UNIVERSITY OF MINNESOTA

TEXAS A&M UNIVERSITY

Graceful Degradation of Low-Criticality Tasks in Multiprocessor Dual-Criticality Systems

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Outline

- Motivation
- Previous Work
- Variable Precision Scheduling Methods
- Experiment Results
- Conclusion

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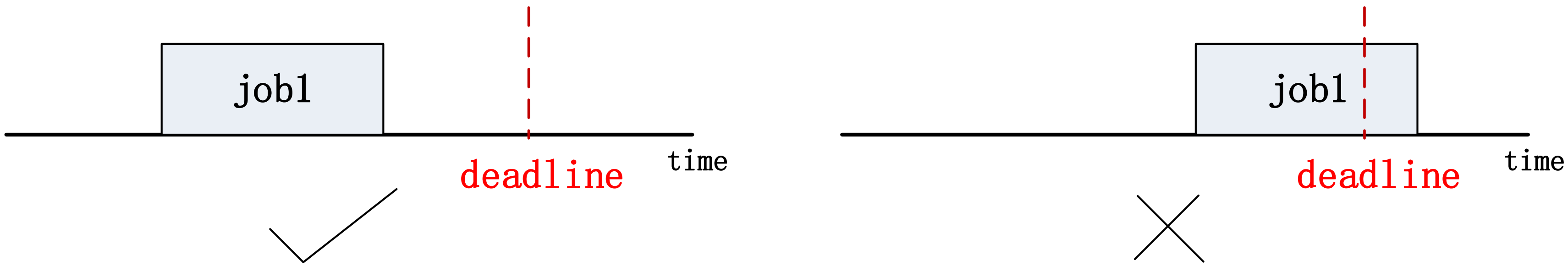
Hard Real Time Scheduling

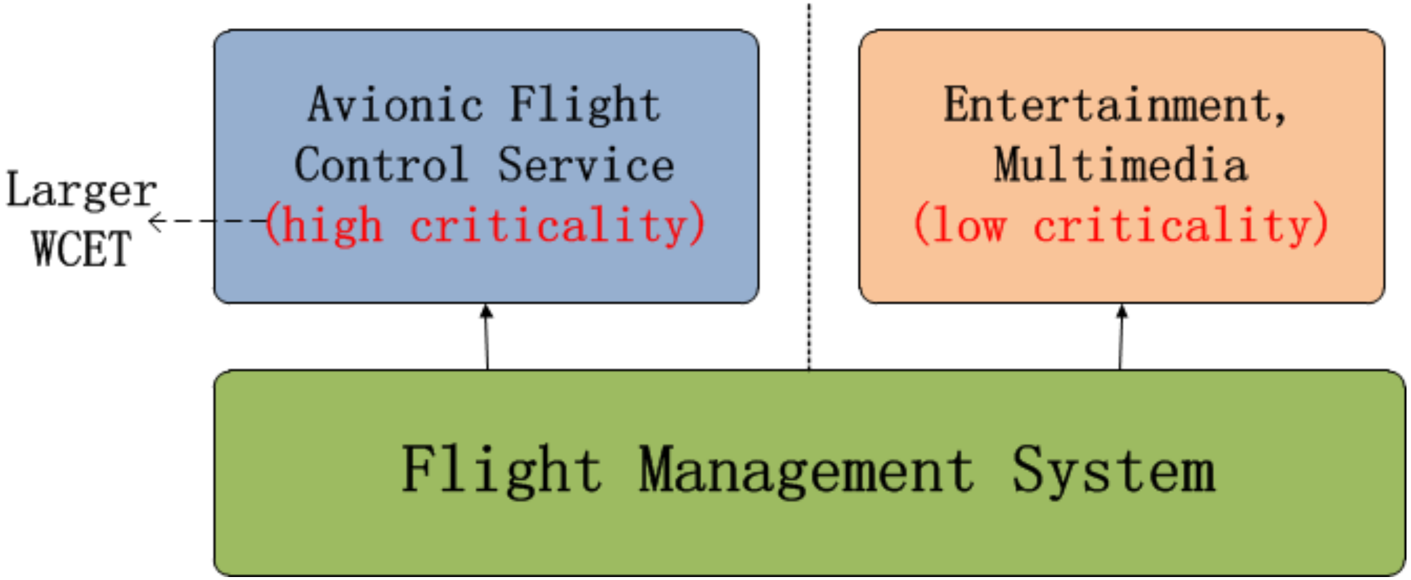
- Real time system: job execution has hard deadline



- WCET (worst case execution time)

Mixed Criticality System (MCS)

- Integrate multiple functionalities (tasks with different criticality levels)



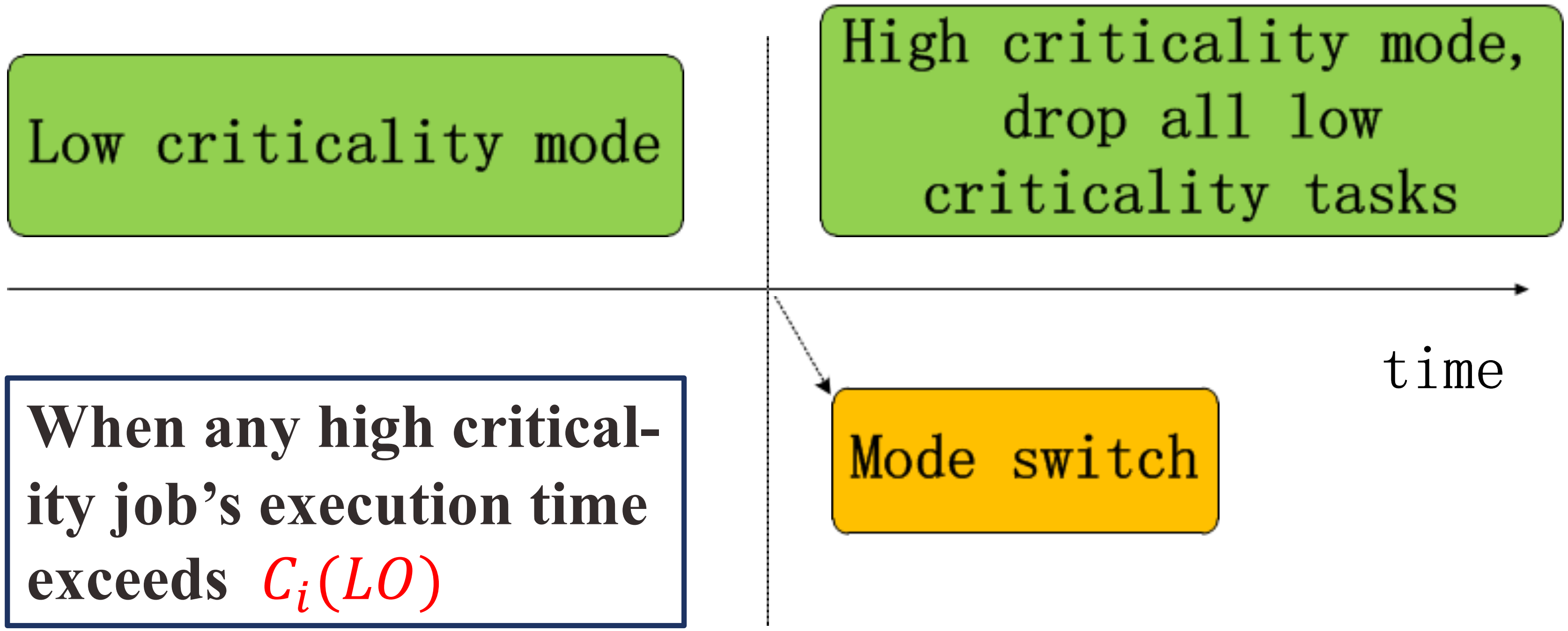
Conventional System Model for MCS

- $T = \{\tau_1, \tau_2, \cdots, \tau_n\}$: *a set of independent sporadic tasks*

