On Bounding Execution Demand under Mixed-Criticality EDF

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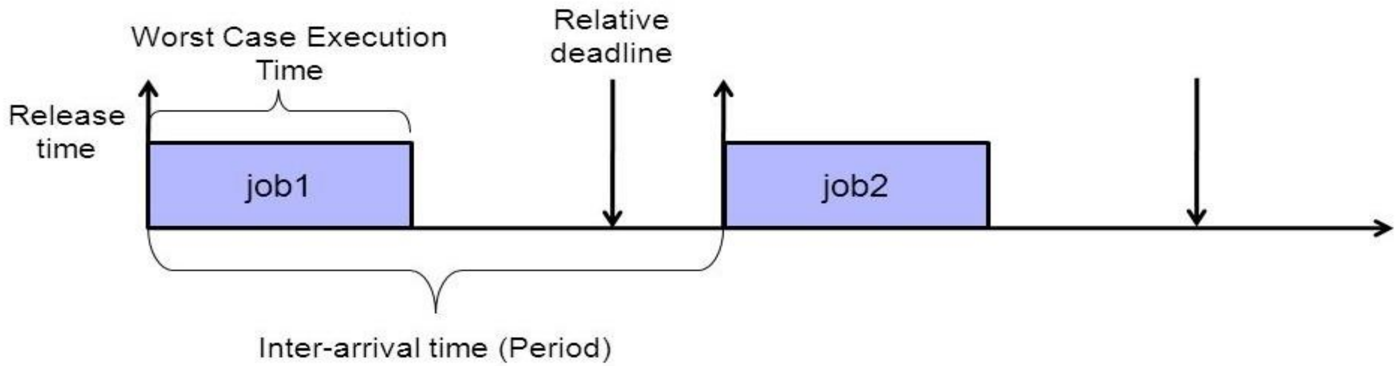
Introduction

- Problem of scheduling mixed-criticality systems under EDF
- System implements two operation modes: LO mode and HI mode
- Difficult to accurately bound the execution demand by carry-over jobs
- Known demand bound for mixed-criticality EDF are pessimistic



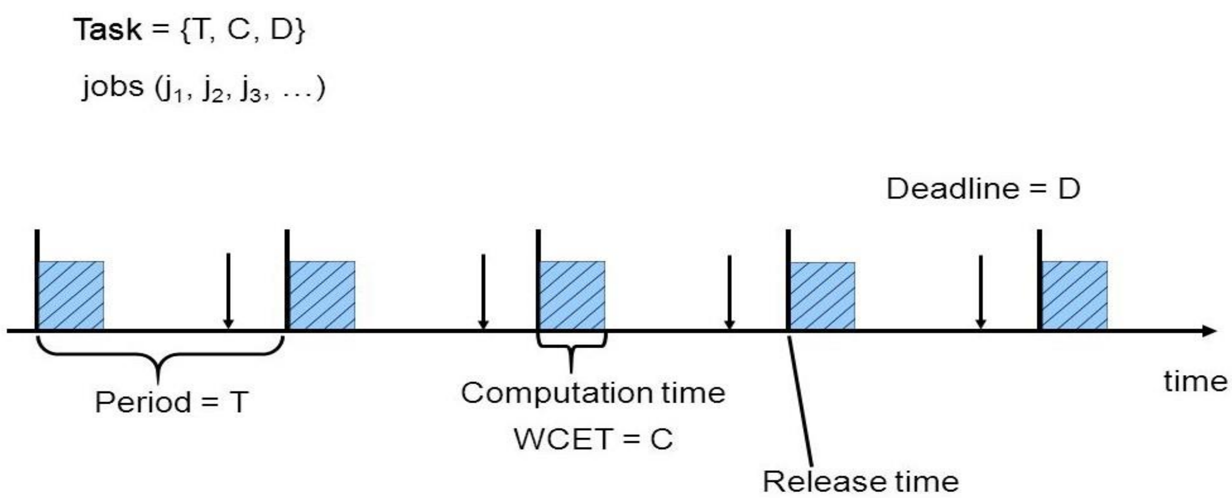
Contributions

A technique that allows better bounding the execution demand under mixed-criticality EDF.

