Non-Work-Conserving Scheduling in Non-Preemptive Event-Driven Real-Time Systems

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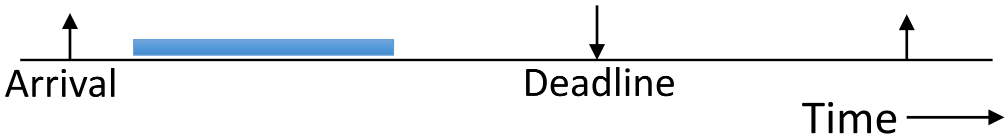
Real-Time Systems

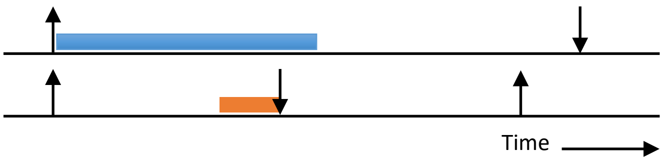
A systems correctness depends on

Logical correctness of results

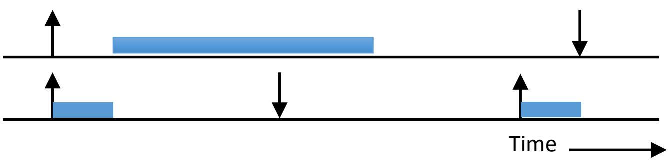
Timing correctness of results

What is scheduling?





Important to schedule the correct task!



Non-preemptive scheduling

Why non-preemptive scheduling?

No preemption support — Small microcontrollers

Timing predictability — More predictably cache

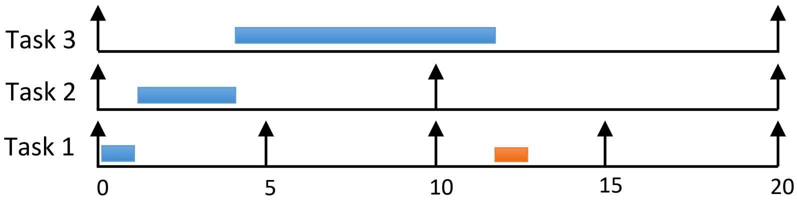
Lower overhead — No context switches

Non-preemptive scheduling is hard

- No known optimal scheduling policy
- No known optimal idle-time insertion policy

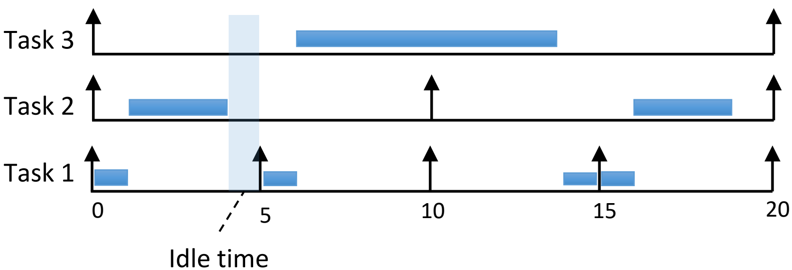
Try all possible combinations of tasks and idle times…

Non-preemptive scheduling anomalies



Non-Preemptive Rate Monotonic (NP-RM)

Schedule the next pending job with the smallest period



Non-work-conserving

Before scheduling, verify no deadline miss.
If so? Wait…

Existing non-work-conserving policies

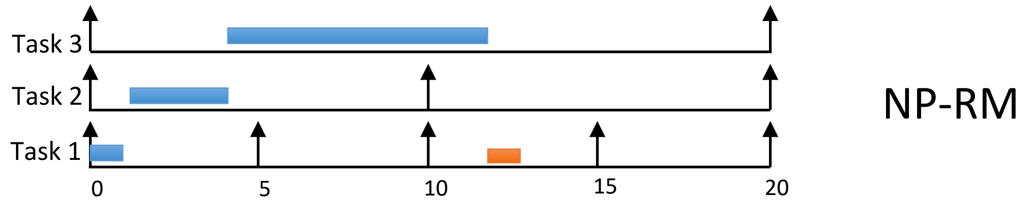
- **Precautious-RM (PRM)** [1]
  - Lower success rate in meeting deadlines (schedulability)
  - Small overhead: PRM checks deadline miss for only 1 task.

- **Critical-Window EDF (CW-EDF)** [2]
  - Higher schedulability
  - Considerable overhead: CW-EDF checks deadline miss for all tasks.

