Schedulability-Driven Frame Packing for Multi-Cluster Distributed Embedded Systems

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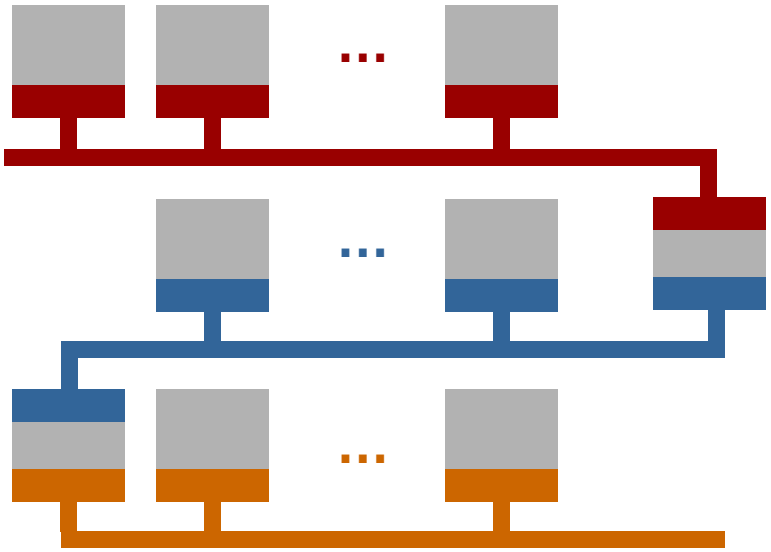
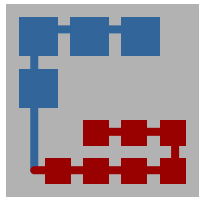
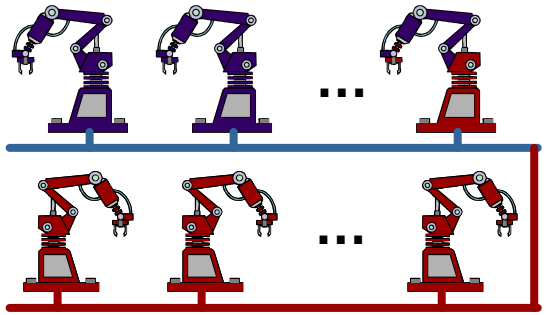
Heterogeneous Networks



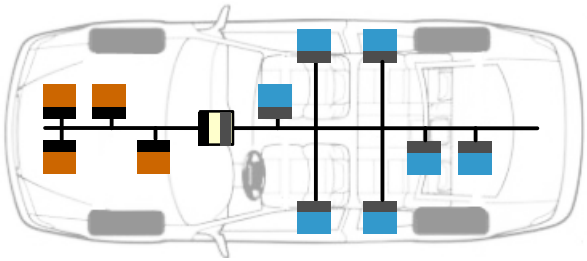
Heterogeneous Networks
Multi-Cluster Systems