- Separate demand bound function for transitions and prove its validity.
- Leads to a tighter bound on the execution demand under MC EDF
- Derive a simpler schedulability test for MC systems than other approaches
- Present evaluation results by a large set of experiments

Models and Assumptions

- τ the set of n independent sporadic tasks τ_i;
- The minimum separation: T_i
- D_i denotes a task's relative deadline
- Dual-criticality systems with two levels of criticality, $\chi_i \in \{LO, HI\}$.
- A LO task: WCET C_i^{LO}
- A HI task: optimistic WCET C_i^{LO} and conservative WCET estimate C_i^{HI}



Models and Assumptions (2)

- Two operation modes m : LO and HI mode.

- Utilization by LO and HI tasks in the LO and HI mode as follows:

$$\boldsymbol{U_{\chi}^{m}} = \sum_{\chi_i=\chi} \frac{\boldsymbol{C_i^m}}{\boldsymbol{T_i}}$$

Mixed-Criticality EDF.

- To shorten the deadlines of HI jobs in LO mode;

- Virtual deadline equal to $x_i.D_i$ with $x_i \in (0, 1]$;

- Deadline scaling factor: x_i

Bounding Execution Demand

- Characterizing the execution demand by applying demand bound function
- Derive third demand bound function for the transition between modes
- **Schedulability in LO mode**: LO tasks need to scheduled together with HI tasks.
- The demand bound function $\mathrm{dbf}_{\mathrm{LO}}(t)$ in LO mode is given by:

$$\begin{aligned}\mathrm{dbf}_{LO}(t) &= \sum_{\chi_i = LO} \left(\left\lfloor \frac{t - D_i}{T_i} \right\rfloor + 1 \right) C_i^{LO} \\ &+ \sum_{\chi_i = HI} \left(\left\lfloor \frac{t - x_i \cdot D_i}{T_i} \right\rfloor + 1 \right) C_i^{LO}. \qquad (1)\end{aligned}$$

- The system is schedulable in LO mode, if $\mathrm{dbf}_{\mathrm{LO}}(t) \leq t$ holds for all t

Bounding Execution Demand (2)

- we can remove the floor function in (1)

$$\hat{t}_{LO} \leq \frac{\sum_{\chi_i=LO}(T_i - D_i)\frac{C_i^{LO}}{T_i}}{1 - U_{LO}^{LO} - U_{HI}^{LO}} + \frac{\sum_{\chi_i=HI}(T_i - x_i \cdot D_i)\frac{C_i^{LO}}{T_i}}{1 - U_{LO}^{LO} - U_{HI}^{LO}}. \quad (2)$$

- This bound maximizes for all $x_i = 0$

$$\hat{t}_{LO} \leq \frac{\sum_{\chi_i=LO}(T_i - D_i)\frac{C_i^{LO}}{T_i}}{1 - U_{LO}^{LO} - U_{HI}^{LO}} + \frac{\sum_{\chi_i=HI} C_i^{LO}}{1 - U_{LO}^{LO} - U_{HI}^{LO}}, \quad (3)$$

Bounding Execution Demand (3)

- **Schedulability in HI mode**. LO tasks do not run and HI tasks run for their corresponding C_i^{HI}

$$\mathrm{dbf}_{HI}(t) = \sum_{\chi_i = HI} \left(\left\lfloor \frac{t - D_i}{T_i} \right\rfloor + 1 \right) C_i^{HI}, \qquad (4)$$