Task: $(p_i,\ C_i\ , L_i\ )$. p_i: period C_i : WCET

L_i: criticality level. high(hi), low(lo)

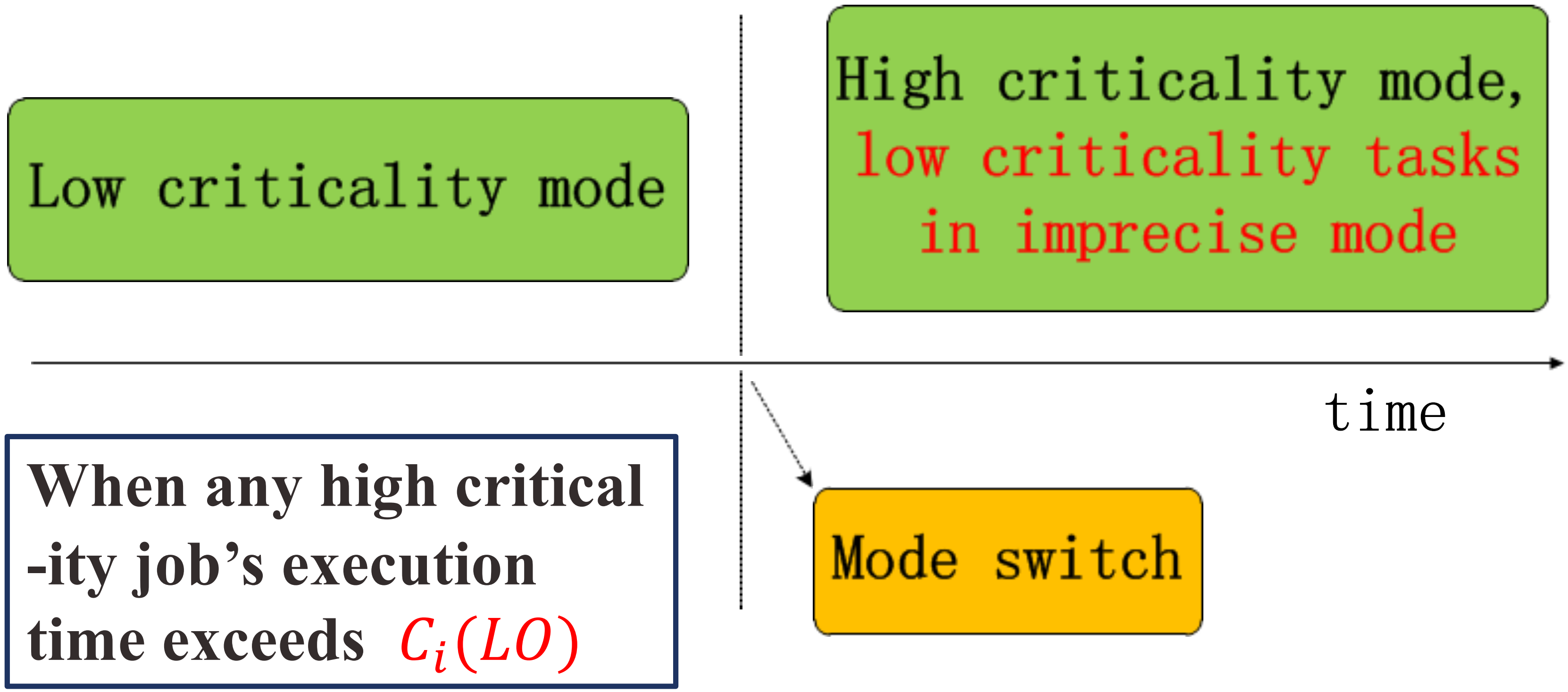
For high criticality task, $C_i(HI) > C_i(LO)$



Imprecise Mixed Criticality System (IMCS)

- For high criticality task, $C_i(HI) > C_i(LO)$

  For low criticality task, $C_i(HI) < C_i(LO)$



Our Work

➢ **Variable Precision Mixed Criticality System (VPMCS)**

Do precision optimization for low criticality tasks

An motivation example of doing precision optimization

task	L_i	C_i(LO)	C_i(HI)	p_i	e_i
t1	hi	2	5	10	-
t2	lo	6	3	15	0.1
t3	lo	4	2	20	5

No optimization: Average_error=2.55

With our precision optimization: Average_error=0.55

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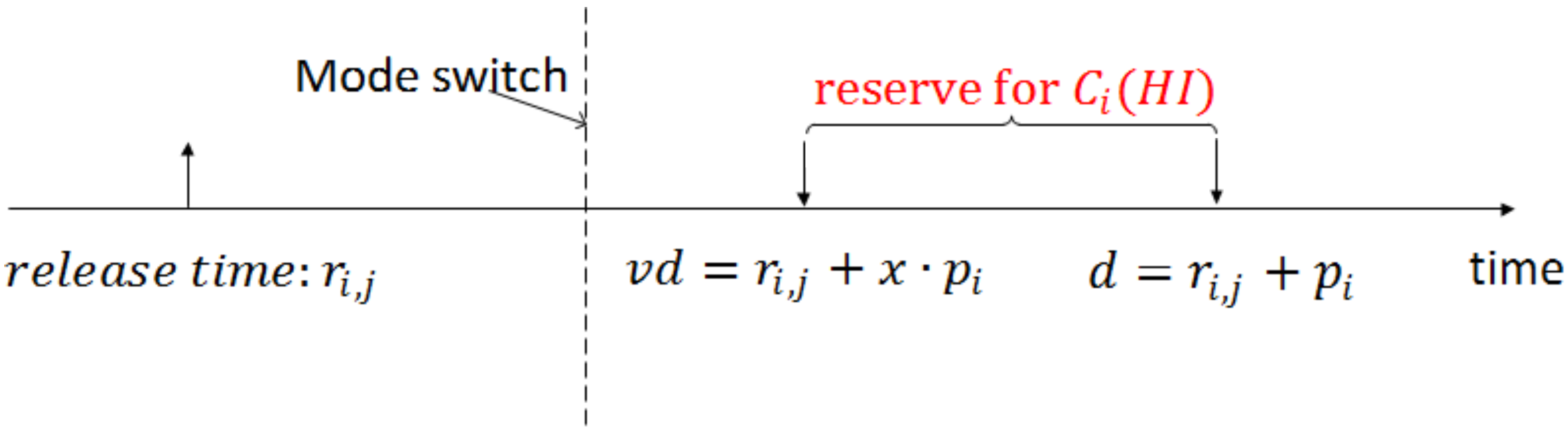
Earliest Deadline First-Virtual Deadline (EDF-VD) Scheduling

➢ Classic EDF-VD scheduling on single processor[1]

- Each high criticality task has a virtual deadline $(vd \leq d, 0 < x \leq 1)$
- Speedup factor=4/3, optimal



[1] S. Baruah, et al. "The preemptive uniprocessor scheduling of mixed-criticality implicit-deadline sporadic task systems." *Real-Time Systems (ECRTS), 2012 24th Euromicro Conference on*. IEEE, 2012.

