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Open Problems in FIFO Scheduling with Multiple Offsets

Mitra Nasri Robert I. Davis Björn B. Brandenburg

First-In-First-Out (FIFO) scheduling

Extremely **simple**

Very **low overheads**

Easy to analyze

Very **low schedulability**

Ideal for

- IoT-class devices
- deeply embedded systems
- hardware implementations

Not good for hard real-time systems

This talk

Reviewing our recent work [Nasri et al., RTAS'2018] on
Improving FIFO's schedulability
by assigning multiple offsets to each task

Open problems in
multiple-offset assignment

Intuition

What is the problem with FIFO scheduling

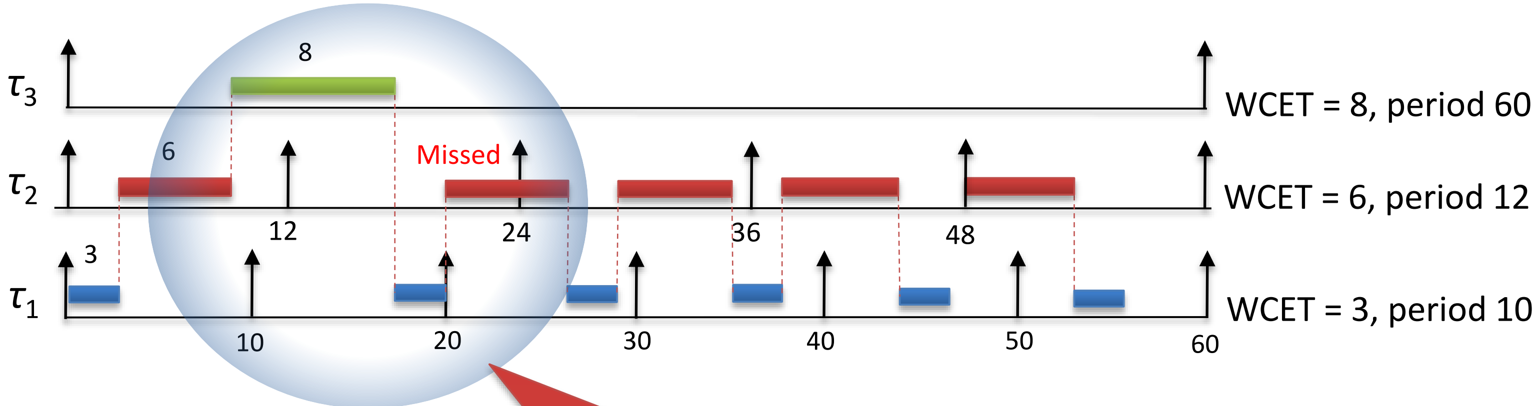
A secret to boost schedulability
(for non-preemptive periodic tasks)

How to improve FIFO's schedulability

From [Nasri et al. RTAS'2018]

What is the problem with the "plain" FIFO?

FIFO schedule of 3 periodic tasks



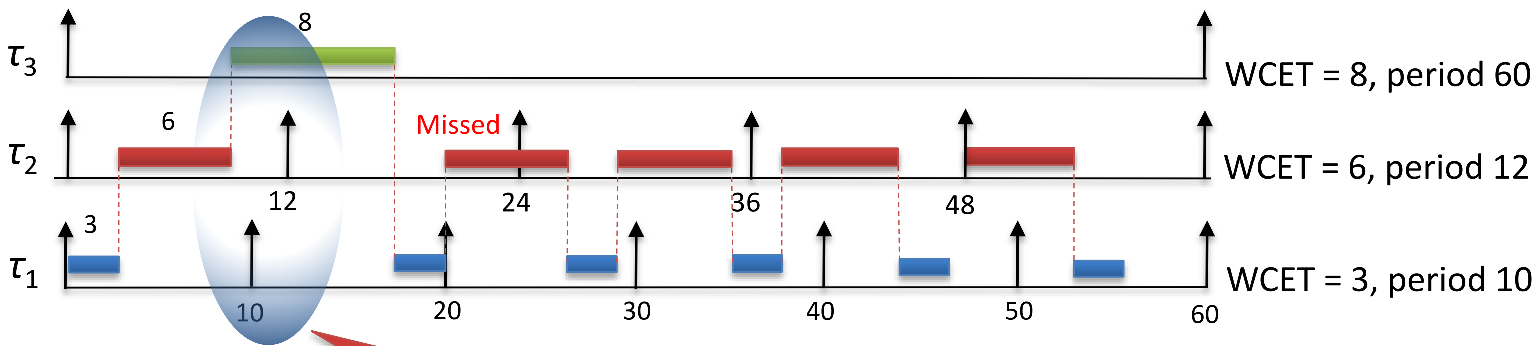
Plain FIFO is **oblivious** to <u>deadlines and priorities</u>

τ_3 comes first ➔ deadline miss for τ_2

WCET: worst-case execution time

Work-conserving scheduling

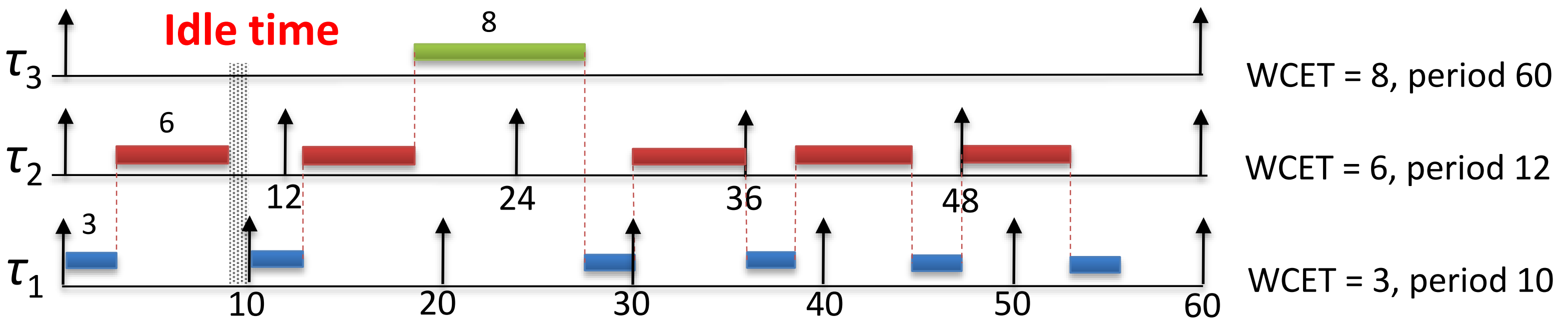
NP-RM and **NP-EDF** schedule of 3 periodic tasks



In fact, any **work-conserving policy** (EDF, RM, …) must schedule τ_3 here ➔ deadline miss for τ_2