NoCs

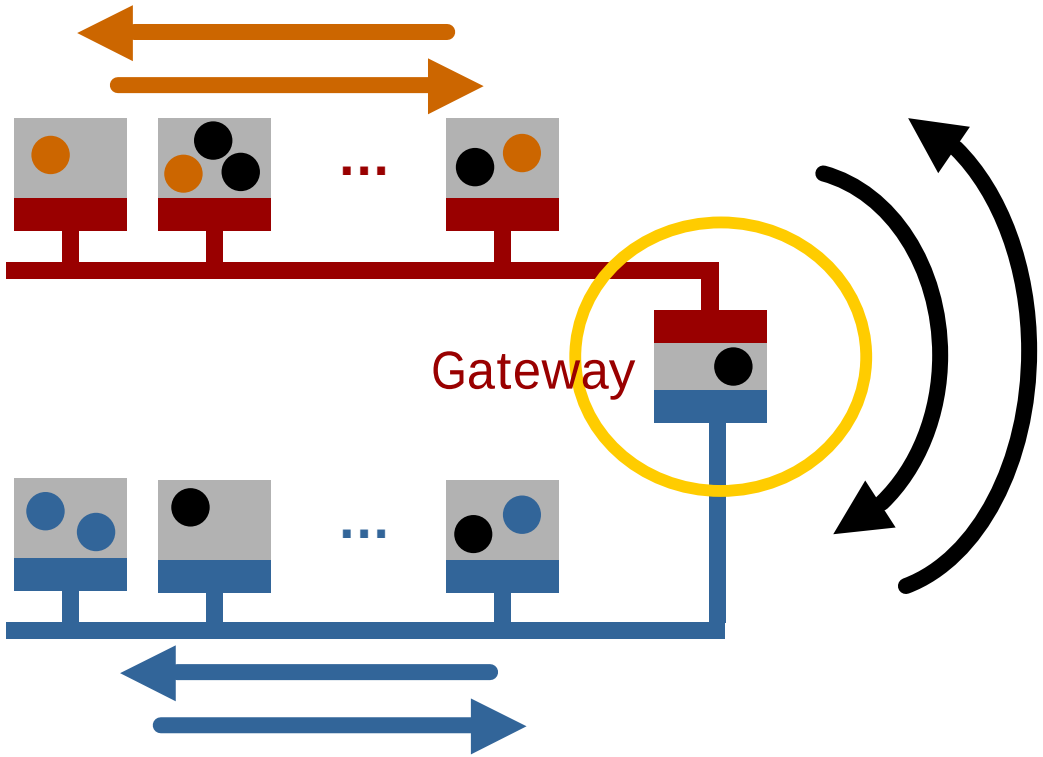


Factory Systems



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

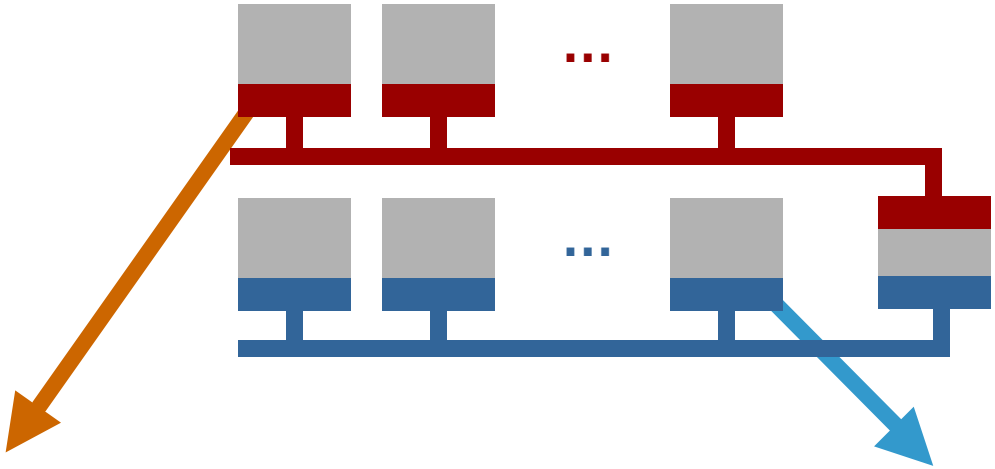
Contributions

- **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 the issue of packing application messages into frames (**frame packing**) for
      - Improving the degree of schedulability of an application
      - Reducing the hardware costs needed to run a schedulable application

Outline

- Motivation
- Contributions
- ➔ System architecture and application model
- Related work
- Schedulability analysis for multi-clusters
- Frame packing for multi-custers
- Experimental results
- Message and future work

Hardware Architecture



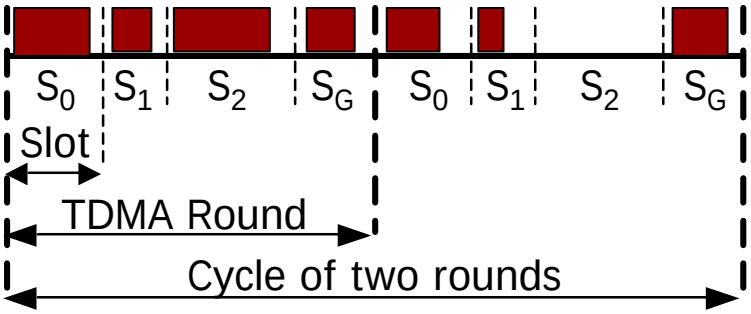
Time-triggered cluster
- Static cyclic scheduling
- Time-triggered protocol

