Putting RUN into practice

Implementation and evaluation

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26th EUROMICRO Conference on Real-time Systems (ECRTS)
Madrid, 9 July 2014

This project and the research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7 / 2007-2013] under grant agreement 611085

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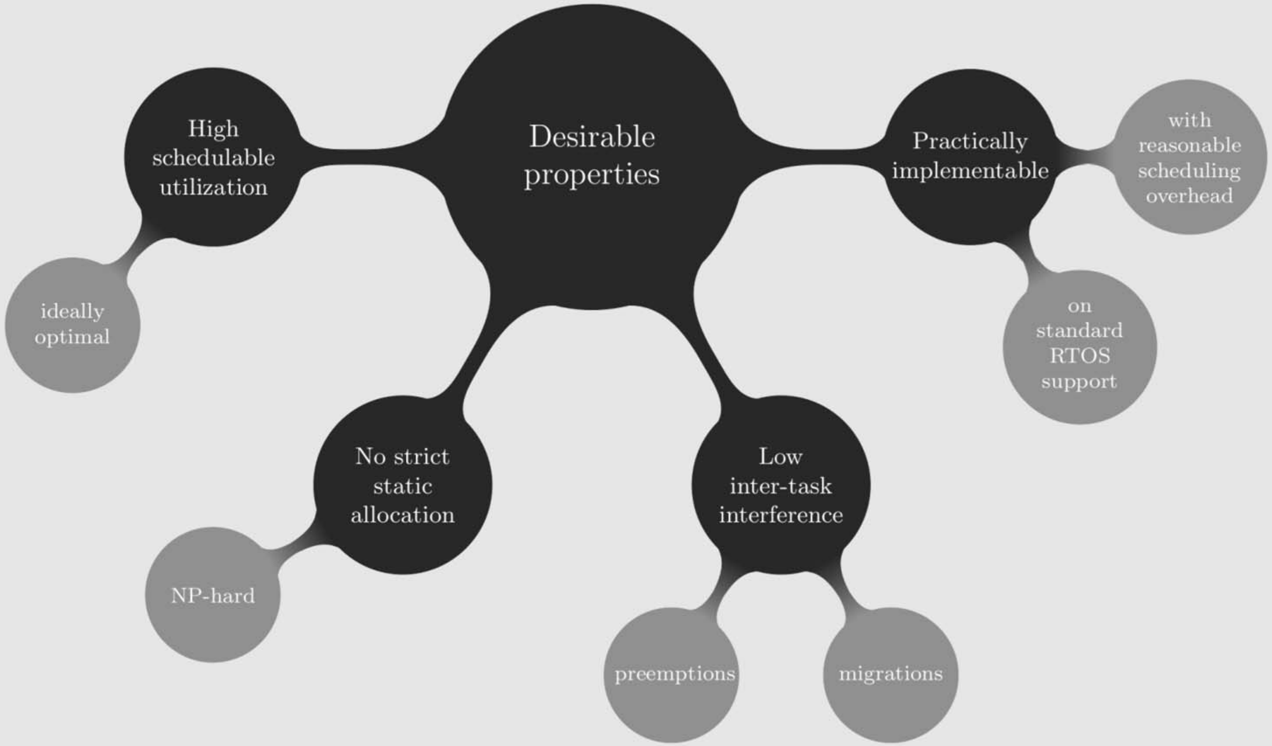
Outline

- Motivation
- Brief recap of Reduction to UNiprocessor
- RUN implementation and evaluation
- Conclusions and future work

Multiprocessor scheduling requisites



- Seeking balance between theoretical properties and viability
  - **Low runtime overhead** and **high system utilization**
  - Standard **RTOS** support and reasonable **scheduling overheads**

Multiprocessor scheduling state-of-the-art

- **Partitioned approaches**
  - Reduce to single-core scheduling with well-known solutions
  - Bin-packing → NP-hard
  - In general cannot guarantee high utilization (50% bound)
- **Global approaches**
  - Work-conserving Sustain relatively higher utilizations
  - Large shared scheduling structures
  - Larger scheduling overheads (e.g., job migration)
- **Hybrid approaches**
  - Flexibility to attenuate the drawbacks of P- and G- approaches
  - More difficult to implement
  - May require non-standard RTOS support

❑ Reduction to UNiprocessor (RUN)

- **Optimal** for *implicit-deadline periodic independent* tasks
- Low interference with **few job migrations**
- Reduces to P-EDF when a perfect partitioning exists

