

# Design Optimization of **Multi-Cluster** Embedded Systems for Real-Time Applications

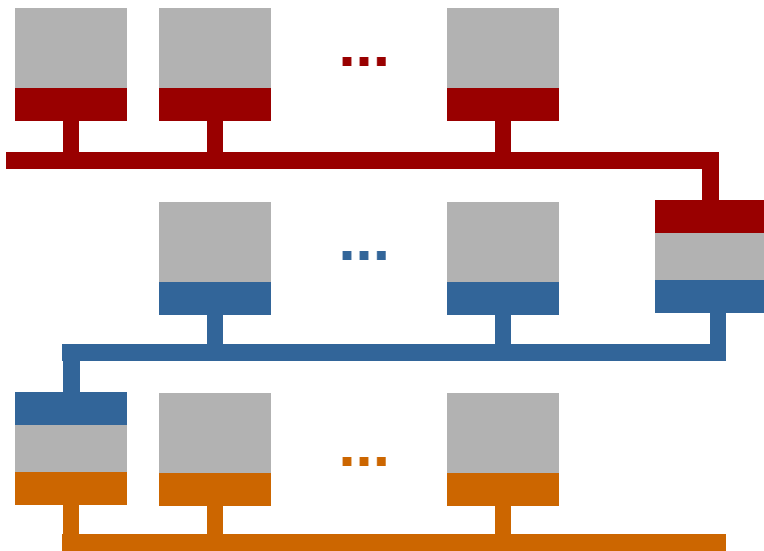
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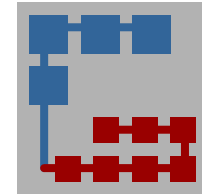
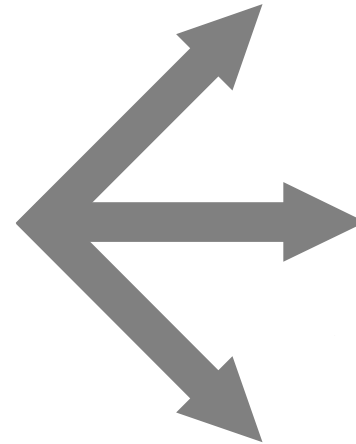


**VOLVO**

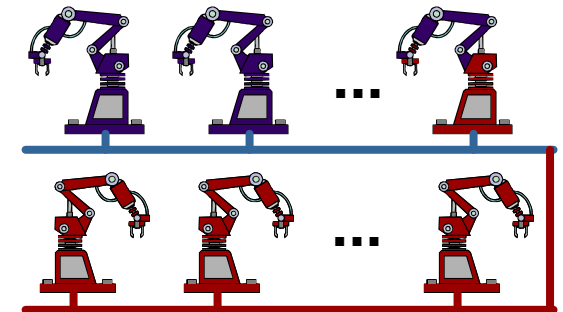
# Heterogeneous Networks



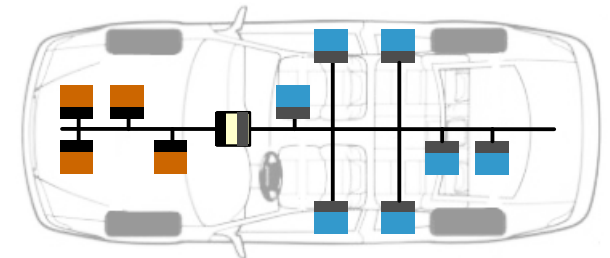
Heterogeneous Networks  
Multi-Cluster Systems