EDF-VD vs EDF

➢ EDF-VD has less conservative schedulability condition

task	L_i	C_i(LO)	C_i(HI)	p_i
t1	lo	1	-	2
t2	hi	1/2	3	4

- Schedulability condition for EDF

$U_{sum} = U_{lo}^{LO} + U_{hi}^{HI} = \frac{1}{2} + \frac{3}{4} > 1$ **not schedulable**

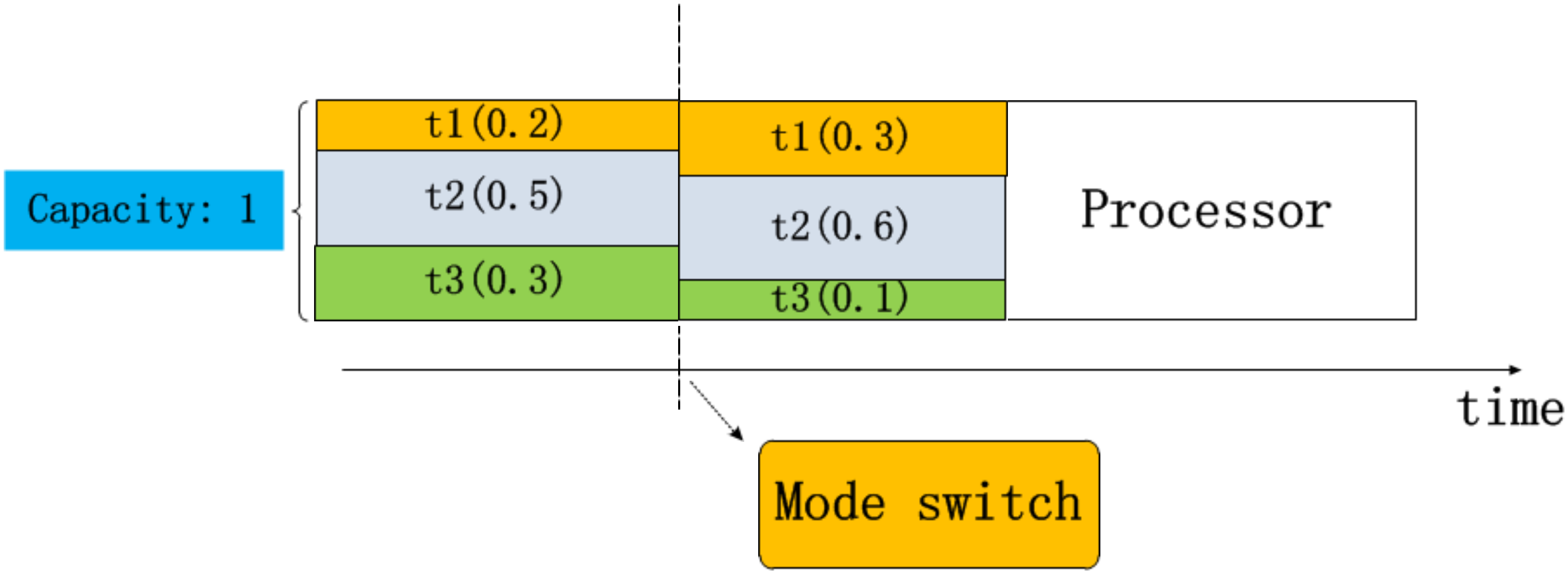
Where: $U_a^b = \sum_{\tau_i \in \tau \wedge L_i = a} \frac{C_i(b)}{p_i}$, $a \in \{hi, lo\}$, $b \in \{HI, LO\}$

- Schedulability condition for EDF-VD

$U_{lo}^{LO} + \min\left(U_{hi}^{HI}, \frac{U_{hi}^{LO}}{1 - U_{hi}^{HI}}\right) = \frac{1}{2} + \min\left(\frac{3}{4}, \frac{1}{2}\right) = 1 \leq 1$ **schedulable**

Fluid Based Method

- R.M.Pathan "Improving the quality of service for scheduling mixed-criticality systems on multiprocessors". ECRTS, 2017
  - Not directly implementable in practice



- Our work: partitioned and global scheduling on multiprocessors

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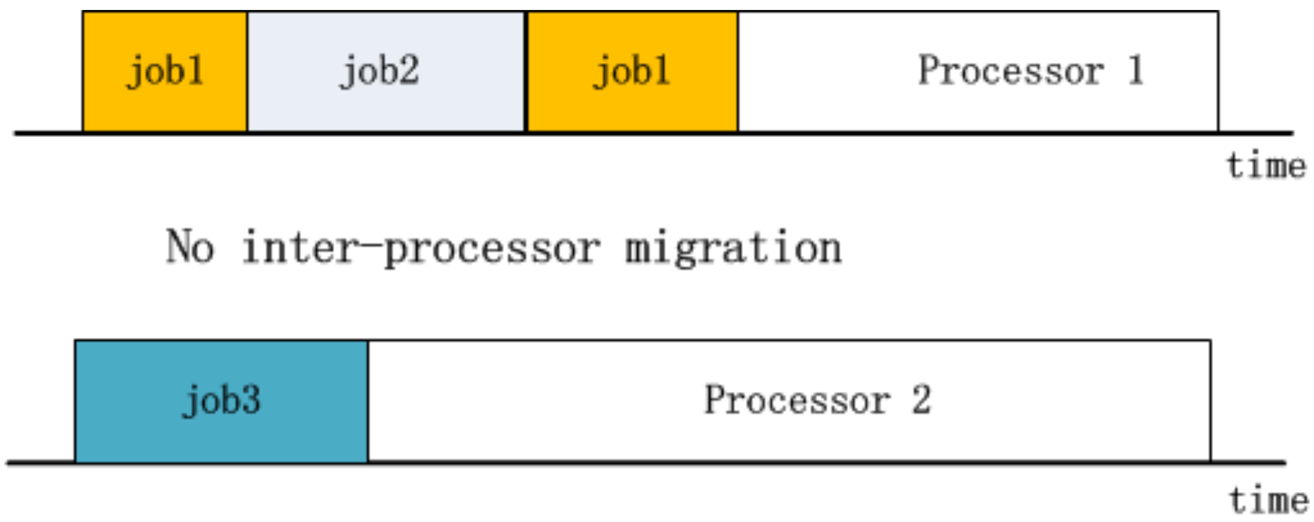
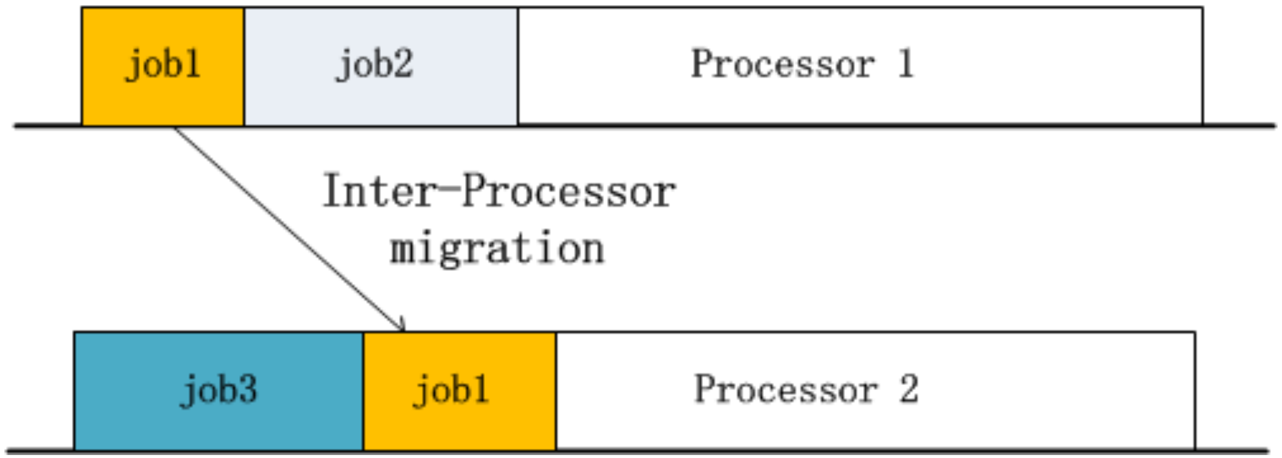
Multiprocessor Scheduling

