A Tool-Chain for Modeling and Evaluation of Automotive Ethernet Networks

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Motivation

Criteria for designing a feasible communication matrix: Busload

Criteria for designing a feasible communication matrix: ?

Metrics for network design and load assessment have to be reconsidered
Outline

A. Modeling of Ethernet-Networks
B. Evaluation Tools for Ethernet-Networks
C. Case Study and Results
D. Discussion and Outlook
Service-oriented Communication

- Modeling of receiver behavior instead of sender behavior as in CAN/FlexRay networks

Diagram:

- Application Layer
  - Client 1, Client 2, ..., Server 1, ...
  - Protocol Stack

- µC, DSP, Switch, ECU
Socket Adapter

- Sockets collect PDUs for an Ethernet frame
- Definition of trigger conditions for the sockets (timer, buffer, always)
Ethernet topology and traffic across the switches:

- OEM specifies topology and network communication
- In case of inter-processor communication via a switch, the supplier will specify the traffic
  - Traffic by supplier and OEM interferes in the switch
  - Communication description needs to be exchanged between supplier and OEM to achieve a feasible communication matrix
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A. Modeling of Ethernet-Networks
B. **Evaluation Tools for Ethernet-Networks**
C. Case Study and Results
D. Discussion and Outlook
Different Approaches to Evaluate Ethernet Traffic

Evaluation Tools for Ethernet-Networks

Load scenarios and topology

Simulation
calculated
real
Average case
Worst case
real
Worst case
calculated
Latency
[ms]
Probability

Analysis

Experiment

Simulation/Experiment

Analysis

Best case
Average case
Worst case
Best case
Average case
Worst case
Different Approaches to Evaluate Ethernet Traffic

Load scenarios and topology

**Simulation**
- Simple modeling of different scenarios
- Traceability (Gantt-Charts, statistical distributions, etc.)
- Computationally intensive
- Abstraction of real world
- Result depends on stimuli

**Analysis**
- Simple modeling of different scenarios
- Corner cases can be evaluated (clear upper and lower bounds)
- Over approximation of worst case
- Abstraction of real world

**Experiment**
- Good approximation of the real world behavior
- Representative statistical results
- Special hardware and software required
- Complexity for setting up the test cases
- Result depends on stimuli

Combination of three approaches to benefit from the specific advantages.
Evaluation Tools for Ethernet-Networks

Tool Chain

AUTOSAR-XML converter for specific input formats of evaluation tools

Simulation
SymTA/S by Symtavision

Analysis
pyCPA connected to SymTA/S

Experiment
Spirent Testcenter and Switch Hardware

Merging of results
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Case Study and Results

Scenario

Topology:
- 8x ECUs
- 2x Switches
- 7x 100MBit/s and 2x 1Gbit/s links
- No Shaping

Load scenario:
- 56x Messages with two different priorities
- Payload sizes: 1–1400Byte
- Periods: 0.1 – 1000 ms
- Uni-/Multi-/Broadcast-Messages

![Diagram of network topology and load scenario]
Case Study and Results

Latency

The chart above illustrates the latency measurements for various Ethernet messages. The y-axis represents latency in milliseconds (ms), ranging from 0.00 to 1.00. Each bar represents a different message, with colors indicating different types of analysis: Simulation, Experiment, Best Case Analysis, and Worst Case Analysis.

The data suggests a wide range of latency values, with some messages showing significantly higher latency compared to others. This variation is crucial for identifying potential bottlenecks and optimizing network performance in automotive Ethernet networks.
Discussion of Results

Three cases can be distinguished:

1. If required latency of a message is larger than analyzed worst case, the system will definitely work

2. If required latency of a message is between worst case of analysis and simulation/experiment, the system might work (more detailed testing or redesign might be a consequence)

3. If required latency of a message is lower than worst case in analysis, simulation and experiment, the system does not hold its deadlines in any case

Conclusion:

- Worst case analysis either guides a designer to find critical messages or approves the fulfilling of latency requirements
Case Study and Results

Histogram of Single Message

- Latency histogram for the evaluation of non-real-time traffic
- Histogram data together with expert knowledge can be used to assess the functional behavior
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Conclusion

• Ethernet requires and allows the introduction of new metrics for system evaluation (end-to-end latency, buffer usage)

• Tool-chain allows a detailed evaluation of Ethernet systems including:
  – Upper and lower bounds for latency and required buffer
  – Experimental and simulation results for specific traffic scenarios

• Room for improvements:
  – Analysis tools and methods are based on periodic event models while service-oriented communication is basically a sporadic approach
  – Reduction of over approximation in worst case analysis
  – Refined modeling of switch behavior (buffer allocation)