Gateway

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

Time Triggered Protocol (**TTP**)

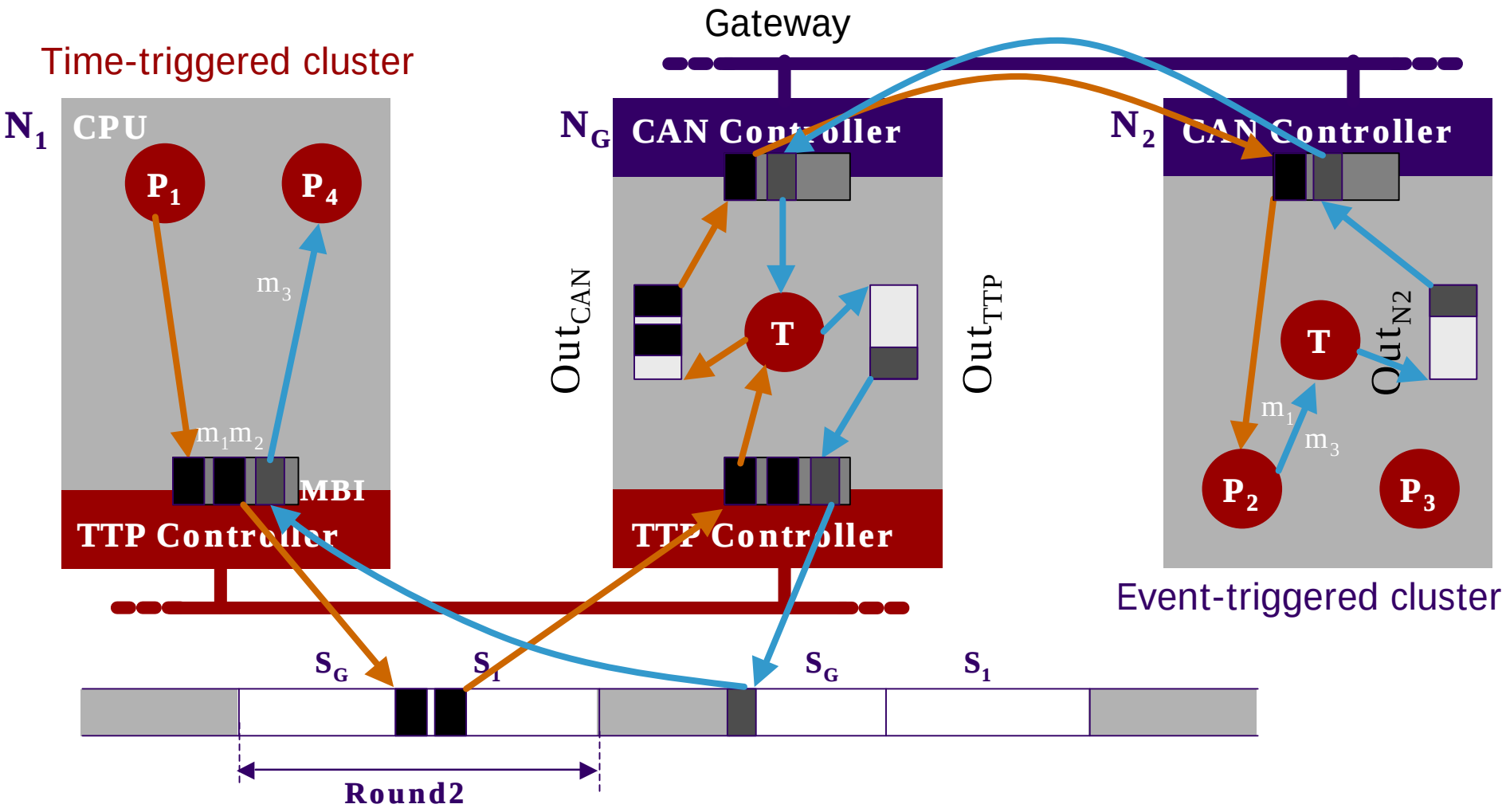
- Bus access scheme:
  time-division multiple-access (TDMA)
- Schedule table located in each TTP controller: message descriptor list (MEDL)



