Reliable Mode Changes in Real-Time Systems with Fixed Priority or EDF Scheduling

TEC Group meeting

Computer Engineering and Networks Laboratory
ETH Zürich, Switzerland

January 13th, 2009

Nikolay Stoimenov, Simon Perathoner, Lothar Thiele

Motivation

- Many application domains require adaptive embedded real-time systems that can change their behavior over time
- Changes between different operating modes at run-time
- Timing constraints need to be guaranteed not only in all operating modes but also during the transition between modes
- Existing approaches are restricted to fixed priority scheduling policies. Most of them are also limited to simple periodic event stream models

Contributions

- Method for timing analysis of single-processor multi-mode systems with EDF or FP scheduling that supports any task activation pattern (system analysis)
- Transformation of non-schedulable mode changes into schedulable ones (system design)
- Case study

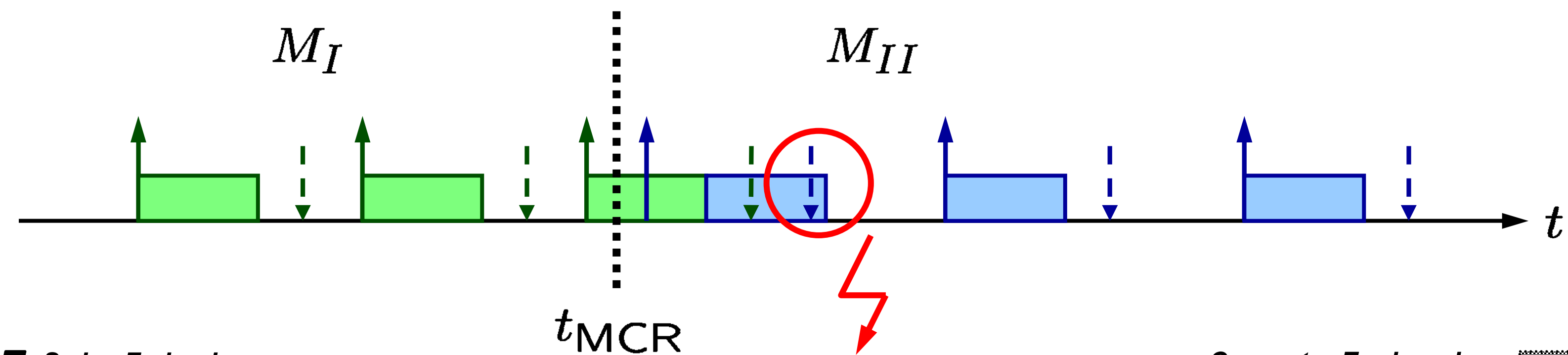
Mode Change

Involves changes in:

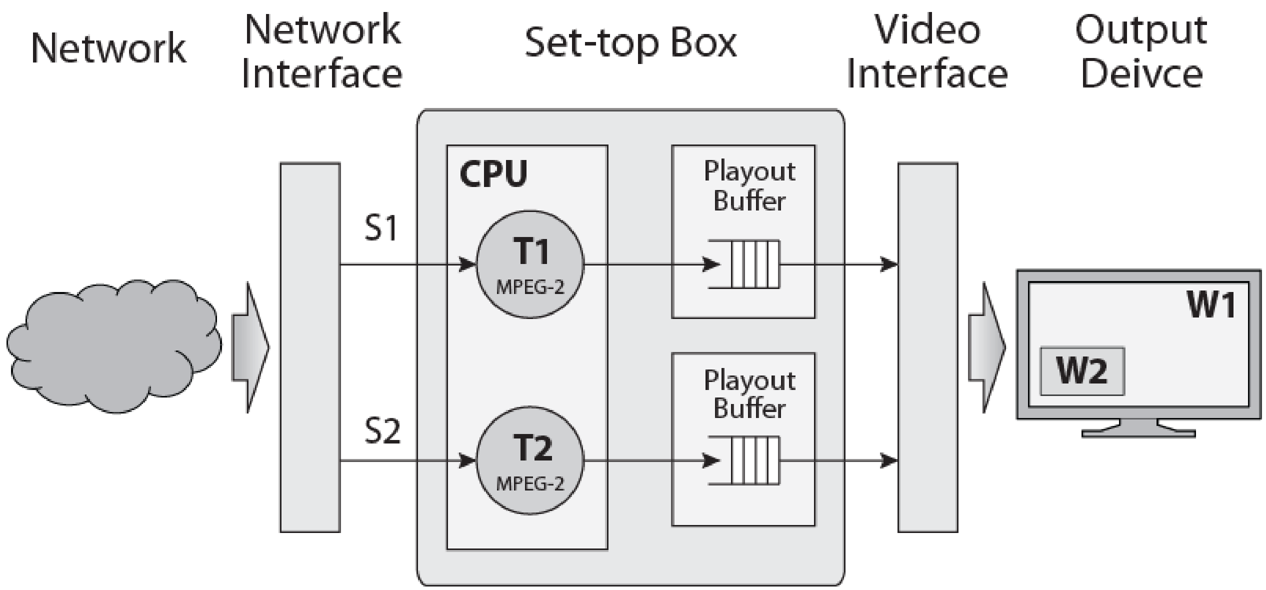
- Set of executed tasks and/or
- Parameters of tasks (BCET, WCET, deadline) and/or
- Activation pattern of tasks