- Partitioned scheduling: no inter-processor migration is allowed



➢ Global Scheduling

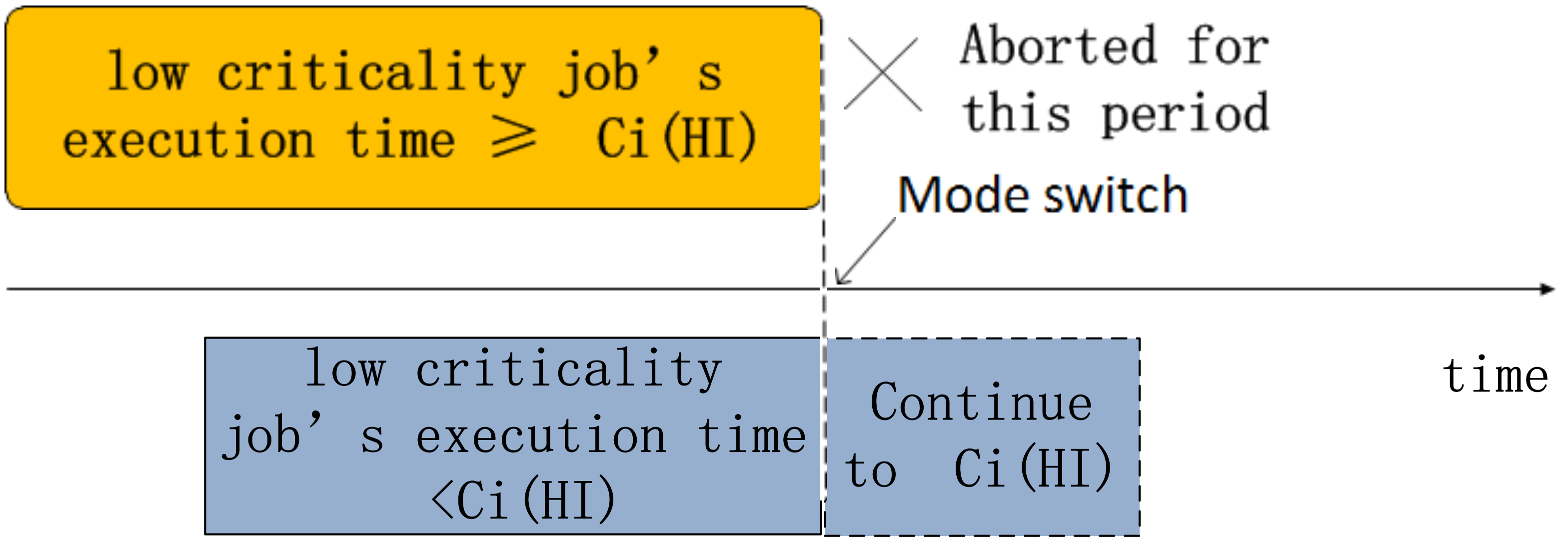
- Inter-processor migration is allowed, overhead



EDF-VD Scheduling for IMCS[2]

Lemma 1: If a task set satisfies the condition $\max\left(U_{lo}^{LO} + U_{hi}^{LO}, U_{lo}^{HI} + U_{hi}^{HI}\right) \leq \frac{3}{4}$, it is schedulable by EDF−VD on a single processor.

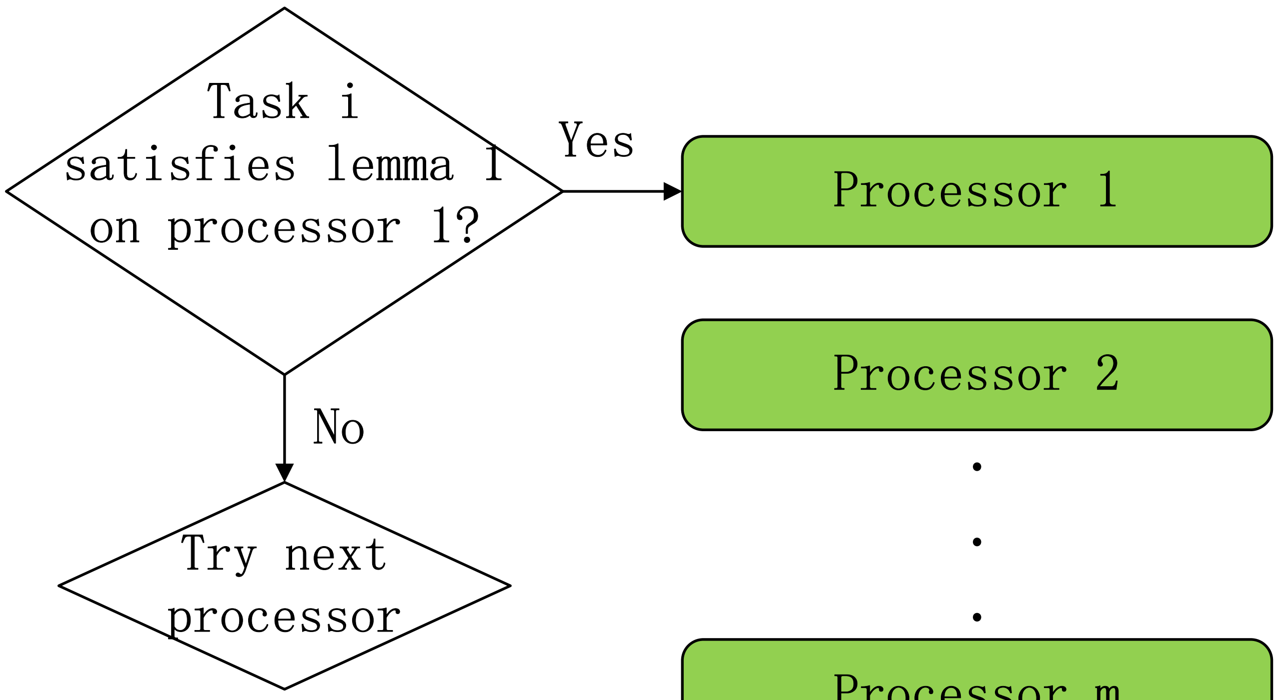
$$U_a^b = \sum_{\tau_i \in \tau \wedge L_i = a} \frac{C_i(b)}{p_i}, a \in \{hi, lo\}, b \in \{HI, LO\}$$



[2] D, Liu, et al. "EDF-VD scheduling of mixed-criticality systems with degraded quality guarantees." *arXiv preprint arXiv:1605.01302* (2016).

