounded minimum inter-arrival time with minimal jitter.



Periodic task: a task released by a periodic event whose computation interval excluding preemption and blocking is constant.

Pros: worst case response time is predictable, bounded delay

Cons: waste of utilization → not suitable for a centralized system where most of tasks are event-driven

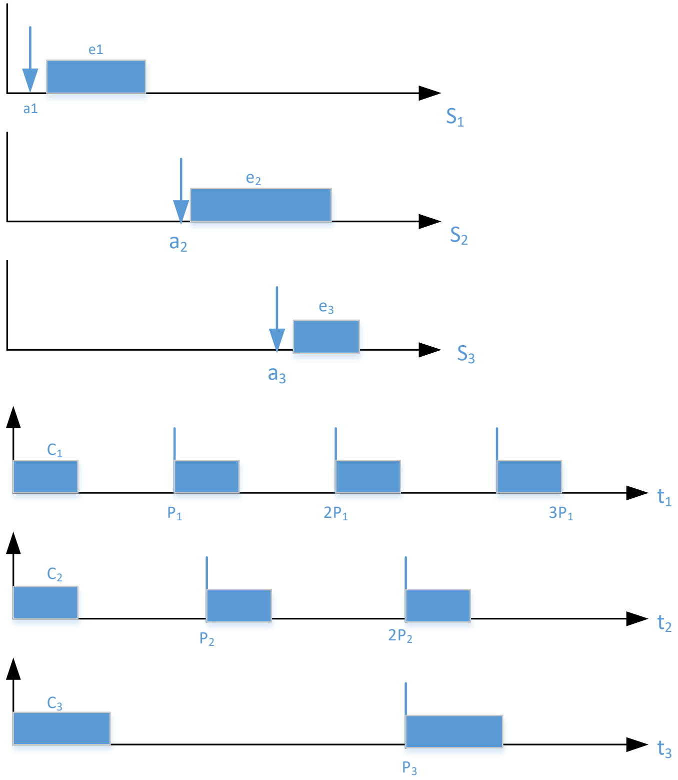
Sporadic event: An event with an arrival pattern that has a bounded minimum interarrival time with stochastic jitter

Sporadic task: a task released by a sporadic event or a task with a stochastic computation interval.

Pros: gain in utilization, shorter response time

Cons: difficult to predict the worst case scenario, less predictable

Modelling of the VCU System Software – A Combined Approach



A set of sporadic tasks that are activated by events (event-driven tasks)

a_i denotes arrival time of sporadic task S_i
e_i denotes execution time of sporadic task S_i

A set of periodic tasks that are pre-loaded and activated by the system clock

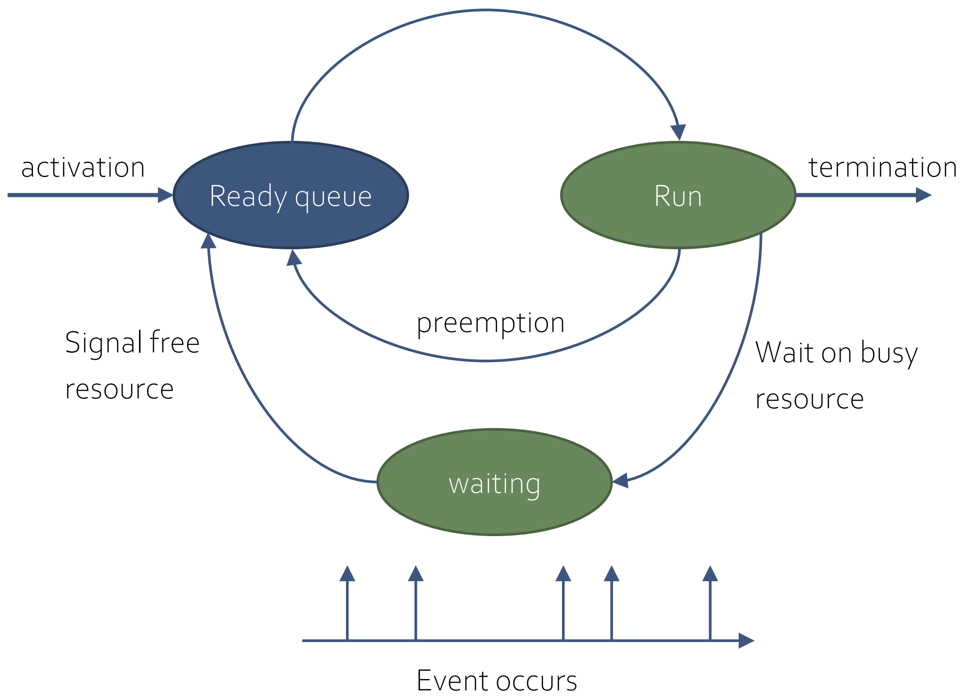
Ci denotes execution time of task τ_i
Pi denotes period of task τ_i
Utilization of all periodic task should be less than or equal to 50%

$$U(periodic\ tasks) \leq 50\%$$

Assumptions

- Each task in the system is assigned a priority
  - A sporadic task has two priority levels: normal and low (POSIX sporadic scheduling)
- Tasks are independent
- A periodic task is activated by system clock
- A sporadic task is activated when its related event occurs
- All tasks are preemptable