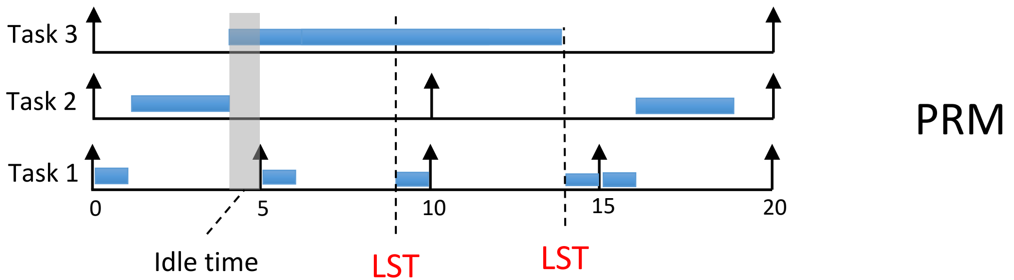
[1] M. Nasri and M. Kargahi. Precautious-RM: A predictable non-preemptive scheduling algorithm for harmonic tasks. Real-Time Syst., 50(4):548–584, July 2014.
[2] M. Nasri and G. Fohler. Non-work-conserving non-preemptive scheduling: Motivations, challenges, and potential solutions. In 2016 28th Euromicro Conference on Real-Time Systems (ECRTS), pages 165–175, 2016.

Precautious-RM

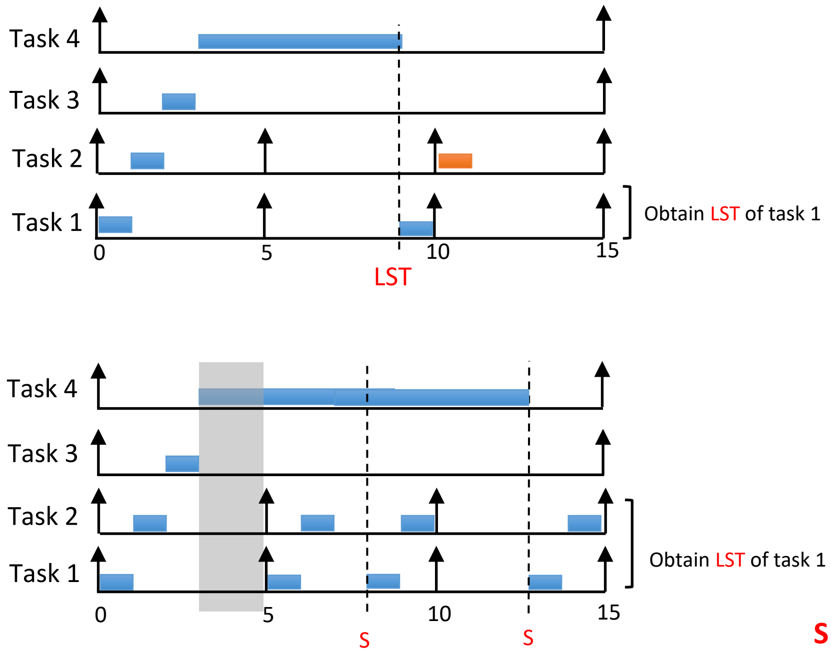
M. Nasri and M. Kargahi. Precautious-RM: A predictable non-preemptive scheduling algorithm for harmonic tasks. Real-Time Syst., 50(4):548–584, July 2014.



Check if the next job can finish before the latest start time (LST) of the next job of task 1



Limitations of Precautious-RM



PRM only checks the LST of task 1.

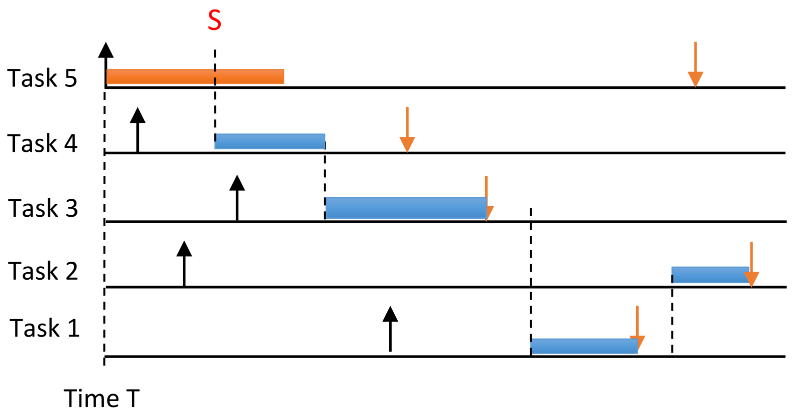
S is the smallest **LST**

M. Nasri and M. Kargahi. Precautious-RM: A predictable non-preemptive scheduling algorithm for harmonic tasks. Real-Time Syst., 50(4):548–584, July 2014.