NoCs

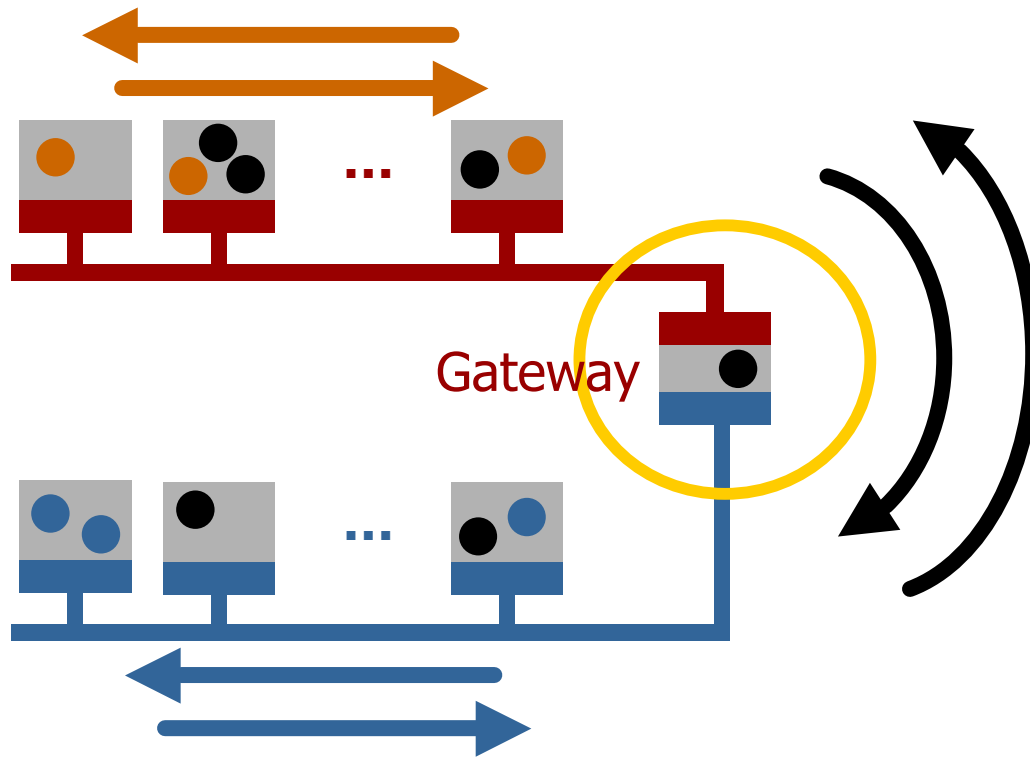


Factory Systems



Automotive Electronics

# Distributed Safety-Critical Applications

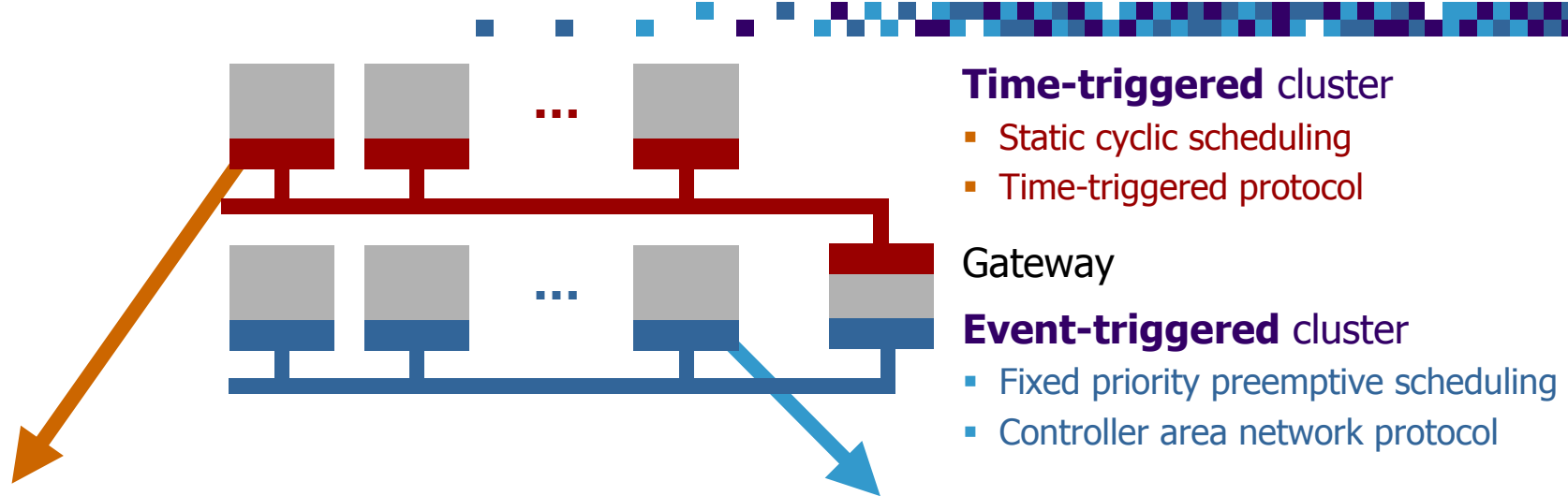


- Applications distributed over the heterogeneous networks
  - Reduce costs: use resources efficiently
  - Requirements: close to sensors/actuators

- Applications distributed over heterogeneous networks are difficult to...
  - **Analyze** (guaranteeing timing constraints) ← [DATE'03]
  - **Design** (partitioning, mapping, bus access optimization) ← **This paper!**

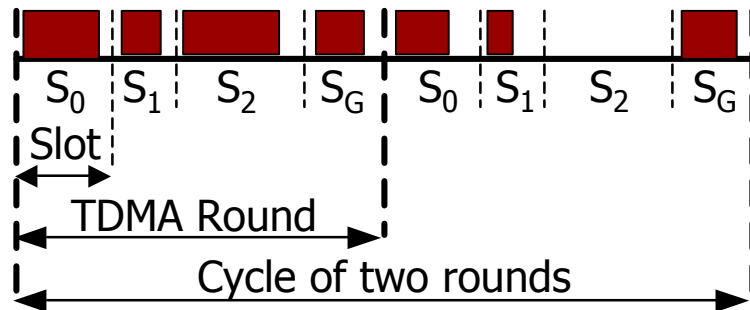
- Motivation
- ➔ System architecture and application model
- Scheduling for multi-clusters [DATE'03]
- Design optimization problems
  - Partitioning
  - Mapping
  - Bus access optimization
- Optimization strategy
- Experimental results
- Contributions and Message

# Hardware Architecture



## Time Triggered Protocol (**TTP**)

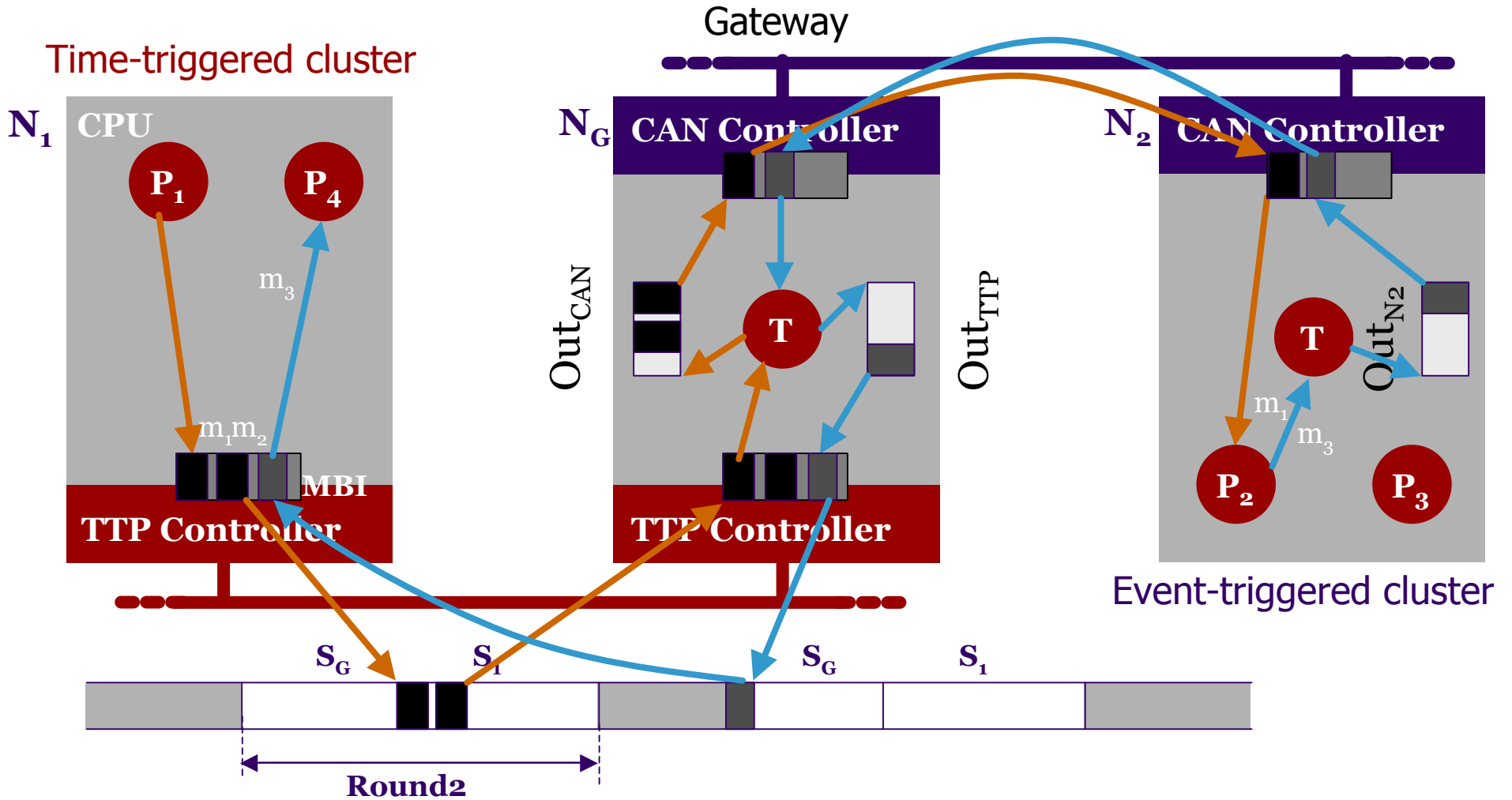
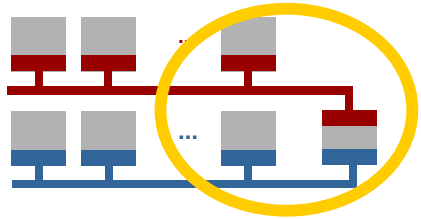
- Bus access scheme: time-division multiple-access (TDMA)
- Schedule table located in each TTP controller: message descriptor list (MEDL)



