Bus Access Optimization for Distributed Embedded Systems Based on Schedulability Analysis

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Outline

- Motivation
- System Architecture
- Schedulability Analysis
- Communication Synthesis
- Experimental Results
- Conclusions

Motivation and Characteristics

- Embedded System Design.

  Scheduling, Communication, Bus Access.

- **Characteristics:**

  - Heterogeneous system architecture.
  - Fixed priority preemptive scheduling for processes.
  - Communications using the time-triggered protocol (TPP).

  H. Kopetz, G. Grünsteidl. TTP-A Protocol for Fault-Tolerant Real-Time Systems. IEEE Computer ‘94

Contributions and Message

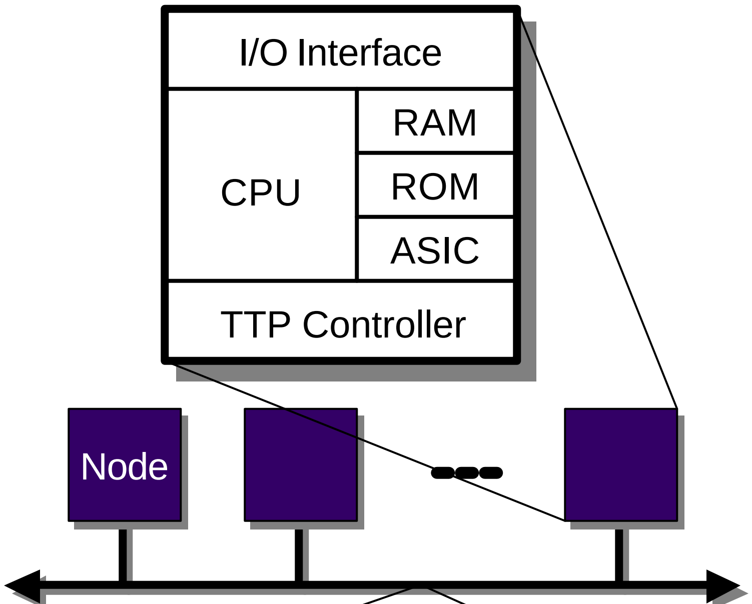
- **Contributions:**
  - Proposed a **schedulability analysis** for distributed hard-real time systems that use the time-triggered protocol.
  - Developed **optimization strategies** for the communication synthesis problem.
- **Message:**
  - By optimizing the buss access scheme the “degree of schedulability” of the system can be significantly improved.

Event-Triggered vs. Time-Triggered

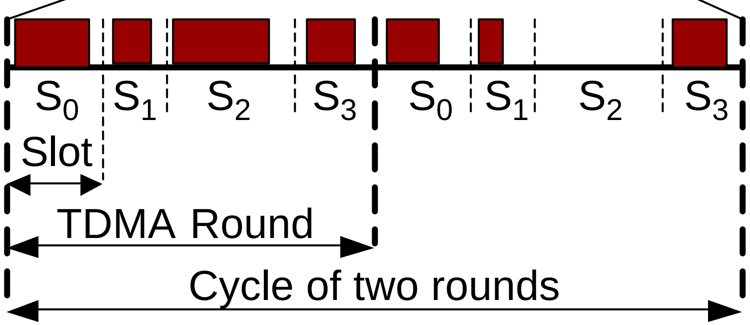
- **Event-triggered**: activation of processes and transmission of messages is done at the occurrence of significant events.
- **Time-triggered**: activation of processes and transmission of messages is done at predefined points in time.