CW-EDF overhead

M. Nasri and G. Fohler. Non-work-conserving non-preemptive scheduling: Motivations, challenges, and potential solutions. In 2016 28th Euromicro Conference on Real-Time Systems (ECRTS), pages 165–175, 2016.

1. Sort non-pending future jobs by deadline
2. Obtain the latest start time of these jobs, called **S**
3. Check if the current job can finish before start time **S**



Further limitations

CW-EDF and PRM require a concrete knowledge of the arrival times of the future jobs

- **Do not support periodic tasks with release jitter**
- **Do not support event-triggered tasks**

Problem statement

- Design a policy for time-triggered tasks which has:
  - Lower overhead than CW-EDF
  - Higher schedulability than PRM
- Design a policy for event-triggered tasks which has:
  - Less deadline misses in a **soft** real-time environment
  - Workloads can be characterized by an **arrival curve**

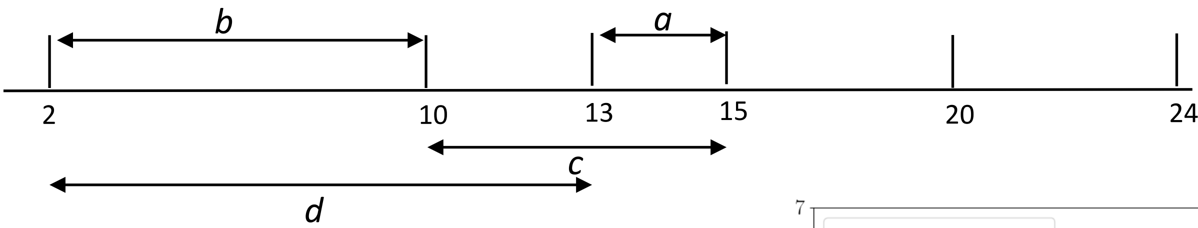
Types of timing constraints

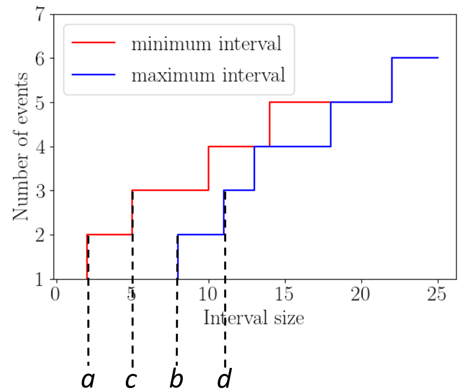
- Hard real-time
  - Missing the deadline may cause catastrophic consequences

- Soft real-time
  - Missing the deadline causes performance degradation

What is an arrival curve?

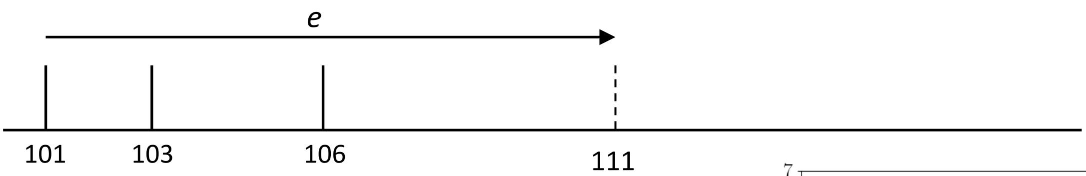
- An arrival curve represents the **lower bound** and **upper bound** on the **inter-arrival time between consecutive events in a system**.
- Arrival curves are obtained from measurements and are widely used in the industry.



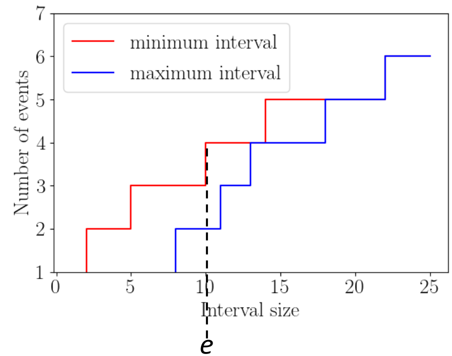


Why handling event-triggered tasks with arrival curves is not straight forward?