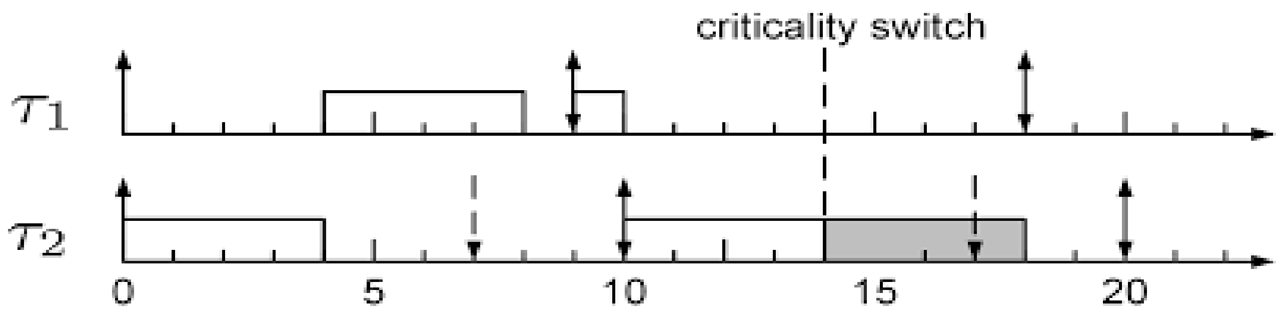
- The system is schedulable in stable HI mode, if $\mathrm{dbf}_{\mathrm{HI}}(t) \leq t$ holds for all t

- We again can remove the floor function in (4)

$$\hat{t}_{HI} \leq \frac{\sum_{\chi_i = HI} (T_i - D_i) \frac{C_i^{HI}}{T_i}}{1 - U_{HI}^{HI}}. \qquad (5)$$

Bounding Execution Demand (4)

- **Schedulability in the transition from LO to HI mode**. The transition from LO to HI mode may happen at an arbitrary point in time



- The problem arises with HI jobs
- The theorem is a generalization of a theorem in [14]:
- Work around carry-over jobs, guarantee schedulability and reduces the amount of pessimism

Bounding Execution Demand (5)

- The set of subtasks is either (1) unschedulable or (2) schedulable in isolation.

- Test schedulability under EDF with period=T_i, deadline= $(1 - x_i).D_i$ and execution time = $C_i^{HI} - C_i^{LO}$

- Allows characterizing the additional execution demand in the transitions

- We test whether deadlines are met or not in [t ′, t ′′]

Finding Valid x_i

- Alg. 1 tests τ 's schedulability in the LO mode (line 1), and in HI mode (line 2).
- If τ is schedulable in LO mode, the function testLO() returns a vector X_{LW}
- Alg. 1 tests schedulability at the transitions from LO to HI mode (line 3).
- If the set of HI tasks in τ is schedulable at transitions from LO to HI, the function testSW() returns a vector X_{UP}
- For each element in the vectors X_{LW} and X_{UP} , the following condition has to hold

$$X_{LW}(i) \leq x_i,$$
$$X_{UP}(i) \leq 1 - x_i,$$
$$\Longrightarrow x_i \leq 1 - X_{UP}(i).$$

Algorithm 1 Schedulability test for mixed-criticality EDF

Require: τ

Require: τ_{HI} /* subset of HI tasks */

1: X_{LW}=testLO(τ)
2: **if** testHI(τ_{HI})='Passed' **and** $X_{LW} \neq \emptyset$ **then**
3:     X_{UP}=testSW(τ_{HI})
4:     **if** $X_{UP} \neq \emptyset$ **and** $X_{LW} \leq 1 - X_{UP}$ **then**
5:         Return ('Passed')
6:     **else**
7:         Return ('Not passed')
8:     **end if**
9: **end if**

Experimental Evaluation

- Evaluate the proposed technique based on synthetic data
- Show how the different algorithms behave with respect to each other.
- Comparing the proposed technique in form of Alg. 1 with EDF-VD [1], with the GREEDY algorithm [2], and with ECDF [3].
- we used the algorithm UUniFast [19][20] to generate sets of 10 and 20 tasks for a varying LO utilization.
- For each curve, a total number of 5, 000 different task sets were created.