Scheduling state machine



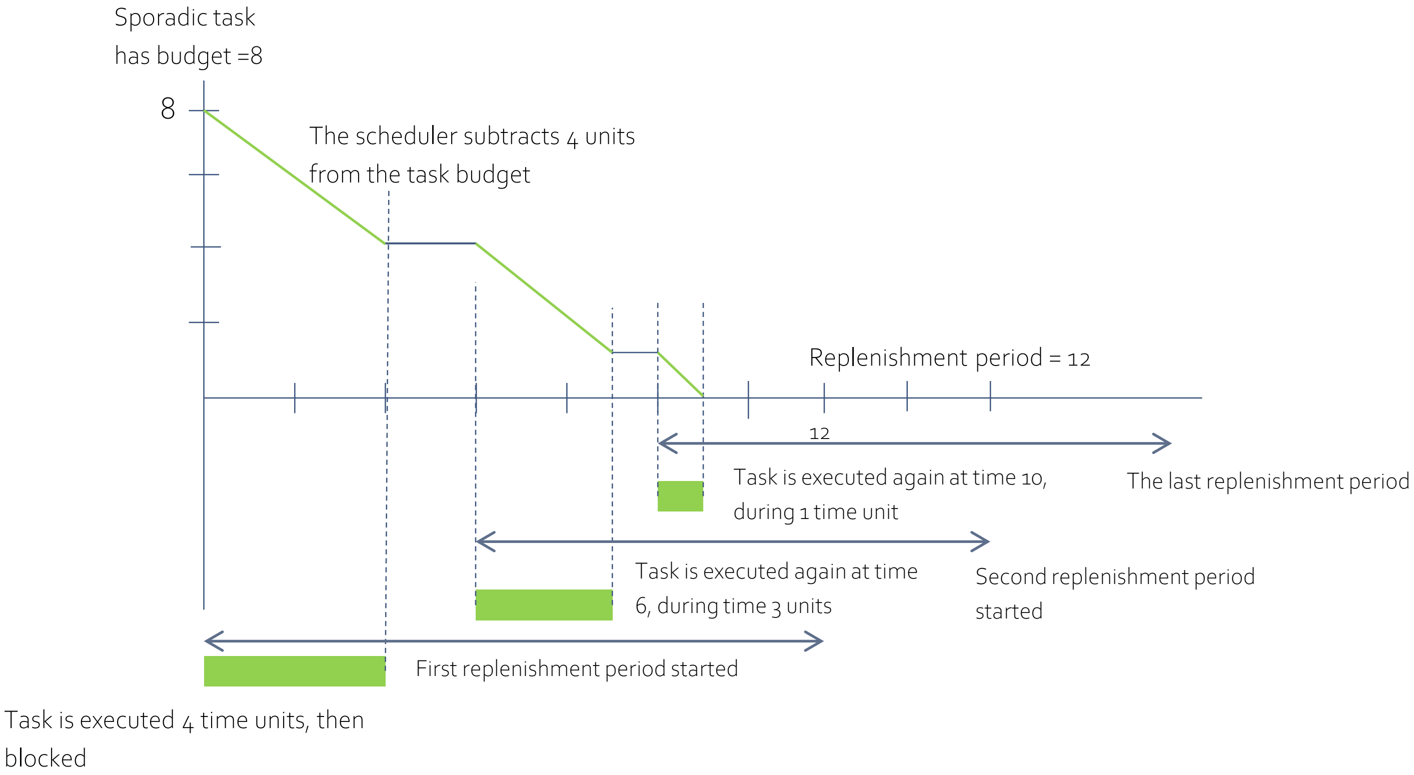
Scheduling of Sporadic Tasks

- The sporadic scheduling policy is specified for handling tasks running within the context of a static-priority preemptive scheduler
- In addition to a single normal priority level, the parameters of a sporadic task includes:
  - a second, lower priority for background processing,
  - a replenishment interval,
  - an execution budget, and
  - a maximum number of replenishments allowed within each replenishment interval.

How to achieve predictably when applying sporadic scheduling?

Sporadic scheduling manages sporadic tasks by wrapping them within a periodic framework. This is an effective technique to handle overload scenarios in static-priority preemptive schedulers.

