Schedulability Analysis and Optimization for the Synthesis of Multi-Cluster Distributed Embedded Systems

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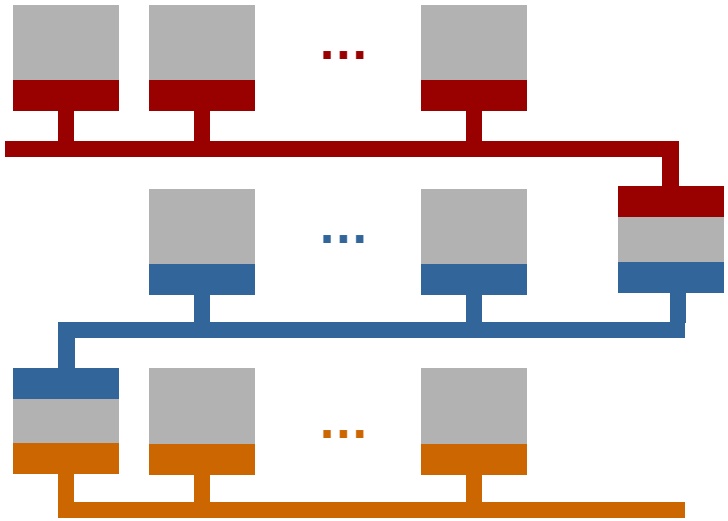
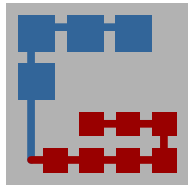
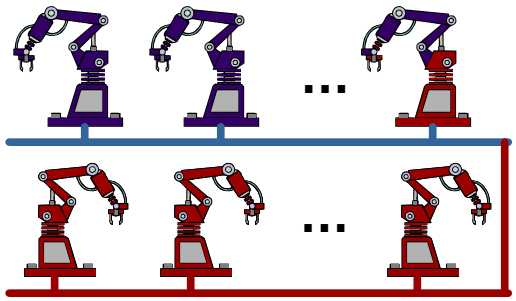
Heterogeneous Networks



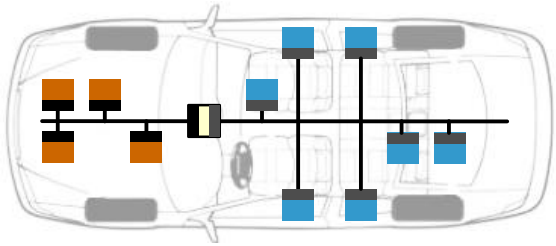
Heterogeneous Networks
Multi-Cluster Systems