Recap of the RUN algorithm

- Reduction to UNiprocessor (RTSS'11)
  - *Semi-partitioned* algorithm (for lack of better term)
  - *Optimal* without resorting to *proportionate fairness*
- Reduction principles
  - **Duality** $\tau_i(T_i, u_i) \overset{dual}{\Longleftrightarrow} \tau_i^*(T_i, 1-u_i)$

$$SCHED(\mathcal{T}_n, U, m) \equiv SCHED(\mathcal{T}_n^*, n-U, n-m)$$

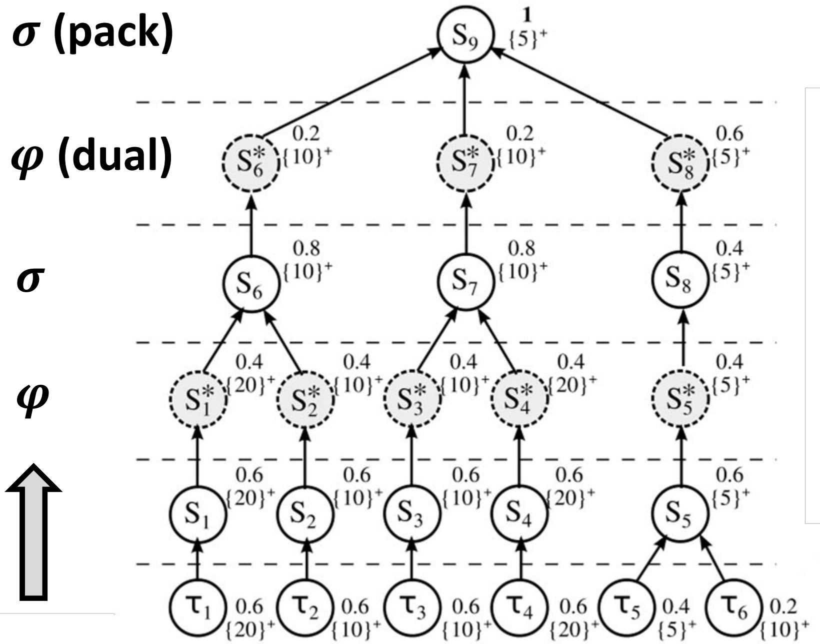
  - **Fixed-rate tasks** and **servers**

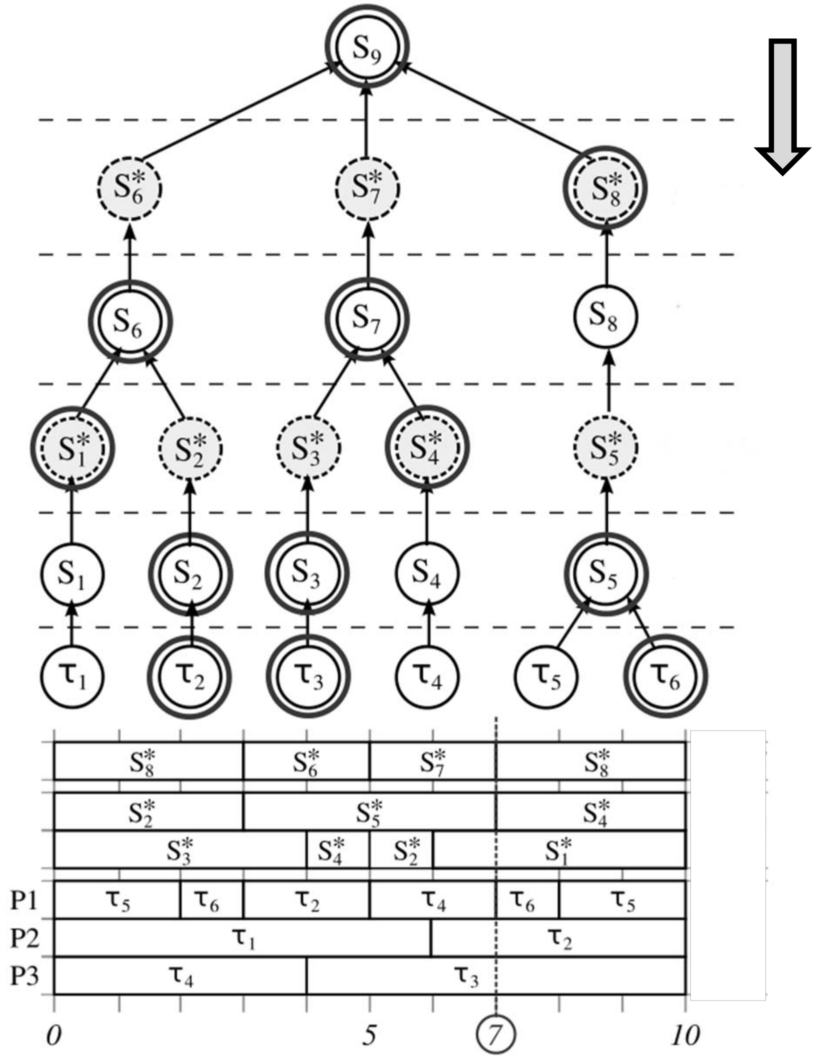
$$\tau_i \overset{\text{def}}{=\!=} (\mu_i, D_i) \Rightarrow S(\textstyle\sum_{\tau_i \in \mathcal{S}} \mu_i, \bigcup_{\tau_i \in \mathcal{S}} D_i)$$