Experimental Evaluation (2)

- Comparison for sets of 10 tasks

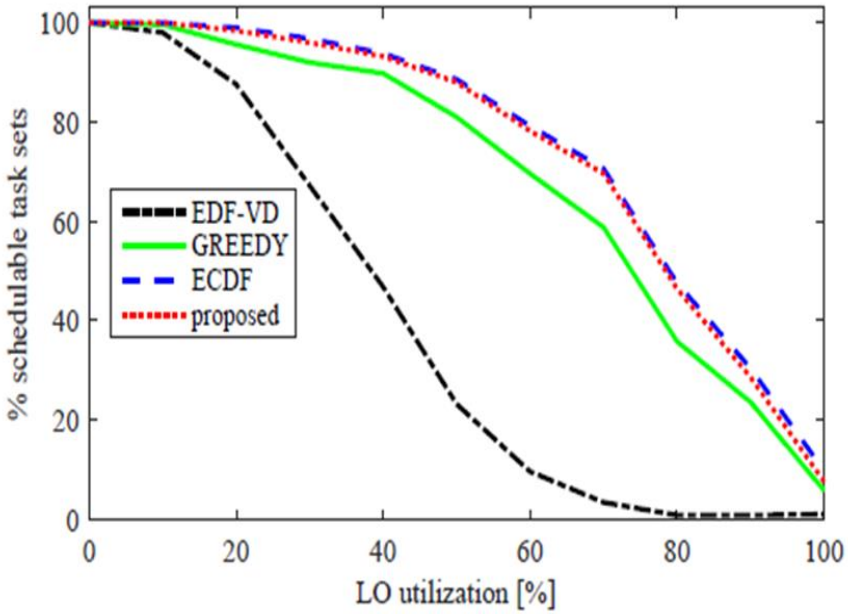


Figure 1: Schedulability vs. LO utilization for n = 10 and 10% of HI tasks with 10% increase of HI execution demand

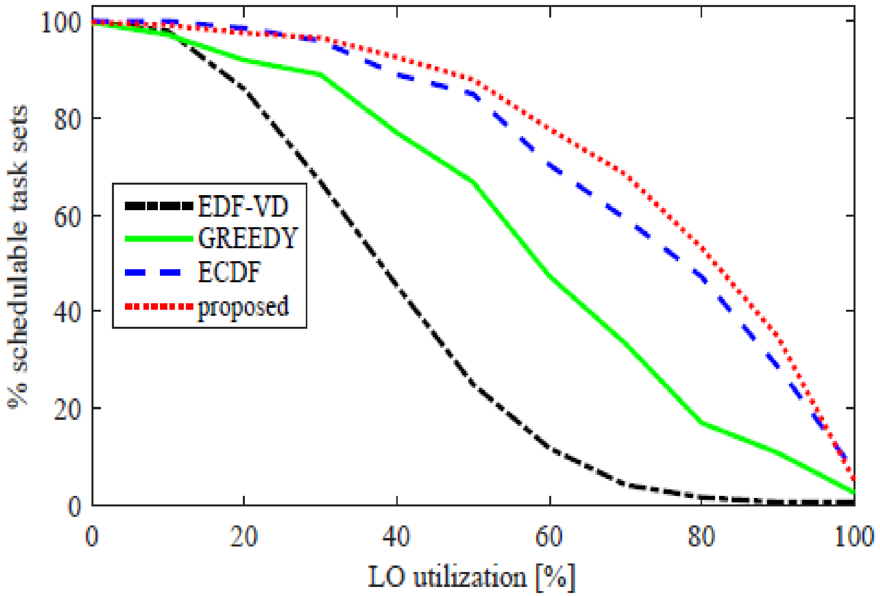


Figure 4: Schedulability vs. LO utilization for n = 10 and 30% of HI tasks with 10% increase of HI execution demand

Experimental Evaluation (3)

