An Extension of the OMNeT++ INET Framework for Simulating Real-time Ethernet with High Accuracy

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Motivation
Why a new in-vehicle communication technology?
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Why a new in-vehicle communication technology?

“Actually already today the electrical system in the whole car is not adequately controllable” and “The complexity continues to increase” ¹

Richard Bogenberger (2008)
BMW Group Research and Technology

Motivation

Why Ethernet?

- Mature technology
- High transmission bandwidth
- Low prices for Ethernet components
- Many development/diagnostic tools and expert developers
Agenda

1 Introduction
2 Background
3 Concept & Model
4 Results & Evaluation
5 Conclusion & Outlook

Simulating Real-time Ethernet

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Introduction
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Real-time Ethernet
Real-time extensions for standard switched Ethernet

- Standard switched Ethernet has no real-time capabilities
- There are extensions of various operational areas
- Extensions can be classified in:
  1. *token-based technologies*
e.g. EtherCAT
  2. *bandwidth-limiting technologies*
e.g. Avionics Full DupleX Switched Ethernet (AFDX)
  3. *time-triggered technologies*
e.g. Profinet, SynqNet, RTnet, POWERLINK, TTEthernet
TTEthernet
A time-triggered real-time Ethernet protocol

- Basis by the Technical University Vienna (2004)
  Today development by TTTech Computertechnik
- Currently standardization by the Society of Automotive Engineers

- 3 traffic classes:
  - Time-triggered (TT)
    highest priority, time-triggered, cyclic, offline planned, requires synchronised time
  - Rate-constrained (RC)
    event-triggered, bandwidth-based (AFDX)
  - Best-effort (BE)
    lowest priority, standard Ethernet
TTEthernet
Synchronisation

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End System
Sync Client

End System
Sync Master

Switch
Compression Master

2. PCF (new Time)

2. PCF (new Time)
Critical-Traffic (time-triggered and rate-constrained) is offline configured

- Critical-Traffic uses Ethernet destination address
- Critical-Traffic is determined by CT-Marker (4 Byte)
- Message is determined by CT-ID (2 Byte)

TTEthernet
Critical-Traffic

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Concept & Model
TTEthernet integration in INET

- TTE Host A
  - TTEthernet Application
  - TTEthernet API
  - TTEthernet LLC
- TTE Switch
  - TTEthernet Application
  - TTEthernet API
  - TTEthernet LLC
- TTE Host B
  - TTEthernet Application
  - TTEthernet API
  - TTEthernet LLC

Application Layer

Data Link Layer

Physical Layer

TTEthernet model
extended INET model
INET model
Clock:

- TTEthernet is a synchronised time-triggered protocol
- Each device has its own clock
- Clocks have inaccuracy (clock drift)
- Clock drift has significant impact on protocol behaviour
- Model of clock drift must be accurate

\[ t' = t + \delta \ast (\Delta t_{Tick} + \Delta t_{Drift}) \]
Concept & Model
TTEthernet model — Clock model

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Concept & Model
TTEthernet model — Clock model

Clock:

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Constant tick length
Variable drift factor
Event
Cycle
Event
Cycle
Event
Cycle

Constant tick length
Variable drift factor
Concept & Model
TTEthernet model — Switch model

TTEthernet-Switch:
- Usage of the introduced clock model
- Combines standard INET and critical traffic switch
- Bypassing of Buffer in MAC-Layer to preserve priorities
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Concept & Model
TTEthernet Model — Buffers

Incoming messages

CT-Switch BE-Switch

DelegatorOut

EtherMAC Frame-Buffer

Outgoing message

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TTEthernet Model — Buffers

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Results
Sample Topology

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Results

Latency TTEthernet and INET switch

Latency [µs] vs. Link utilization [%]

- Standard max.
- Standard min.
- TTEthernet max.
- TTEthernet min.
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Results

Latency distribution

Latency [µs]

Relative traffic per class [%]

Time-Triggered
Rate-Constrained
Best-Effort

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## Evaluation
Comparison simulation model, analytical model and measurement

<table>
<thead>
<tr>
<th>Frame Payload</th>
<th>Simulation Model</th>
<th>Analytical Model</th>
<th>Hardware Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>350 µs Schedule</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>360.5 µs</td>
<td>360.245 µs</td>
<td>360 µs</td>
</tr>
<tr>
<td>Maximum</td>
<td>593.0 µs</td>
<td>592.885 µs</td>
<td>592 µs</td>
</tr>
<tr>
<td><strong>9 µs Schedule</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>19.5 µs</td>
<td>19.245 µs</td>
<td>-</td>
</tr>
<tr>
<td>Maximum</td>
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Conclusion & Outlook

- Real-time Ethernet is a realistic candidate for in-vehicle backbone
- Presented model tightly conforms to
  - TTEthernet specification
  - Analytical model
  - Hardware measurements
- Simulation results have been carefully evaluated
- Framework is currently being prepared for a first public release
- If you are interested visit:
  http://www.informatik.haw-hamburg.de/tte4inet.html
Outlook
Simulating camera based vehicle-environment detection

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Thank you for your attention!

- Website of research group: http://www.informatik.haw-hamburg.de/core.html
- Website for simulation model: http://www.informatik.haw-hamburg.de/tte4inet.html