Assumption: Schedulability for all modes in mutual exclusion

In general, a sudden mode change can have severe impacts on the timing behavior of a system:

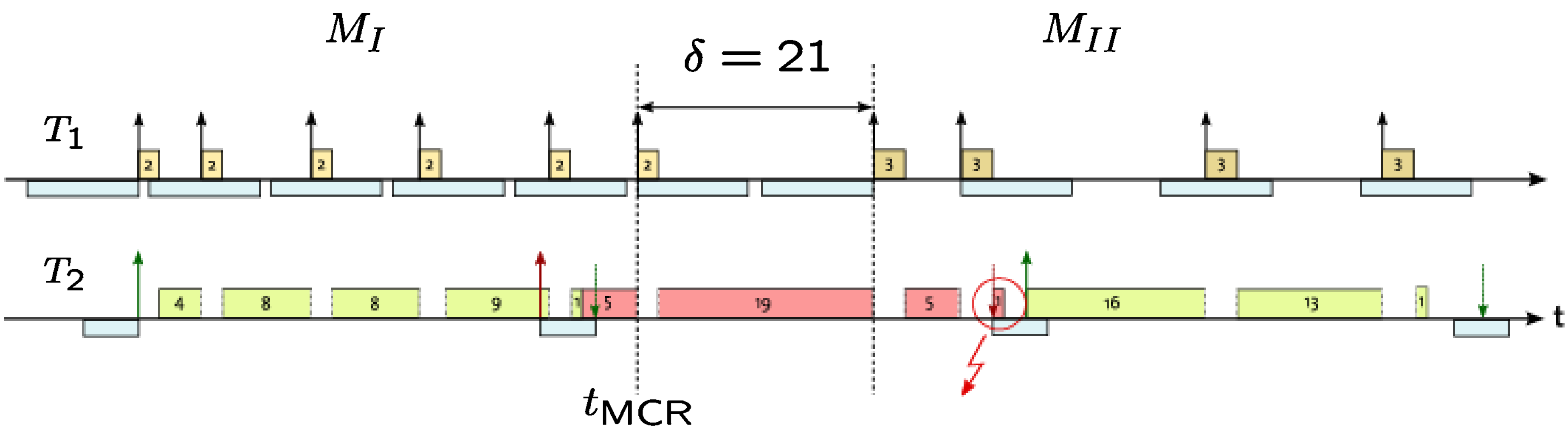


Example



- Video displayed in W1 changes from video stream S1 (mode M_I) to video stream $S1_{new}$ with lower workload (mode M_{II})
- The video displayed in W2 must not be distorted by the switch in W1