Non-work-conserving scheduling

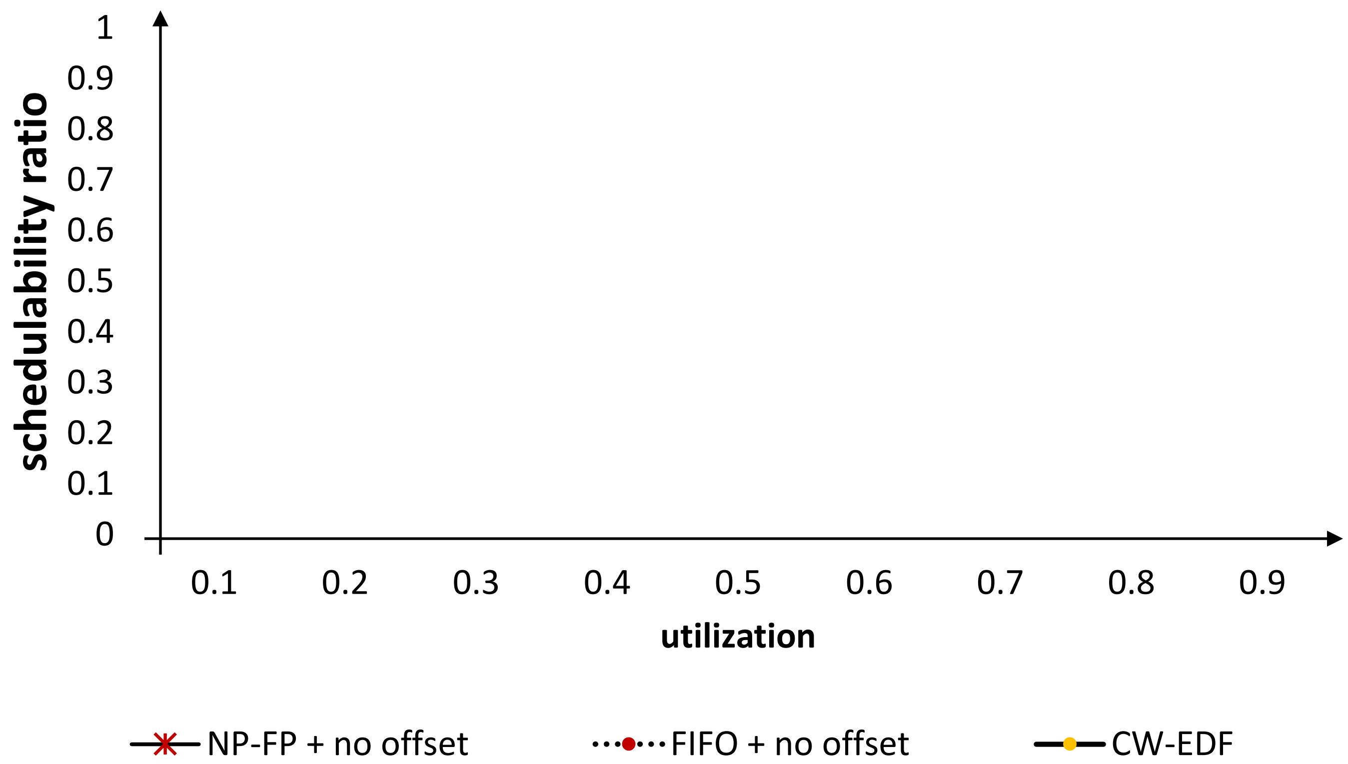
CW-EDF [Nasri et al. ECRTS'2016] schedule of the same 3 periodic tasks



CW-EDF considers ***future job arrivals*** in a "critical window" and postpones τ_3 until later.

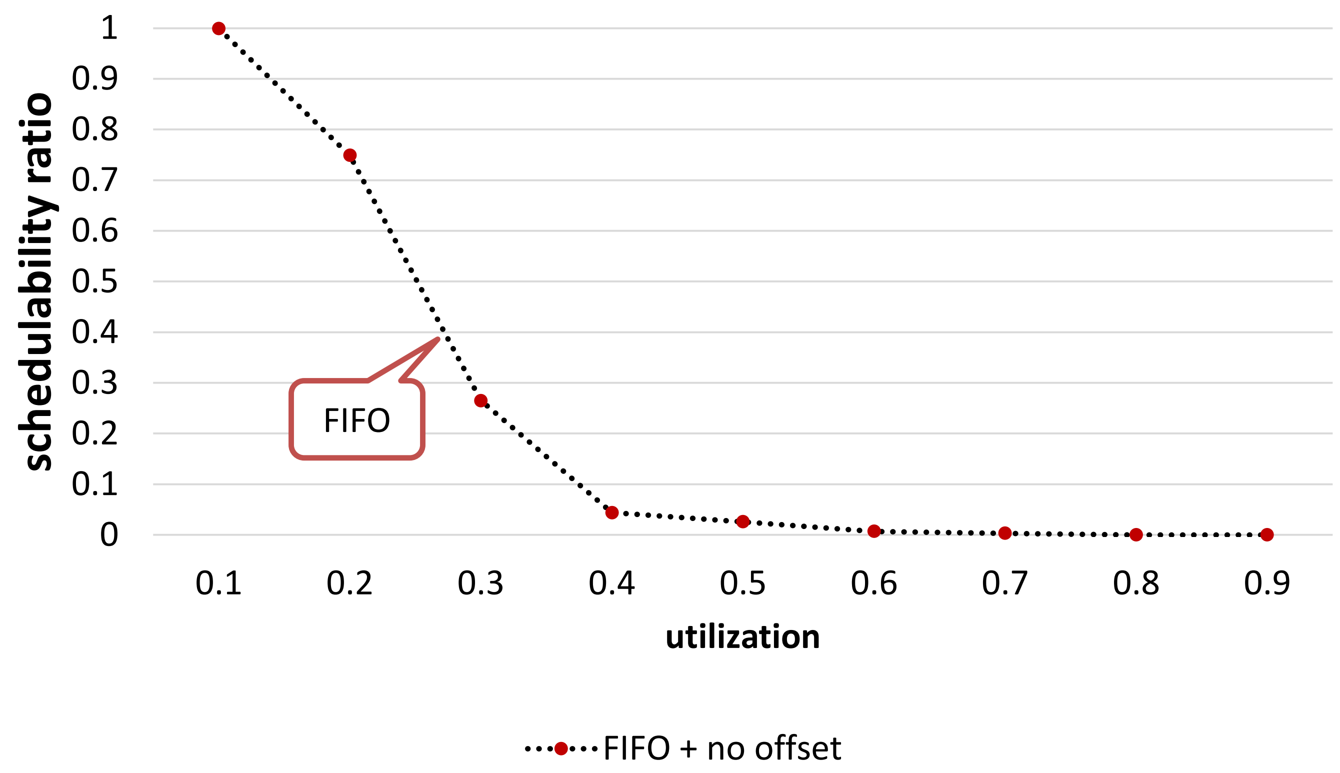
[Nasri'16] M. Nasri and G. Fohler, "Non-work-conserving non-preemptive scheduling: motivations, challenges, and potential solutions," in ECRTS, 2016

Non-work-conserving scheduling



- Periodic tasks that pass necessary schedulability tests, constructed in a similar way as Automotive benchmark tasks [Kramer'15]
- About 30 tasks in a task set.
- Deadline is equal to period.

Non-work-conserving scheduling



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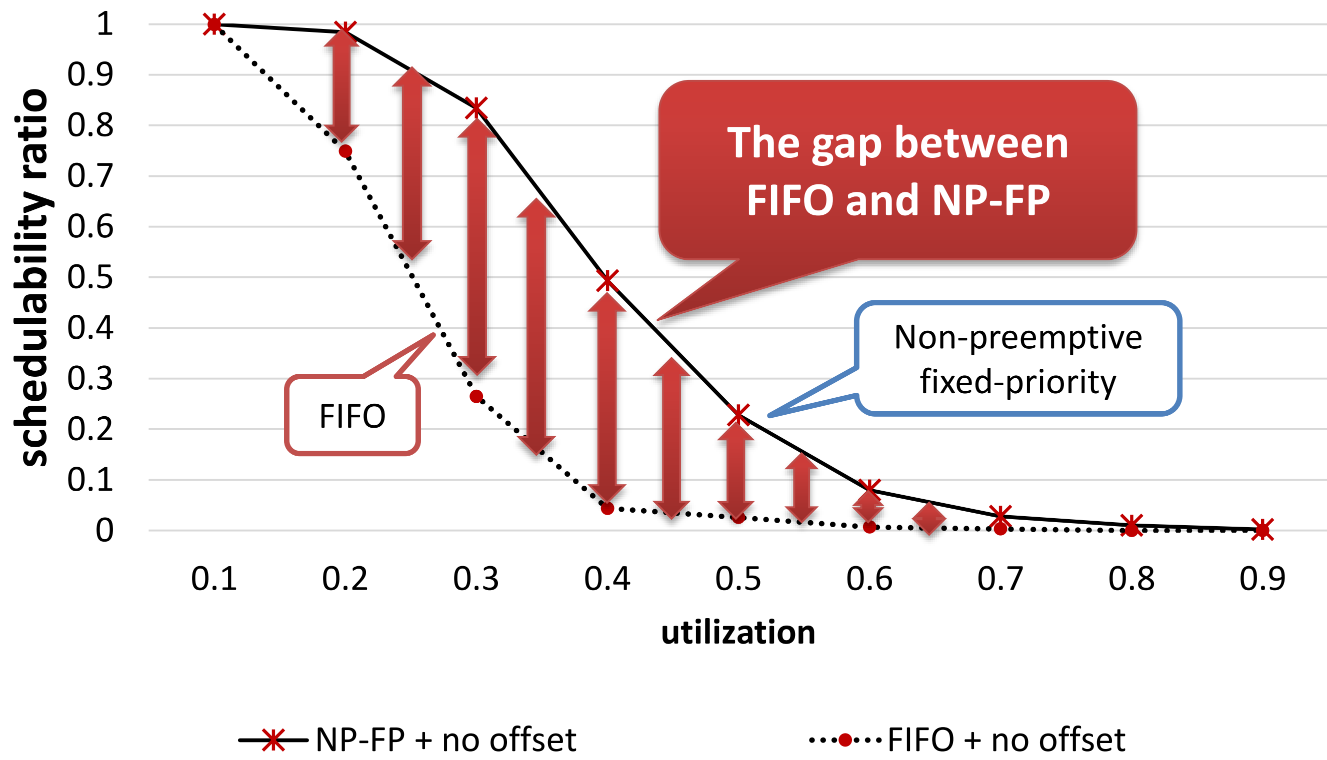