Consumption and Replenishment of Execution Budgets



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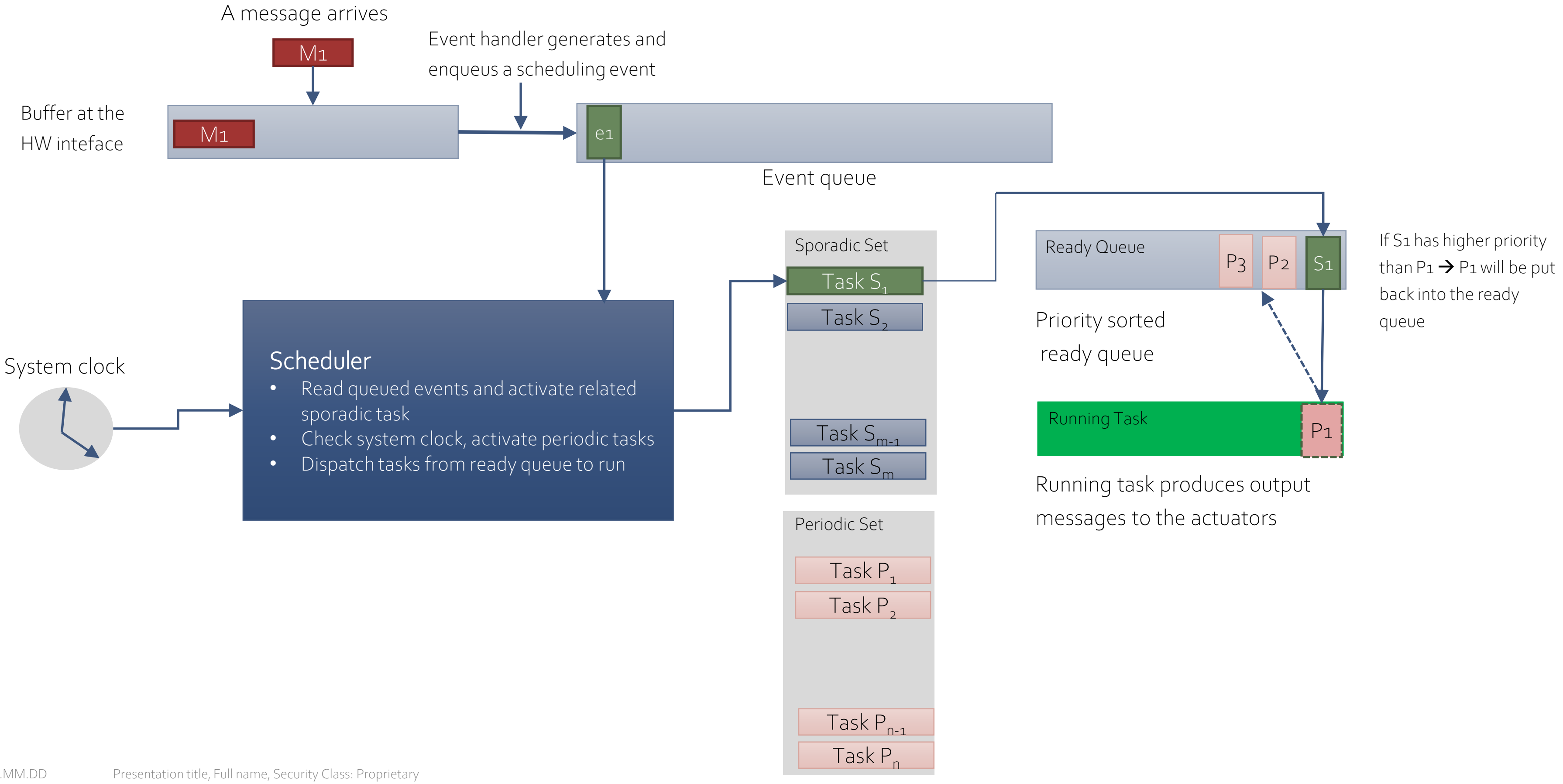
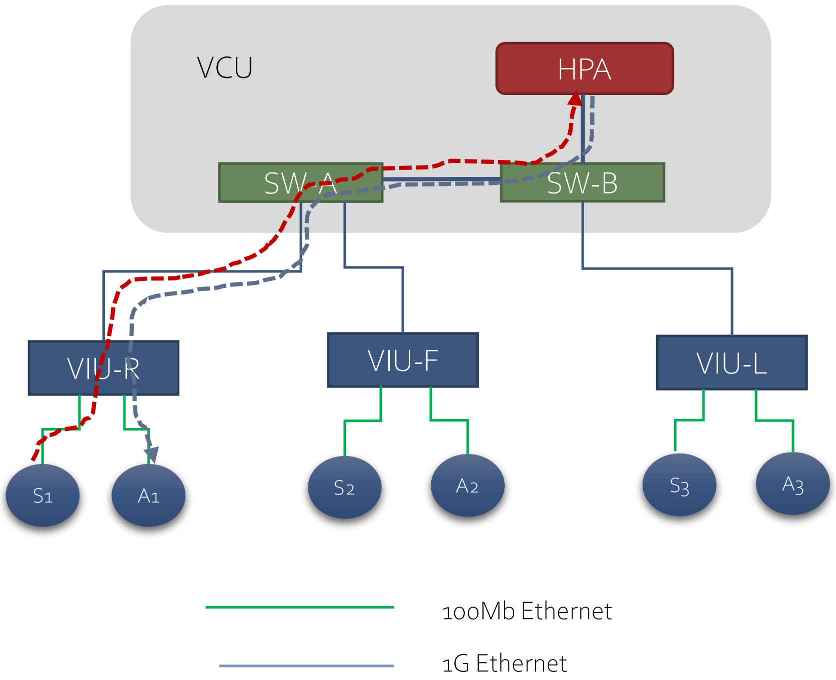
Modeling of the Scheduler for Single Core Processor