- We need a history of prior events
  - Costs memory
  - History must be updated
- How to decide based on history and the curve?
  - Larger history leads to more overhead



Until 111 there is no arrival, because of the minimal arrival time between 4 consecutive jobs



Contributions

A non-work-conserving scheduling policy for time-triggered tasks

- Lower run-time overhead
- Equal schedulability to CW-EDF

A non-work-conserving scheduling policy for event-triggered tasks

- Reduce deadline misses

Building a new non-work-conserving scheduling policy for time-triggered tasks

K-Precautious-EDF (KP-EDF)

The intuition

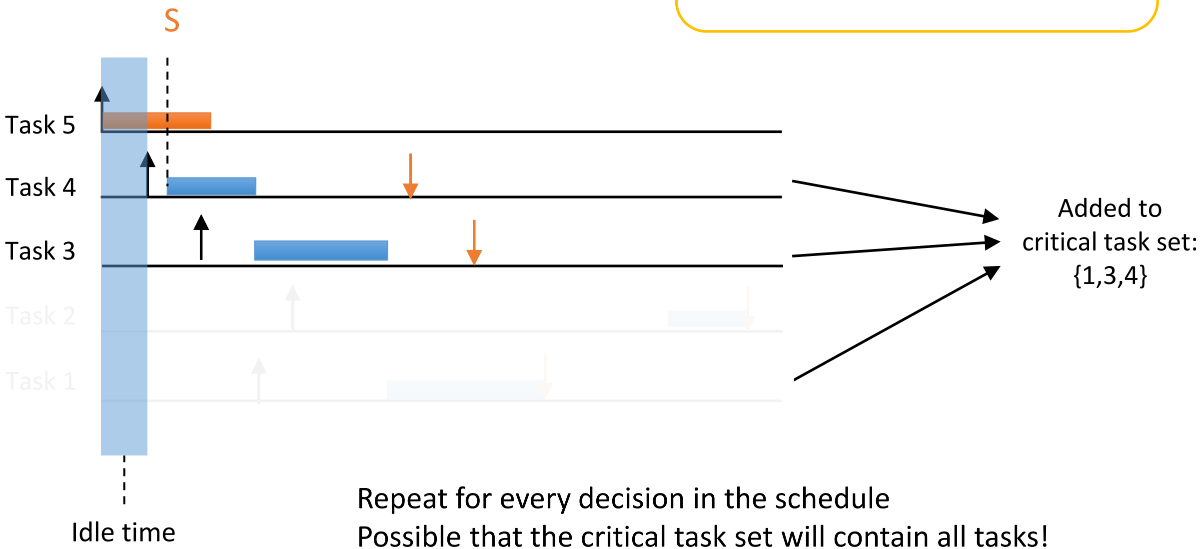
- Use CW-EDF as a baseline
- Reduce the number of tasks we look at for each idle-time decision of CW-EDF

How to identify critical tasks?

How many of those tasks?

Implementation: finding critical tasks

Ignore the task with the latest deadline



Repeat for every decision in the schedule
Possible that the critical task set will contain all tasks!

KP-EDF: Achievements

Reduced overhead

KP-EDF looks at k amount of tasks, instead of all other tasks

Equal schedulability

KP-EDF has the same idle-time decisions as CW-EDF

Evaluation of KP-EDF

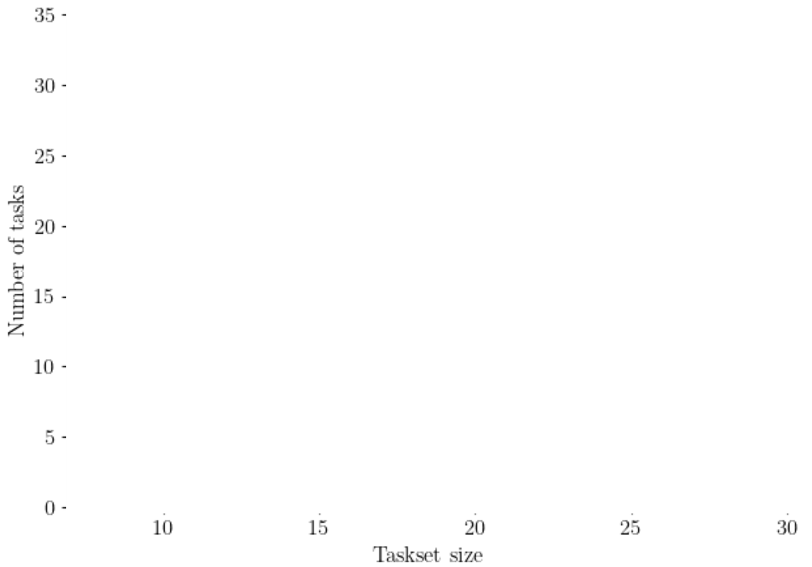
- Inspect influence of
  - Number of tasks n
  - Utilization U

- Random workload generation methods
  - Automotive benchmarks [Kramer, et al. 2015]
  - Log-uniform period generation [Emberson, et al. 2010]