Example

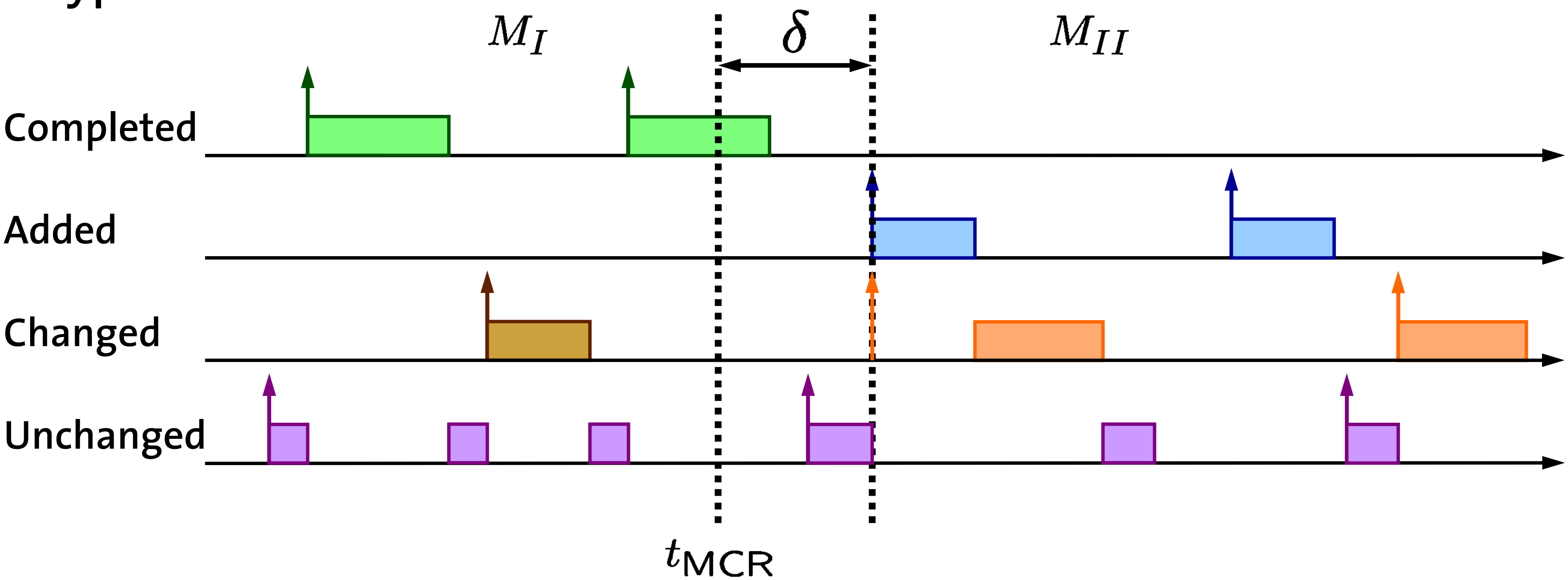


	M_I	M_{II}	M_I, M_{II}
Period	$P_{S1} = 11$	$P_{S1_{new}} = 18$	$P_{S2} = 41$
Jitter	$J_{S1} = 10$	$J_{S1_{new}} = 10$	$J_{S2} = 5$
Exec. time	$C_{S1} = 2$	$C_{S1_{new}} = 3$	$C_{S1} = 30$
Deadline	$D_{S1} = 11$	$D_{S1_{new}} = 18$	$D_{S1} = 41$

Model

Change from mode M_I to mode M_{II}

Types of tasks:

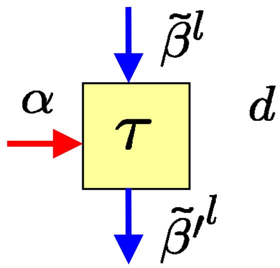


Assumption: A new MCR cannot occur during the transition between two modes

Mode change for FP scheduling

Assumption: $\tilde{\beta}^l$ given that is valid for <u>all</u> intervals $(M_I, M_{II}$ and transition$)$

- If τ is an unchanged task
  => use usual RTC formulae to check schedulability and determine remaining service $\tilde{\beta}'^l$

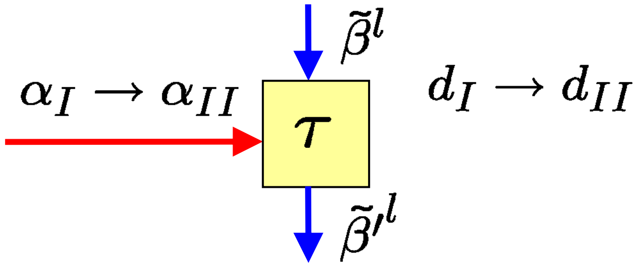


- If τ is a changed task

  => Schedulability check:

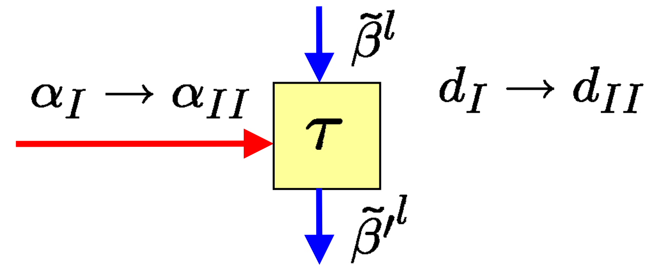
$\mathrm{Del}(\alpha_I^u, \tilde{\beta}^l) \leq d_I$

$\mathrm{Del}(\alpha_{II}^u + \mathrm{Buf}(\alpha_I^u, \beta_I^l) - \tilde{\beta}^l(\delta), \tilde{\beta}^l) \leq d_{II}$

