Incremental Schedulability Analysis of Hierarchical Real-Time Components

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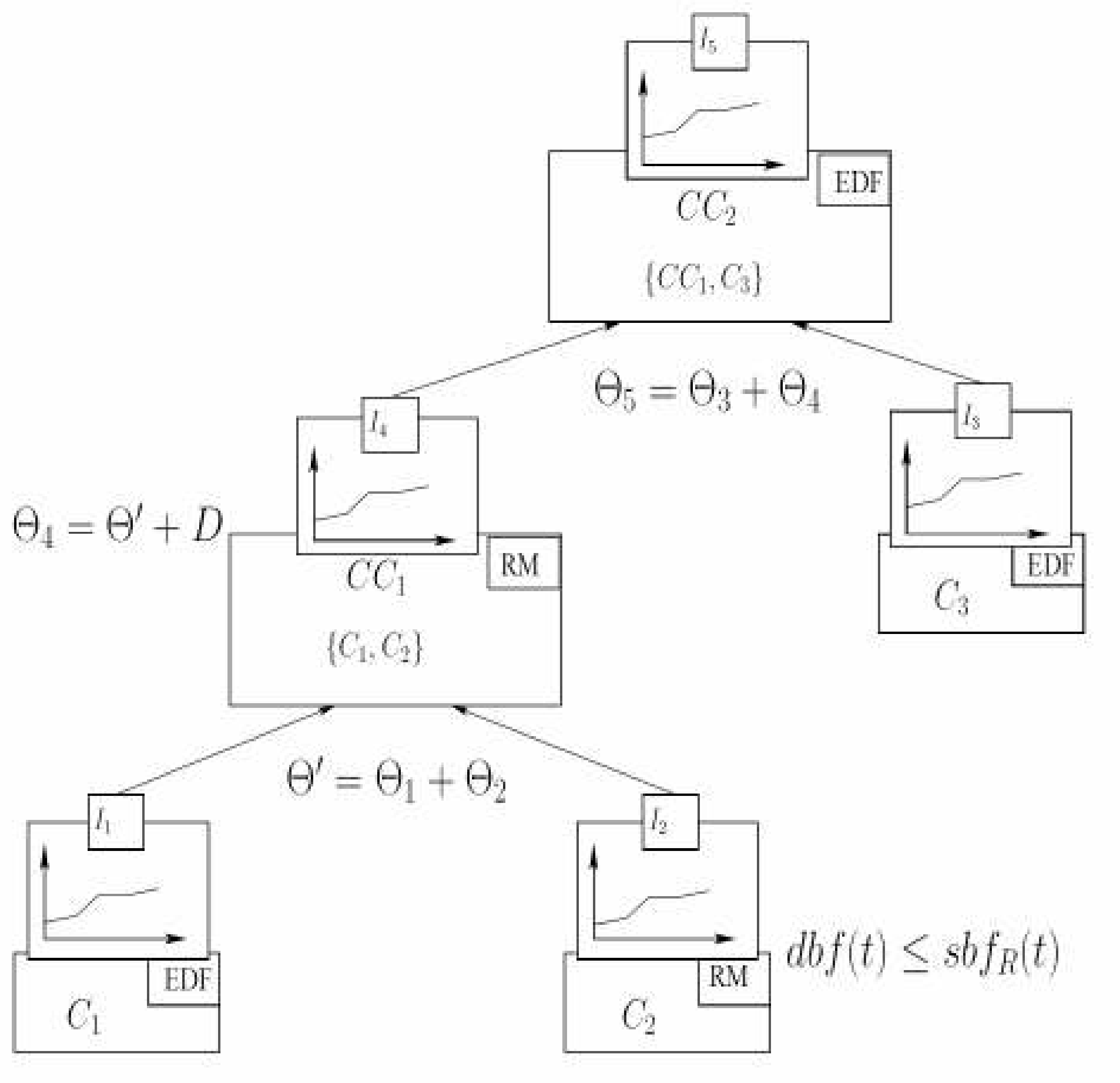
Goals

- Compositional schedulability analysis

  i.e. achieve system level schedulability analysis by combining component interfaces that abstract component-level timing requirements

- Minimize resource demand of components

Hierarchical Real-Time System with Interfaces



Problem Statement (1)

Given a hierarchical real-time system,

1. Generate interfaces for each real-time component such that
   - schedulability of the interface guarantees schedulability of the component
   - interface takes into consideration component context switch overhead

Problem Statement (2)

2. Compose interfaces such that
   – schedulability of the composed interface guarantees schedulability of the individual interfaces
   – composition is associative

3. Minimize the abstracted resource demand for the hierarchical system

Components

- Simple Component

$$C = \left\langle \left\{ T_1, \ldots, T_n \right\}, RM / EDF \right\rangle \text{ where } T_i = \left(p_i, e_i \right) \text{is}$$

a real-time task with period p_i and WCET e_i.