Simulation Tool and Experimental Setup

Scenario

- Control traffic flows from sensors (S1-S3) to the VIUs (Vehicle Integration Unit), to the core network, to the processor (HPA)
- After the data has been processed, response is transmitted over the network to the actuator (A1-A3)
- We only consider scheduling in the processor in the VCU (HPA). Scheduling at the sender and receiver is not included in this work
- We measure the end-to-end delays from sensors to the actuators



HPA: High Performance Processor A

The simulator

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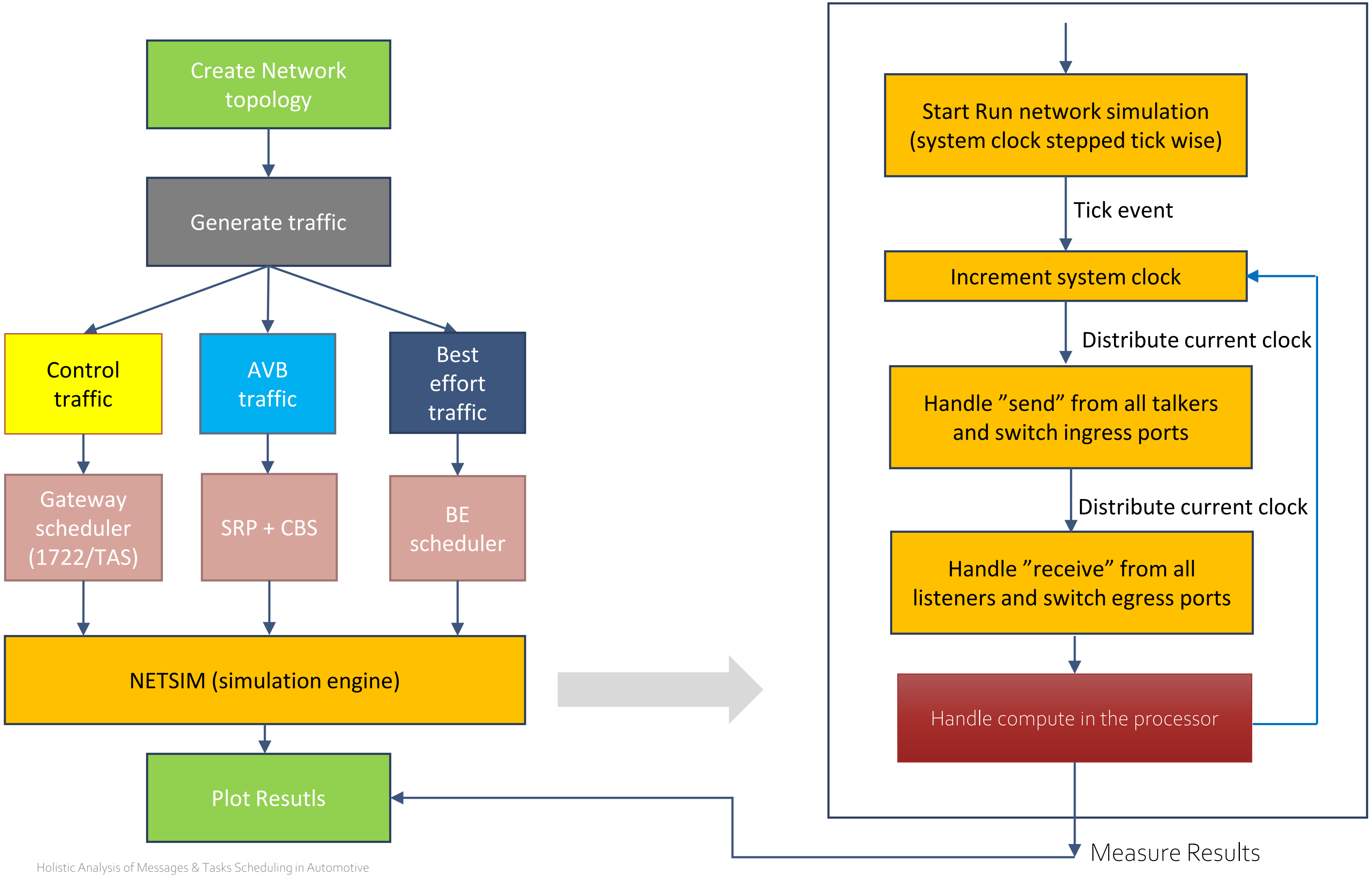