Controller Area Network (**CAN**)

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

Software Architecture



Related Work

- Frame packing for TT systems using TTP
  - H. Kopez, R. Nossal,
    The Cluster-Compiler –
    A Tool for the Design of Time Triggered Real-Time Systems,
    Workshop on Languages, Compilers, and Tools for Real-Time Systems, 1995

- Frame packing for ET sytems using CAN
  - K. Sandström, C. Norström,
    Frame Packing in Real-Time Communication,
    Real-Time Computing Systems and Applications Conference, 2000
  - A. Rajnak, K. Tindell, L. Casparsson,
    Volcano Communications Concept,
    Volcano Communication Technologies AB, 1998

- Frame packing for **multi-clusters** (ET + TT)
  - Has not been addressed previously
  - Cannot be solved separately for each cluster as inter-cluster communication creates a circular dependency

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
  - A mapping of application messages to frames (**frame packing**) such that the application is schedulable
    - Mapping of ET messages to frames
    - Priorities for ET messages
    - Mapping of TT messages to frames
    - TDMA slot sequence

Schedulability Analysis

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

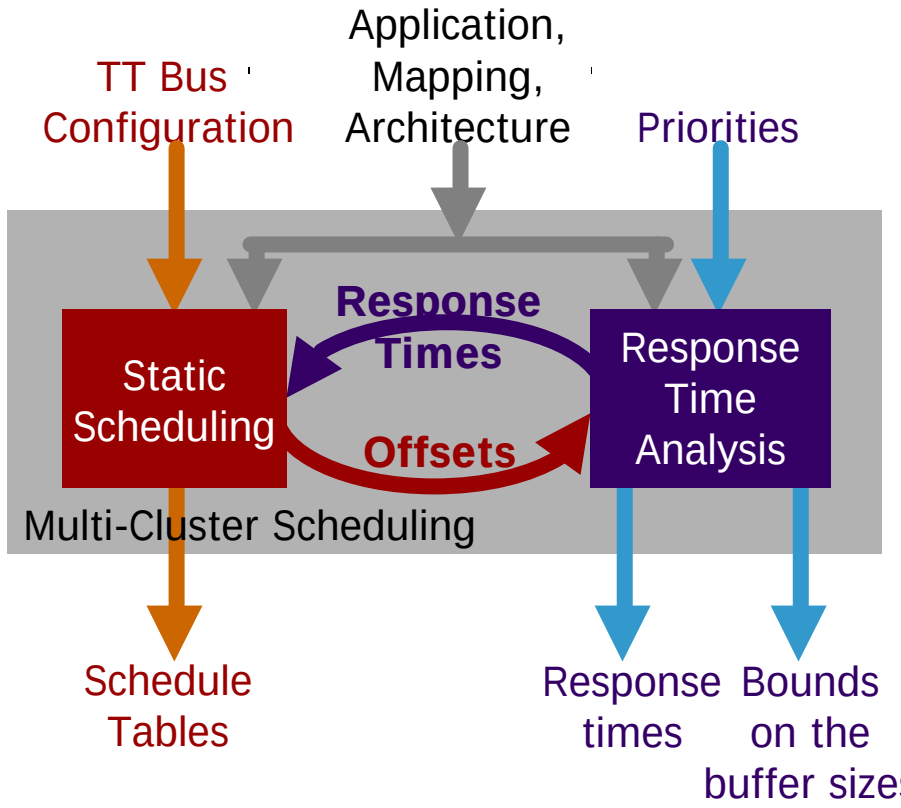
- Scheduling **event-triggered** activities:
  - Response time analysis:
    calculate worst case response times for each process
  - Schedulability test: response times smaller than the deadlines
  - Response times depend on the communication delay
    between sending and receiving a message
  - Communication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