- Scheduling decision taken on **reduction tree**
- Questions
  - *Can it be implemented on standard RTOS support?*
  - *What is the cost of maintaining the reduction tree at run time?*

Scheduling on RUN

- ❑ Off-line: ***reduction tree***
  - ➢ *Dual + Pack*
- ❑ On-line: ***EDF rules***
  - ➢ **Virtual scheduling** of servers
    - *Virtual jobs*
    - Proportionate execution





RUN implementation

- **For real**
  - On top of **LITMUS^{RT}** Linux test-bed (UNC, now MP-SWI)
  - Thus relying on an abstraction of *standard* RTOS support
- Main implementation choices and challenges
  - *Scheduling on the reduction tree*
    - How to organize the data structure
    - How to perform virtual scheduling and trigger tree updates
    - Intrinsic influence of the packing policy
  - *Mixing global and local scheduling*
    - Global release event queue vs. local *level-0* ready queue
    - Handling simultaneous scheduling events
      - Job release, budget exhaustion (possibly from different sub-trees)
  - *Meeting the full-utilization requirement*
    - Variability of tasks' WCET and lower utilization

Empirical evaluation

- **Empirical evaluation** instead of simulation-based

- Focus on **scheduling interference**
  - Cost of scheduling primitives
  - Incurred preemptions and migrations

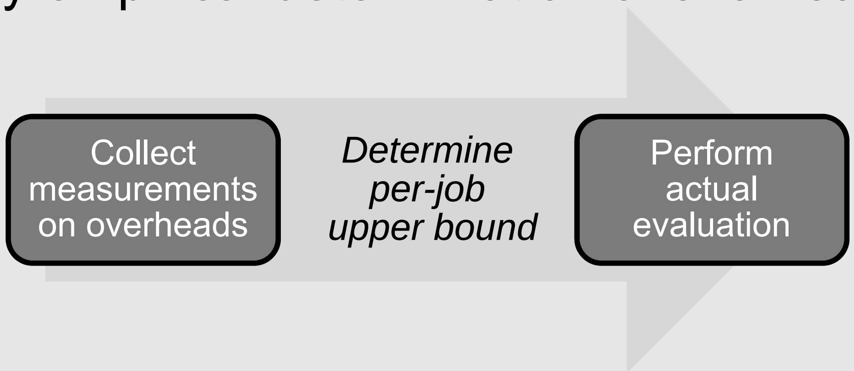
- RUN compared against **P-EDF** and **G-EDF**
  - RUN shares something in common with both
  - Way better than **Pfair** (S-PD^2 in $LITMUS^{RT}$)
    - RUN has superior performance for preemptions and migrations