Simulation Scenario – Network Streams

Periodic streams

- Stream 1: S1 → VIU-R → SWA→SWB → HPA
- Stream 2: HPA →SWB→SWA→VIU-R→A1

Period = 256μs, payload = 1171 bytes

- Stream 3: S2→VIU-F → SWA→SWB→ HPA
- Stream 4: HPA →SWB→SWA→VIU-F→A2

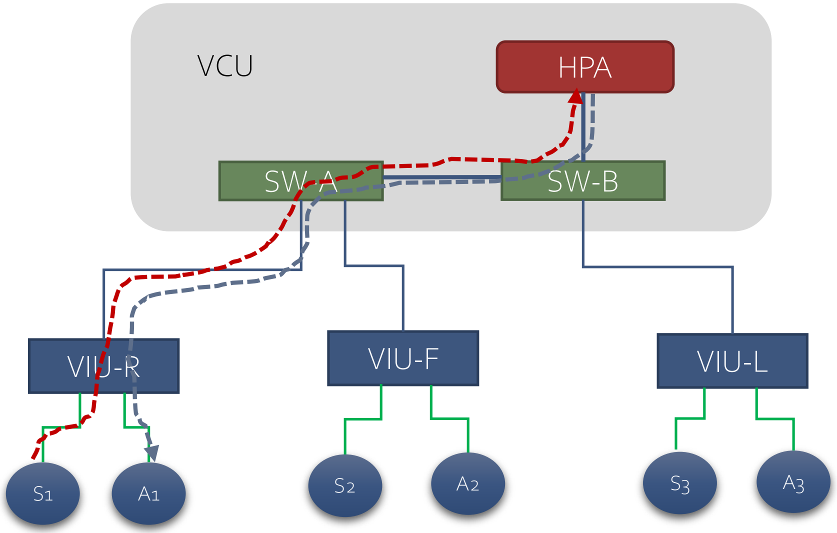
Period = 512; payload =1171 bytes

- Stream 5: S3→VIU-L→SWB→ HPA
- Stream 6: HPA → SWB→VIU-L

Period = 1ms; payload =1171 bytes

Sporadic stream (poisson distributed)

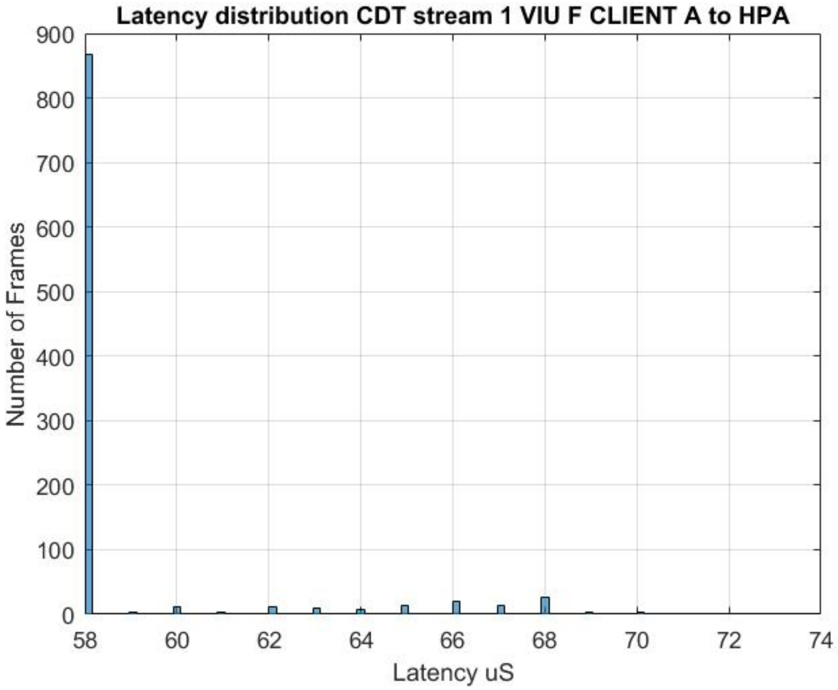
- Stream 7: S2→VIU-F→SWA→SWB→ HPA
- Stream 8: HPA →SWB→SWA→VIU-F→A2
- Stream 9: S3→VIU-L→SWB→ HPA
- Stream 10: HPA → SWB→VIU-L→A3