Deadline of T_i is assumed to be same as p_i.

- Complex Component

$$C = \left\langle \left\{ C_1, \ldots, C_n \right\}, RM / EDF \right\rangle \text{ where } C_i \text{ is either}$$

a simple component or another complex component.

Demand Bound Function

- Gives maximum resource demand of a component within a given time interval t

Example for EDF:

$$dbf(t) = \sum_{i=1}^{n} \left\lfloor \frac{t}{p_i} \right\rfloor e_i$$

$$T_i = (\text{period } p_i, \text{wcet } e_i)$$

Periodic Resource Model

- Periodic resource model

  $R = (\Pi, \Theta)$ guarantees a minimum resource supply of Θ units in an time interval consisting of Π units.

- Supply bound function

  $sbf_R(t)$ gives the minimum resource supply that the resource model R is guaranteed to supply within a given time period interval t.

  $lsbf_R(t)$ gives the linear lower bound of $sbf_R(t)$

Schedulability

- Component C is schedulable under EDF using resource model R if (only sufficient)

$$\forall t \in (0, LCM], dbf(t) \leq lsbf_R(t)$$

- For a period Π a minimum resource capacity Θ can be computed so that C is schedulable

Interface

- Consists of set of periodic resource models R for different values of period Π

$$I = \left\{ (\Pi, \Theta) \mid 1 \le \Pi \le P^* \right\}$$

- This allows the selection of a periodic resource model that minimizes the collective real-time requirements of an component (minimize utilization Θ/Π)

Compact Interface Representation

- Compact interface representation of a component C gives for a range of period Π a value for time instant and for the demand bound at that time instant.

$$RI = \left\{ RI_j = \left\langle \Pi, t_j, dbf(t_j) \right\rangle \mid j_{\min} \le \Pi \le j_{\max}, 1 \le j \le k \right\}$$

$$\text{where, } 1_{\min} = 1, k_{\max} = P^* \text{ and } \forall j, j_{\min} = (j-1)_{\max} + 1$$

- Algorithm computes RI for component C

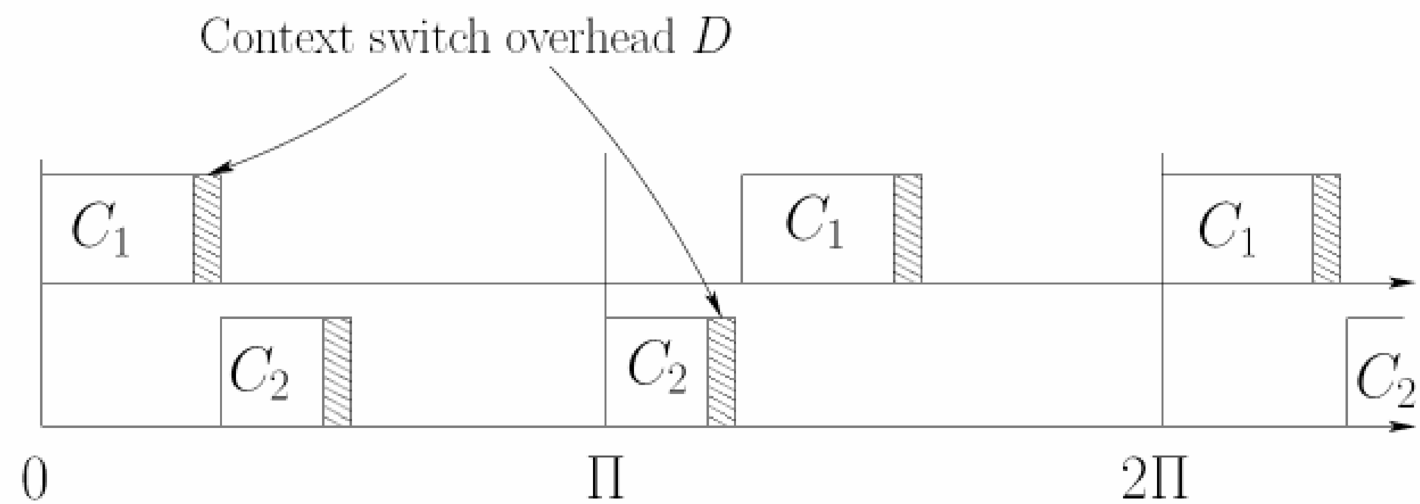
Interface Composition

- Simple addition of resource capacities Θ of individual interfaces for each value of period Π
- Take into account context switch overhead D

$$I_4 = \left\{ (\Pi, \Theta_1 + \Theta_2 + D) \mid (\Pi, \Theta_1) \in I_1, (\Pi, \Theta_2) \in I_2, 1 \le \Pi \le P^* \right\}$$