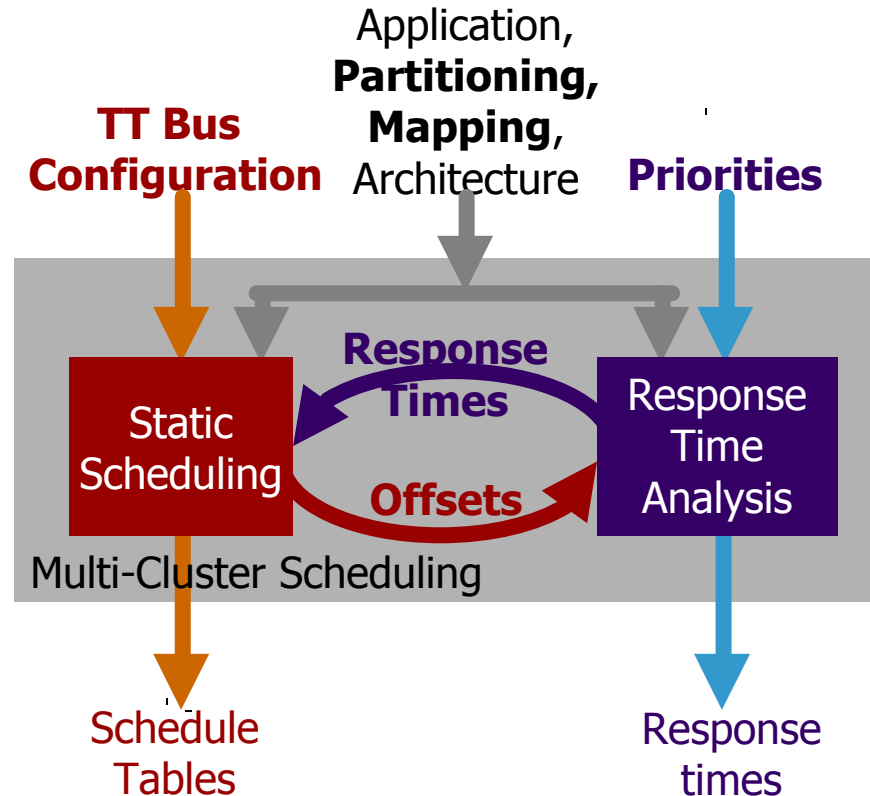
## Controller Area Network (**CAN**)

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

# Software Architecture



# Multi-Cluster Scheduling [DATE'03]



- **MultiClusterScheduling** algorithm
  - Schedulability analysis: communication delays through the gateway
  - Scheduling: cannot be addressed separately for each cluster

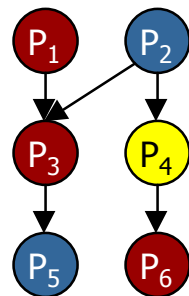
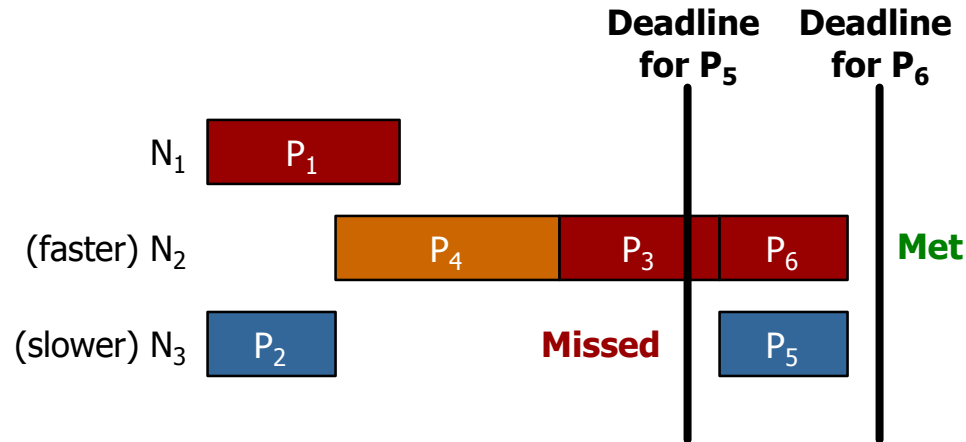
# Problem Formulation

- Input
    - System architecture
    - Application
    - **Partial** partitioning and mapping, based on the designer's experience
  - Output
    - Design implementation such that the application is schedulable
      - Partitioning for each un-partitioned process
      - Mapping for each un-mapped process
      - Priorities for ET messages
      - TDMA slot sequence and sizes for the TT bus
      - Priorities for ET processes
      - Schedule table for TT messages
- } Partitioning and mapping
- } Communication infrastructure
- } Scheduling information

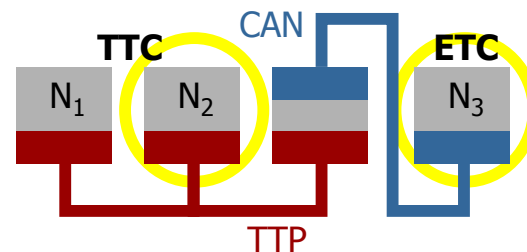


# Motivational Example #1/1

In which cluster to place process  $P_4$ ?