NoCs

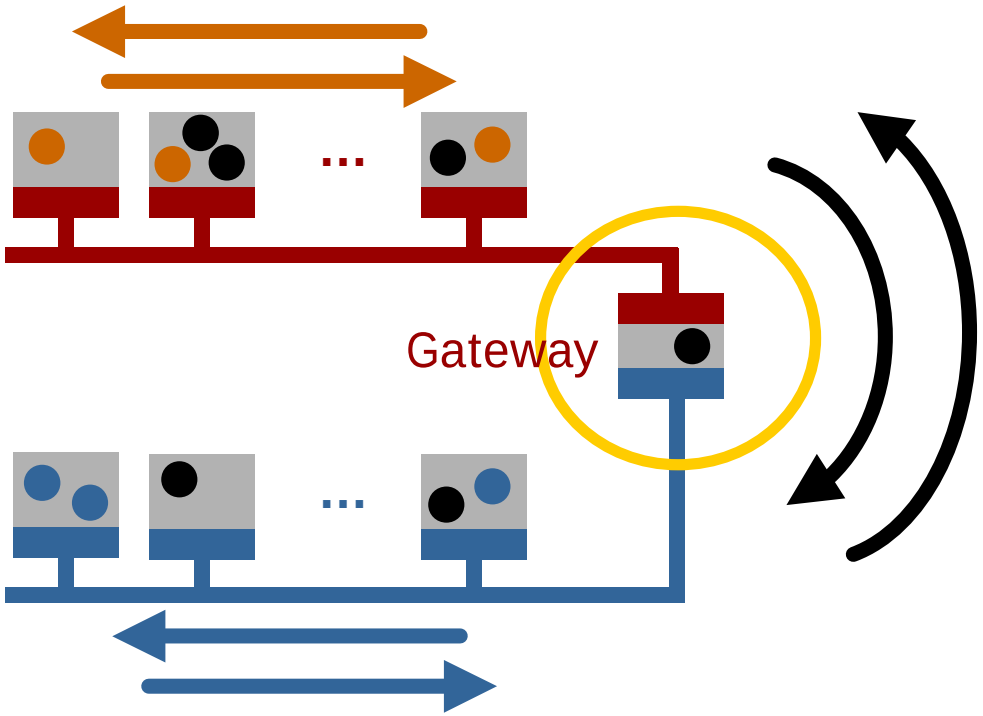


Factory Systems



Automotive Electronics

Distributed Safety-Critical Applications



- Applications distributed over the heterogeneous networks
  - Reduce costs:
    use resources efficiently
  - Requirements:
    close to sensors/actuators

- Applications distributed over heterogeneous networks are difficult to…
  - Analyze (e.g., guaranteeing timing constraints)
  - Design (e.g., efficient implementation)

Unsolved problems

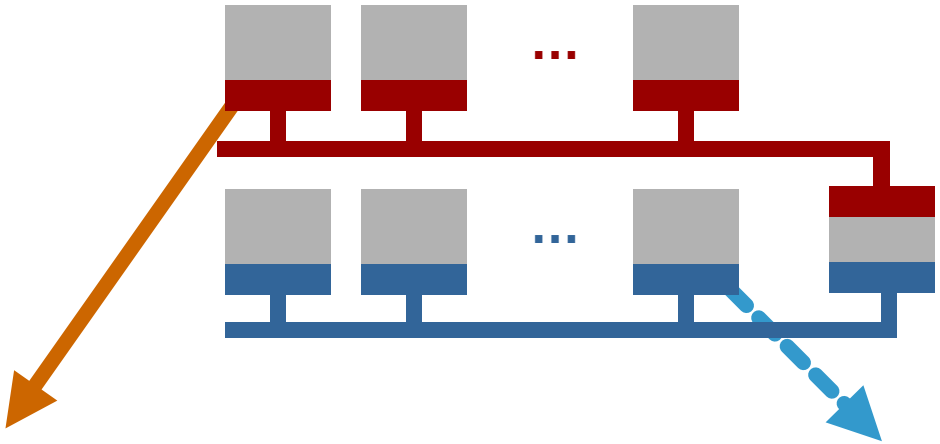
Contributions

- **Analysis** and **design** of Multi-Cluster Embedded Systems
  - **Analysis**
    - Proposed a schedulability analysis for safety-critical **hard real-time** applications mapped on multi-cluster distributed embedded systems
      - Is the application schedulable? (Are deadlines satisfied?)
      - Bounds on the communication delays and communication buffer sizes
  - **Design optimization**
    - In this paper we have addressed communication synthesis and priority assignment for
      - Improving the degree of schedulability of an application
      - Minimizing communication buffer sizes needed to run a schedulable application

Outline

- Motivation
- Contributions
- ➔ System architecture and application model
- Schedulability analysis for multi-clusters
- Optimization strategies
- Experimental results
- Message and future work

Hardware Architecture



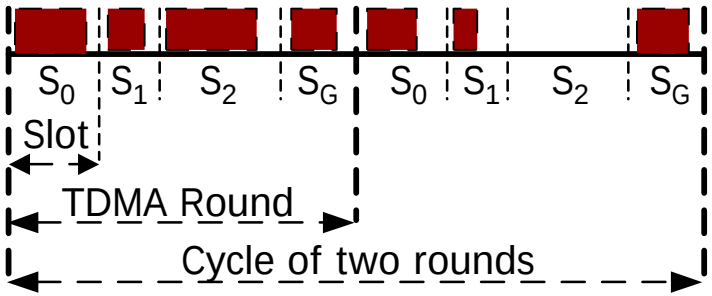
Time-triggered cluster
- Static cyclic scheduling
- Time-triggered protocol