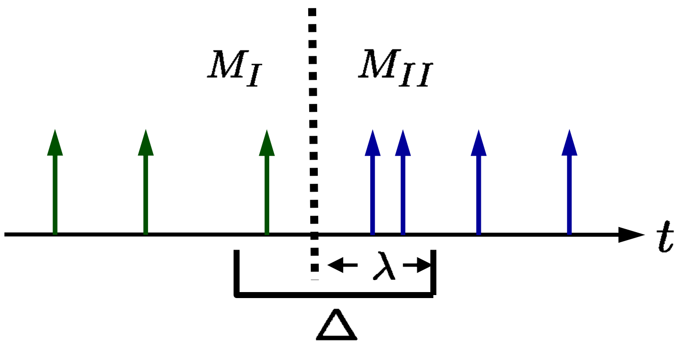


Mode change for FP scheduling

=> Remaining service:
- determine $\tilde{\alpha}^u$ that is valid for all intervals
- compute remaining service as usual



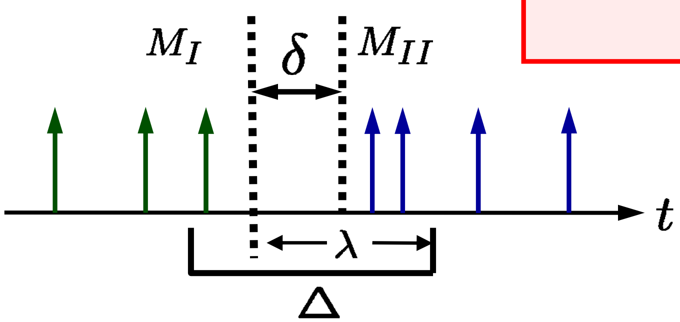
Case 1: $\delta = 0$



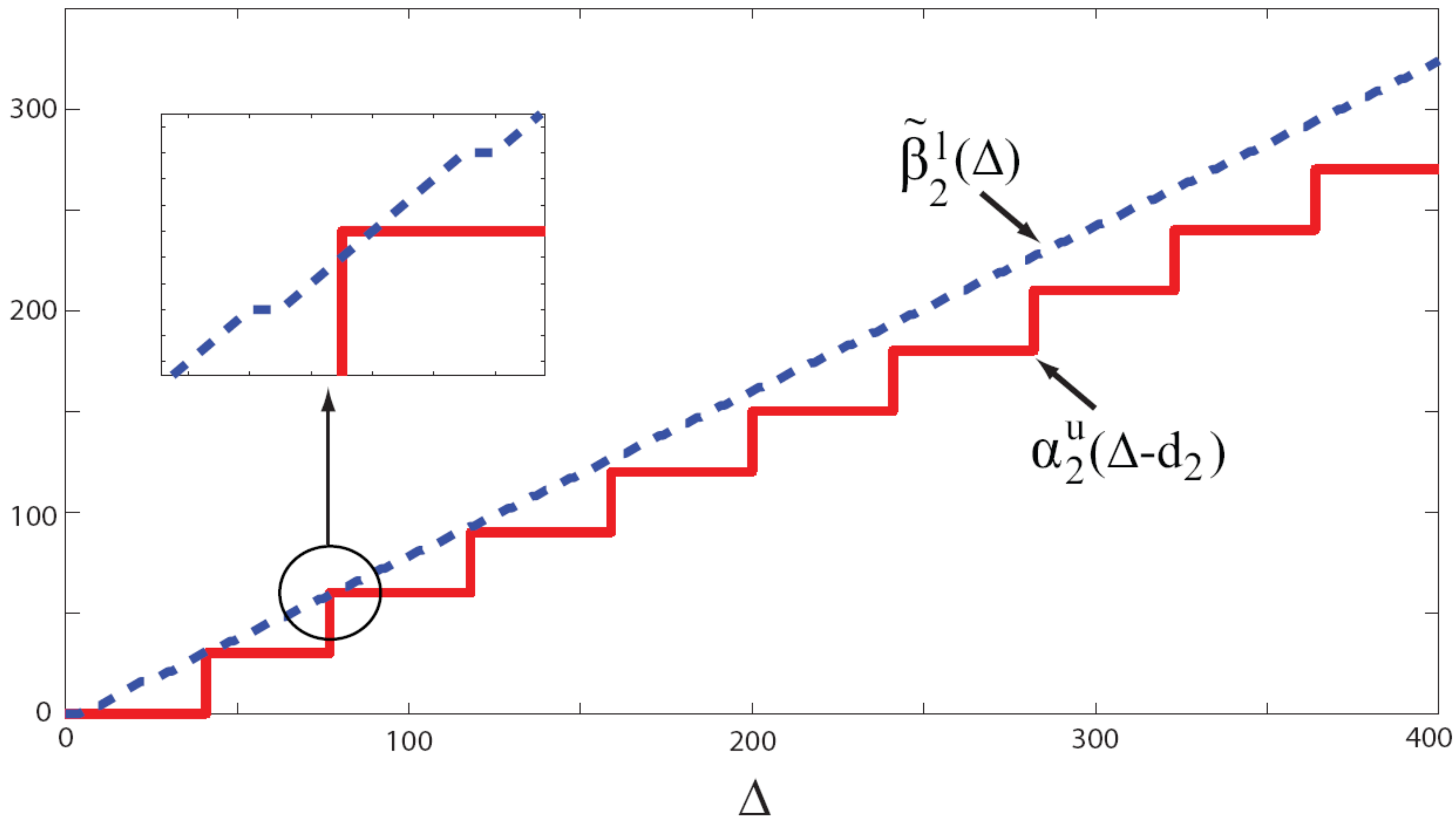
$$\tilde{\alpha}^u(\Delta) = \sup_{0 \leq \lambda \leq \Delta} \{\alpha_I^u(\Delta - \lambda) + \alpha_{II}^u(\lambda)\}$$