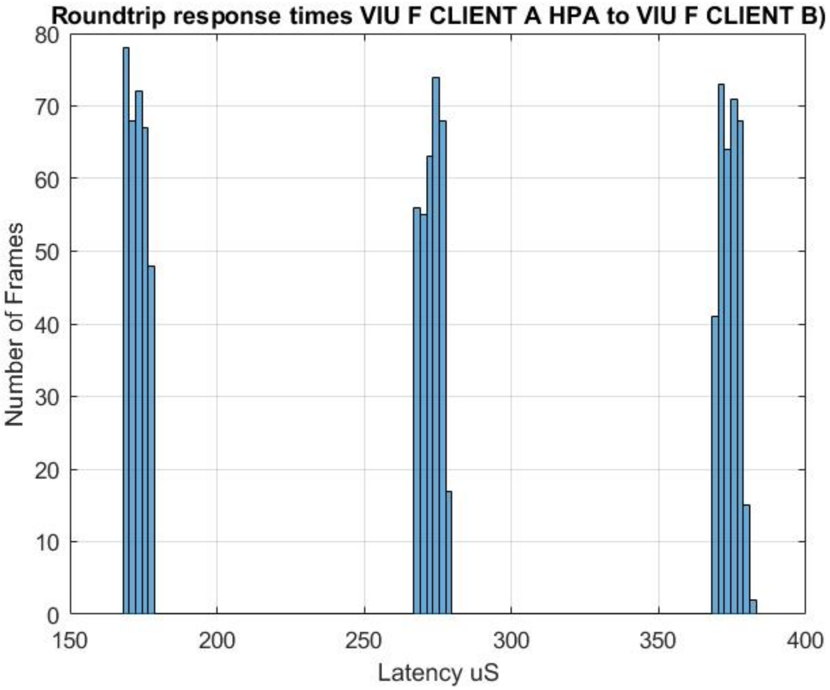


Simulation Scenario – Task Set

Task #	Periodic/Sporadic	Prio normal	Prio_low	Period/replenish period	Excution time	Budget
1	periodic	11	-	300	20	
2	periodic	9	-	1300	50	
3	periodic	7	-	3000	100	
4	Sporadic	10	1	600	200	100
5	Sporadic	8	1	400	100	50

Simulation Results





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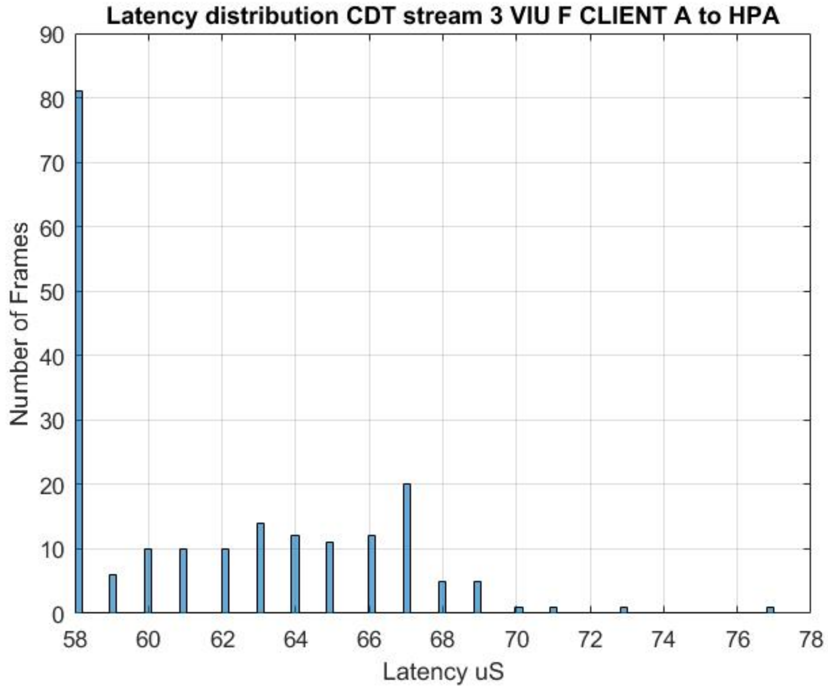