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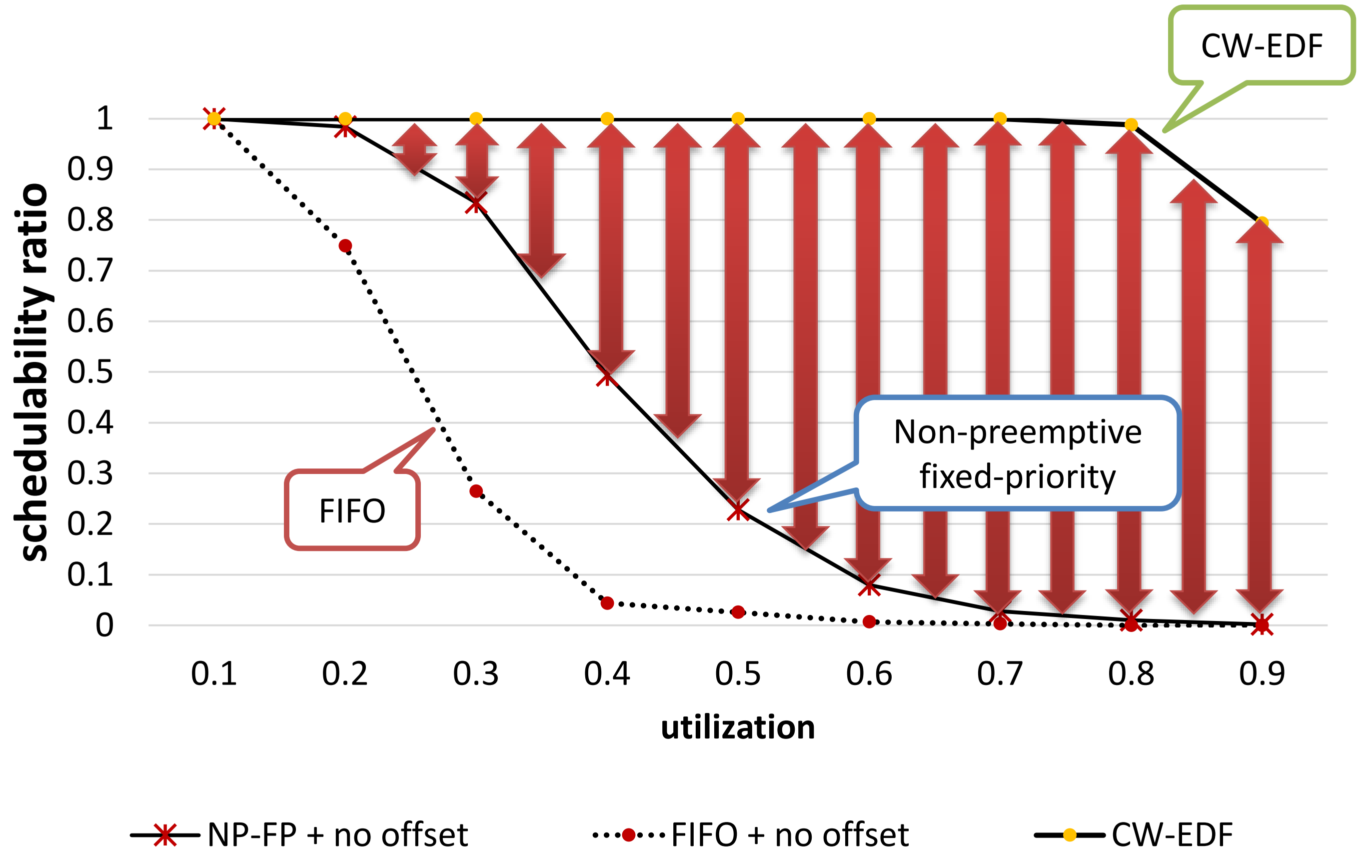

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Non-work-conserving scheduling

CW-EDF looks like a Promising solution

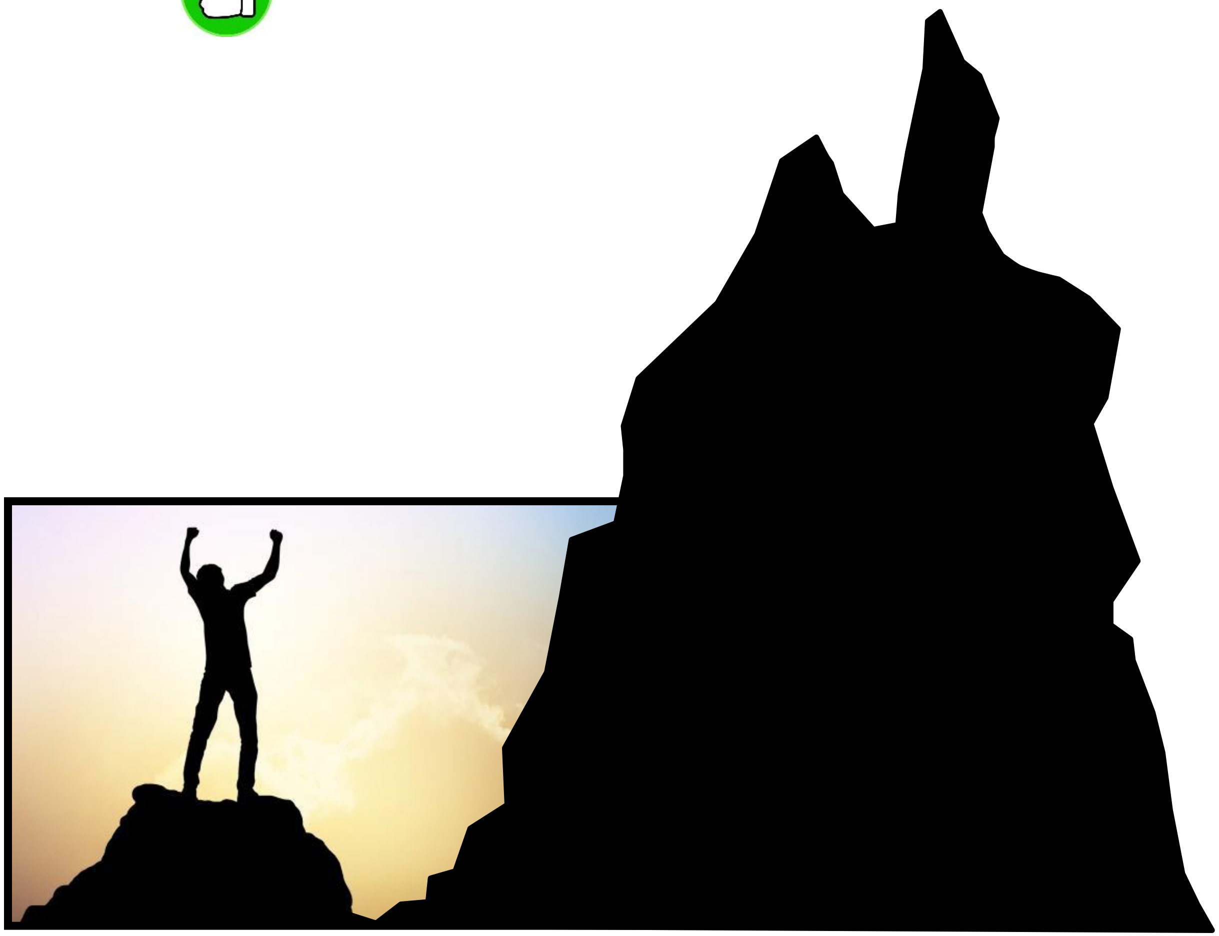
Non-work-conserving scheduling

CW-EDF looks like a Promising solution

however

Current implementations of CW-EDF has a considerable runtime overhead!