Gateway

Event-triggered cluster
- Fixed priority preemptive scheduling
- Controller area network protocol

Time Triggered Protocol (**TTP**)

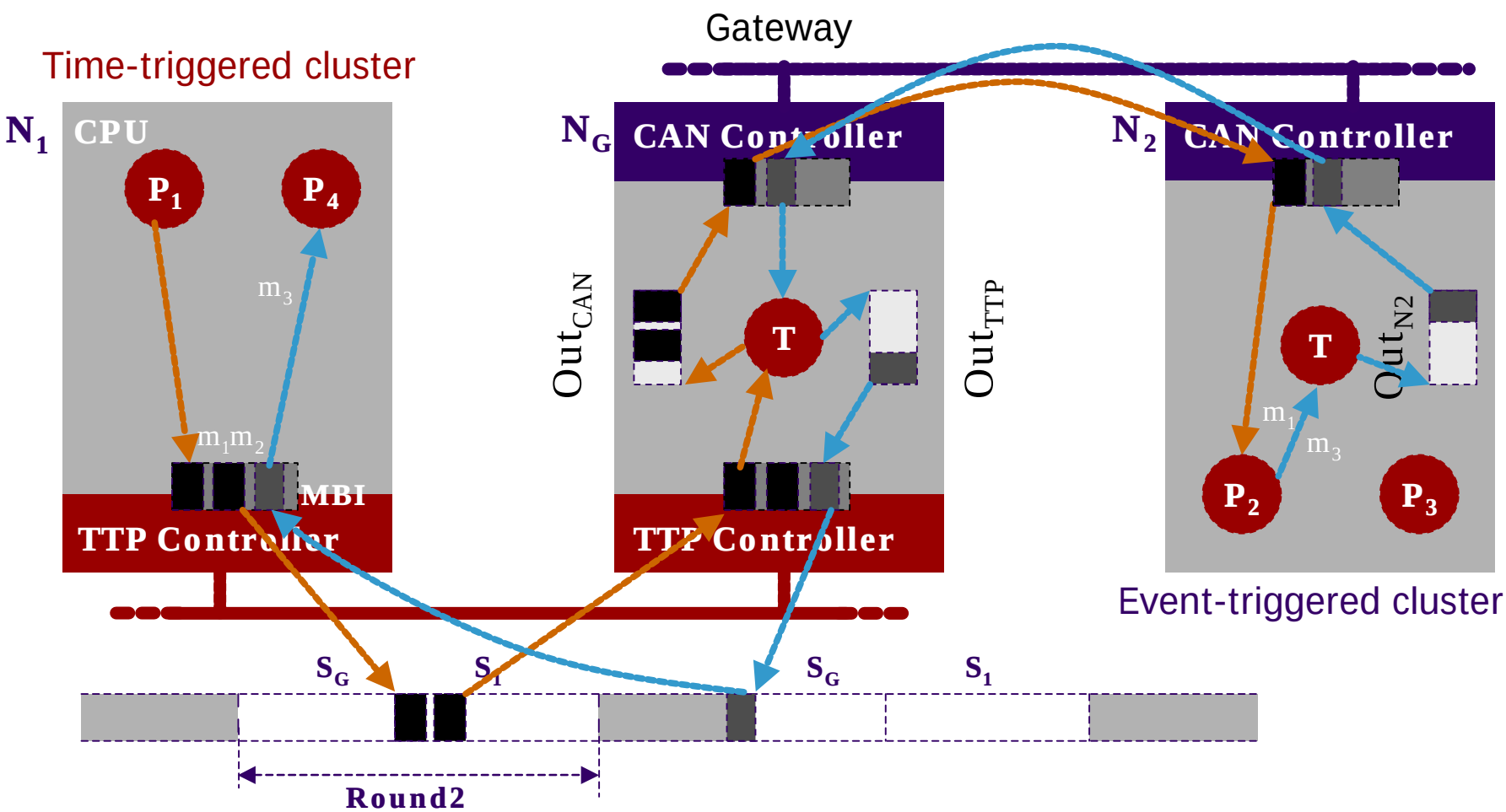
- Bus access scheme:
  time-division multiple-access (TDMA)
- Schedule table located in each TTP controller: message descriptor list (MEDL)



