Software Stacks for Mixed-critical Applications: Consolidating IEEE 802.1 AVB and Time-triggered Ethernet in Next-generation Automotive Electronics

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Stacks for Mixed-critical Applications
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1. Introduction
2. Background
3. Architecture
4. Implementation & Results
5. Conclusion & Outlook
Motivation
What is a Mixed-critical Application

Definition
A Mixed-Critical Application joins traffic flows and tasks of different classes of real-time requirements

Typical Characteristics
- Traffic flows with diverging timing requirements
- Different communication patterns
  - Synchronous (time-triggered)
  - Asynchronous (event-triggered)
Motivation
Example of a Mixed-critical Application

Advanced Driver Assistance Systems, e.g. Active Body Control (ABC)-System

- Synchronization of (Stereo) Cameras
  - Transmission with medium precision and latency requirements.
  - Calculation of timestamps requires highest precision

- Transfer Raw Images
  - Transfer images with low latency.
  - Jitter is allowed up to 10% of image cycle (order of milliseconds)

- Control actuators (e.g. active suspension)
  - Physical control loop
  - Least latency required for best control results
  - Least jitter required to guarantee stable system
Problem
Challenges for Automotive Mixed-critical Application

- Challenging timing
  - Latency below 250 µs
  - Jitter below 10 µs
- High bandwidth
  - For cameras, laser, radar up to 100 Mbps (soon more)
- Limited hardware resources
  - Weak processors
  - Low memory
  - Low energy consumption
Software-Stack Architecture

- For automotive Embedded Systems
- Providing parallel support for
  - Time-triggered real-time communication
  - Ethernet AVB streams
- Prototype implementation for upcoming IEEE 802.1Qbv
Background
Audio/Video Bridging (IEEE 802.1BA\textsuperscript{1})

Basic parts:

- Credit Based Shaper (IEEE 802.1Qav)
- Stream Reservation Protocol (IEEE 802.1Qat)
- Link Layer Discovery Protocol (IEEE 802.1AB)
- Subset of PTP (IEEE 802.1AS)

Traffic classes:

- Class A (max. latency 2 ms within 7 hops)
- Class B (max. latency 50 ms within 7 hops)
- Best-Effort (BE)

\textsuperscript{1} Institute of Electrical and Electronics Engineers: \textit{IEEE 802.1BA - IEEE Standard for Local and metropolitan area networks - Audio Video Bridging (AVB) Systems}. Sept. 2011.
Background
Credit Based Shaper (CBS)

- Key part for extending AVB with additional traffic
- Separate credit per SR Class
- Credit value changes with two gradients:
  - Sendslope, represents: reserved bandwidth - max. bandwidth
  - Idleslope, represents: reserved bandwidth
Background
Credit Based Shaper (CBS)

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Introduction
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Ethernet AVB
Time-Triggered Architecture
Implementation & Results
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Basic elements:

- Synchronisation
- Static scheduling

Characteristics:

- Statically configured forwarding routes
- Statically configured send and receive times
- End-to-end latency of less than 100µs possible
- Jitter in the order of nanoseconds
System Architecture
Software Partitioning

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Scheduling & Queueing
Realization of AVB with TT traffic

Time-triggered

AVB Class-A
AVB Class-B
Best-Effort

Time-triggered Scheduler (TT)
Priority Based Selection
CBS

Schedule
Clock

Time-Aware CBS

Time-triggered + AVB + Best-Effort Egress

Dataflow
Controlflow

TT TT Prio TT Prio TT Prio Prio TT
0 5 4 3 0 1 2 3

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Platform

- System-on-chip design
- 4 concurrently usable channels (ALU)
- 200 MHz ARM9 CPU
  - 8 kB data- and 16 kB instruction cache
  - 8 kB tightly coupled data memory
- Data switch architecture instead of system bus architecture
- Timestamping with nanosecond resolution
- Rate correctable system time with $2^{-28}$ ns resolution

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## Significant Modules

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<tr>
<th>Module</th>
<th>Memory Consumption [kB]</th>
<th>%</th>
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<tbody>
<tr>
<td>Talker</td>
<td>4.7</td>
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<tr>
<td>Credit Based Shaper</td>
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<tr>
<td>AVB</td>
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<td>AVB API</td>
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<td>4.6</td>
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<td>AVB Timer</td>
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<tr>
<td>MRP</td>
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<tr>
<td>MMRP</td>
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<td>MVRP</td>
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<td><strong>Total</strong></td>
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<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
Performance

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Platform
Ressources
Performance
Conclusion & Outlook
Conclusion

- Real-time Ethernet likely to enter in-car domain
- Mixed-critical applications require specialised system software
- First approach to IEEE 802.1Qbv capable software stack
- Joins IEEE 802.1 AVBs credit-based shaper with scheduler for time-triggered traffic
- Low footprint microcontroller based communication architecture
- Prototype shows feasibility on system-on-chip with ARM9
Outlook

- Improve performance
- Analyze possible hardware support for shaper
- Evaluate the feasibility in automobile prototype
Thank you for your attention!

Website of CoRE research group: http://www.haw-hamburg.de/core
References I


Extending AVB with TT traffic
Time aware credit based shaper

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