Example: on ATMega2560 @ 16 MHz, the overhead is 9.2x more than RM



How can we get

High schedulability

+

Low overheads

The secret behind CW-EDF's success

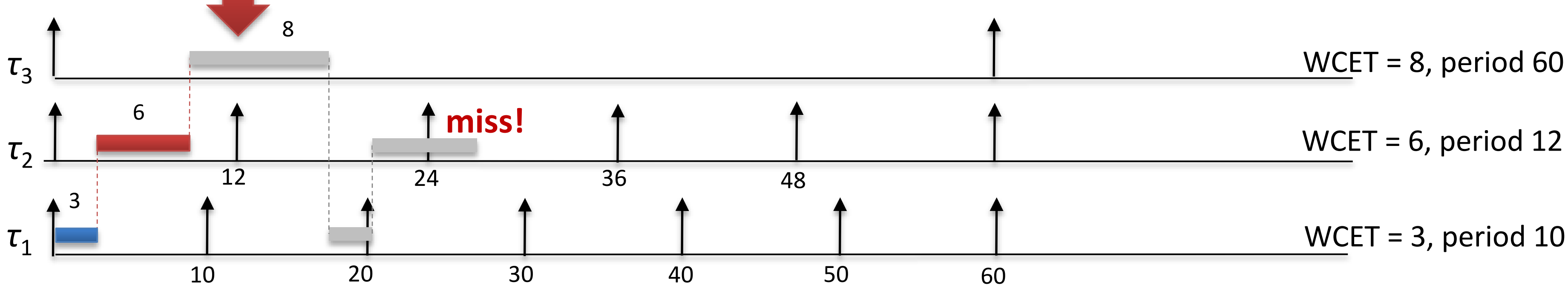
CW-EDF is able to leave the processor idle at the "right" moment

This is not possible in a work-conserving policy
unless the workload is **shaped**

Offset assignment is one way to shape (here only to "shift") **the workload**

τ_3 causes a deadline miss if it is released before time 12

To avoid that, we use an offset!



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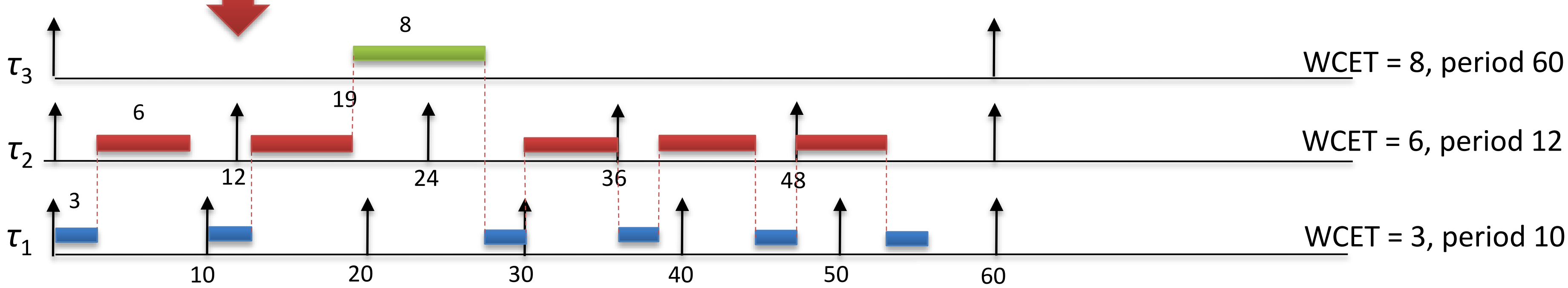


The state of the art

Single offset assignment for FIFO scheduling

1. Altmeyer, Sundharam, & Navet, 2016:

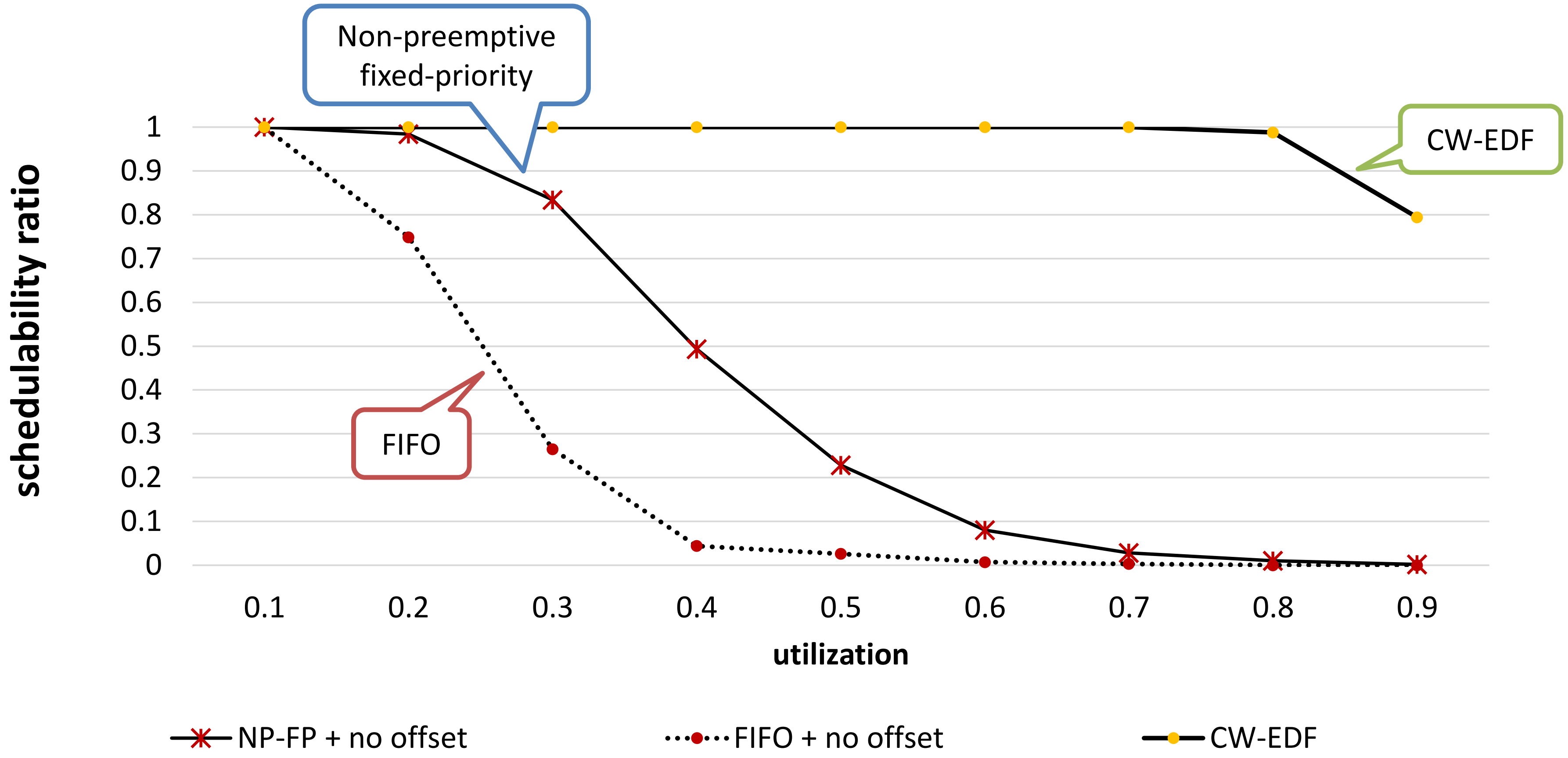
   Try many randomly assigned offsets

   This approach does not scale with the number of tasks and an increase in utilization