Experimental setup

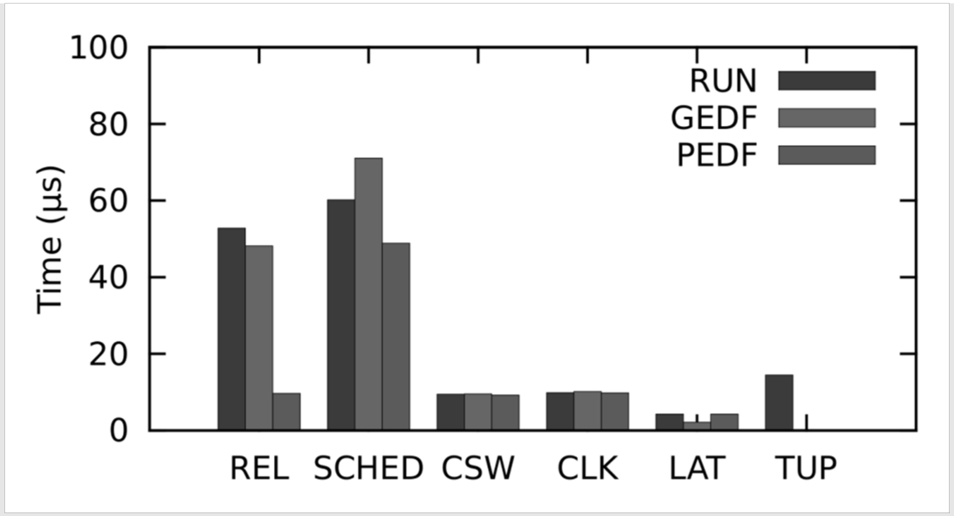
- **LITMUS^{RT}** on an 8-core AMD Opteron™ 2356

- Collected measurements for RUN, P-EDF, G-EDF
  - Hundreds of automatically generated task sets
  - Harmonic and non-harmonic, with global utilization @ 50%-100%
  - Representative of small up to large tasks

- **Two-step process**
  - Preliminary empirical determination of overheads



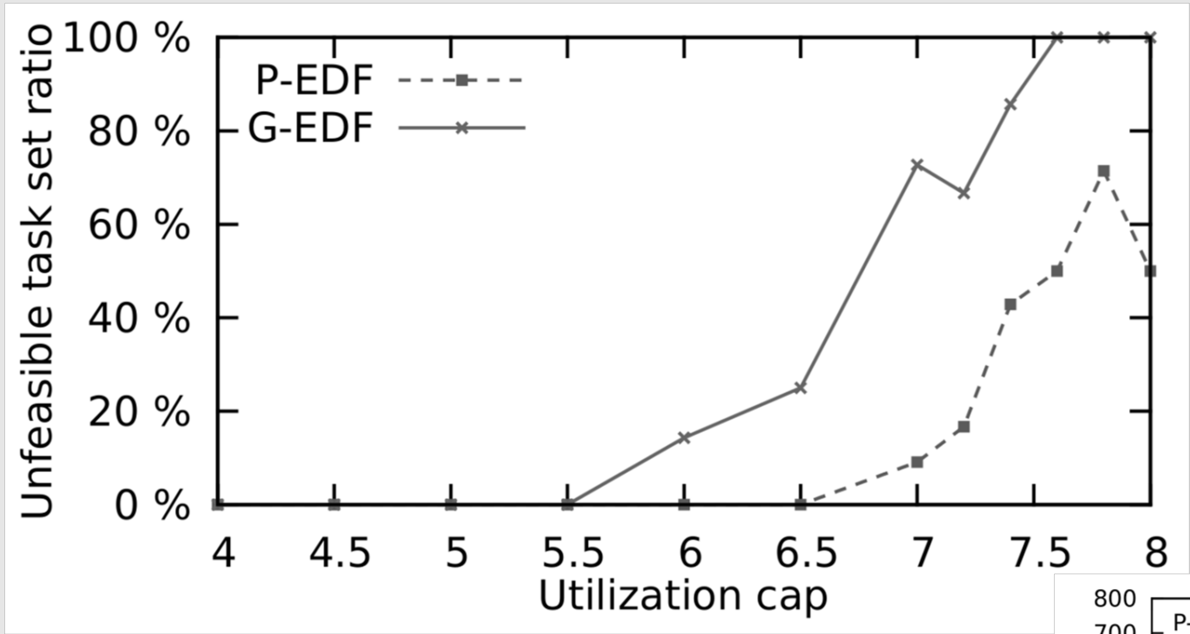
Primitive overheads and empirical bound

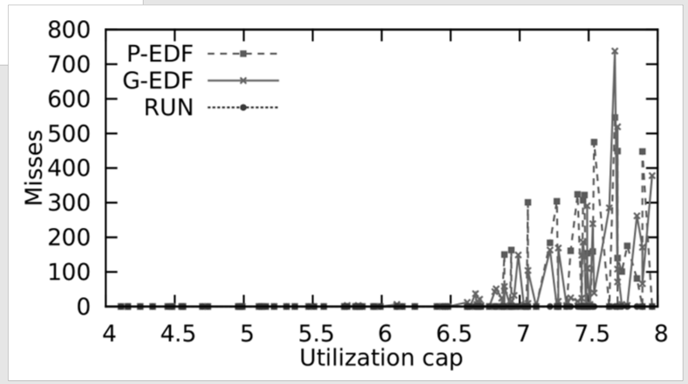


- Expectations confirmed
  - P-EDF needs lighter-weight scheduling primitives
- **Tree update** (TUP) triggered upon
  - *Budget exhaustion* event
  - Job release → REL includes TUP
- Empirical upper bound on RUN scheduling overhead
  - $OH_{RUN}^{Job} = REL + \widehat{SCHED} + CLK + k \times (TUP + \widehat{SCHED} + max(PRE, MIG))$