	processes	messages
event-triggered	X	
time-triggered		X

Hardware Architecture



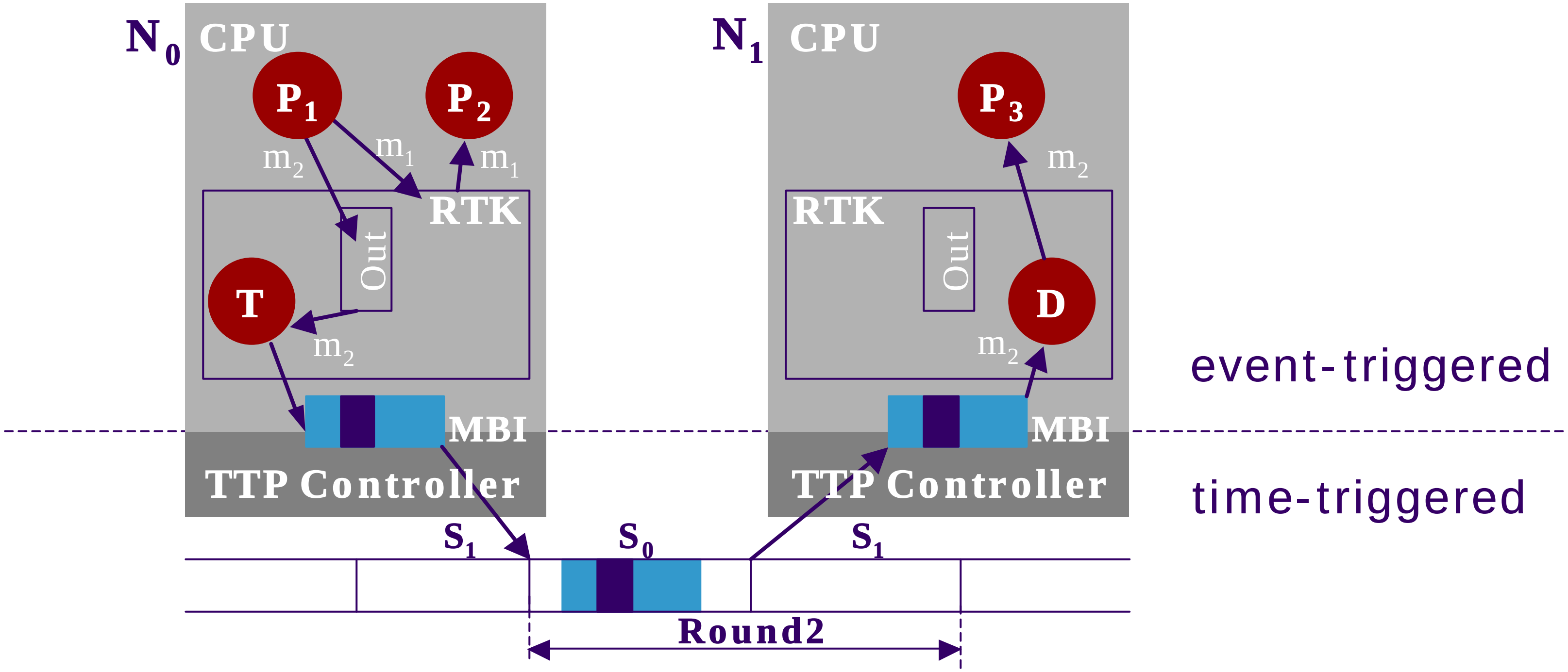
- Hard real-time distributed systems.
- Nodes interconnected by a broadcast communication channel.
- Nodes consisting of: TTP controller, CPU, RAM, ROM, I/O interface, (maybe) ASIC.
- Communication between nodes is based on the time-triggered protocol.



- Bus access scheme: time-division multiple-access (TDMA).
- Schedule table located in each TTP controller: message descriptor list (MEDL).

Software Architecture

- Real-Time Kernel running on the CPU in each node.
- The worst case administrative overheads are known.
- Fixed priority preemptive scheduling.
- Tick scheduler in each kernel.