- Comparison for sets of 20 tasks

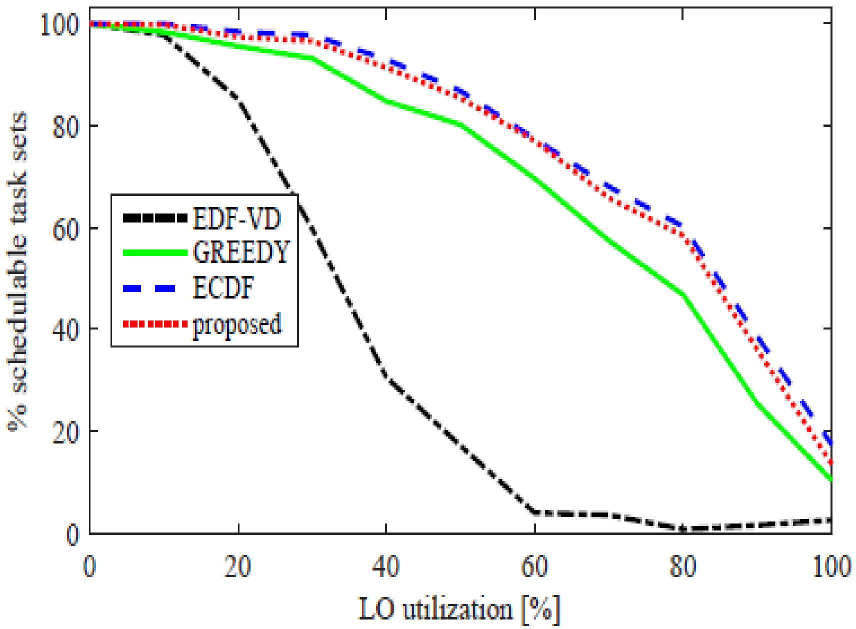


Figure 7: Schedulability vs. LO utilization for n = 20 and 10% of HI tasks with 10% increase of HI execution demand

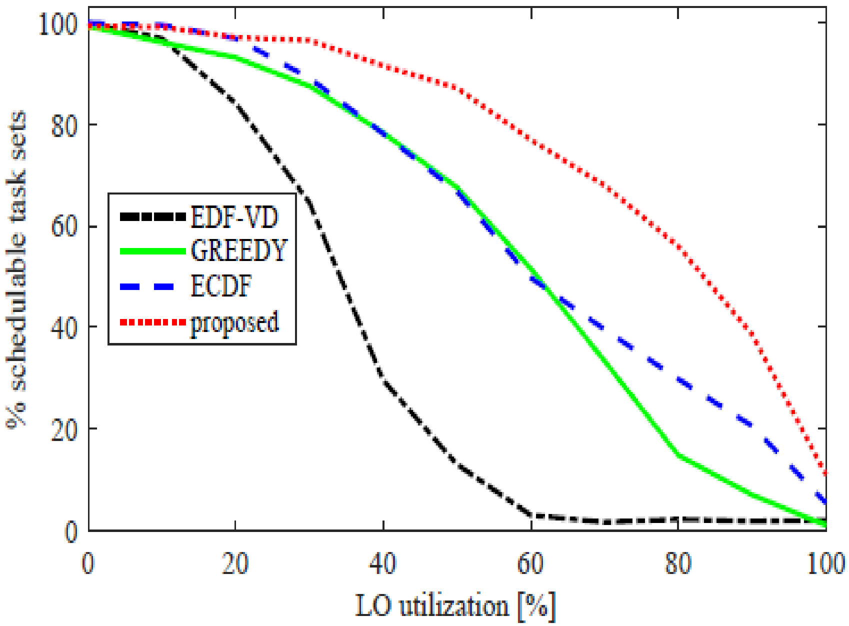


Figure 10: Schedulability vs. LO utilization for n = 20 and 30% of HI tasks with 10% increase of HI execution demand

Conclusion

- We studied the problem of mixed-criticality scheduling under EDF
- Derive a separate demand bound function for transition to HI mode
- Working around carry-over-jobs, reducing pessimism and relaxing schedulability condition in HI mode under MC EDF
- Resulting in simpler schedulability test and tighter bound on execution demand under mixed-criticality EDF
- We illustrated this by a large set of experiments based on synthetic data.

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