$k = \lceil (3p+1)/2 \rceil$ and $\widehat{SCHED} = SCHED + CSW + LAT$

Empirical schedulability



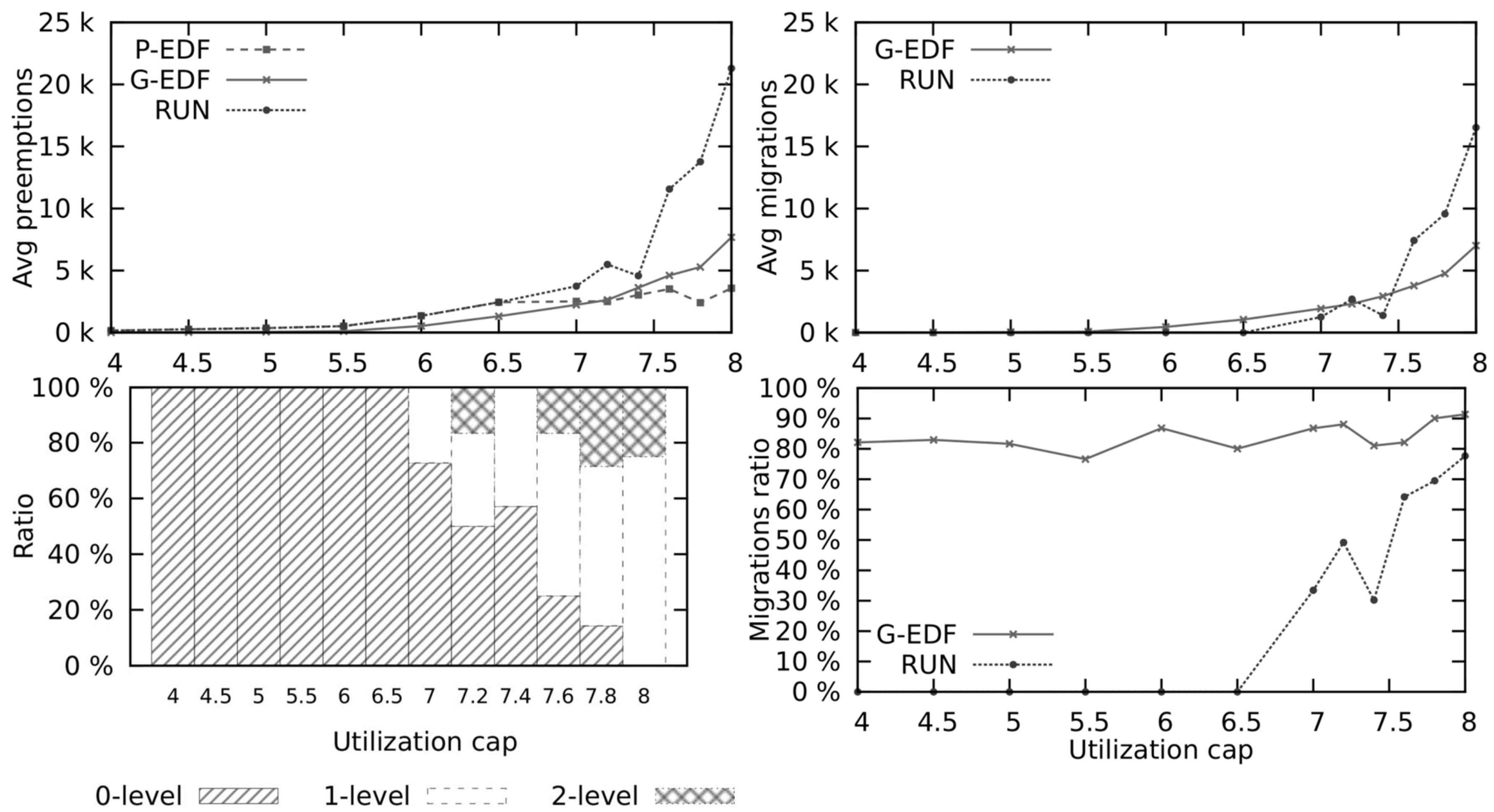


- Task sets exhibiting at least one miss
- RUN suffered **no misses**
  - Optimality and tailored overhead