- Overhead measured on Arduino Mega

Automotive: critical task set size

Periods: 1, 2, 5, 10, 20, 50, 100, 200, 500, 1000

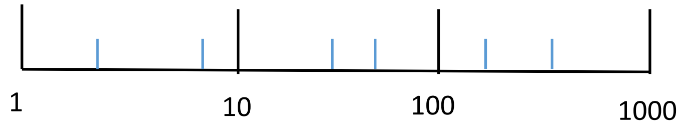


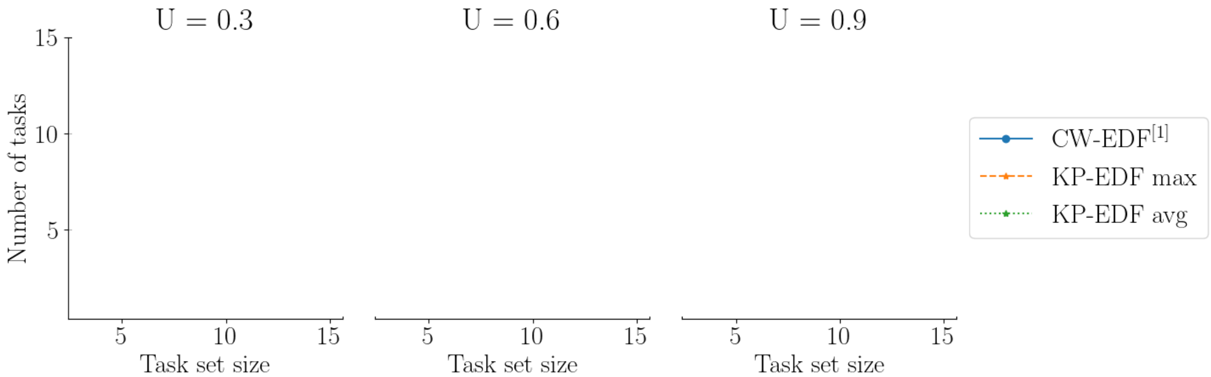
KP-EDF has the same overhead as PRM

[1] M. Nasri and G. Fohler. Non-work-conserving non-preemptive scheduling: Motivations, challenges, and potential solutions. In 2016 28th Euromicro Conference on Real-Time Systems (ECRTS), pages 165–175, 2016.

Log-uniform periods: critical task set size

Periods:

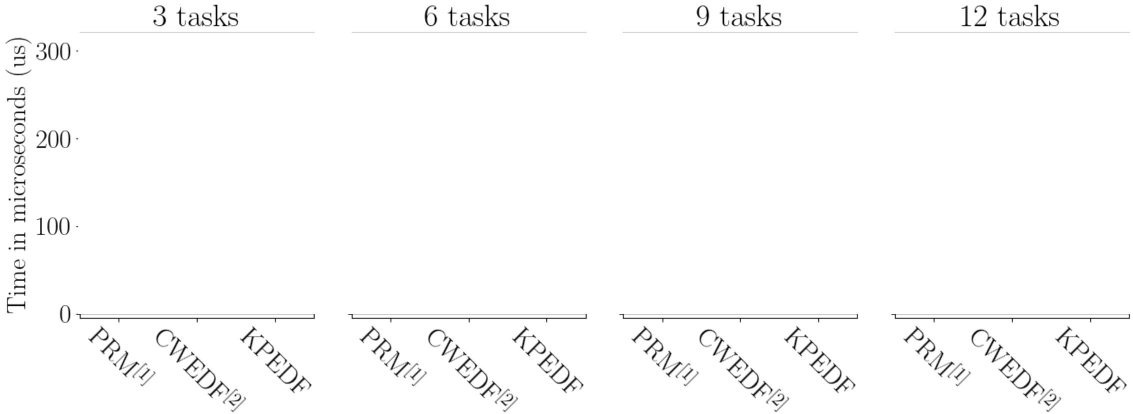




KP-EDF has low overhead for log-uniform task sets

[1] M. Nasri and G. Fohler. Non-work-conserving non-preemptive scheduling: Motivations, challenges, and potential solutions. In 2016 28th Euromicro Conference on Real-Time Systems (ECRTS), pages 165–175, 2016.