Controller Area Network (**CAN**)

- Priority bus, collision avoidance
- Highest priority message wins the contention
- Priorities encoded in the frame identifier

Software Architecture



Problem Formulation

- Input
  - An application modeled as a set of process graphs
  - Each process has an worst case execution time, a period, and a deadline
  - Each message has a known size
  - The system architecture and the mapping of the application are given

- Output
  - Worst case response times and bounds on the buffer sizes
  - Design implementation
    such that the application is schedulable and buffer sizes are minimized
    - Schedule table for TT processes
    - Priorities for ET processes
    - Schedule table for TT messages
    - Priorities for ET messages
    - TT bus configuration
      (TDMA slot sequence and sizes)

Communication infrastructure parameters

System configuration parameters

Schedulability Analysis

- Scheduling **time-triggered** activities:
  - Building a schedule table:
    static cyclic scheduling (e.g., list scheduling)

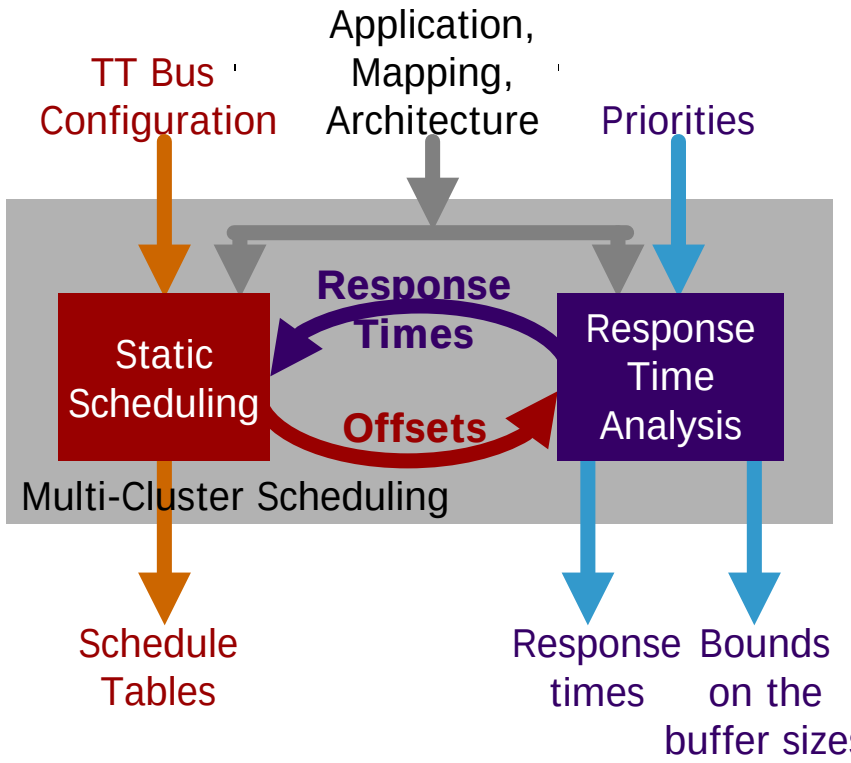
- Scheduling **event-triggered** activities:
  - Response time analysis:
    calculate worst case response times for each process
  - Schedulability test: response times smaller than the deadlines
  - Response times depend on the communication delay
    between sending and receiving a message
  - Communication delays depend on the type of message passing