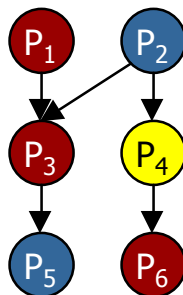
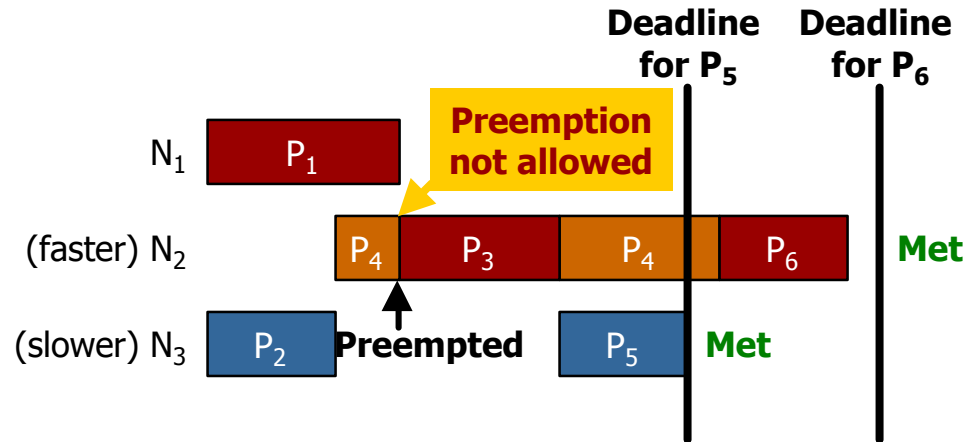


	$N_1$	$N_2$	$N_3$
$P_1$	70	X	X
$P_2$	X	X	40
$P_3$	X	50	X
$P_4$	X	70	90
$P_5$	X	X	40
$P_6$	X	40	X

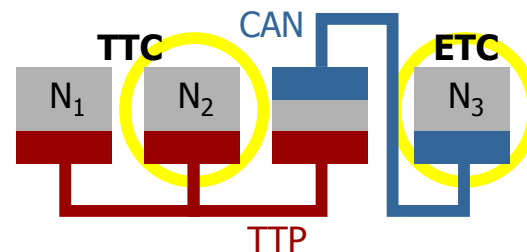


# Motivational Example #1/2

In which cluster to place process  $P_4$ ?

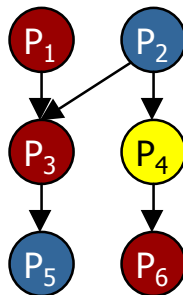
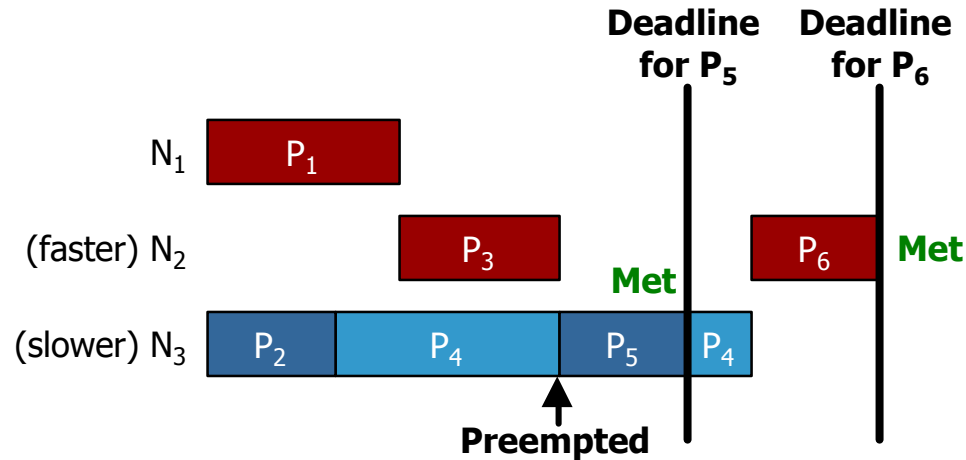


	$N_1$	$N_2$	$N_3$
$P_1$	70	X	X
$P_2$	X	X	40
$P_3$	X	50	X
$P_4$	X	70	90
$P_5$	X	X	40
$P_6$	X	40	X

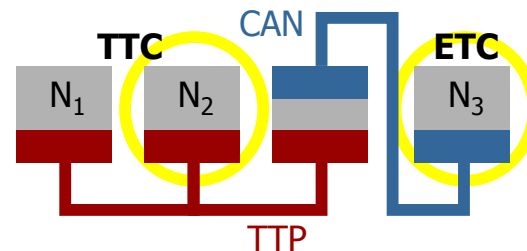


# Motivational Example #1/3

In which cluster to place process  $P_4$ ?