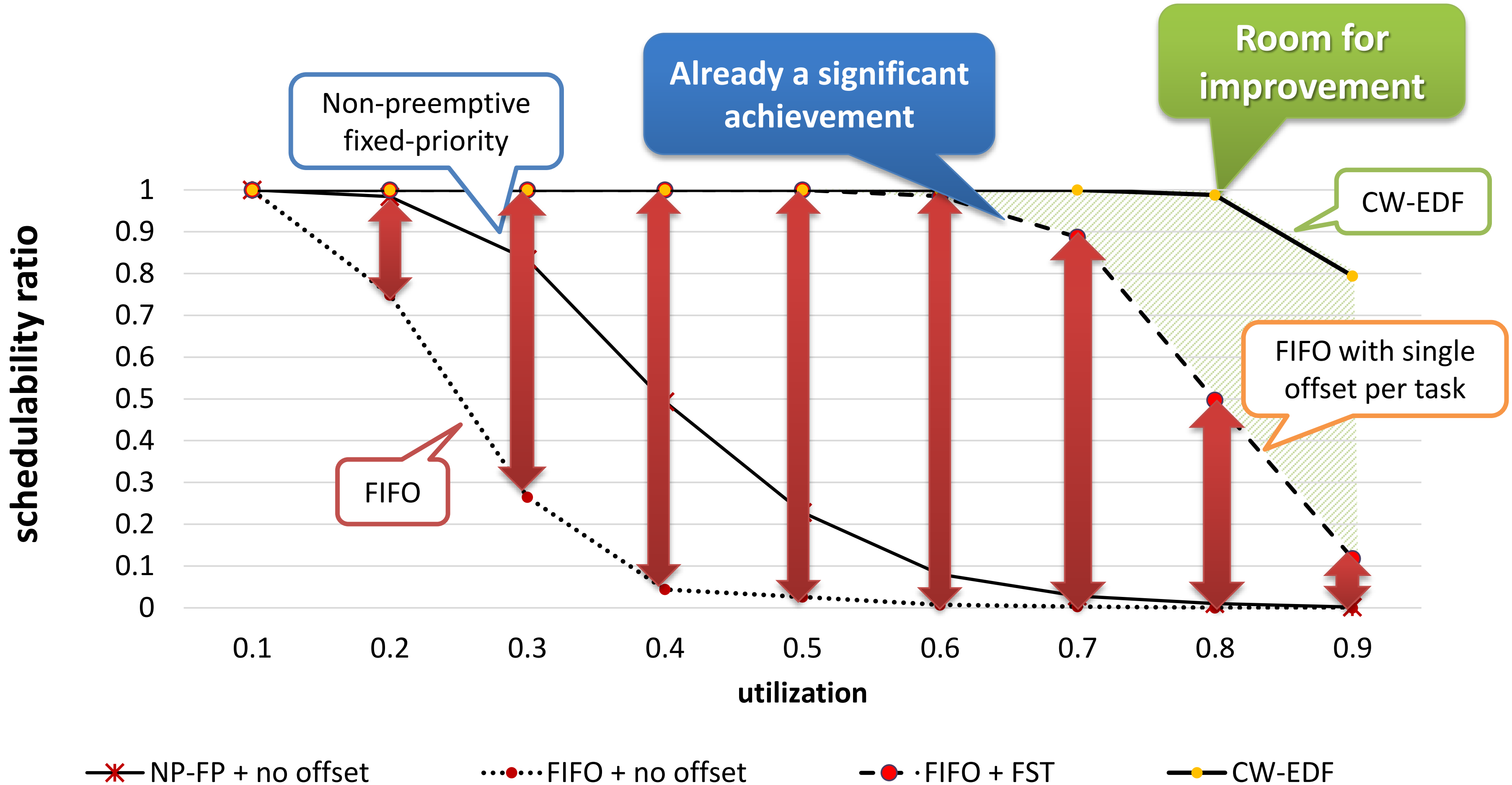
2. Nasri, Davis, & Brandenburg, RTAS'2018:

   Offset of a task is the start time of the first job of that task in a CW-EDF schedule (called FST approach)

Single offset assignment for FIFO scheduling

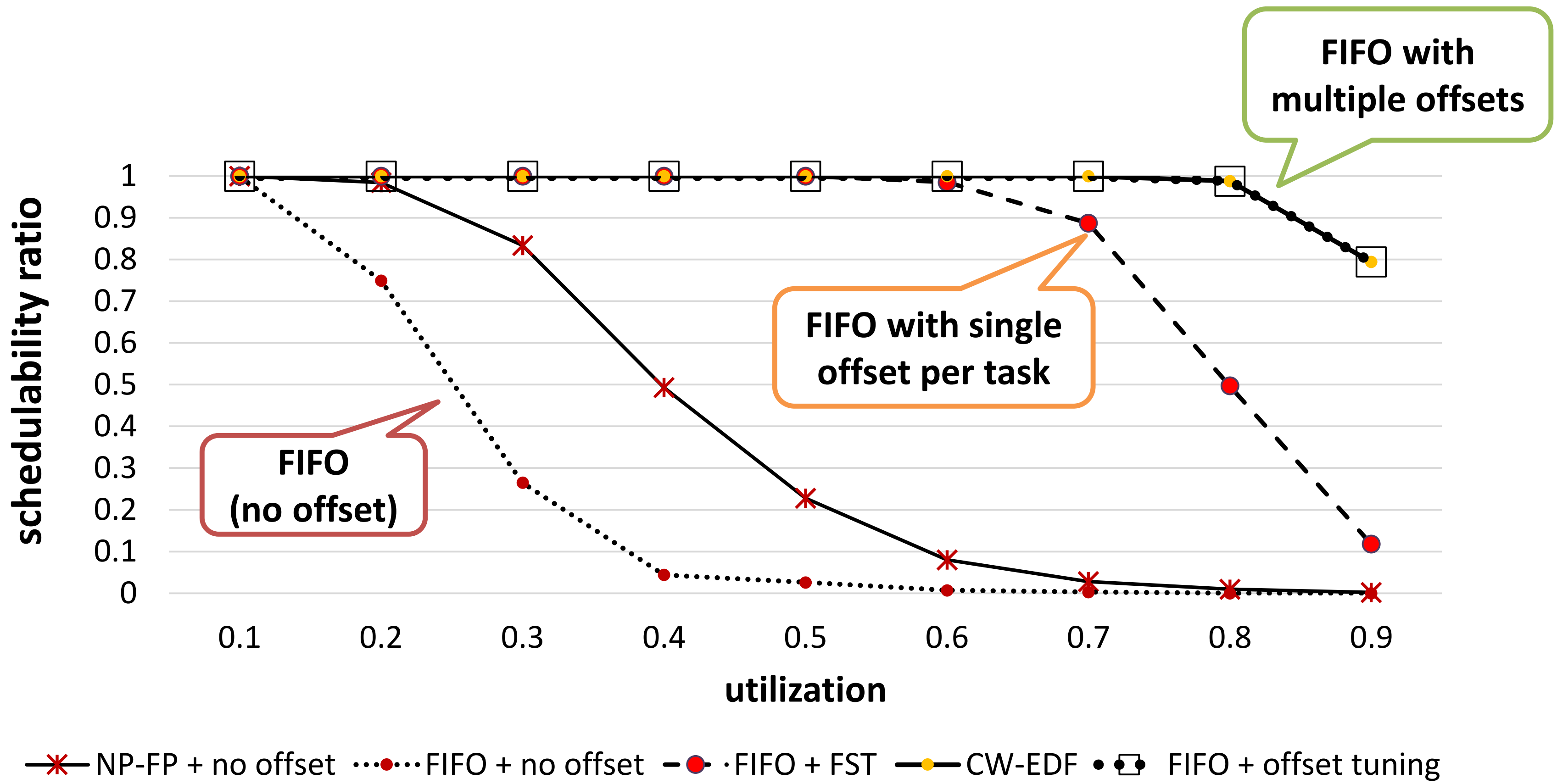


Single offset assignment for FIFO scheduling



Can we get even better results? Yes!

Our recent work showed that
by assigning **multiple offsets** to a task,
FIFO becomes as good as CW-EDF!



[Nasri, Davis, & Brandenburg, RTAS'2018]

Offset tuning technique [Nasri et al. RTAS'2018]

Intuition

Infer offsets from a given **feasible reference schedule**

while greedily **reducing the number of offset partitions**!