PROXIMA

Kernel interference

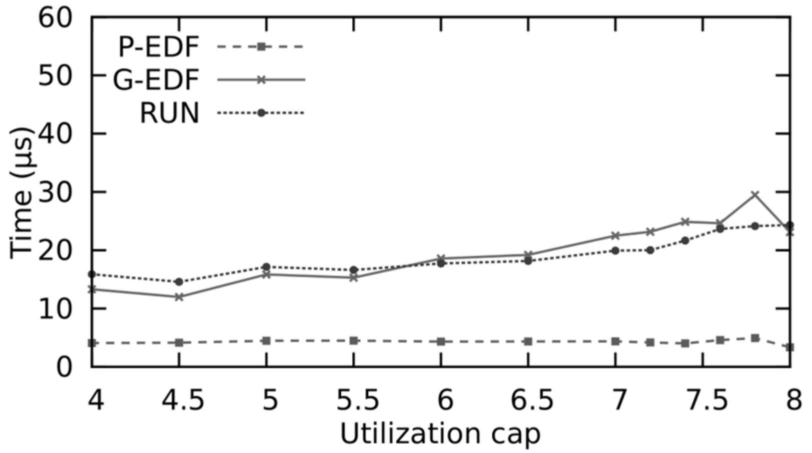
- Observing average preemptions and migrations