1. **TTC → TTC**
2. **TTC → ETC**
3. **ETC → ETC**
4. **ETC → TTC**

- Communication delays
- Bounds on the buffer sizes

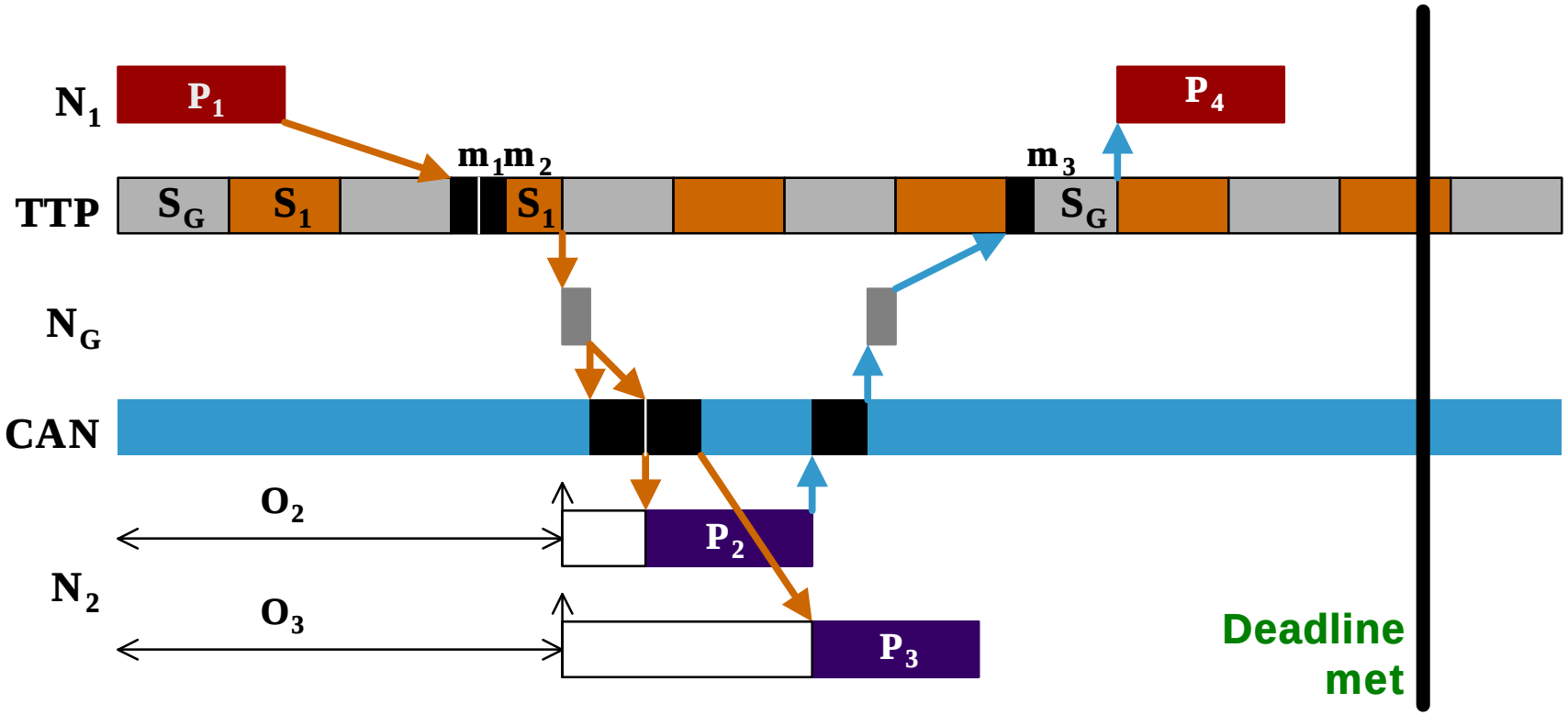
Multi-Cluster Scheduling

- Scheduling cannot be addressed separately for each type of cluster
- The inter-cluster communication creates a **circular dependency**:
  - TTC static schedules (offsets) Þ ETC response times
  - ETC response times Þ TTC schedule table construction