KP-EDF Overhead



Significant lower overhead up to 60%

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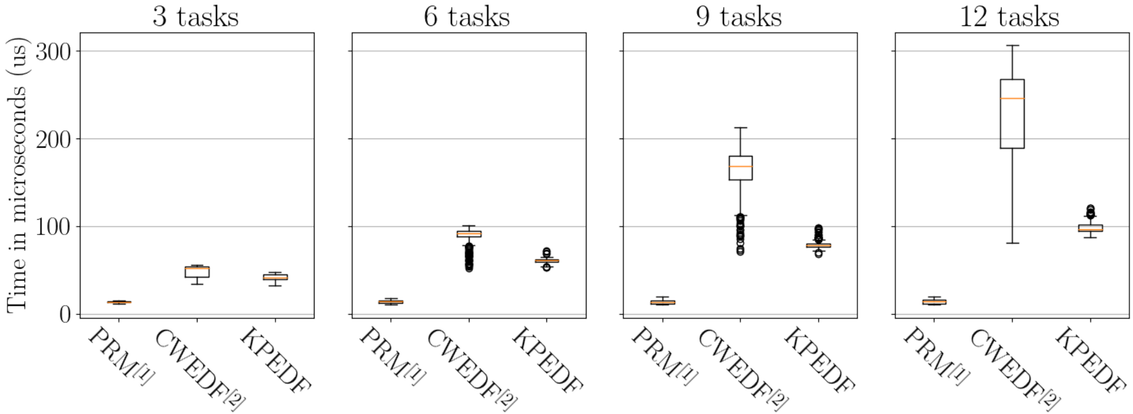
Using log uniform task sets with a utilization of [0.50,0.95]

KP-EDF Overhead



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Contributions

A non-work-conserving scheduling policy for time-triggered tasks

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A non-work-conserving scheduling policy for event-triggered tasks

- Reduce deadline misses

Building a new non-work-conserving scheduling policy for event-triggered tasks

Arrival Curve-EDF (ArC-EDF)

The intuition

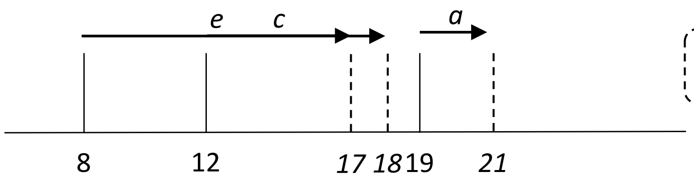
- Use CW-EDF as baseline
- Use the arrival curve to estimate the next arrival

Estimate based on last arrivals in the history

Use the best estimation as next arrival time

Implementation: estimating next arrival

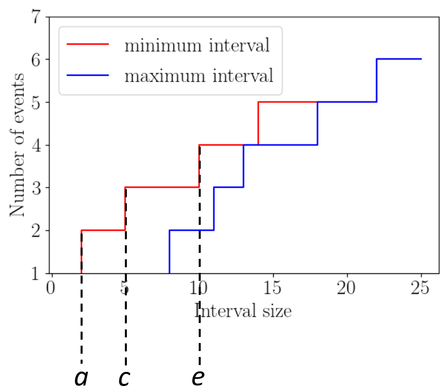
History: 8, 12, 19



Use maximum: 21

Calculate multiple estimates of the next arrival

Add minimal inter-arrival time to history



Implementation: different inter-arrival times

Pick value between the minimum and maximum inter-arrival times

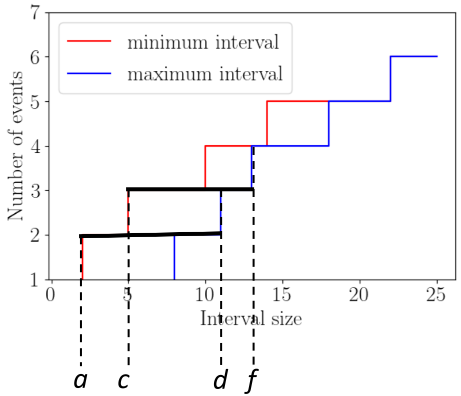
For two consecutive events: between *a* and *d*

For three consecutive events: between *c* and *f*

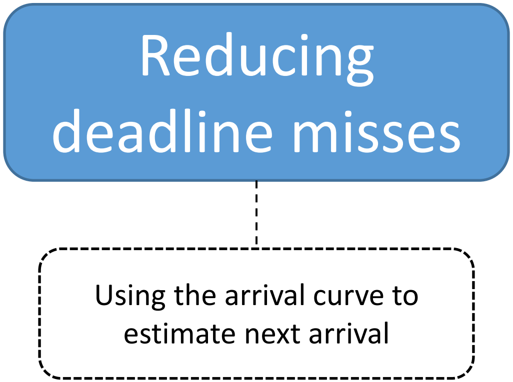
…

One set for the entire policy

ArC-EDF with chosen values is one policy



Achievements: ArC-EDF



Evaluation of ArC-EDF

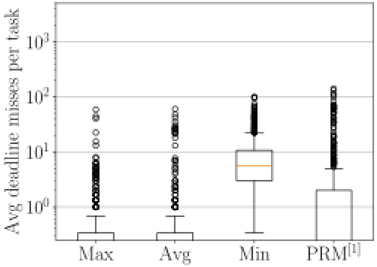
- Inspect impact of
  - Number of tasks n
  - Utilization U
  - History size
  - Release jitter factor

