Providing Weakly-Hard Guarantees using TWCA

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Beyond the Deadline

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Outline

Basics of TWCA

Improvements using combinations

How to obtain input data for TWCA through tracing

Extensions of TWCA

Conclusion and perspectives

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What is TWCA?

TWCA:

- means **Typical Worst-Case Analysis**
- is a method for computing **weakly-hard** bounds on response times and deadline misses.
- applies to systems with **sporadic overload**
- does not provides guarantees for sporadic tasks

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Advantages

- This approach is computationally efficient
- m-out-of-k constraints are easy to understand
- We make no assumptions w.r.t. dependencies

TWCA in a nutshell

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- Response-time view:
  1. a hard bound on its response times: *WCRT*
  2. a so-called typical bound: *TWCRT*
  3. a function *err* s.t. out of every k consecutive executions, at most $err(k)$ response times may be larger than *TWCRT*

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  3. a function *err* s.t. out of every k consecutive executions, at most $err(k)$ response times may be larger than *TWCRT*
- Deadline miss view: a **deadline miss model**, i.e., a function *dmm* such that out of every k consecutive executions, at most $dmm(k)$ jobs may miss their deadline.

Basic principle: preliminary definitions

System model

- Uniprocessor with Fixed-Priority Preemptive (FPP) scheduling
- Tasks: C_i, π_i and an **activation model**

Activation model: we use arrival curves

- $\delta_i^-(k)$ lower bounds the minimum size of an interval containing k activations of task i
- δ_i^- can be converted into a time-based functions η_i^+
- non-sporadic tasks also have an upper bound δ_i^+

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For TWCA, tasks have 3 curves:

- a worst-case bound δ_i^-
- a typical bound $\delta_{i,typ}^-$
- an overload bound $\delta_{i,over}^-$

Basic principle: preliminary definitions

Level-i **quiet time**: instant t such that all tasks of priority higher than or equal to i released strictly before t have completed at t.

Level-i **busy window**: interval $[t_1, t_2[$ such that:

- a task with a priority higher than or equal to i is activated at t_1;
- t_1 and t_2 are level-i quiet times;
- there is no other level-i quiet time between t_1 and t_2.

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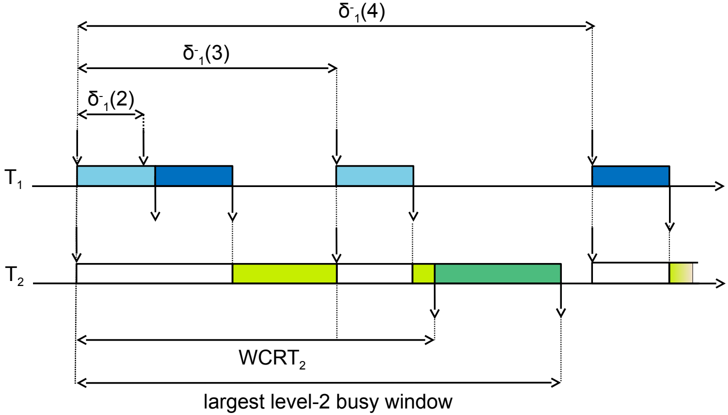
- there is no other level-i quiet time between t_1 and t_2.

The longest level-i busy window is bounded by $BW_i = B_i^+(K_i)$ where

$$B_i^+(q) = C_i \times q + \sum_{j \in hpe(i)} (\eta_j^+(B_i^+(q)) \times C_j)$$

$$K_i = min\{q \geq 1 \mid B_i^+(q) \leq \delta_i^-(q+1)\}$$

Basic principle: preliminary definitions



Basic principle: computation of *WCRT* and *TWCRT*

- The worst-case response time of task i is bounded by

$$WCRT_i = \max_{1 \leq q \leq K_i} \{B_i^+(q) - \delta_i^-(q)\}$$

- $TWCRT_i$ is obtained following the same approach but using the $\delta^-_{i,typ}$ curves.

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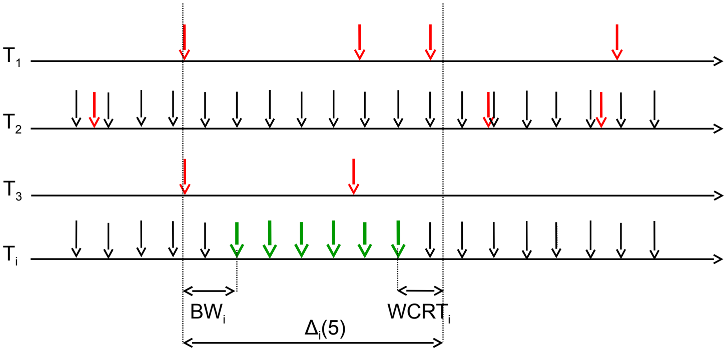
We now focus on the computation of err_i: the number of jobs in a sequence of k consecutive executions that may have a response time larger than *TWCRT*