Problem Formulation

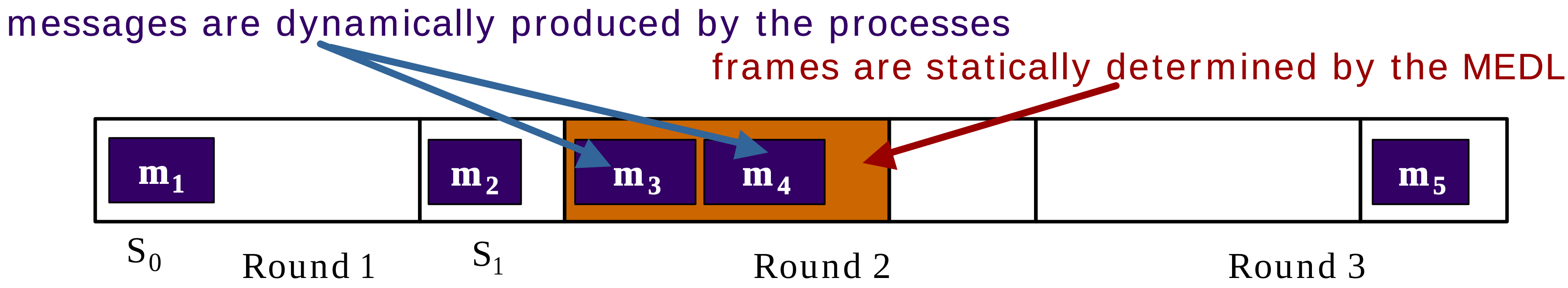
Input

- An application modelled as a set of processes.
- Each process has an execution time, a period, a deadline, and a priority.
- The system architecture and mapping of processes to nodes are given.
- Each message has a known size.

Output

- A schedulability analysis (response time analysis) for hard real-time systems that use the time-triggered protocol for communications.
- The MEDL for the TTP controllers so that the process set is schedulable on an as cheap (slow) as possible processor set.

Scheduling of Messages over TTP



1. Single message per frame, allocated statically:
   Static Single Message Allocation (**SM**)

2. Several messages per frame, allocated statically:
   Static Multiple Message Allocation (**MM**)

3. Several messages per frame, allocated dynamically:
   Dynamic Message Allocation (**DM**)

4. Several messages per frame, split into packets, allocated dynamically
   Dynamic Packets Allocation (**DP**)

Schedulability Analysis

- **Starting point**: schedulability analysis for distributed hard real-time systems with communication based on a simple TDMA protocol.

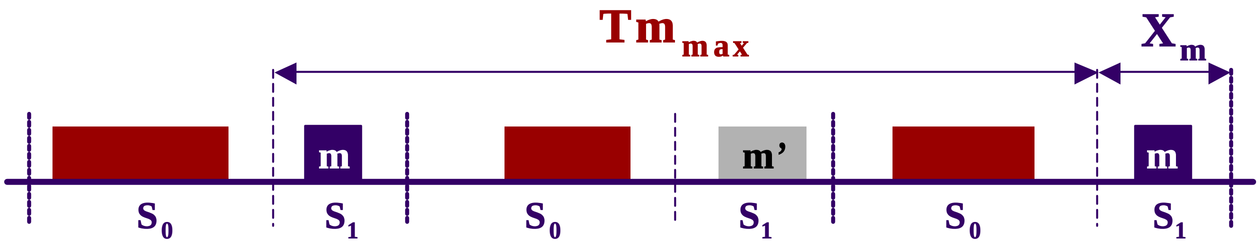
  K Tindell, J. Clark. Holistic Schedulability Analysis for Distributed Hard Real-Time Systems. Micro'94
- Schedulability test: **response time** $r_i \leq$ **deadline** D_i for each process.

- The **response time** r_i depends on the **communication delay** between sending and receiving a message.
- The **communication delay** is calculated differently for each of the four approaches to message scheduling over TTP (SM, MM, DM, DP):

Schedulability Analysis (Continued)