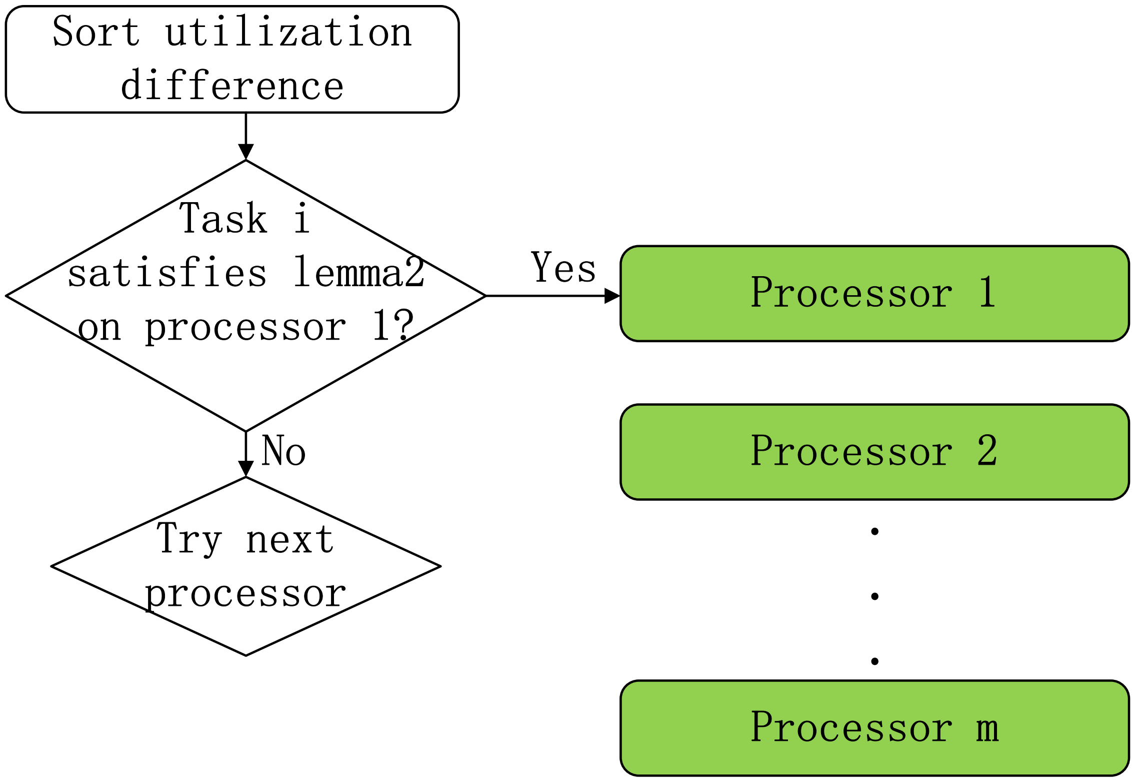
VPMCS Partitioning with EDF-VD Scheduling

- Speedup factor: $(8m - 4)/3m$, same as conventional MCS



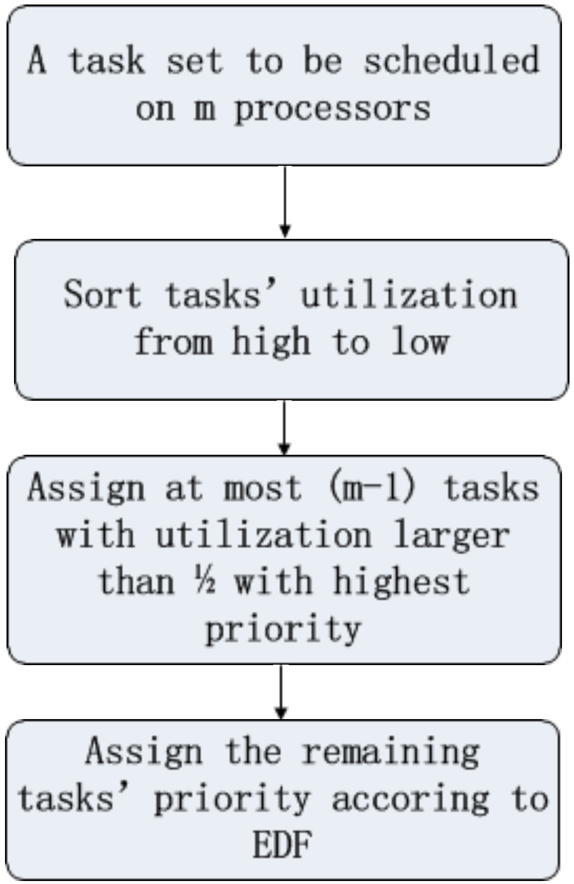
Enhanced VPMCS Partitioning

- *Lemma* 2: *If a task set satisfies the condition* $\frac{U_{hi}^{LO}}{1-U_{lo}^{LO}} \leq \frac{1-(U_{hi}^{HI}+U_{lo}^{HI})}{U_{lo}^{LO}-U_{lo}^{HI}}$, it is schedulable by EDF-VD on a single processor.
- *Lemma*1 $\Longrightarrow$ *Lemma* 2



Global Scheduling

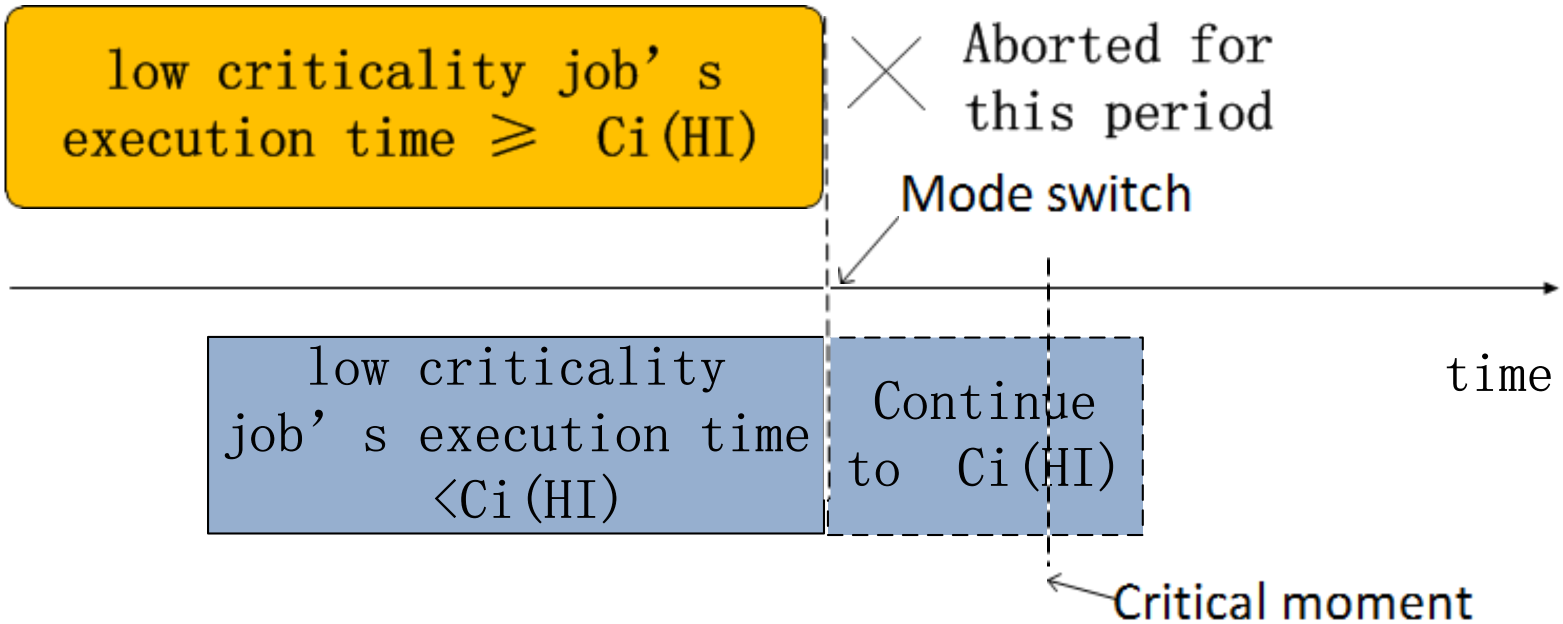
- Classic fpEDF method on m multiprocessors[3]
- Optimal w.r.t schedulable utilization



[3] S. Baruah. "Optimal utilization bounds for the fixed-priority scheduling of periodic task systems on identical multiprocessors." *IEEE Transactions on Computers* 53.6 (2004): 781-784.