- Addition is associative and so composition is associative

Context Switches

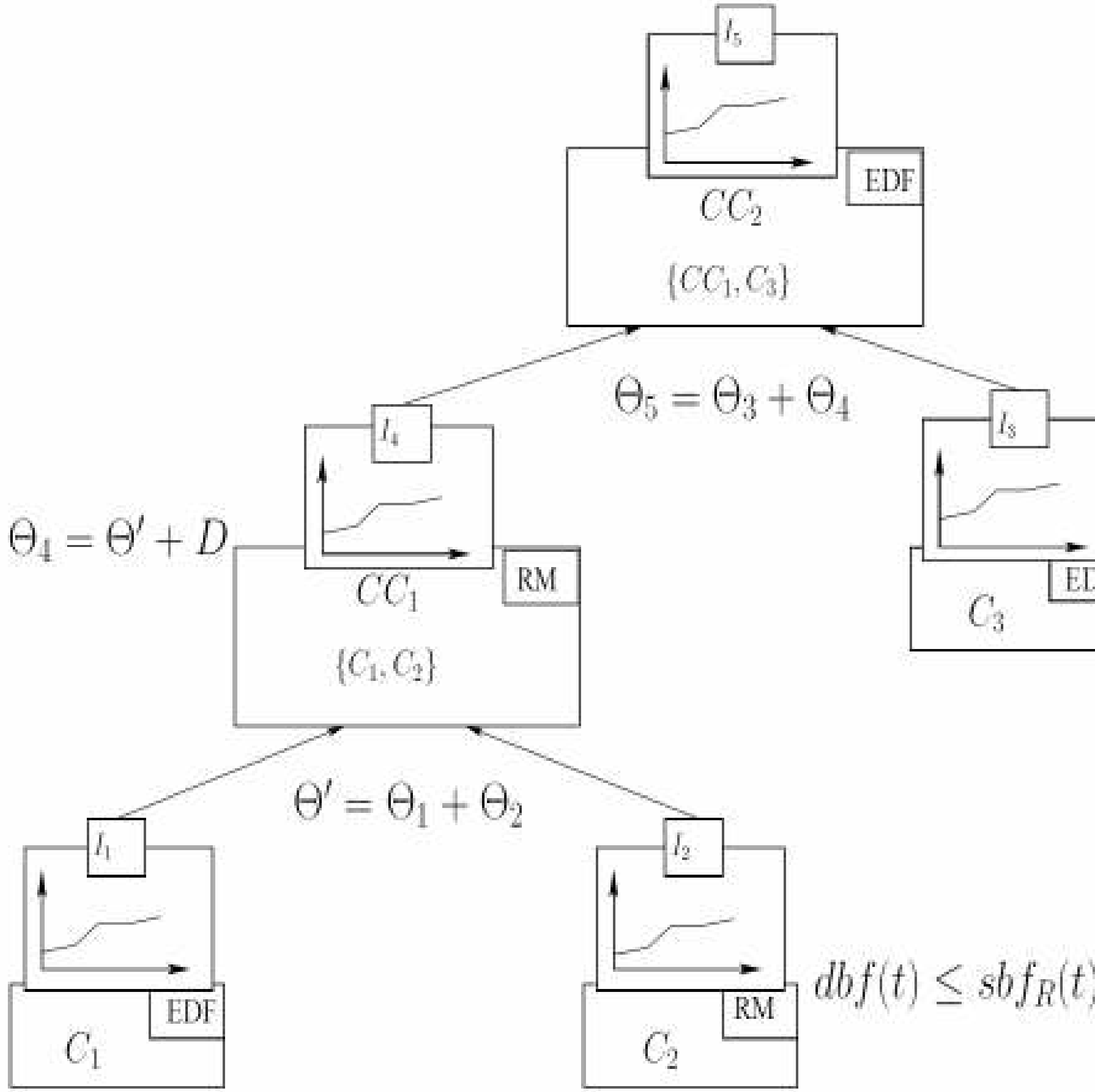


modified linear lower bound function $lsbf_R(t)$
takes context switches into account

Resource Demand Minimization

- Generate single interface I for the entire system, select value for period Π which minimizes resource demand Θ/Π.
- Export this single period to the OS for scheduling
- All interfaces have the same priority – so the OS can assign arbitrary priorities