Case 2: $\delta > 0$

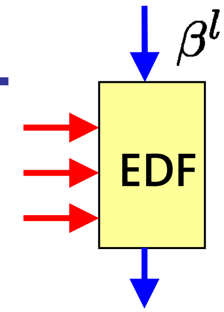
$$\tilde{\alpha}^u(\Delta) = \max\left\{\alpha_{II}^u(\Delta), \sup_{0 \leq \lambda \leq \Delta} \{\alpha_I^u(\Delta - \lambda) + \alpha_{II}^u(\lambda - \delta)\}\right\}$$



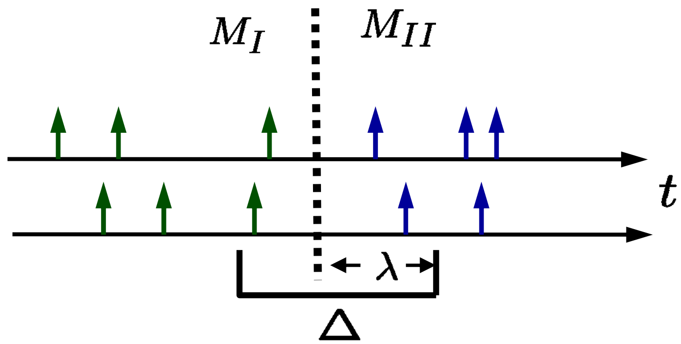
Insufficient remaining service for T_2



Mode change for EDF scheduling



$$\Omega_U(\Delta) + \Omega_C(\Delta) \le \beta^l(\Delta) \quad \forall \Delta \in \mathbb{R}^{\ge 0}$$