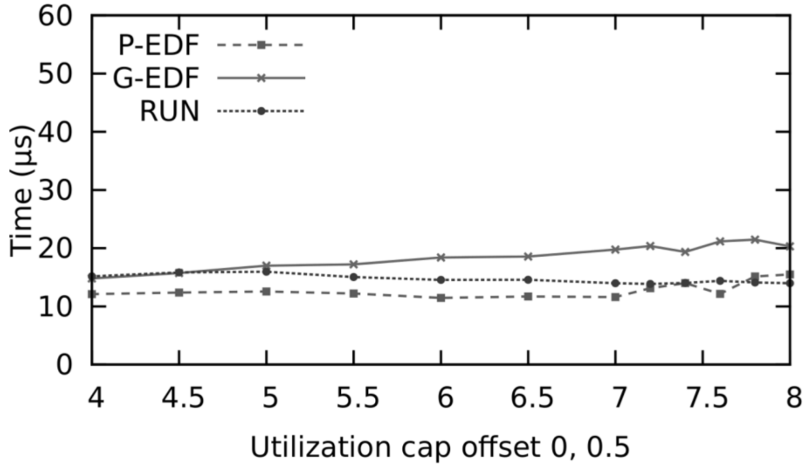
PROXIMA

Scheduling cost

- Average cost of core scheduling primitives



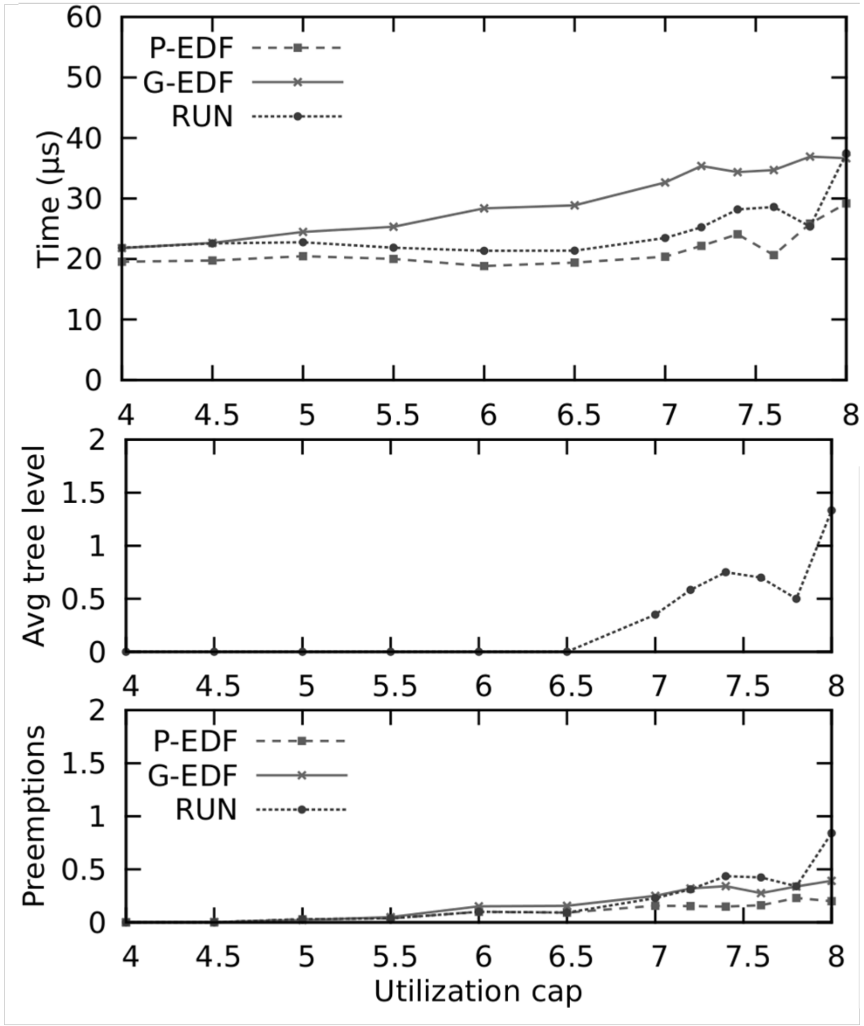
Average job release



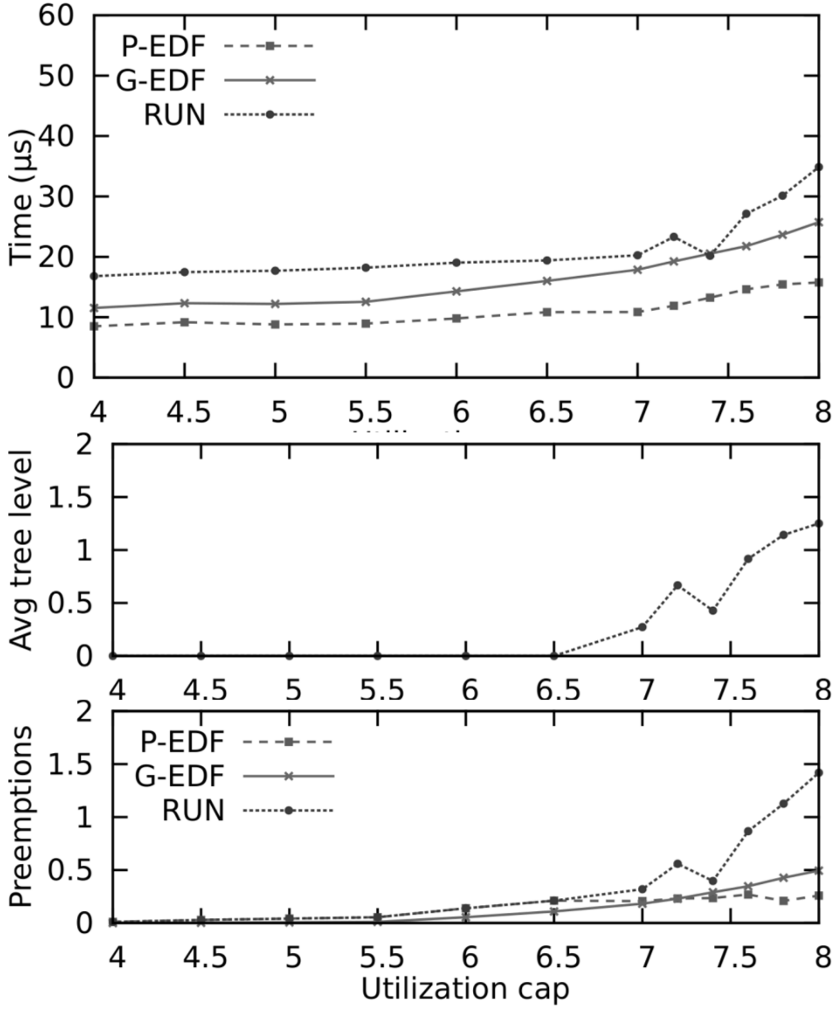
Average schedule

PROXIMA

Per-job scheduling overhead



Harmonic task set

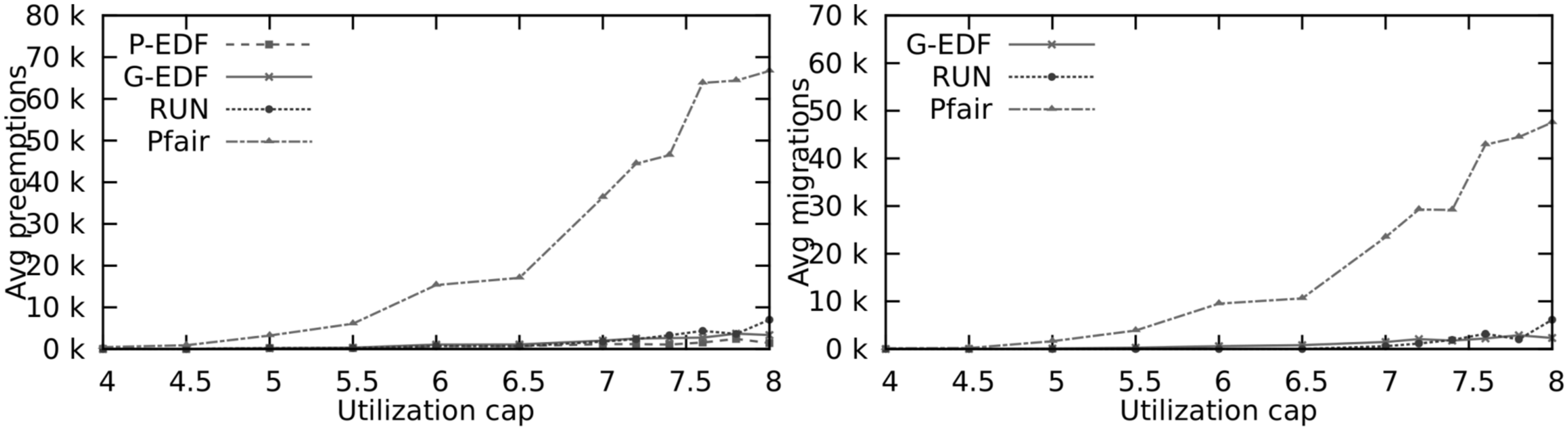


Non-harmonic task set

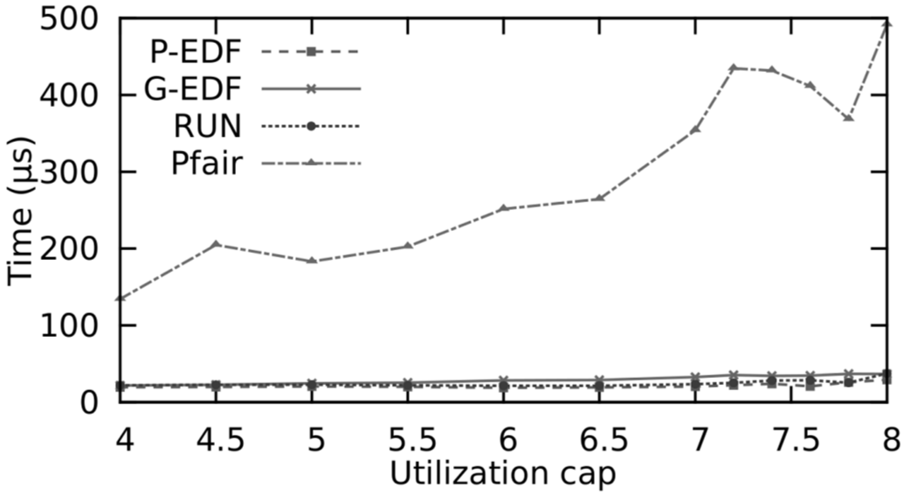
Conclusions and future work

- Good news on RUN from this evaluation
  - It can be **practically** and **efficiently implemented**
  - It may exhibit **very modest kernel overhead**
    - Acceptable even on non-harmonic task sets
  - It causes a tiny amount of **migrations**
    - Hence low inter-task interference
- Essential improvements
  - Handle *sporadic task sets*
  - Allow sharing of *logical resources*
- Further work
  - Better understanding of the role of **packing policies**
    - Affecting the reduction tree, hence preemptions/migrations
  - Further **comparisons** against other optimal solutions
    - High interest in *Quasi-Partitioned Scheduling* (QPS)

Evaluation against S-PD^2



Observed preemptions and migrations



Per-job kernel overhead

Reduction tree at run time