We used CW-EDF schedule as a reference

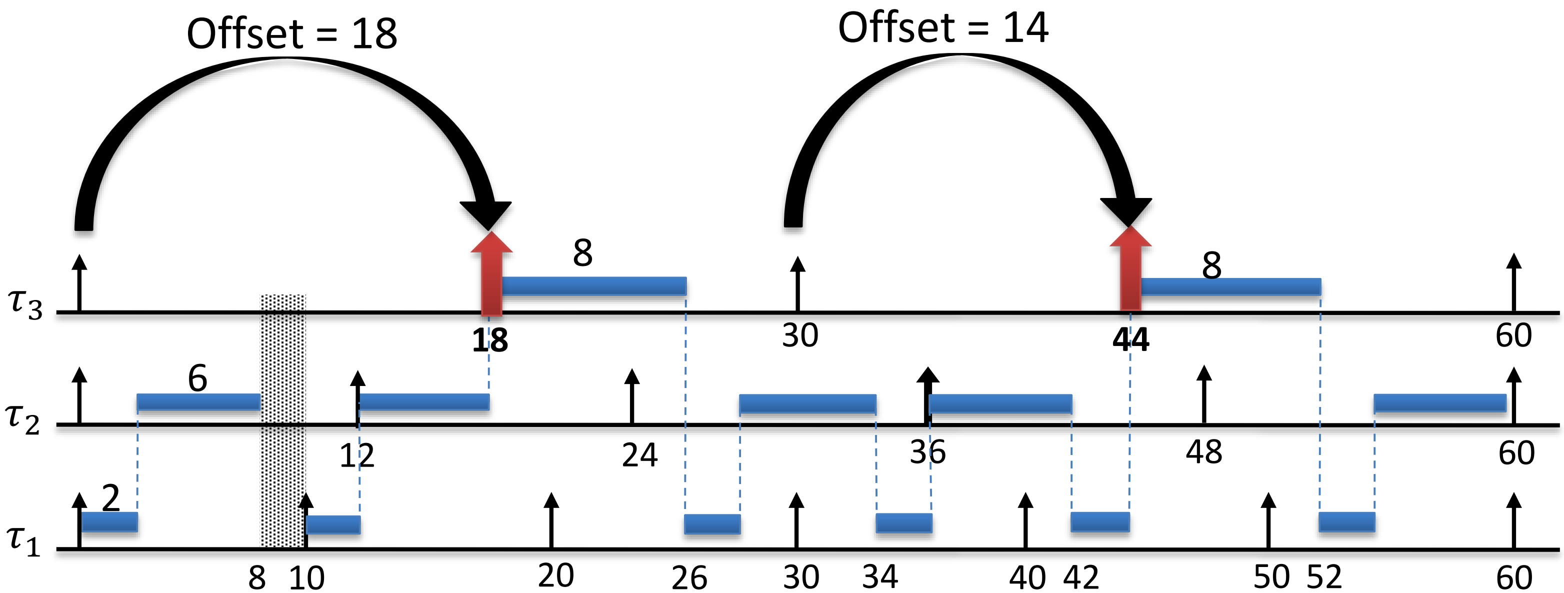
(since it has a very good schedulability ratio)

However, offset tuning is capable to force FIFO to rebuild "any" desired schedule at runtime

- ILP/SAT solving
- bespoke planning heuristics
- …

How to reduce the number of offsets? [Nasri et al. RTAS'2018]

CW-EDF reference schedule

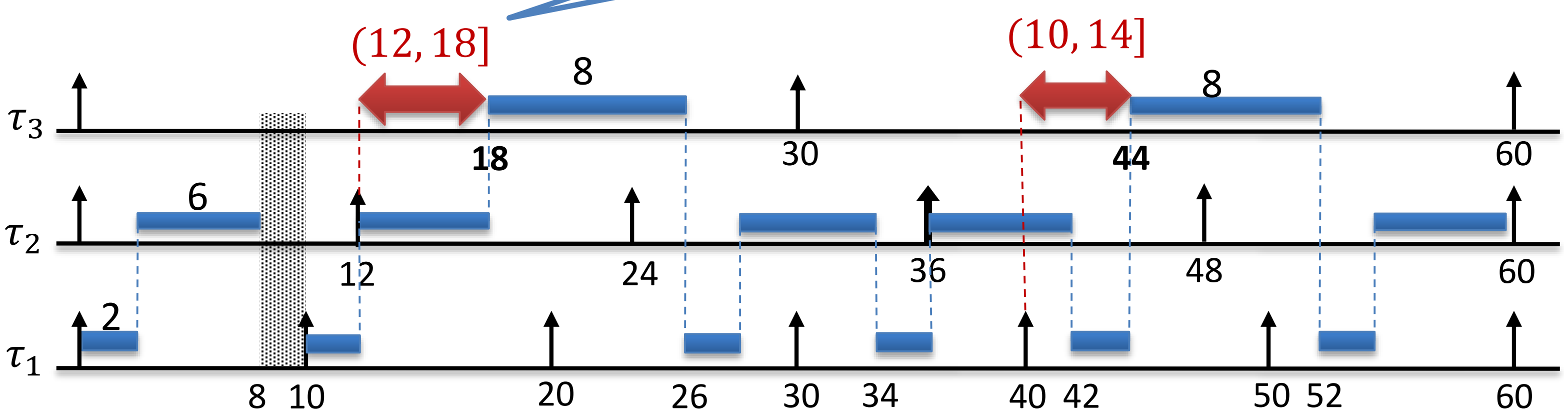


Can we use only one offset for both jobs?

How to reduce the number of offsets? [Nasri et al. RTAS'2018]

because FIFO schedules jobs with their **release order**

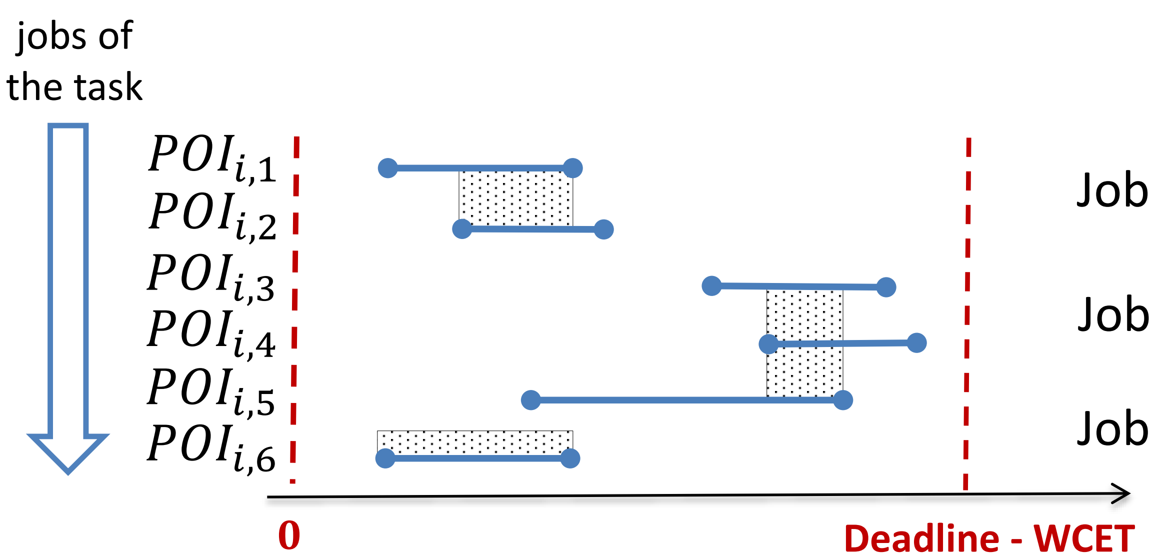
Any offset assignment within interval (12, 18] creates the **same job ordering**
(τ_3 will be scheduled after the second job of τ_2)



Any offset assignment from the **intersection** of (12, 18] and (10, 14] creates the desired **job ordering** for both jobs $J_{3,1}$ and $J_{3,2}$

How to reduce the number of offsets? [Nasri et al. RTAS'2018]

1. We defined **schedule equivalency**
2. We defined **potential offset intervals (POI)**
3. We introduced a **greedy heuristic** to find largest **job partitions** that can use the same relative offset