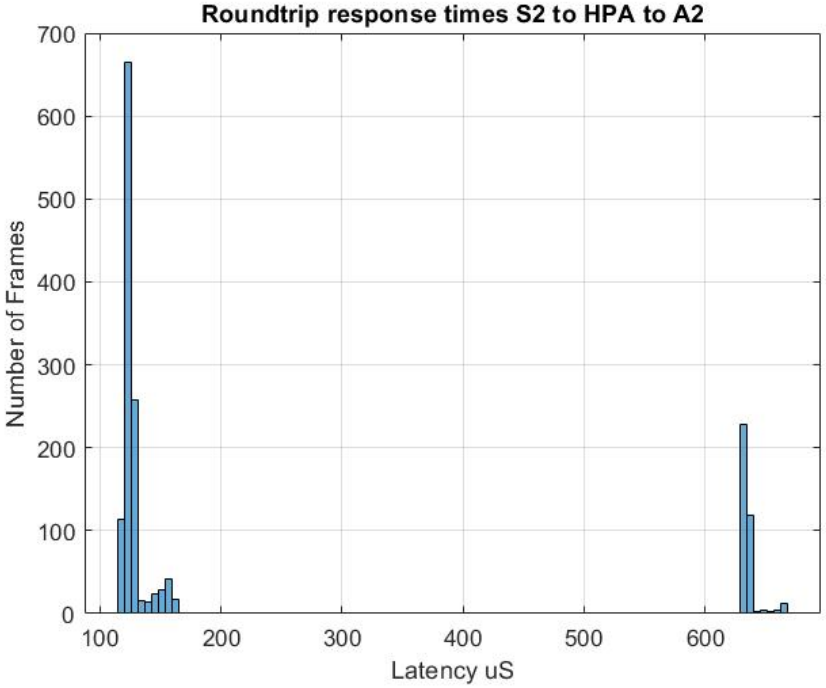

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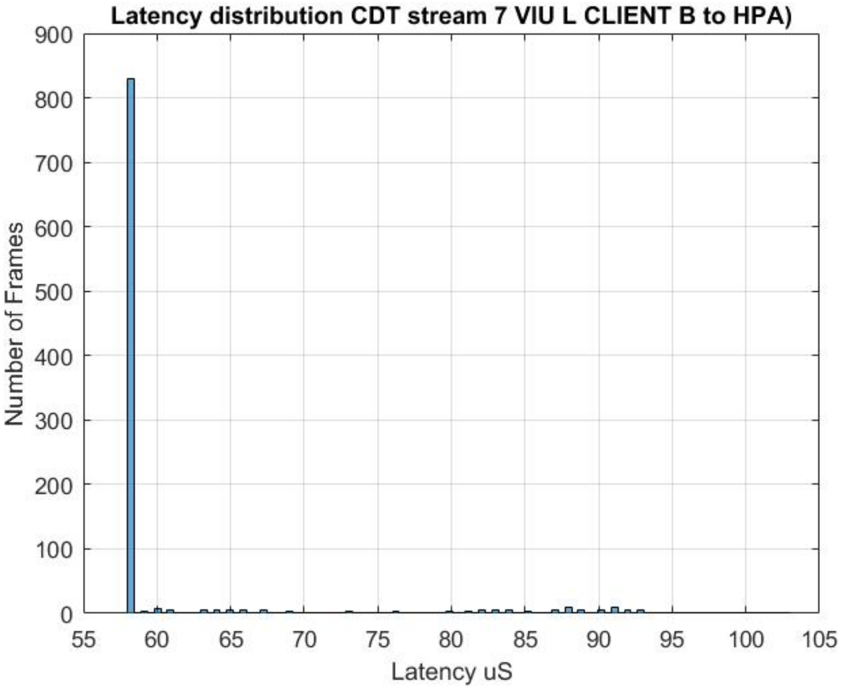