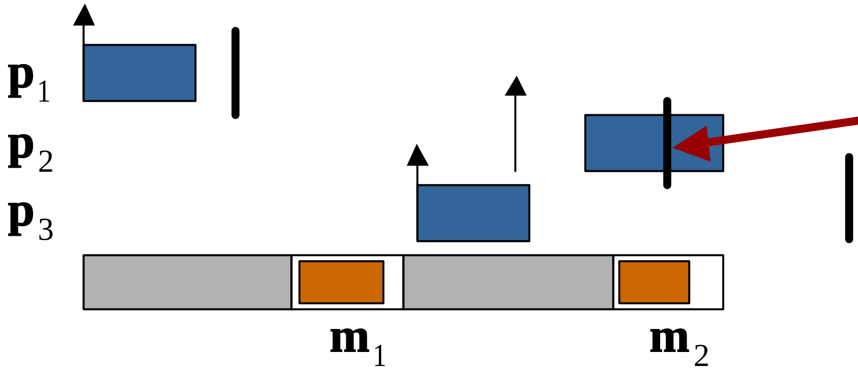
- The **communication delay** for a message **m** depends on:

1. Static Single Message Allocation (SM): Tm_{max}
2. Static Multiple Message Allocation (MM): Tm_{max}

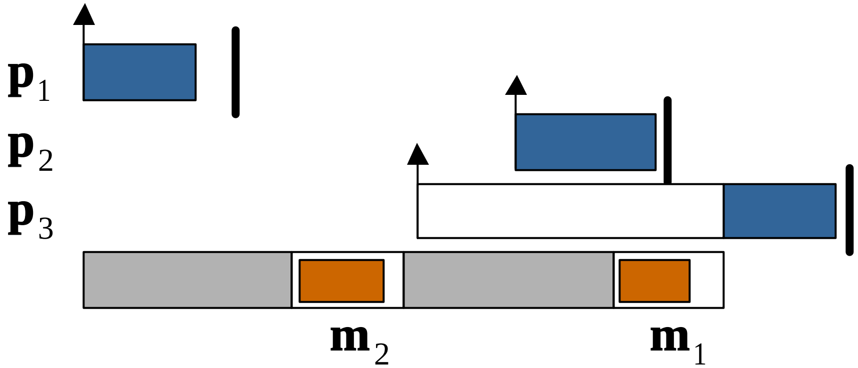


3. Dynamic Message Allocation (DM): slot sizes in a TDMA round.
4. Dynamic Packets Allocation (DP): slot sizes in a TDMA round, packet size.

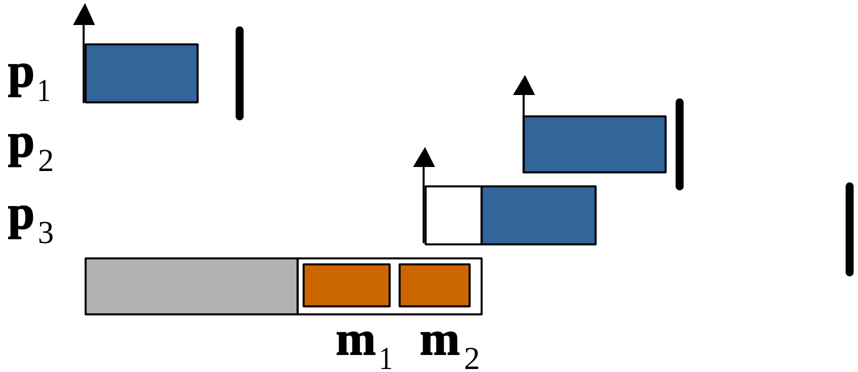
Optimizing Buss Access (SM and DM)



Process P_2 misses its deadline!



Swapping m_1 with m_2:
all processes meet their deadlines.