Hierarchical Real-Time System with Interfaces



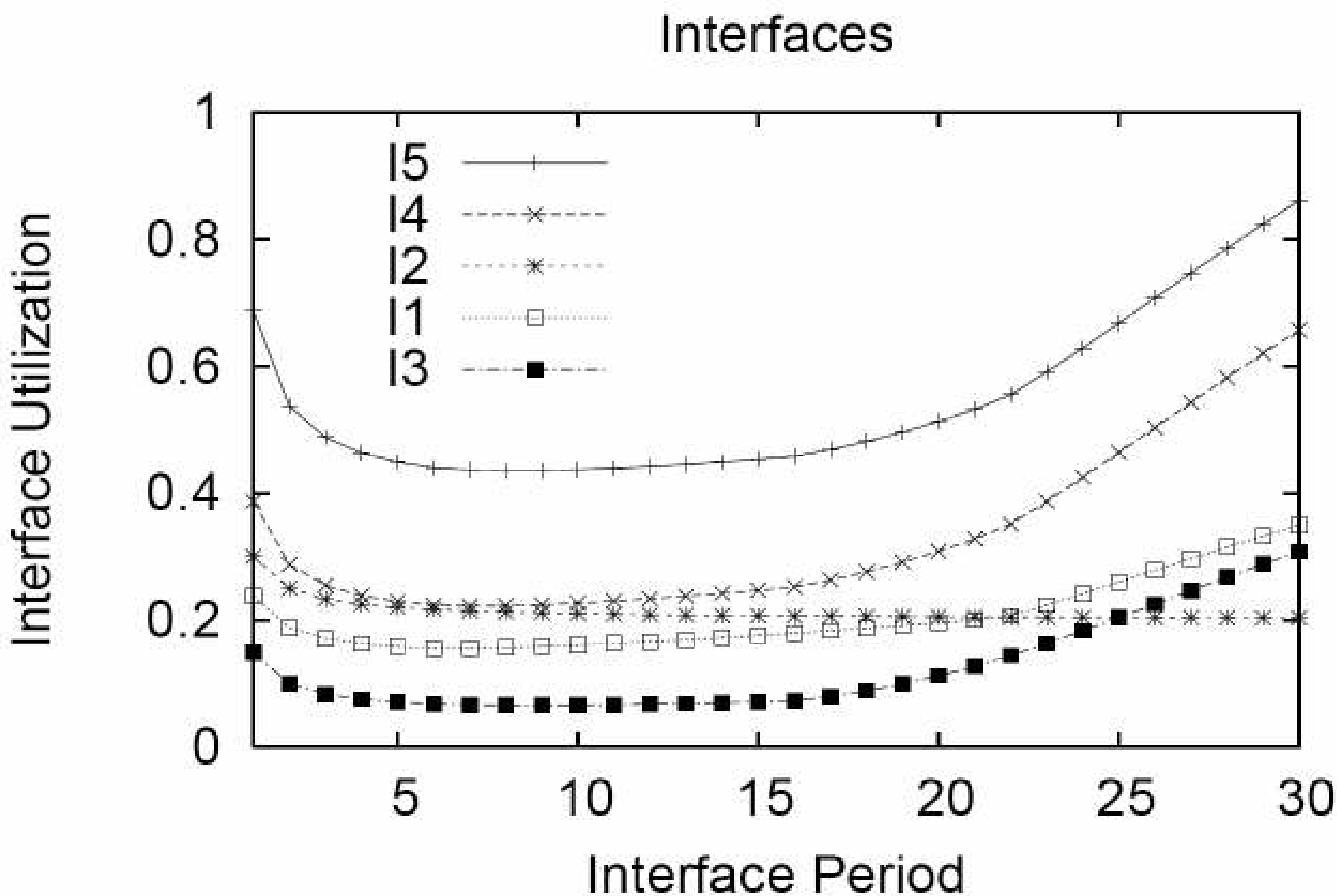
Example

$$C_1 : T_1 = (45,2), T_2 = (65,3), T_3 = (85,4)$$

$$C_2 : T_1 = (45,1), T_2 = (75,2)$$

Interface I_1			Interface I_3		
Π	t	$\texttt{dbf}(t)$	Π	t	$\texttt{dbf}(t)$
[1,1]	9945	1369	[1,1]	675	33
[2,4]	2210	304	[2,6]	225	11
[5, 6]	270	117	[7,16]	90	4
[7,21]	90	11	$[17,\infty]$	45	1
$[22,\infty]$	45	2			

Example



Interfaces
1
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30
Interface Utilization
Interface Period
I5
I4
I2
I1
I3

Example

I´: approach from previous paper

	Π	Θ	Θ/Π
$I_5 = (I_1 \| \| I_2) \| \| I_3$	8	3.4808	0.435
I_1'	6	0.932	0.155
I_2'	148	29.8	0.201
I_3'	9	0.593	0.066
$I_4' = I_1' \| \|' I_2'$	4	1.563	0.391
$I_5' = I_3' \| \|' I_4'$	2	1.100	0.550
$I_5'' = I_1' \| \|' I_2' \| \|' I_3'$	5	2.248	0.450

Open problem

- Whether incremental schedulability analysis (requiring associative composition) can be done with periodic resource models with varying periods