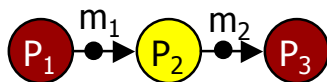
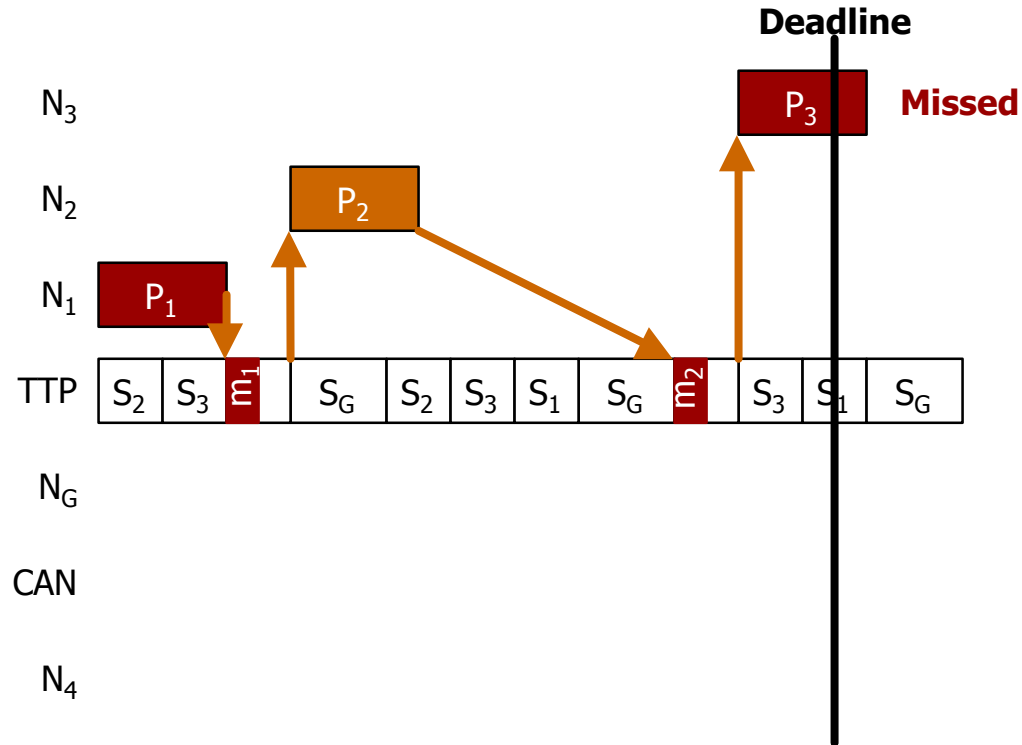


	$N_1$	$N_2$	$N_3$
$P_1$	70	X	X
$P_2$	X	X	40
$P_3$	X	50	X
$P_4$	X	70	90
$P_5$	X	X	40
$P_6$	X	40	X

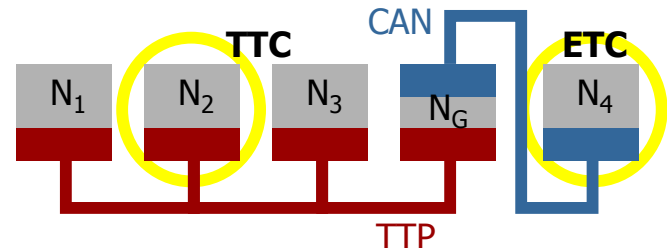


# Motivational Example #2/1

Where to map process  $P_2$ ?

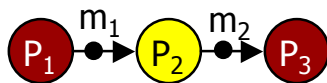
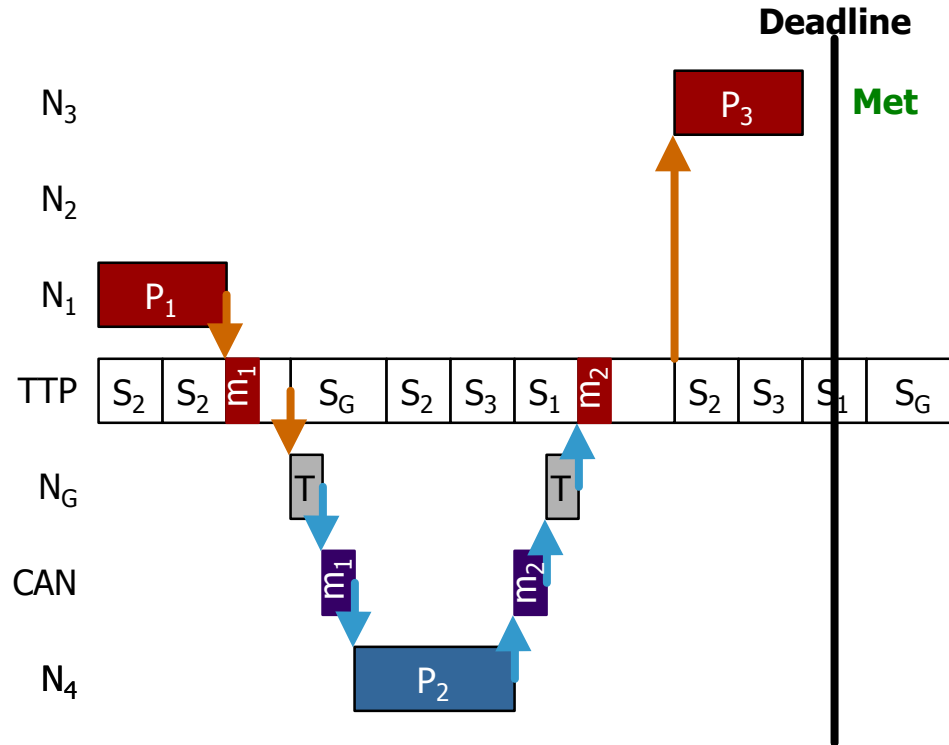


	$N_1$	$N_2$	$N_3$	$N_4$
$P_1$	20	X	X	X
$P_2$	X	40	X	50
$P_3$	X	X	20	X

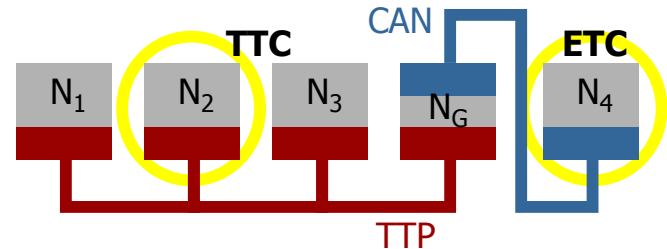


# Motivational Example #2/2

Where to map process  $P_2$ ?