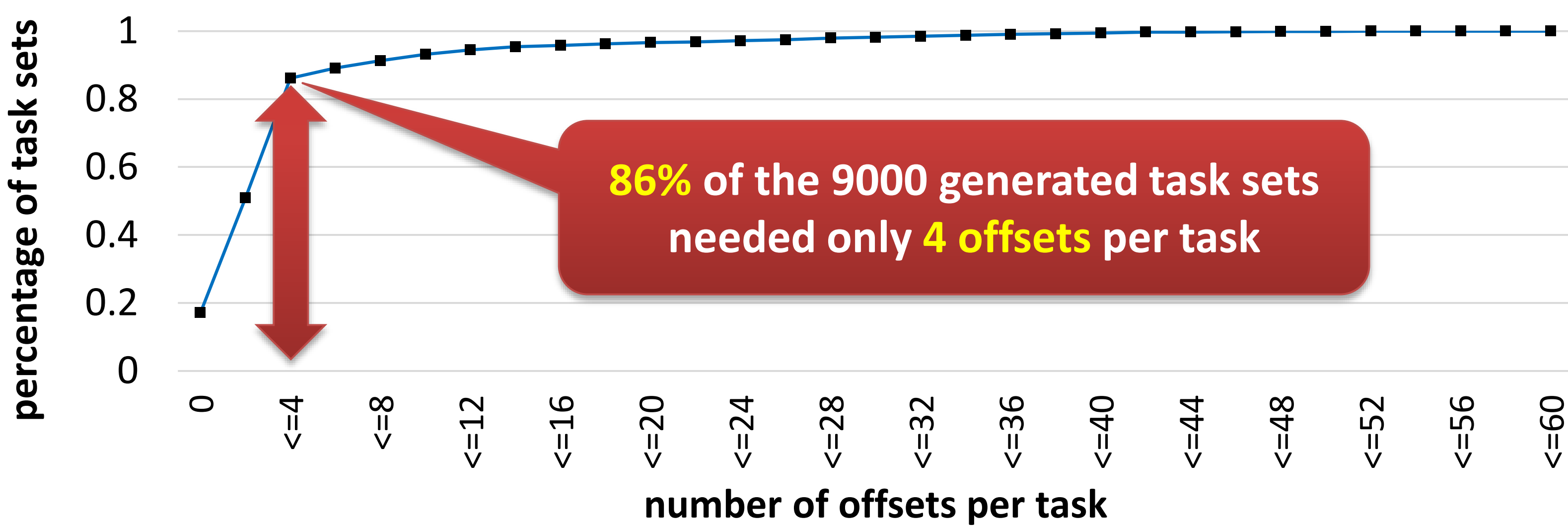


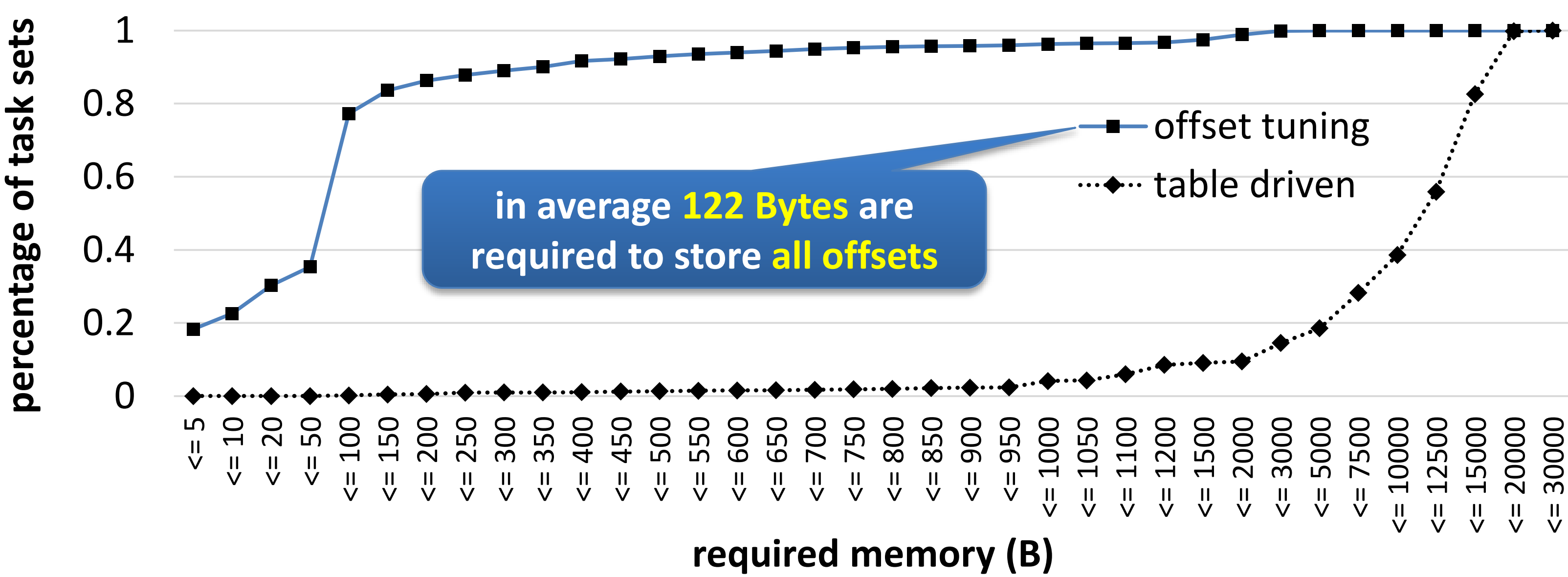
Job partition 1: $\{J_{i,1}, J_{i,2}\}$

Job partition 2: $\{J_{i,3}, J_{i,4}, J_{i,5}\}$

Job partition 3: $\{J_{i,6}\}$

Some results





Same experimental setup: About 30 tasks in a task set. Deadline is equal to period. Periodic tasks that pass necessary schedulability tests, constructed in a similar way as Automotive benchmark tasks [Kramer'15]

Open problems

Outline

Open Problem 1:
How to find offsets?

Open Problem 2:
How to minimize the number of offsets?

Open Problem 3:
How to deal with release jitters?

Open Problem 1

Initial offset

Given a set of $\boldsymbol{n}$ *periodic tasks*

(characterized C_i, T_i, D_i, O_i, where O_i is the initial offset),

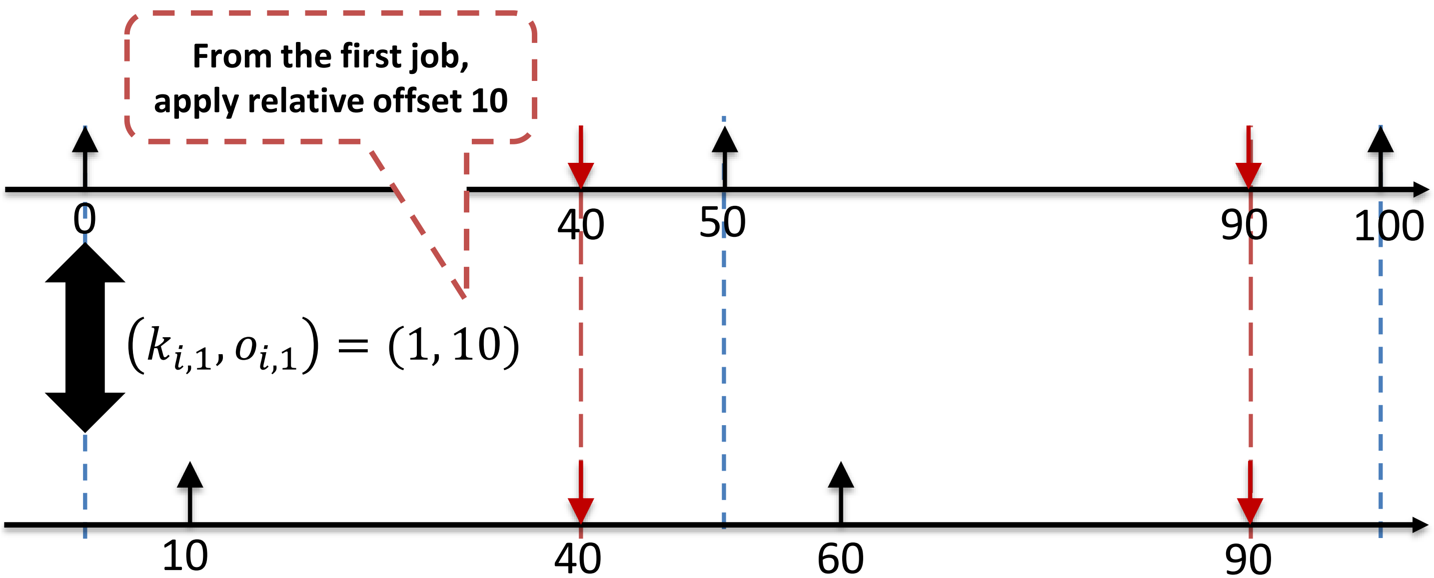
Relative offset

Find a set of offset pairs $\hat{O} = \{(k_{i,1}, o_{i,1}), (k_{i,2}, o_{i,2}), \ldots, (k_{i,m_i}, o_{i,m_i})\}$

such that the resulting task set is **FIFO schedulable**.