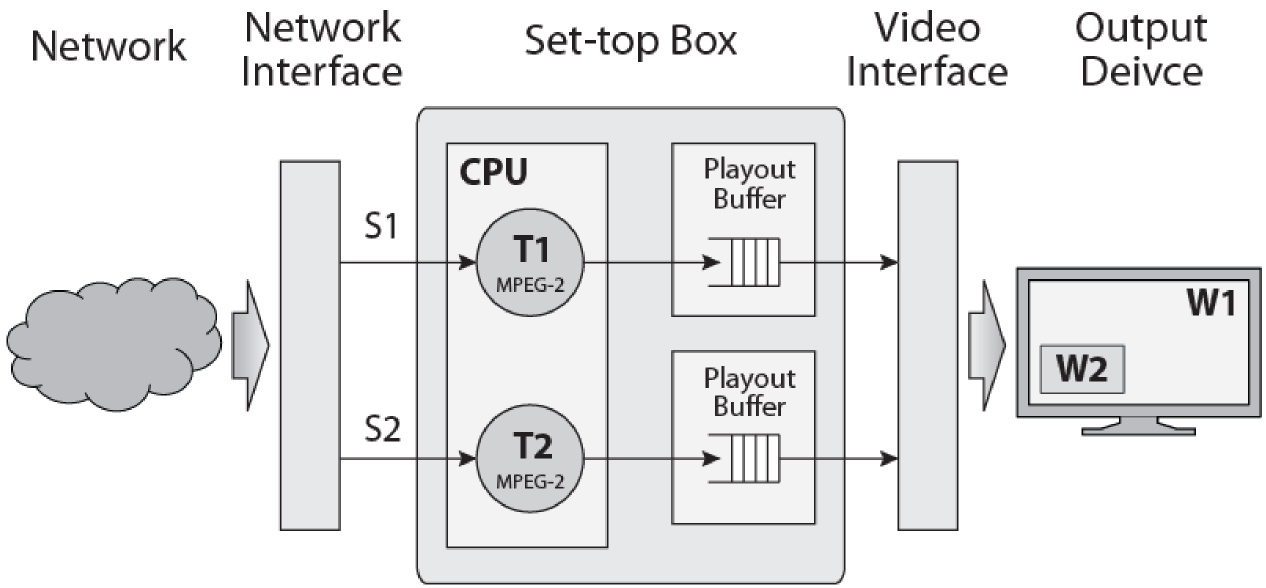
Case 1: $\delta = 0$

$$\Omega_C = \sup_{0 \le \lambda \le \Delta} \left\{ \sum_{\tau \in \Gamma_{\mathrm{I}}} \alpha_\tau^u(\Delta - \max\{d_\tau, \lambda\}) + \sum_{\tau \in \Gamma_{\mathrm{II}}} \alpha_\tau^u(\lambda - d_\tau) \right\}$$

Case 2: $\delta > 0$

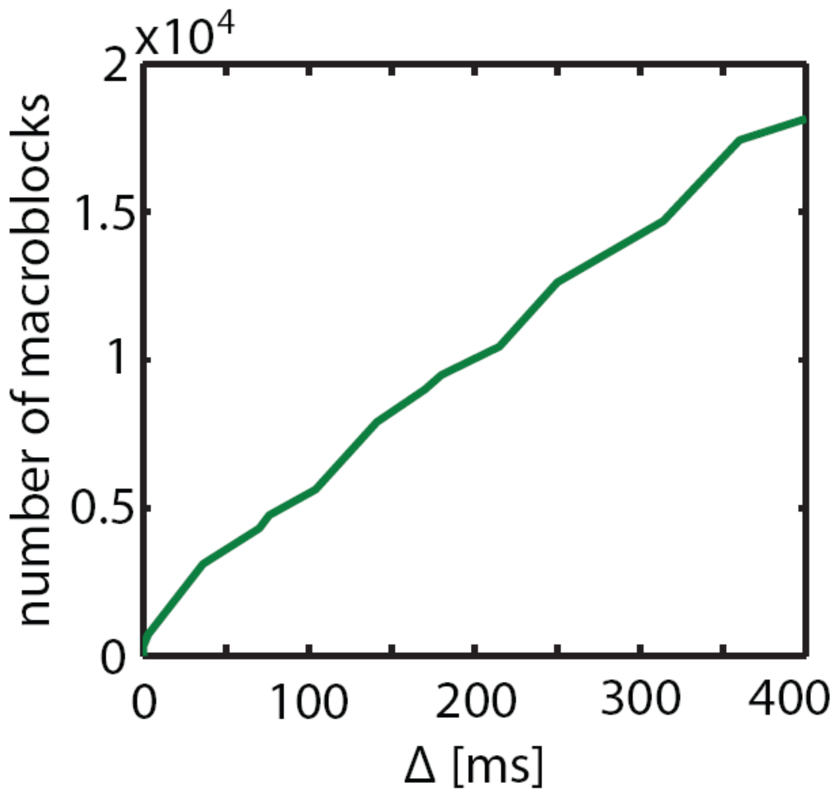
$$\Omega_C = \max \left\{ \sum_{\tau \in \Gamma_{\mathrm{II}}} \alpha_\tau^u(\Delta - d_\tau), \sup_{0 \le \lambda \le \Delta} \left\{ \sum_{\tau \in \Gamma_{\mathrm{I}}} \alpha_\tau^u(\Delta - \max\{d_\tau, \lambda\}) + \sum_{\tau \in \Gamma_{\mathrm{II}}} \alpha_\tau^u(\lambda - d_\tau - \delta) \right\} \right\}$$