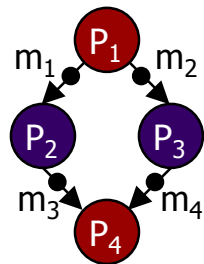
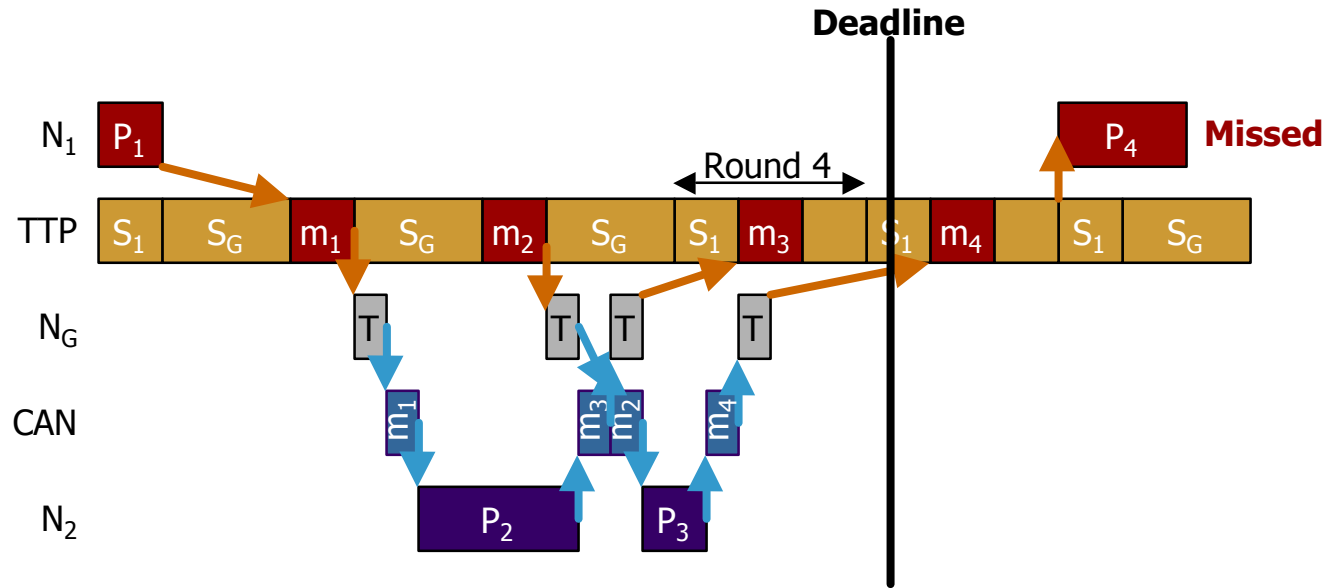


	$N_1$	$N_2$	$N_3$	$N_4$
$P_1$	20	X	X	X
$P_2$	X	40	X	50
$P_3$	X	X	20	X

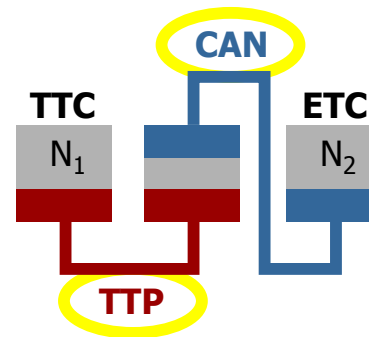


# Motivational Example #3/1

What are the priorities on ETC?  
Which slot should come first on the TTC?

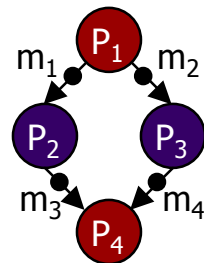
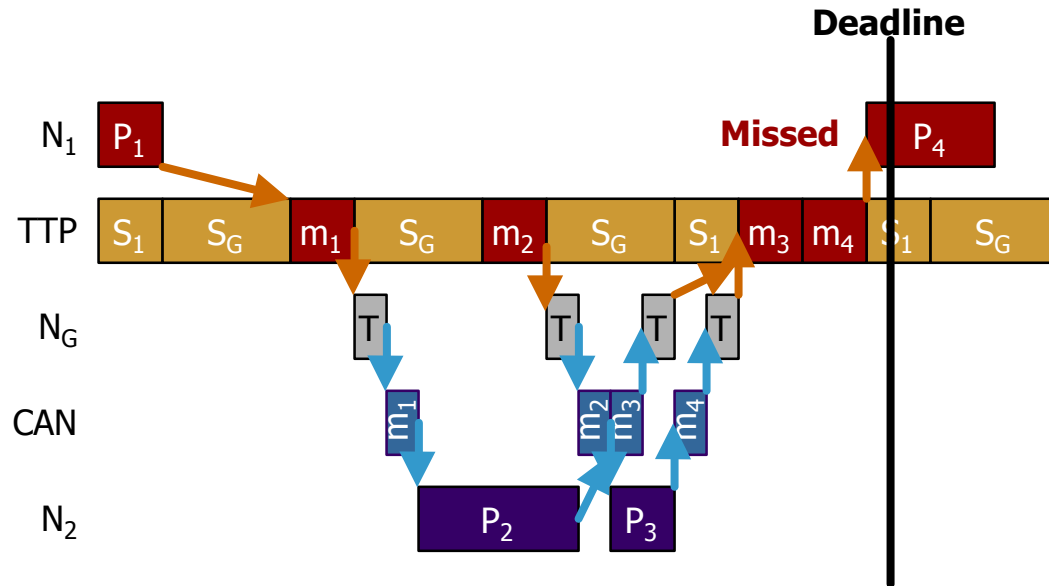


	$N_1$	$N_2$
$P_1$	20	X
$P_2$	X	40
$P_3$	X	20
$P_4$	40	X

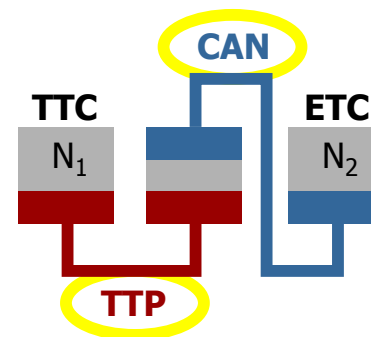


# Motivational Example #3/2

What are the priorities on ETC?  
Which slot should come first on the TTC?