Job # from which the relative offset is applied

We assume that **job's relative deadline** is **not affected** by relative offsets!



Open Problem 1

Given a set of $\boldsymbol{n}$ *periodic tasks*

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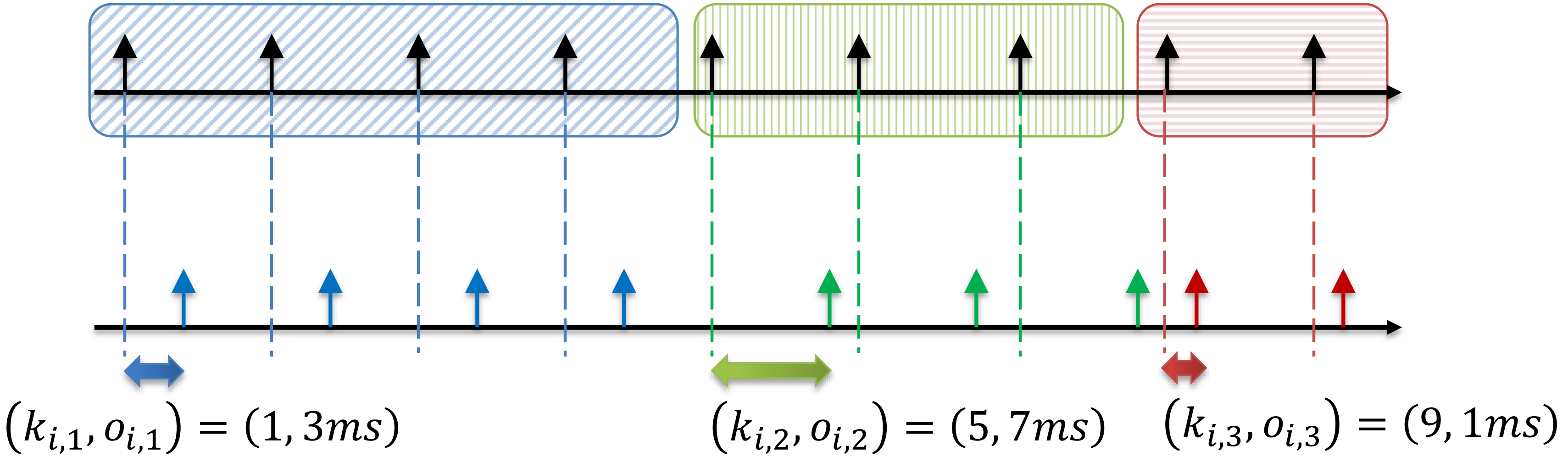
Visualization of offset pairs:



Challenges of Open Problem 1

As an extreme case,

assume we assign an **offset** **to each** **job** of a task

Now, the problem is reduced to

finding a non-preemptive schedule for a set of periodic tasks

Open problem 1 is strongly NP-Hard

Since non-preemptive scheduling of periodic tasks is a strongly NP-Hard problem [Jeffay 1991]

In our recent work [Nasri et al. RTAS'2018] we find solution **only if** the task set is **CW-EDF schedulable**.

Challenges of Open Problem 1

As an <u>extreme case</u>,

assume we assign an **offset to each job** of a task

↓

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↓

Open problem 1 is strongly NP-Hard

Since non-preemptive scheduling of periodic tasks is a strongly NP-Hard problem [Jeffay 1991]

The space of possible offsets is large and unstructured

↓

Iterative approaches cannot be easily applied

Storing too many offsets per task might not be feasible

When the system has a **limited memory**

Open Problem 2

Given a set of $\boldsymbol{n}$ *periodic tasks*

(characterized C_i, T_i, D_i, O_i, where O_i is the initial offset),

Find a set of offset pairs $\hat{O} = \{(k_{i,1}, o_{i,1}), (k_{i,2}, o_{i,2}), \ldots, (k_{i,m_i}, o_{i,m_i})\}$

such that the resulting task set is **FIFO schedulable**

and the **total number of offset pairs** is **minimized**, i.e.,

$$\text{Min} \sum_{i=1}^{n} |\widehat{O_i}|$$

In our prior work [Nasri, Davis, Brandenburg RTAS'2018],

we solve Open Problem 1

while trying to **reducing** **the number of offset pairs**

Other practical aspects

In practice, systems usually have release jitter

due to interrupt handling routine, buffers, networking delays, etc.

FIFO scheduling is NOT sustainable w.r.t. release jitter

An offset assignment is needed that guarantees schedulability in the presence of release jitter

Open Problem 3

Bounded release jitter

Given a set of $\boldsymbol{n}$ *periodic tasks*

(characterized C_i, T_i, D_i, O_i, J_i, where J_i is the **release jitter**),

Find a set of offset pairs $\hat{O} = \{(k_{i,1}, o_{i,1}), (k_{i,2}, o_{i,2}), \dots, (k_{i,1}, o_{i,m_i})\}$

such that the resulting task set is **FIFO schedulable**.

Challenge

there is no FIFO schedulability analysis that considers release jitters

Summary

Our recent work [Nasri et al. RTAS'2018] showed that

FIFO schedulability can be significantly improved with the help of offsets

Open problems

How to **find** offsets that make FIFO schedulable?

How to **minimize** The total number of offsets?

How to assign offsets in the presence of **release jitters**?

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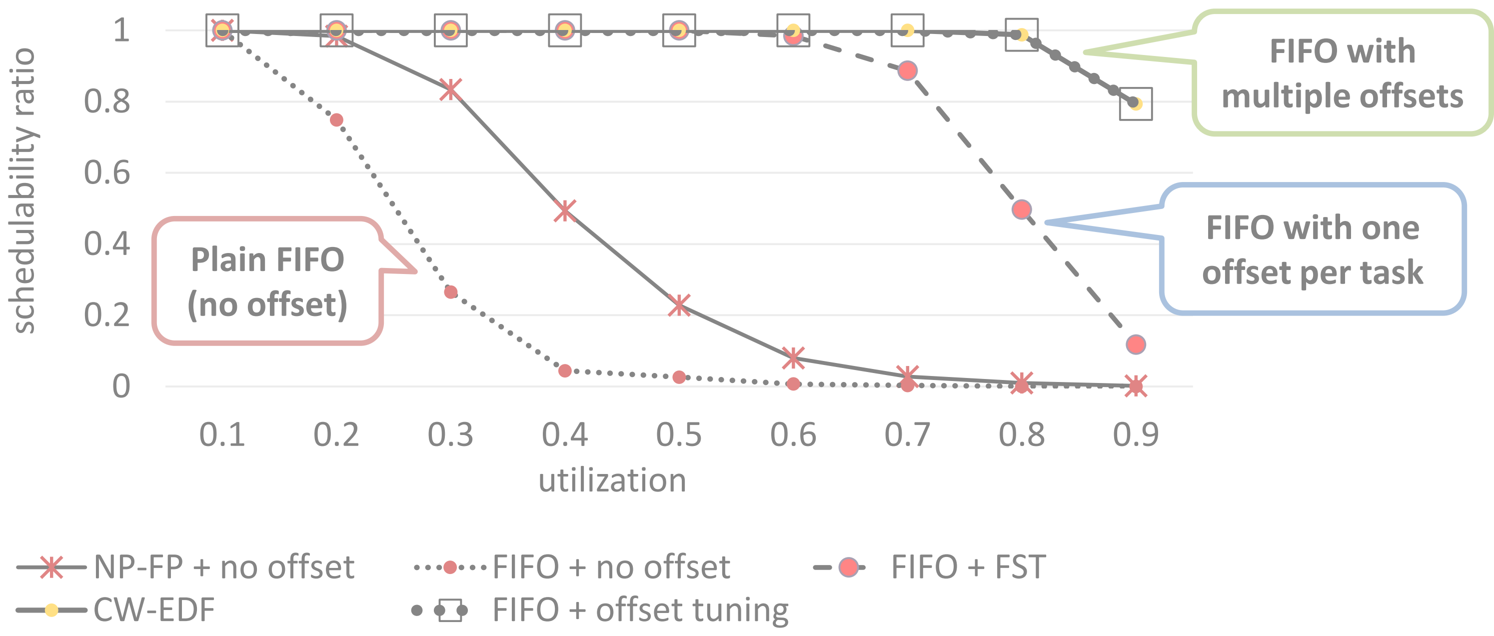

Thank you