Basic principle: computation of err_i

1. compute $\Delta_i(k)$, the time interval during which a higher priority overload activation may impact one of the k activations
2. bound the number of overload activations of each higher priority task in $\Delta_i(k)$
3. bound their impact



Basic principle: computation of err_i

1. $\Delta_i(k) = BW_i + \delta_i^-(k) + WCRT_i$
2. number of overload activations of each higher priority task in $\Delta_i(k)$ is bounded by $\eta_i^+(\Delta_i(k))$
3. impact of each overload activation: at most K_i

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$$err_i(k) = K_i \times \sum_{j \in hpe(i)} \eta_{j,over}^+ \Delta_i(k)$$

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$$err_i(k) = K_i \times \sum_{j \in hpe(i)} \eta^+_{j,over} \Delta_i(k)$$

The impact of each activation is largely overestimated!
Example: not all activations in the worst-case busy window miss their deadlines ($N_i \leq K_i$).

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NB: Focus on deadline misses rather than response times

Schedulable combination $\bar{c}$: a set of tasks that may experience overload in the same busy window without any deadline miss

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Schedulable combination $\bar{c}$: a set of tasks that may experience overload in the same busy window without any deadline miss

Improved deadline miss model:

$$dmm_i(k) = \min_{\bar{c} \in \mathcal{S}} \{dmm_i^{\bar{c}}(k)\}$$

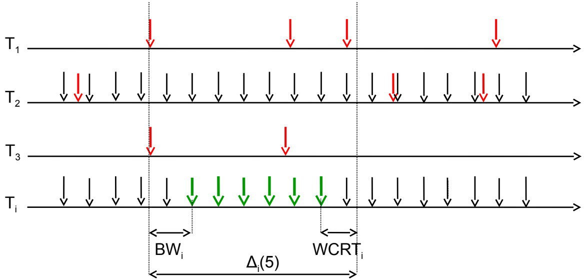
where

$$dmm_i^{\bar{c}}(k) = N_i \times \sum_{\substack{j \in hpe(i) \\ j \notin \bar{c}}} \eta^{+}_{j,over}(\Delta_i(k))\}$$

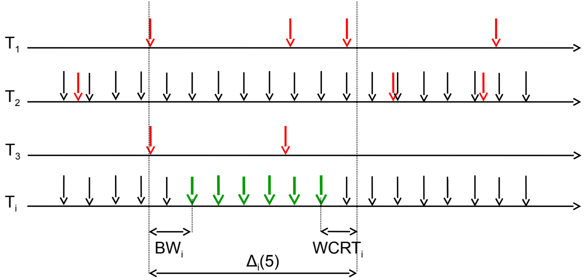
and $\mathcal{S}$ denotes the set of schedulable combinations ($\mathcal{U}$ is the set of schedulable combinations).

Improvements using combinations

Further improvement: knapsack problem formulation where the objective is to pack as many unschedulable combinations as possible into $\Delta_i(k)$



Improvements using combinations



Improved deadline miss model:

$$dmm_i(k) = \max\{N_i \times \sum_{\bar{c} \in \mathcal{U}} x_{\bar{c}} \mid \forall j \in hpe(i), \sum_{\substack{\bar{c} \in \mathcal{U} \\ \text{s.t. } j \in \bar{c}}} x_{\bar{c}} \leq \eta^{+}_{j,over}(\Delta_i(k))\}$$

where $x_{\bar{c}}$ is the number of busy windows which correspond to $\bar{c}$

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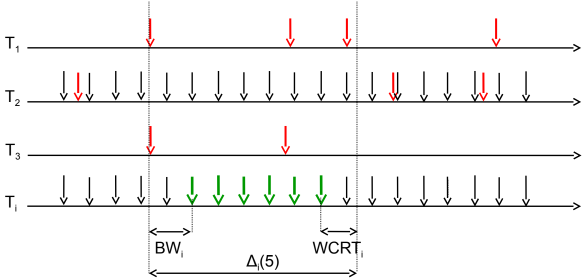

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$\longrightarrow$ ILP problem

Outline

Using traces to get the input models

Trace analysis and overload extraction

- based on assumptions similar to derived worst-case analysis
- automated overload extraction possible for some activation models: e.g. mixed messages in a CAN bus

Outline

Extensions of TWCA

- extension to FPNP (other policies in progress)
- TWCA at the runnable level
- TWCA for task chains
- TWCA for budgeting (TAS case study)
- TWCA in presence of limited buffers

Outline

Conclusion and perspectives

Summary: TWCA so far

- uniprocessor
- static priority (non) preemptive scheduling
- dependent tasks with arbitrary activation patterns

Case studies

- Anonymized trace from an OEM
- CAN bus analysis for Daimler
- TAS case study

Work in progress

- extension to multiprocessor systems
- identification of the main sources of pessimism in the analysis