Offset
earliest possible start time for an **event-triggered** activity

Optimization Example

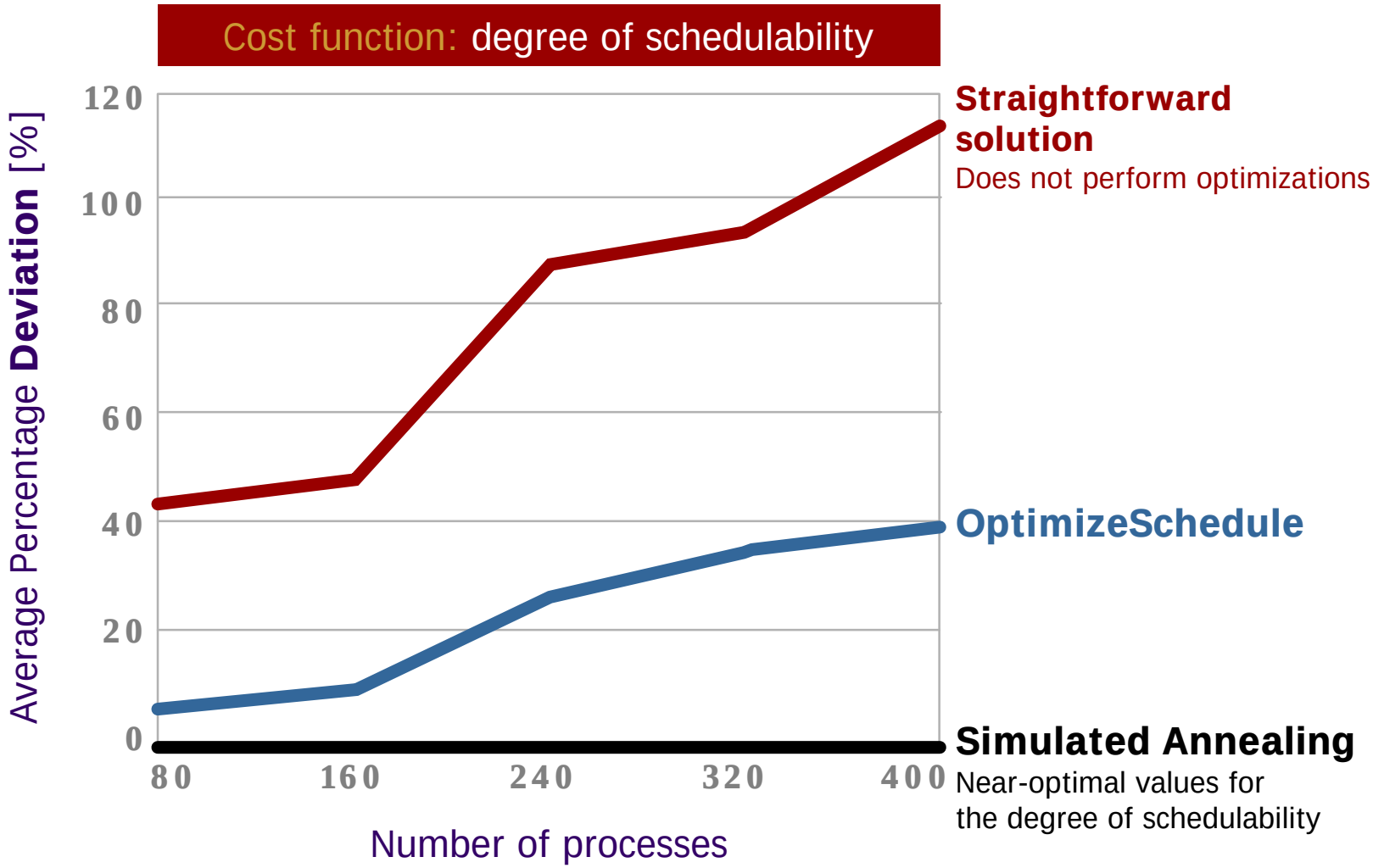


Transformation: P_2 is the high priority process on N_2

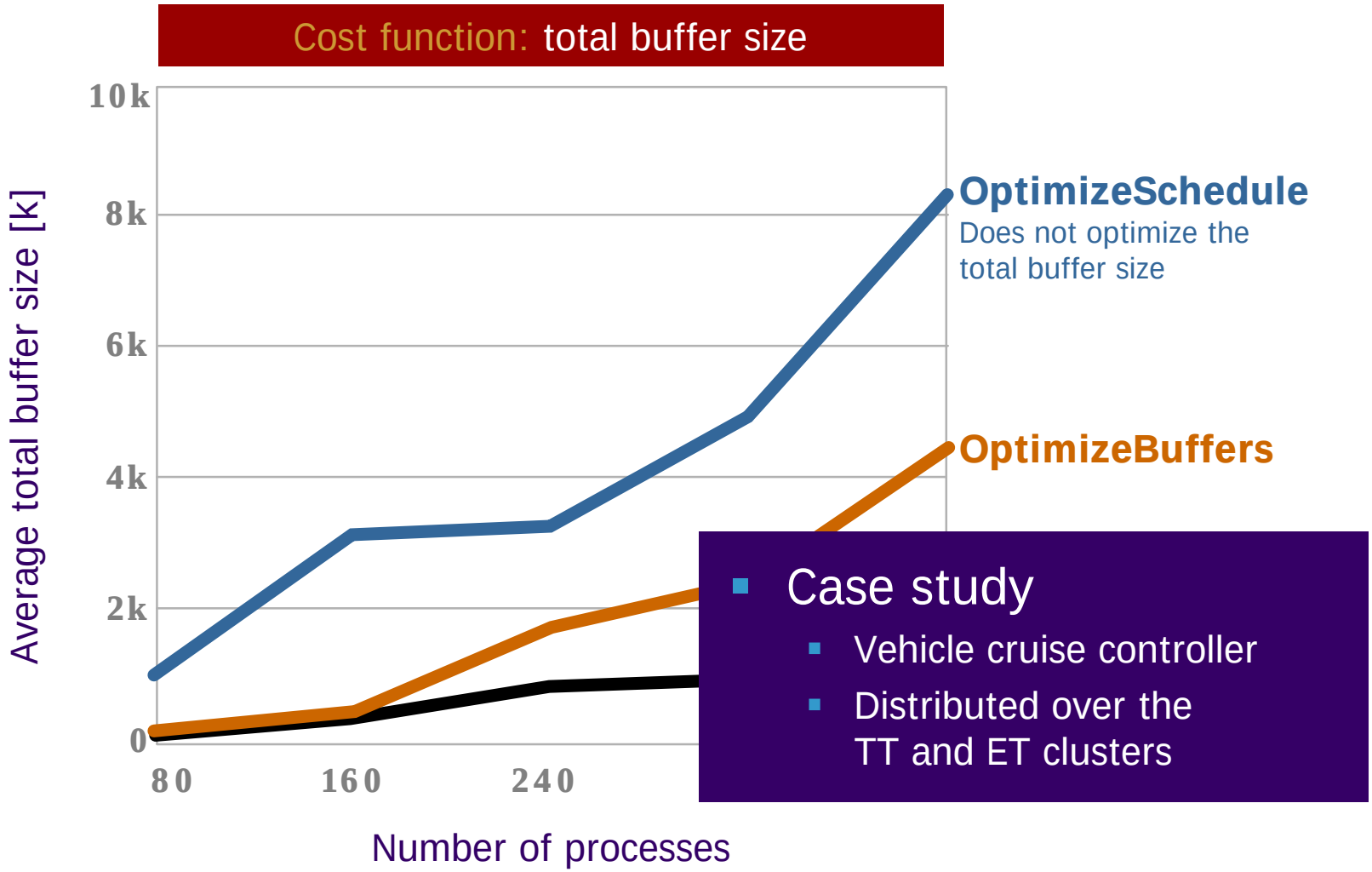
Optimization Strategies

- **OptimizeSchedule**
  - Synthesizes the communication and assigns priorities to obtain a schedulable application
  - Based on a greedy approach
    - Cost function: degree of schedulability
- **OptimizeBuffers**
  - Synthesizes the communication and assigns priorities to reduce the total buffer size
  - Based on a hill-climbing heuristic
    - Cost function: total buffer size
- **Straightforward solution**
  - Finds a schedulable application
  - Does not consider the optimization of the design

Can We Improve Schedulability?



Can We Reduce Buffer Sizes?



Message and Future Work

Analysis and optimization methods are needed for the efficient implementation of applications distributed over interconnected **heterogeneous networks**.

- Future Work
  - Explore more design problems
    - Mapping for multi-clusters
    - How to partition an application in ET and TT activities?