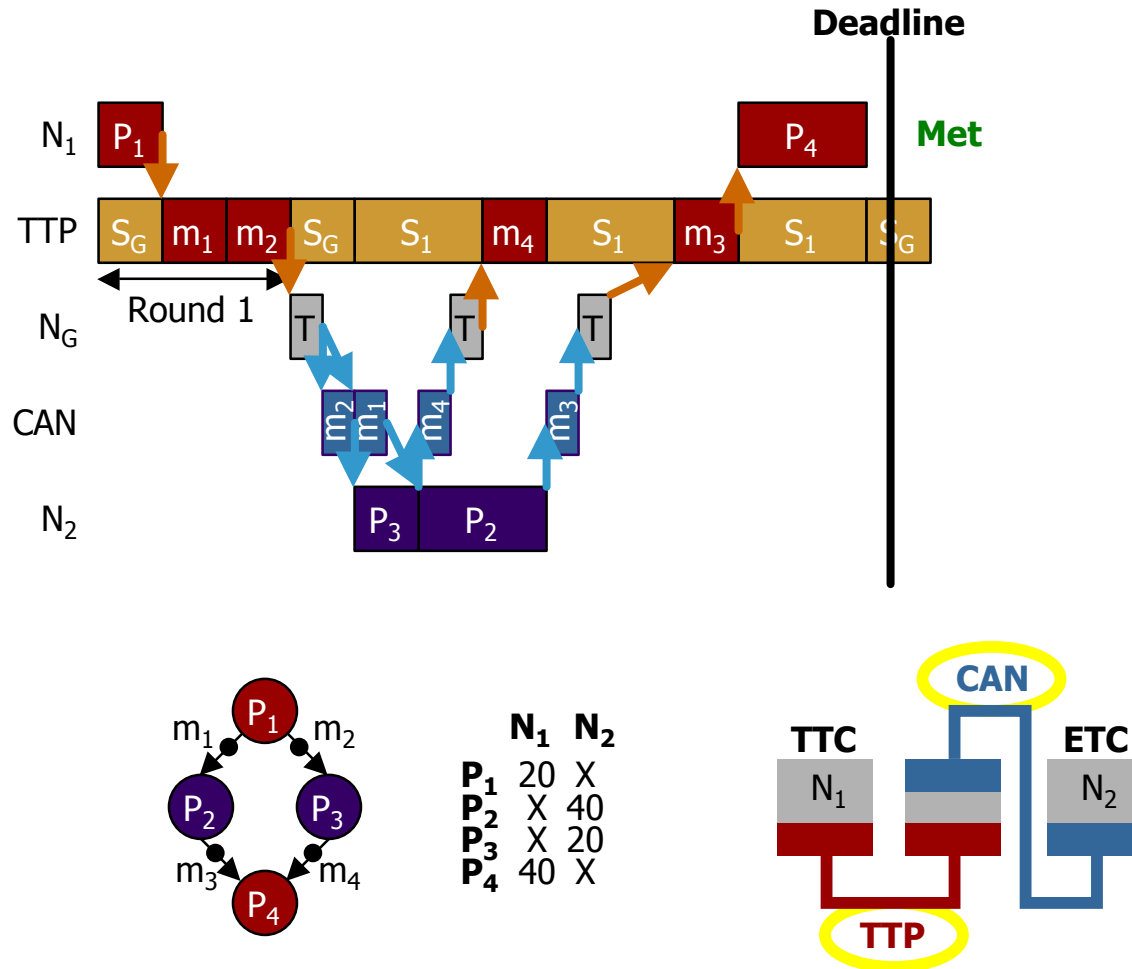


	N <sub>1</sub>	N <sub>2</sub>
P <sub>1</sub>	20	X
P <sub>2</sub>	X	40
P <sub>3</sub>	X	20
P <sub>4</sub>	40	X



# Motivational Example #3/3

What are the priorities on ETC?  
Which slot should come first on the TTC?





# Optimization Strategy

- **Multi-Cluster Configuration**

1. **Initial Partitioning and Mapping**

- Determines an initial partitioning and mapping
- List scheduling-based greedy approach
  - Priority of ready processes: **critical path**

2. **Partitioning and Mapping Heuristic**

- Iteratively improves on the initial partitioning and mapping
- Intelligent design transformations that improve schedulability
  - Based on feedback from **MultiClusterScheduling**

3. **Bus Access Optimization**

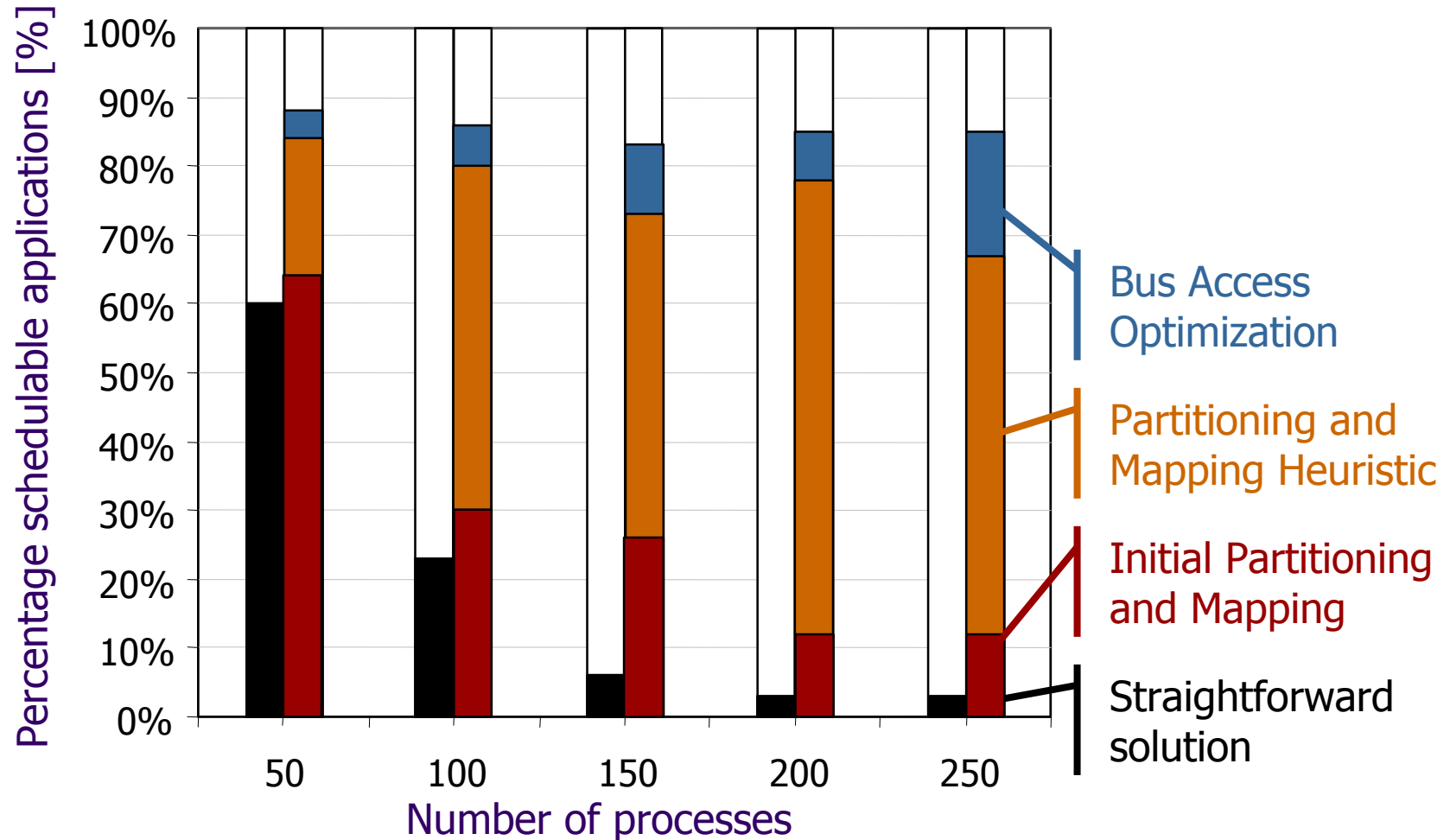
- Determines the slot sequence and lengths on the TTC, message priorities on the ETC
- Greedy optimization heuristic