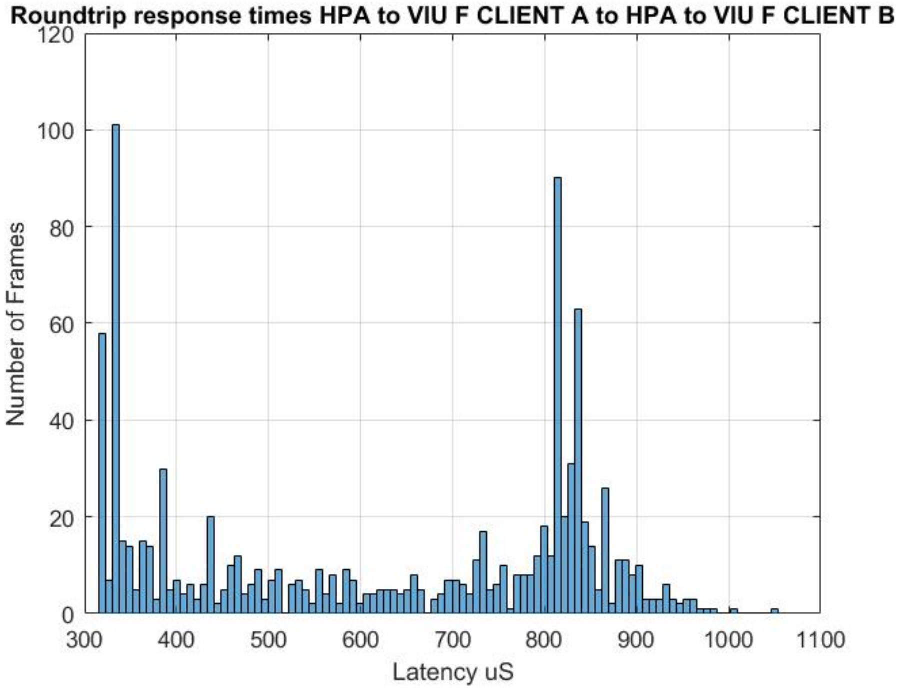

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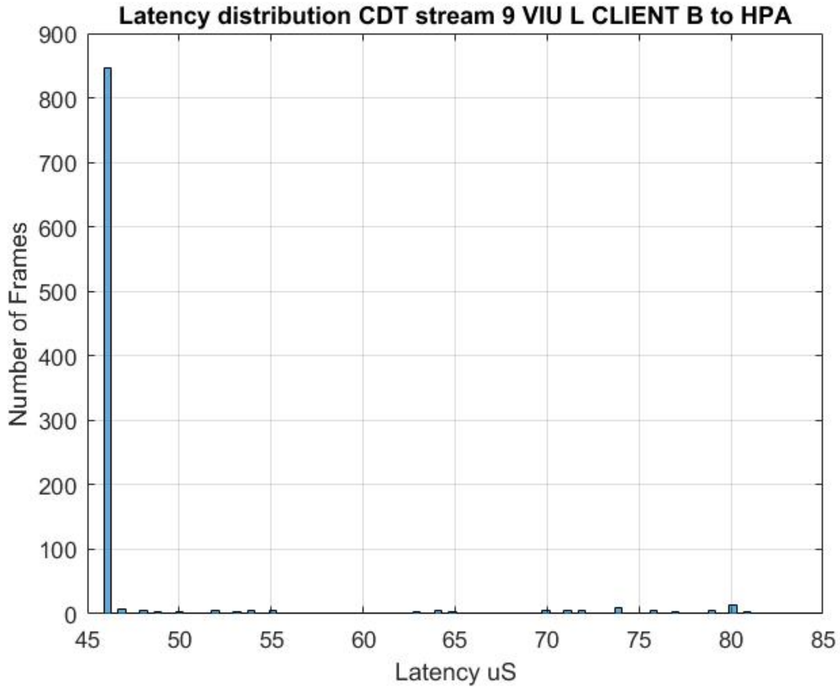

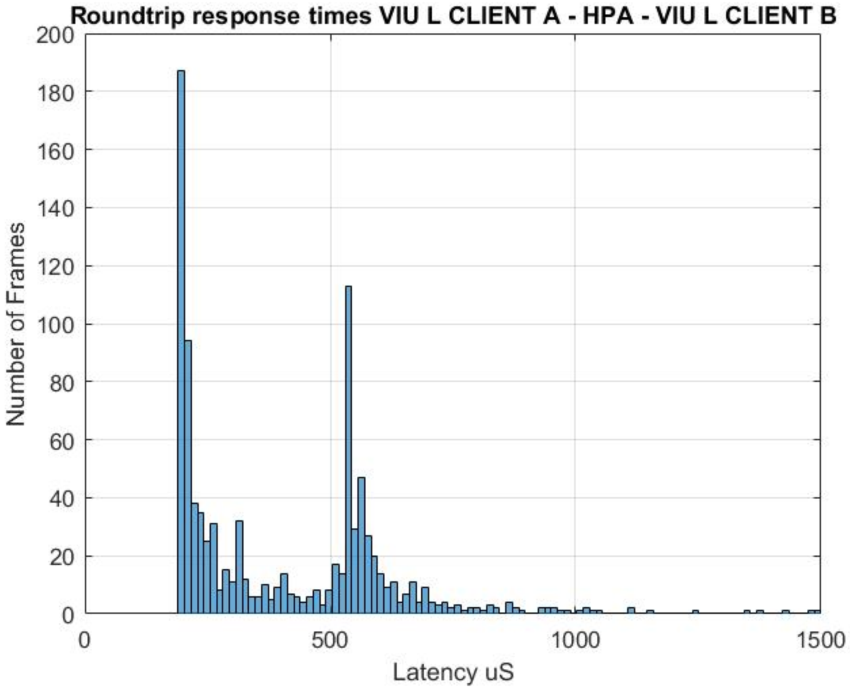

Summary

- We have presented a holistic approach for modeling and analysis of network and processor perfomance in automotive systems
- The tool has capability to calculate response times of sporadic and periodic events/ tasks in automotive real-time systems
- We will extend the processor model to capture multicore scheduling

Reference
[1] Hoai Hoang Bengtsson, Martin Hiller and Samuel Sigfridsson, TSN Ethernet as core network in the centralized architecture, challenges and possible solutions, "Ethernet/IP@Automotive Technology Day 2019, Detroit, 2019.