Case study

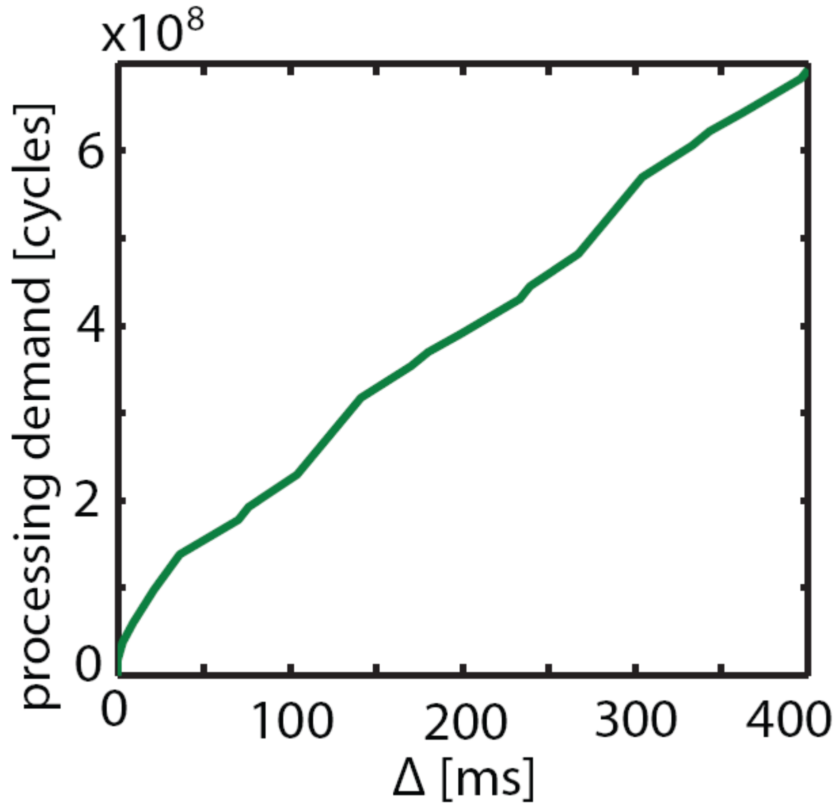


- Analysis of mode change for realistic MPEG2 video streams
- Arrival patterns and workload demands of streams characterized by simulation

Characterization of video stream (high motion)