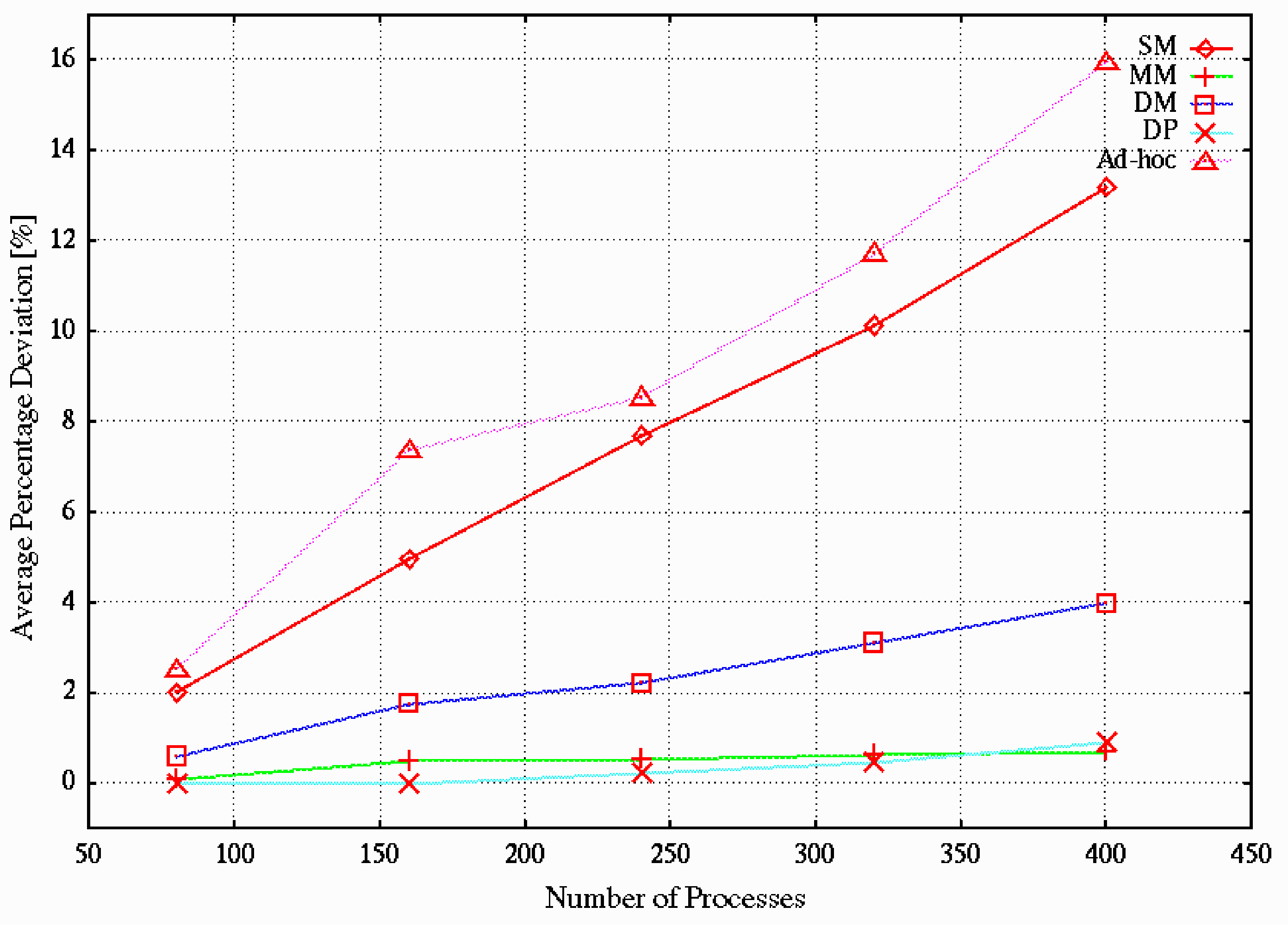
Putting m_1 and m_2 in the same slot:
all processes meet their deadline,
the communication delays are reduced.

Optimization Strategy

- The synthesis of the MEDL is performed off-line: optimization process.
- Comparison of the four messages scheduling approaches: fair only for **near-optimal** results.
- Optimization strategies based on **Greedy Approaches** and **Simulated Annealing**.
- Cost function: **degree of schedulablity**.