Global Scheduling

- ➢ fpEDF-VD (fpEDF and EDF-VD)
- Speedup factor: $\sqrt{5}+1$, same as conventional MCS
- Low criticality task may lose its job once

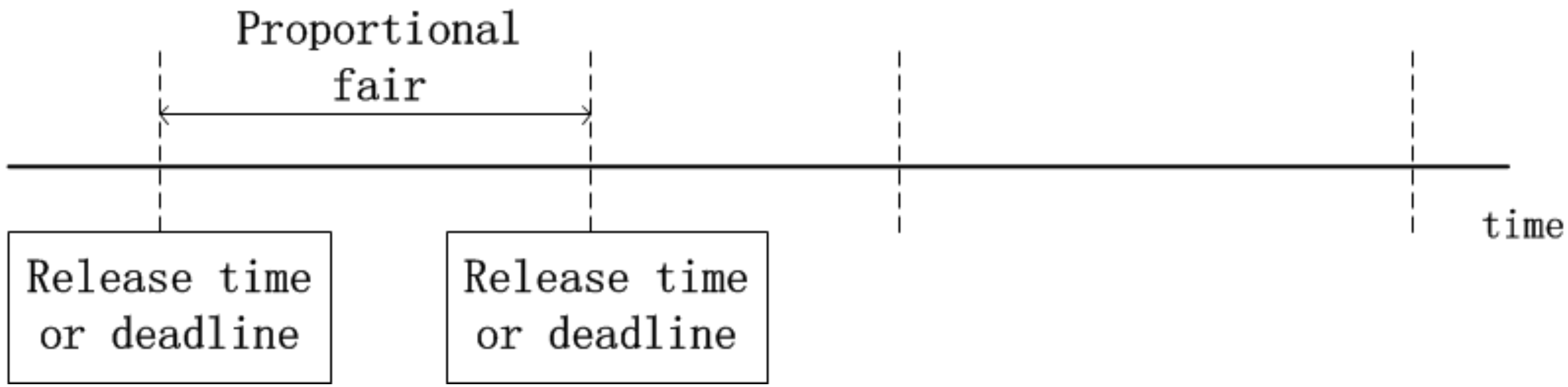


➢Dual virtual-deadline for fpEDF
- Guarantee no job is abandoned

Fluid Scheduling

- ➢ Classic fluid scheduling
- • Optimal w.r.t speedup factor (4/3)

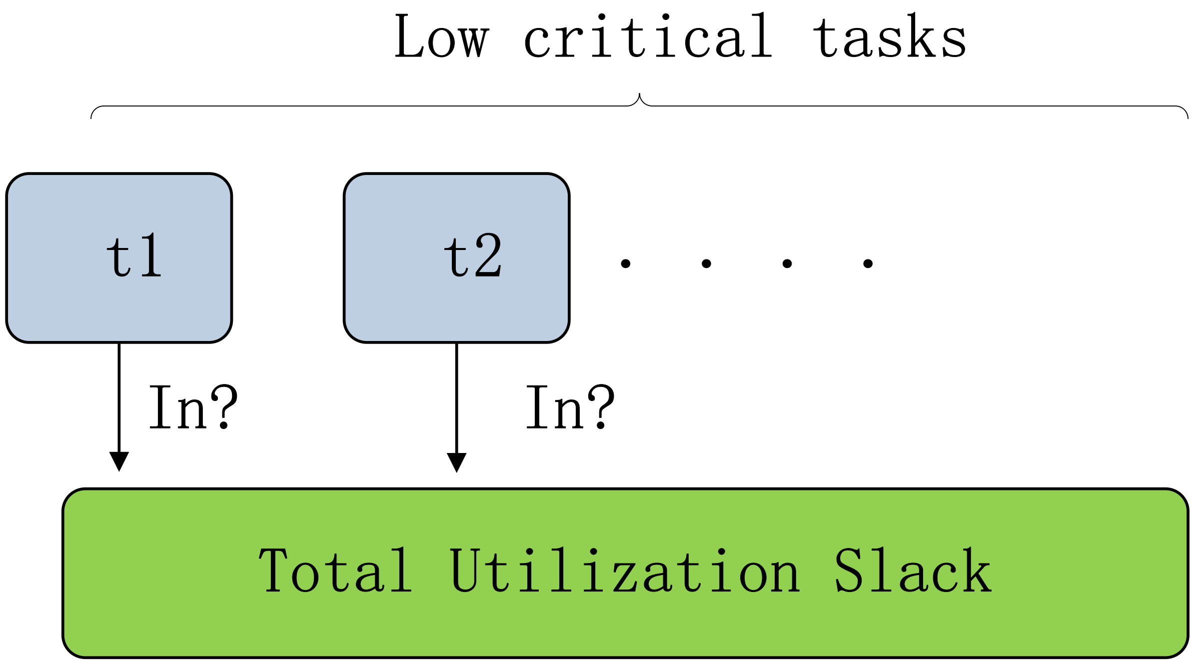
- ➢ Deadline Partition-Fair
- • Correctness of the implementation



Offline Precision Optimization

➢ Formulate the problem as a 0-1 knapsack problem

- Objective: minimize average error for low criticality tasks in high criticality mode
- Constraint: total utilization slack



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Experiment Setup

Simulation

- ➢ Random test cases
- • The probability of a task being high criticality: 0.5
- • Utilization range: [0.05,0.9]
- • Period range: [50,500]
- • Imprecise computing error range: [1,10]

Linux prototyping

- ➢ 1.9GHZ Intel i3 4-processor machine
- ➢ Linux 4.10
- ➢ Test cases: newton-raphson method, steepest descent method

Experiment Comparison

Partitioned scheduling methods:

- Partition-MC: partitioned scheduling with conventional model (drop low critical tasks)
- Partition-VPMC: our VPMCS Partitioning with EDF-VD Scheduling
- Partition-VPMC-E: our enhanced VPMCS Partitioning

Global scheduling methods:

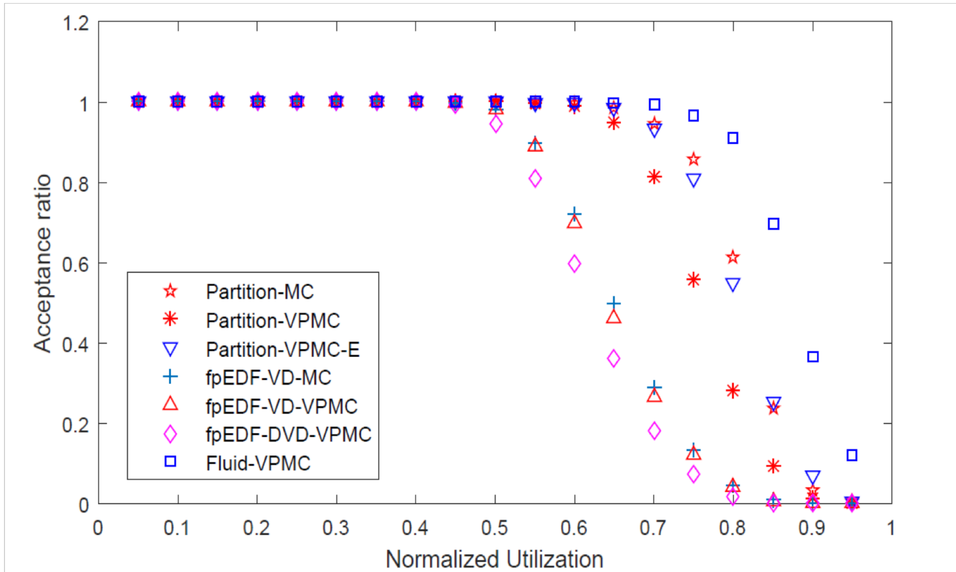
- fpEDF-VD-MC: fpEDF-VD scheduling with conventional model (drop low critical tasks)
- fpEDF-VD-VPMC: our fpEDF-VD scheduling method
- fpEDF-DVD-VPMC: our dual virtual-deadline for fpEDF

Fluid scheduling methods:

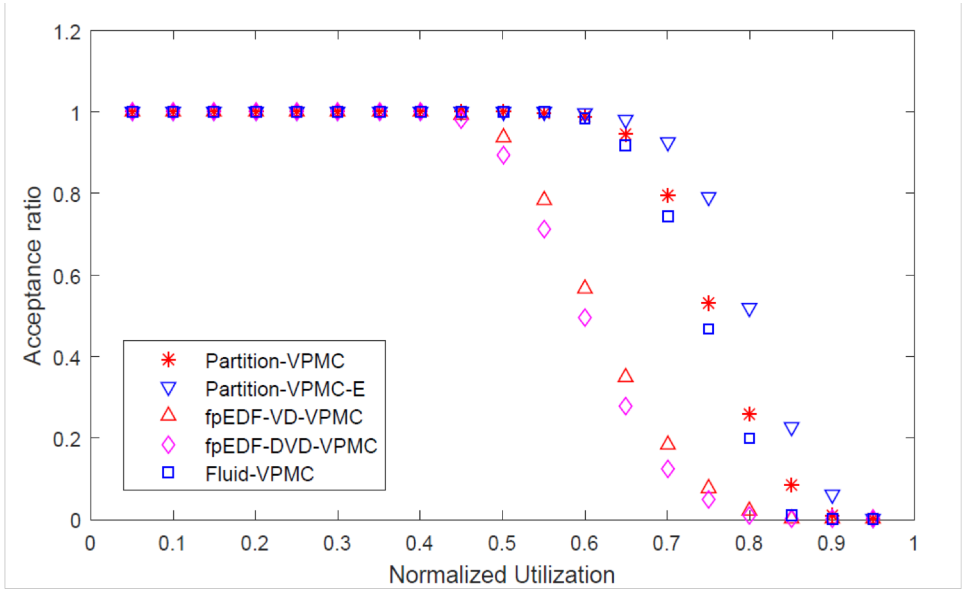
- Fluid-VPMC: fluid method which is theoretically optimal
- VPMC-DP-Fair: real hardware implementation of Fluid-VPMC

Acceptance Ratio versus Utilization

- Our Partition-VPMC-E performs best when considering scheduling overhead



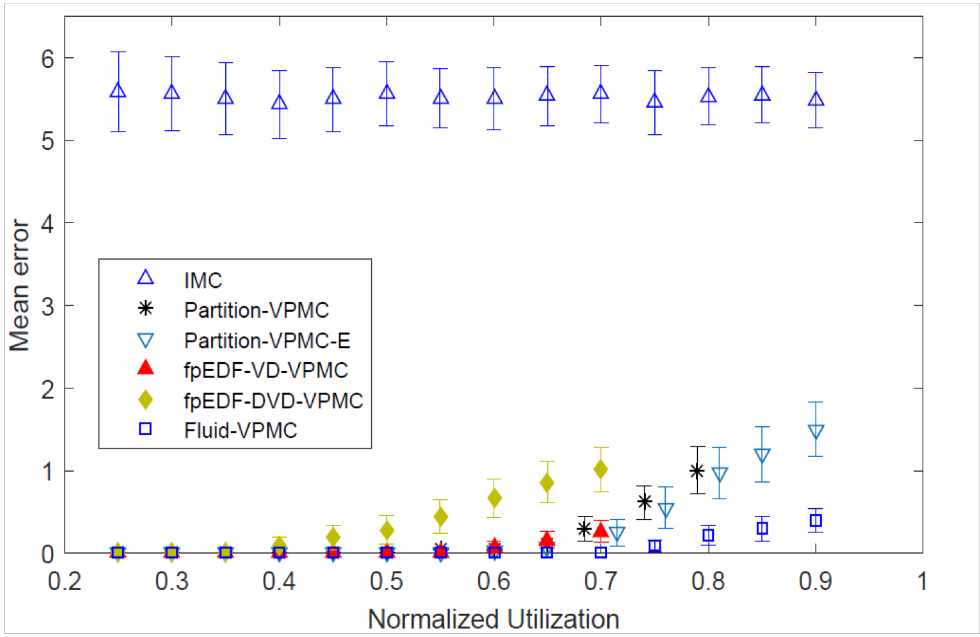
Acceptance ratio versus utilization on 4 processors