- Based on log uniform task sets
  - Add random (uniform) release jitter to time-triggered tasks

ArC-EDF: Impact of number of tasks

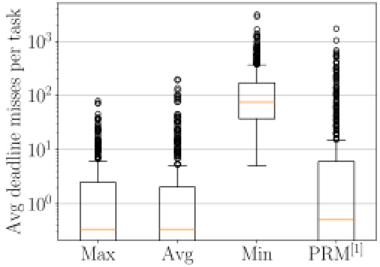
U = 0.8
History = 1
Factor = 1

3 tasks



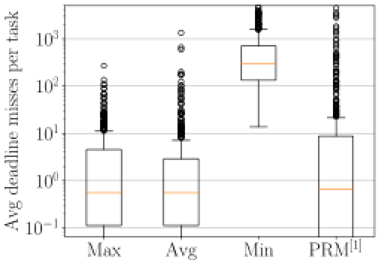
Our work

6 tasks



Our work

9 tasks



Our work

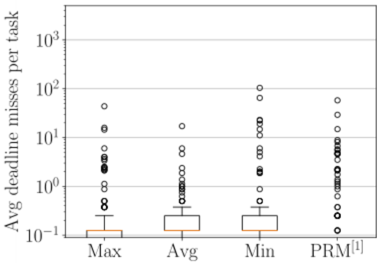
ArC-EDF inserts many idle-times when using the minimum inter-arrival time

[1] M. Nasri and M. Kargahi. Precautious-RM: A predictable non-preemptive scheduling algorithm for harmonic tasks. Real-Time Syst., 50(4):548–584, July 2014.

ArC-EDF: Impact of utilization

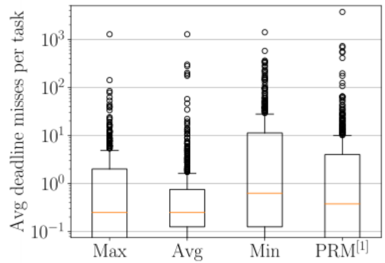
N = 8
History = 1
Factor = 1

30%



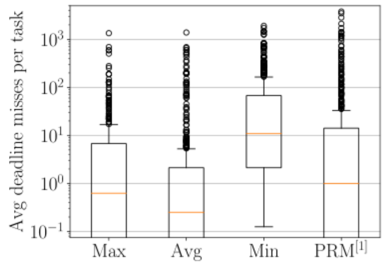
Our work

60%



Our work

90%



Our work

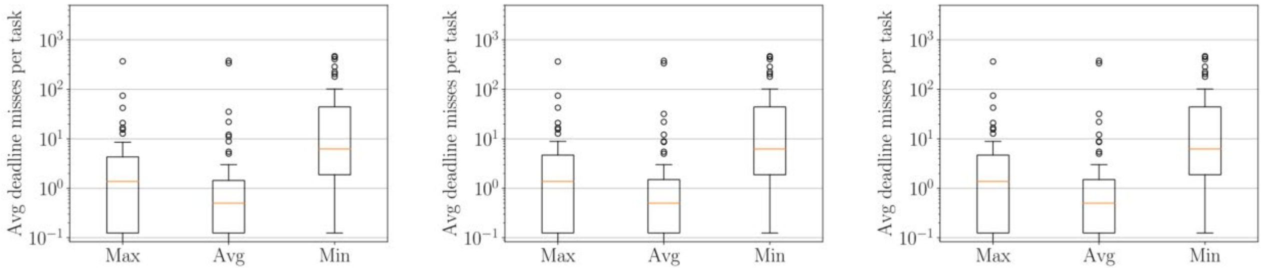
ArC-EDF has less deadline misses when using the average inter-arrival time

[1] M. Nasri and M. Kargahi. Precautious-RM: A predictable non-preemptive scheduling algorithm for harmonic tasks. Real-Time Syst., 50(4):548–584, July 2014.