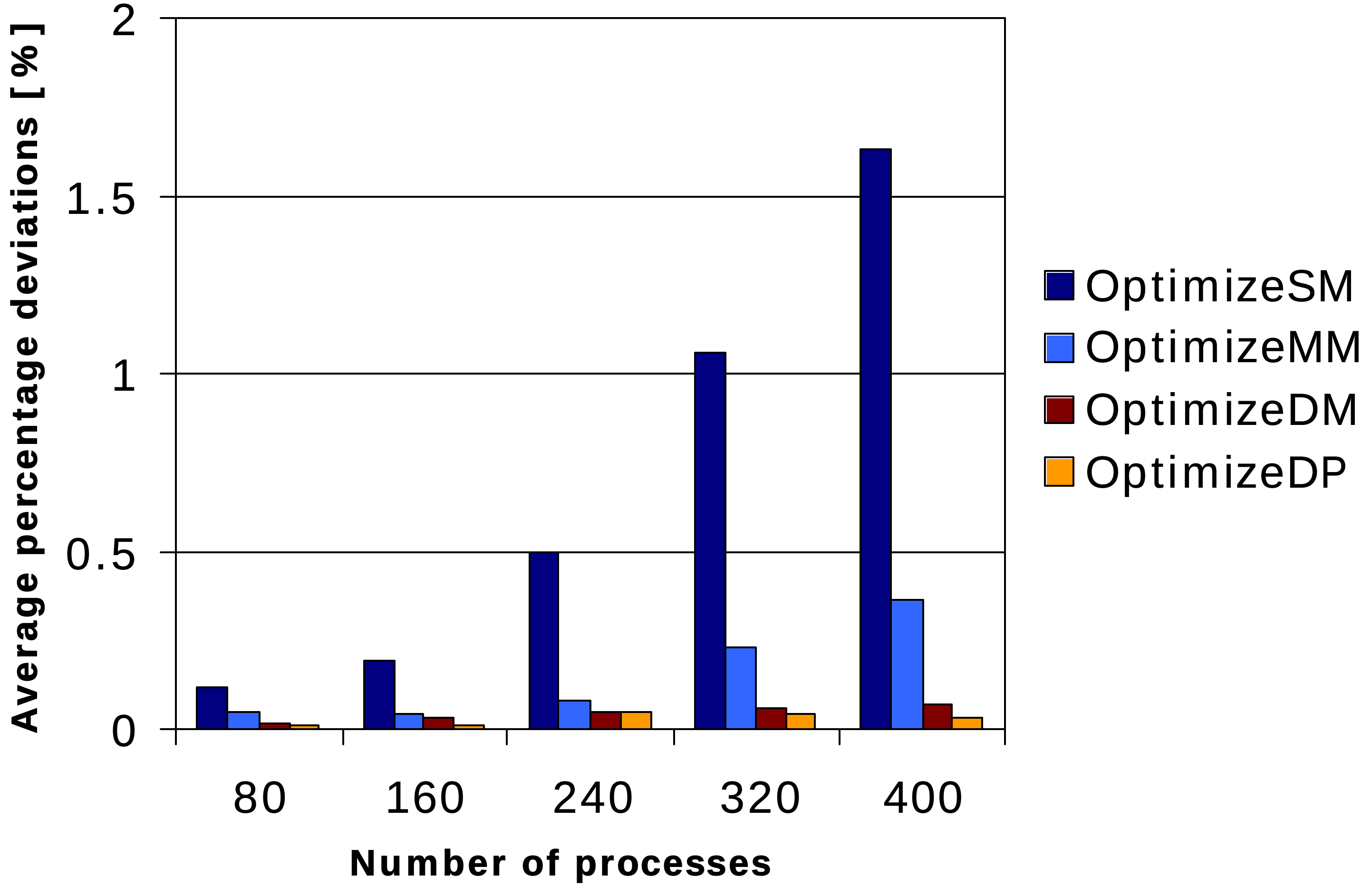
Experimental Results

Average percentage deviation from the best among the four message scheduling approaches:



Experimental Results (Continued)

The quality of the greedy optimization heuristics:



Conclusions

- Static priority preemptive process scheduling. Communications based on a time-triggered protocol.

- Four different message scheduling policies over TTP:
  - **analysis** of the communication delays and
  - **optimization** strategies for the buss access scheme.

- Approaches compared using extensive experiments:
  - guidelines for designers.

- Optimizing the buss access scheme the “degree of schedulability” of the system can be significantly improved.