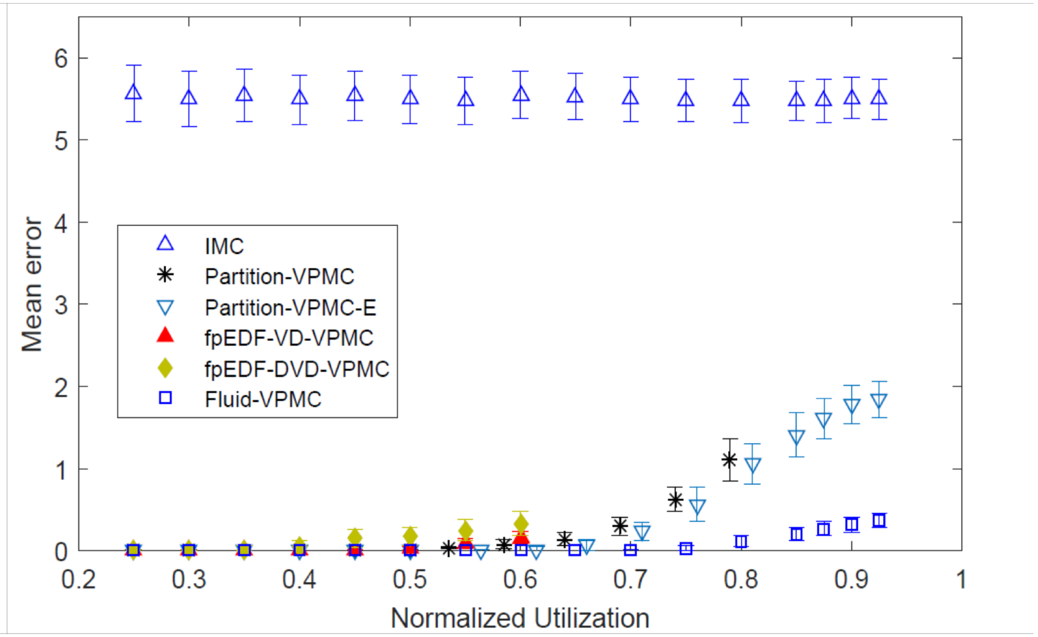


Acceptance ratio versus utilization on 4 processors considering overhead

Mean Error versus Utilization

- IMC: all low critical tasks in imprecise mode





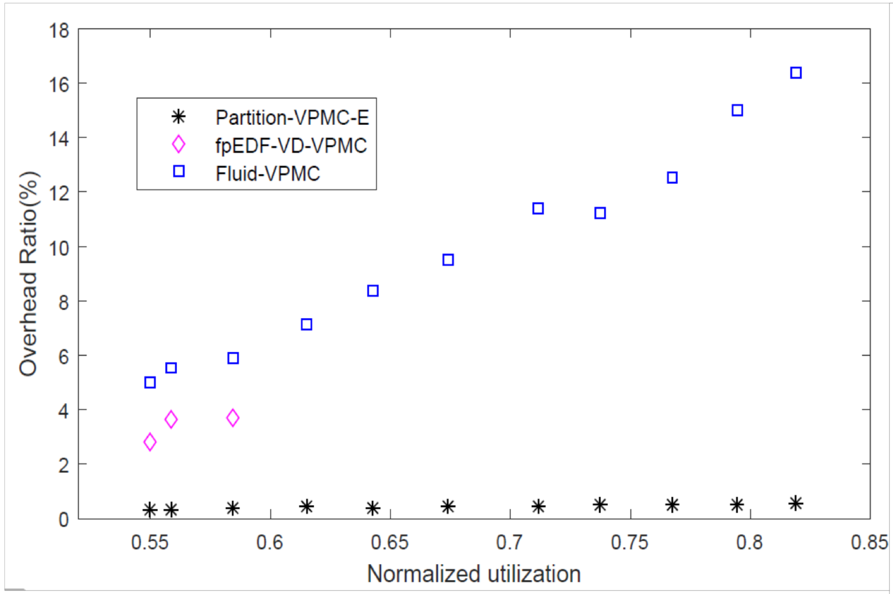
Mean error with standard derivation versus Utilization on 4 processors

Mean error with standard derivation versus Utilization on 8 processors

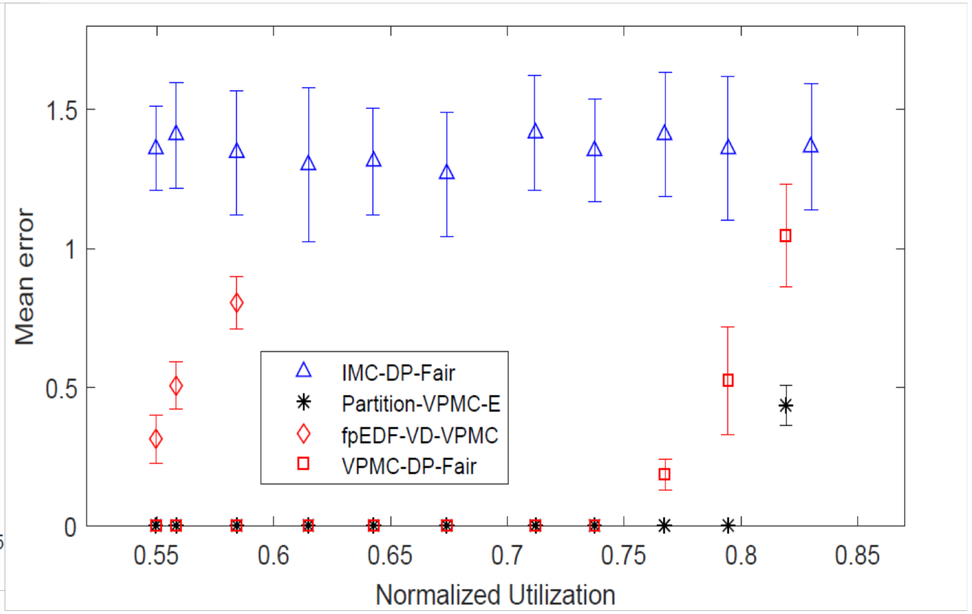
Linux Prototyping

- Mean error and overhead

Partitioned method has lowest overhead ratio and smallest mean error.



Overhead ratio versus Utilization

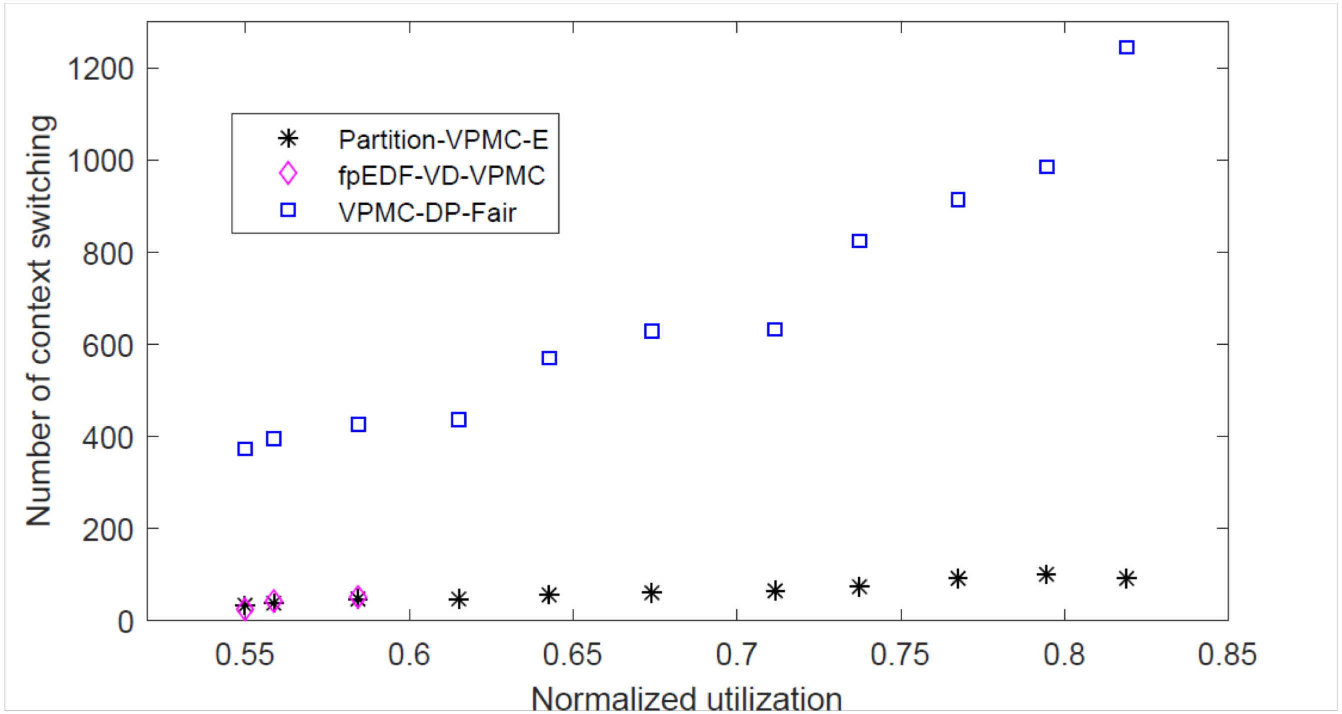


Mean error versus Utilization

Linux Prototyping

➢ Number of context switching

VPMC-DP-Fair has much larger number of context switching than global and partitioned scheduling method.



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Conclusion

- Our proposed methods can significantly reduce the error compared to IMCS scheduling

- The proposed methods could achieve smaller overhead compared to fluid based method

Thank you