ArC-EDF: Impact of history size

N = 8
U = 0.8
Factor = 1

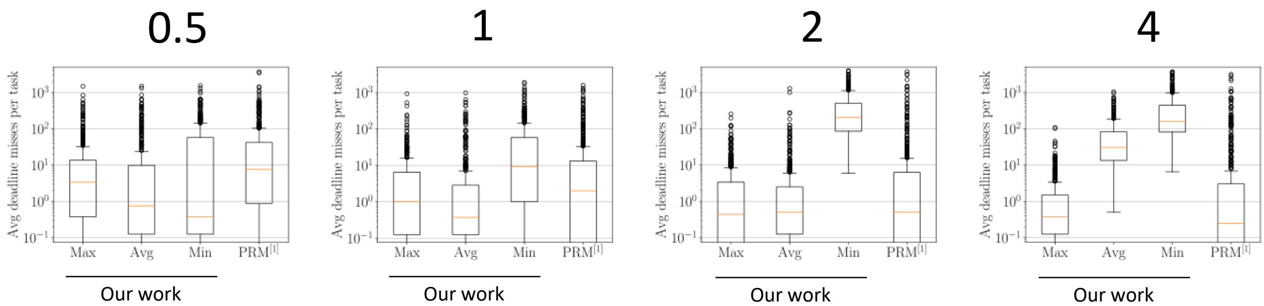
Size 1 | Size 5 | Size 10



History has no impact on deadline misses

ArC-EDF: Impact of release jitter factor

n = 8
U = 0.8
History = 1



More uncertainty leads to false idle-time insertions

[1] M. Nasri and M. Kargahi. Precautious-RM: A predictable non-preemptive scheduling algorithm for harmonic tasks. Real-Time Syst., 50(4):548–584, July 2014.

Summary

- Designed a time-triggered policy (KP-EDF)
  - Lower overhead (up to 60%)
  - Equal schedulability to CW-EDF
- Designed an event-triggered policy (ArC-EDF)
  - Inserts many idle-times
  - History has no effect

Future work

- KP-EDF
  - Calculate the critical tasks

- ArC-EDF
  - Arrival curves and history might have an effect for non-uniform distributed inter-arrivals

Thank you

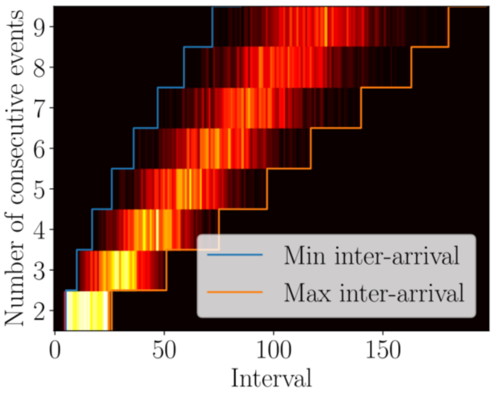
KP-EDF

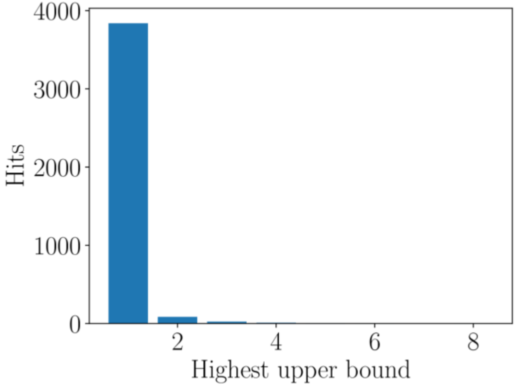
Efficient policy for time-triggered tasks

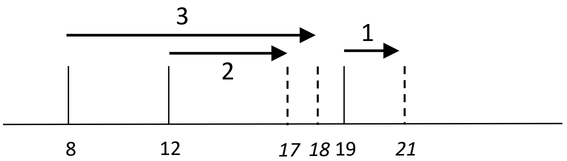
ArC-EDF

Arrival curve has no effect on deadline misses and inserts too many idle-times

ArC-EDF: Why history has no impact



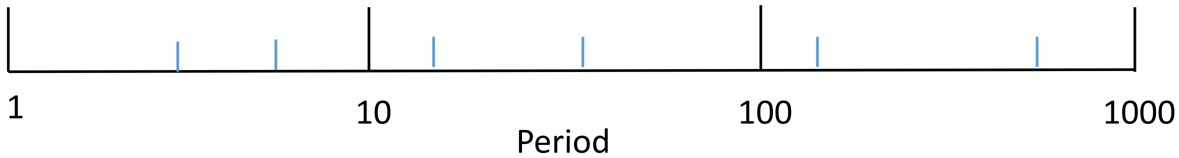




More history only introduces less likely scenario's

History of 1 is the best estimation in 96%

Logarithmic: generation



Randomly pick n periods
Randomly divide U between the n tasks

U: [0.1,…,0.9]
n: [1,…,20]

Automotive: task set generation

Period (ms)	Avg execution time (us)	Distribution (%)
1	5.00	3
2	4.20	2
5	11.01	2
10	10.1	25
20	8.75	25
50	17.56	3
100	10.53	20
200	2.56	1
1000	0.43	4

Keep picking and merging runnables from the table until U is reached

ArC-EDF: Work-conserving