- **Straightforward solution**

- Partitioning and mapping that balances the utilization of processors and buses
- Could be produced by a designer without optimization tools

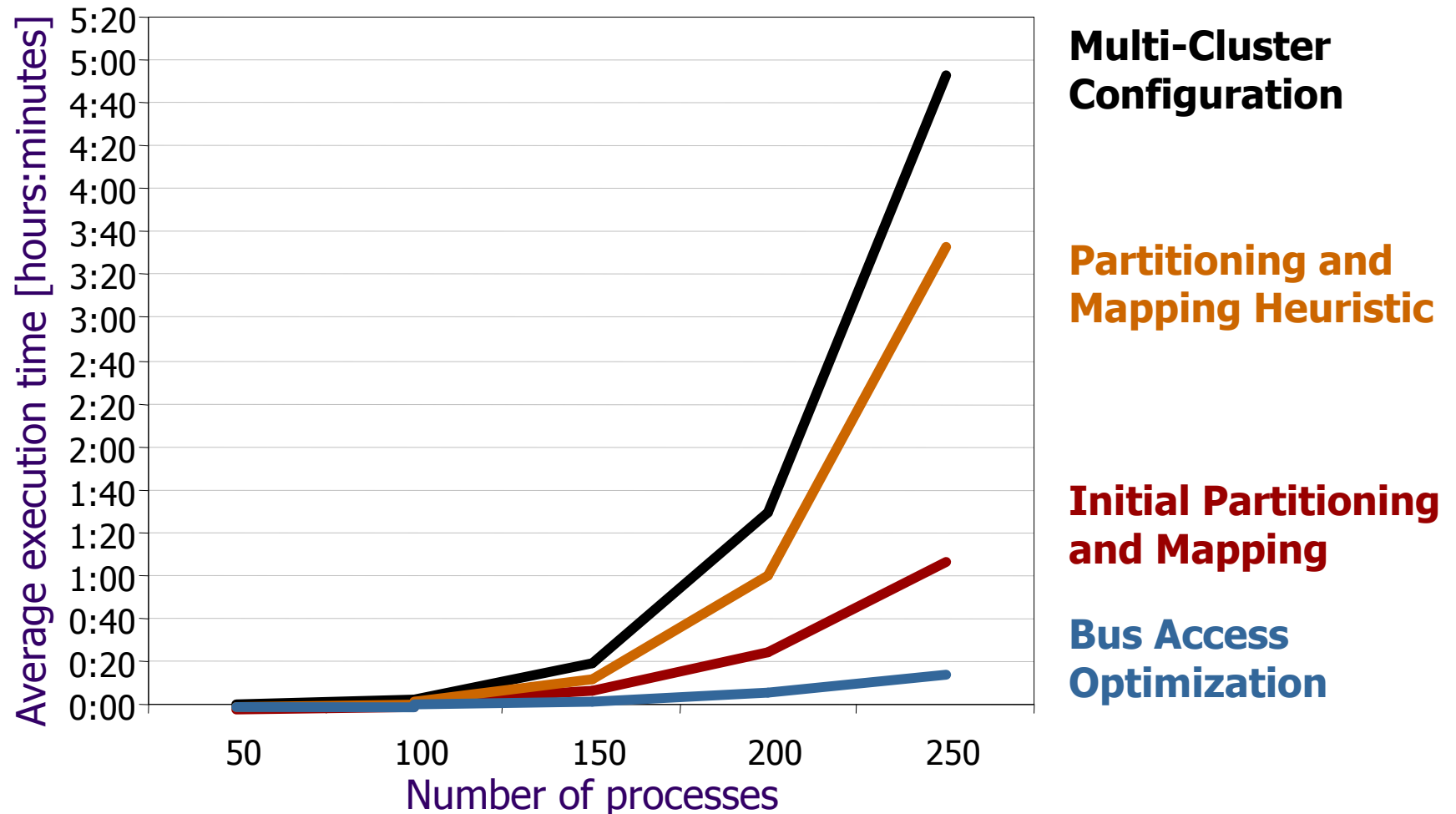
# Experimental Results

Can we increase the number of schedulable applications?



# Experimental Results, Cont.

How time-consuming is our optimization strategy?



# Contributions and Message



- Contributions
  - Addressed design problems characteristic to **multi-clusters**
    - Partitioning
    - Mapping
    - Bus Access Optimization
  - Proposed heuristics for design optimization

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