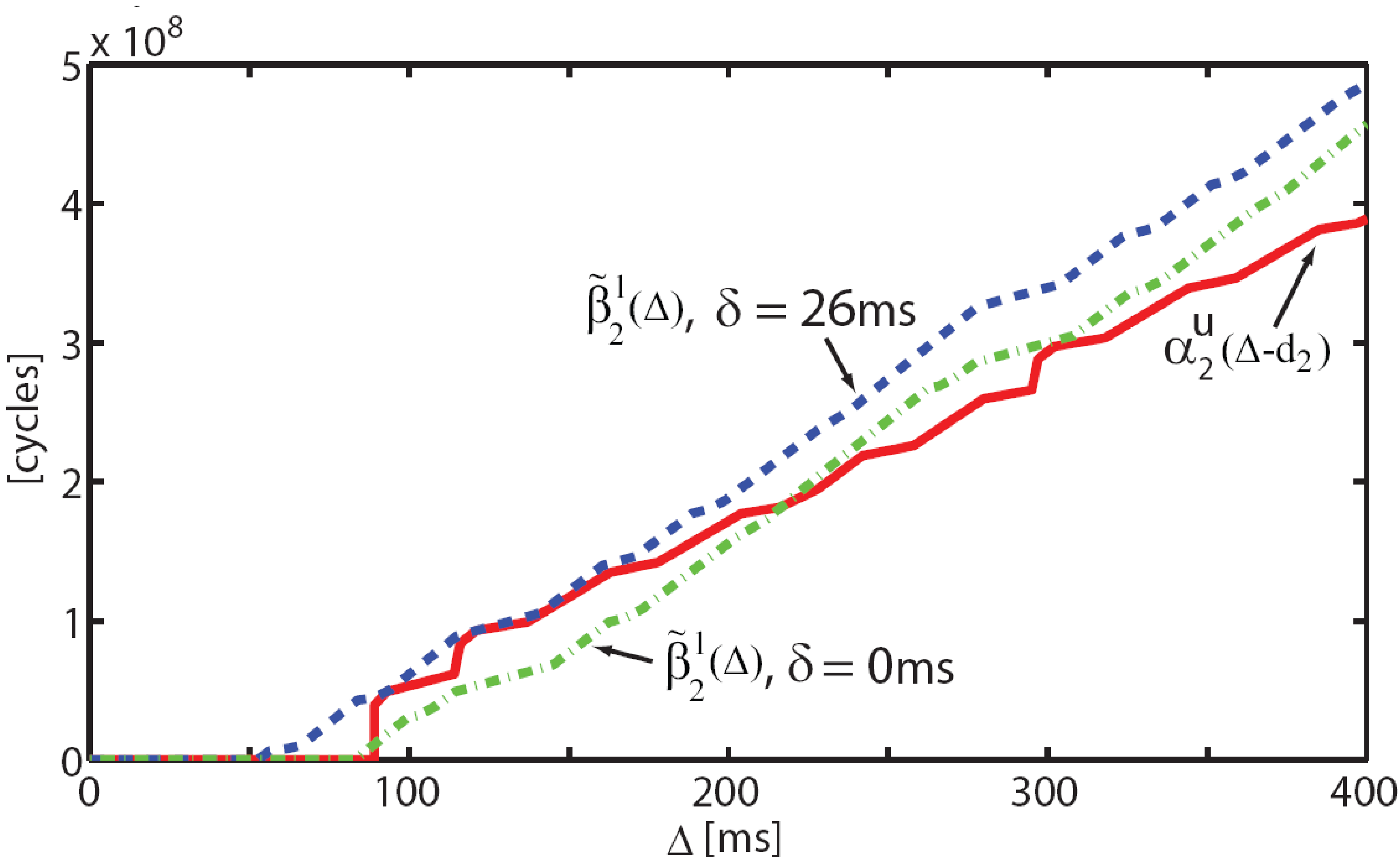


Arrival pattern

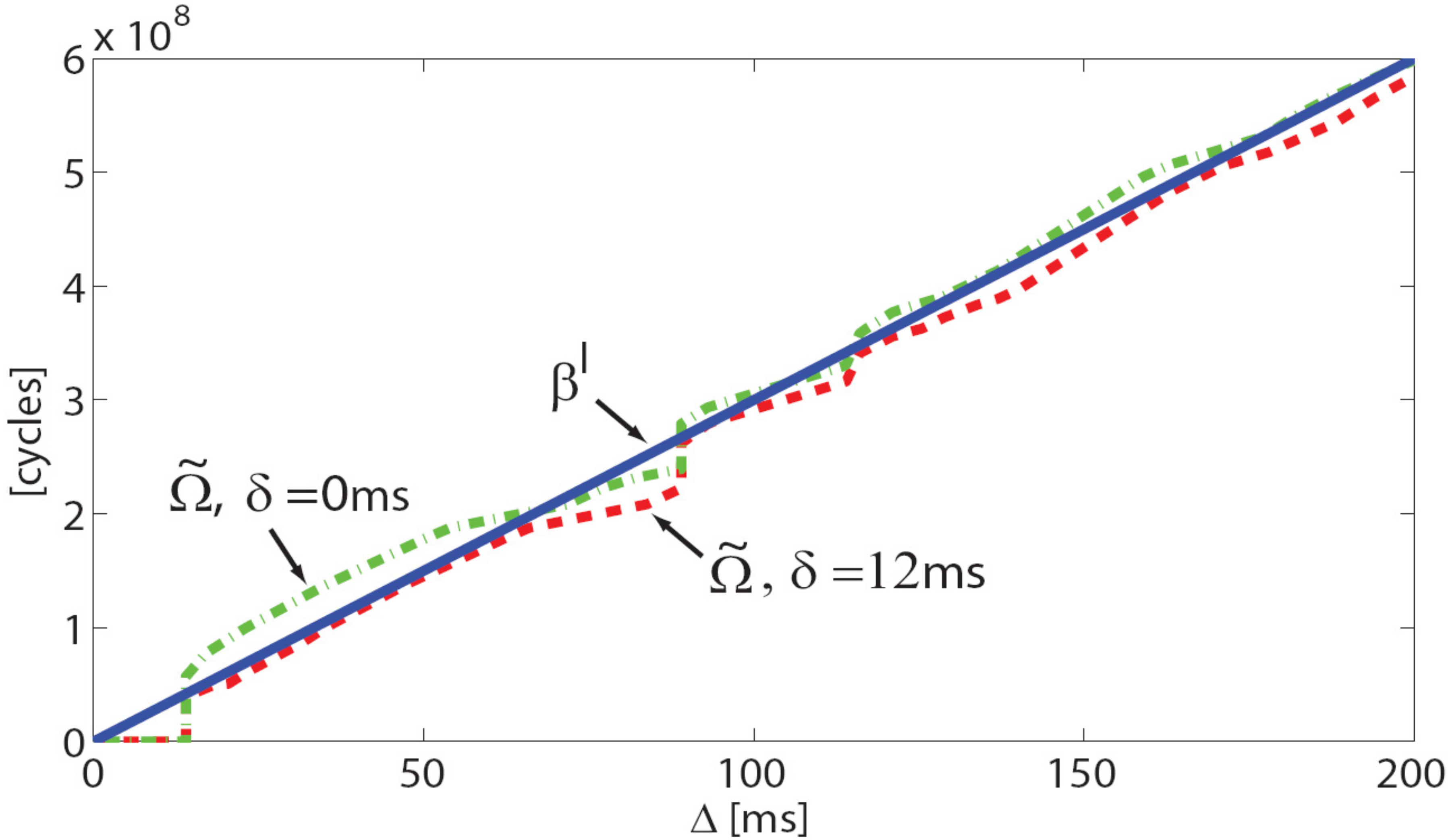


Workload demand

Case study – Results (FP scheduling)



Case study – Results (EDF scheduling)



Conclusions

- New approach for design and analysis of adaptive multi-mode real-time systems

- Supports FP and EDF scheduling as well as any hierarchical combination of the two

- Simple binary search approach to find an offset sufficiently large to guarantee schedulability