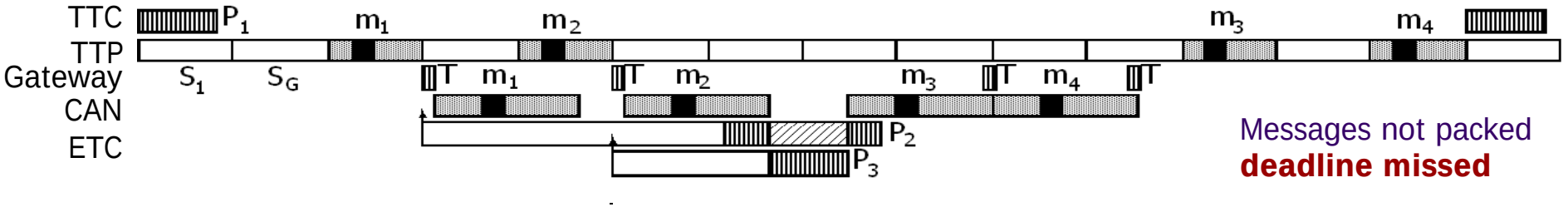
Multi-Cluster Scheduling

- 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

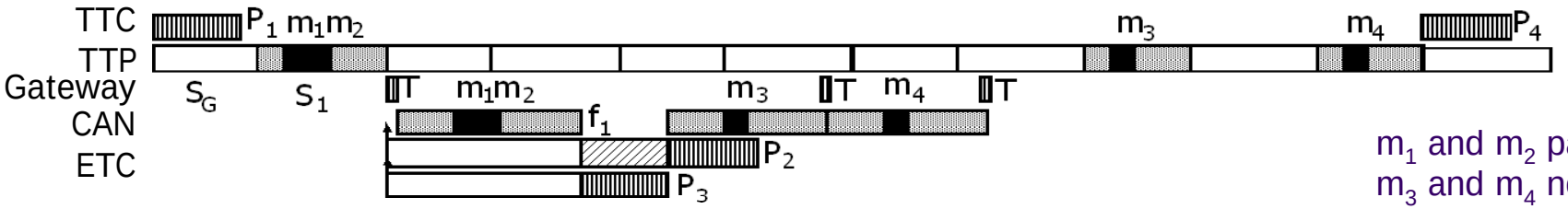


Offset
earliest possible start time for an **event-triggered** activity

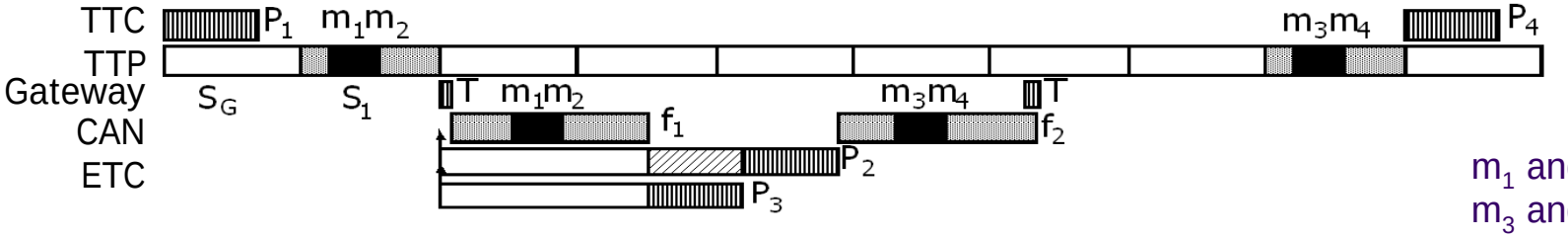
Frame Packing Example



Messages not packed
deadline missed



m_1 and m_2 packed in f_1,
m_3 and m_4 not packed,
deadline missed

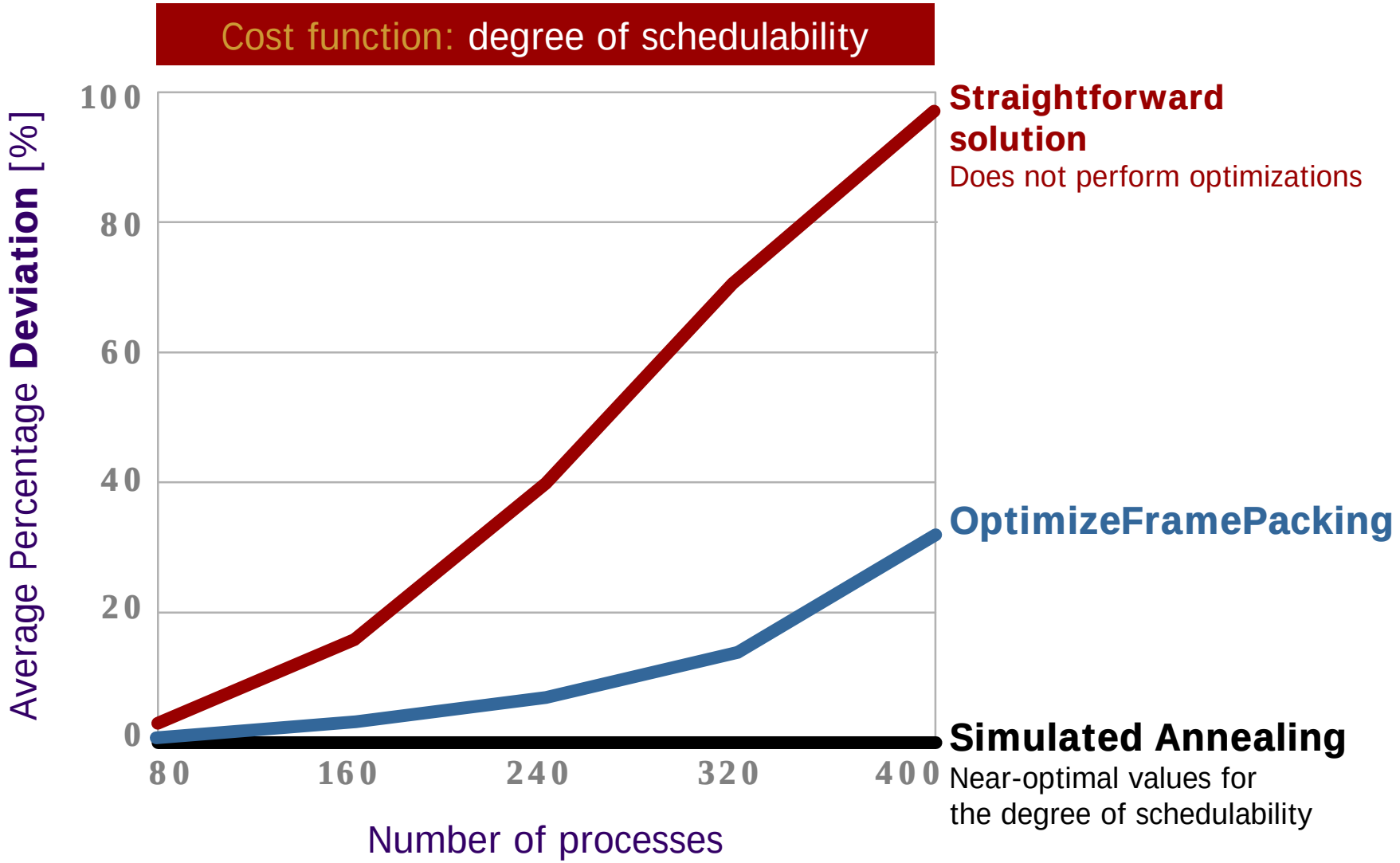


m_1 and m_2 packed in f_1,
m_3 and m_4 packed in f_2,
deadline met

Frame Packing Optimization Strategies

- **Simulated Annealing**
  - Based on a simulated annealing approach
    - Cost function: degree of schedulability
    - Obtains near-optimal values for the degree of schedulability
- **OptimizeFramePacking**
  - Based on a greedy approach
    - Cost function: degree of schedulability
- **Straightforward solution**
  - Finds a schedulable application
  - Does not consider the packing of messages to frames

Can We Improve Schedulability?



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?