Real-Time Scheduling for Energy Harvesting Sensor Nodes

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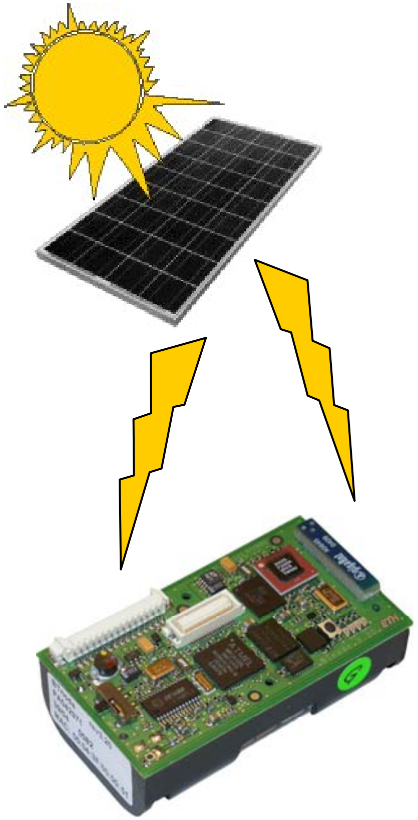
Outline

- System Model
- Problem Statement
- Lazy Scheduling
- Admittance Test
- Simulation
- Conclusion



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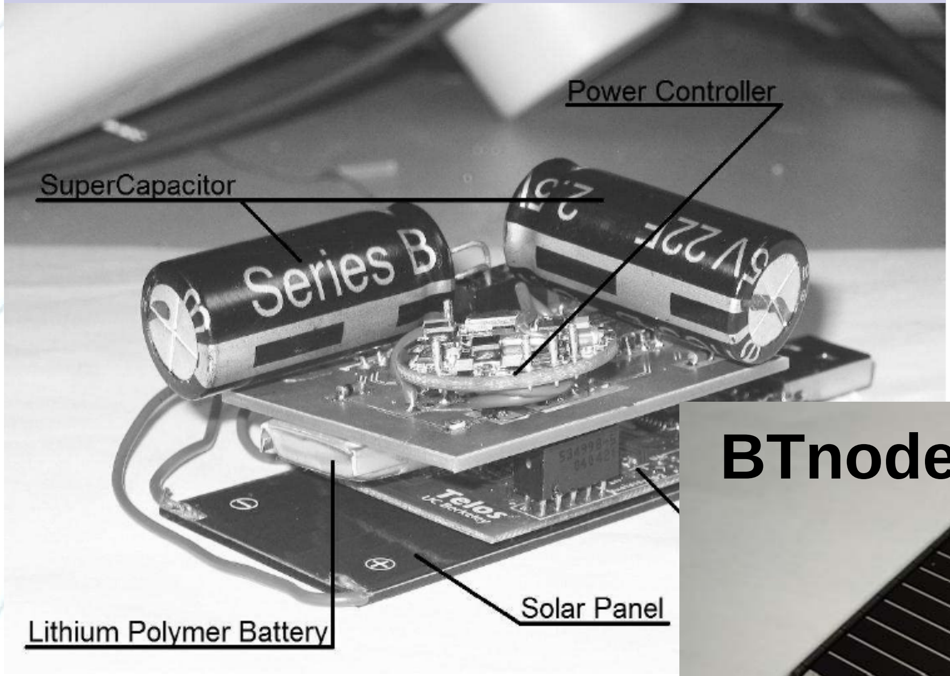
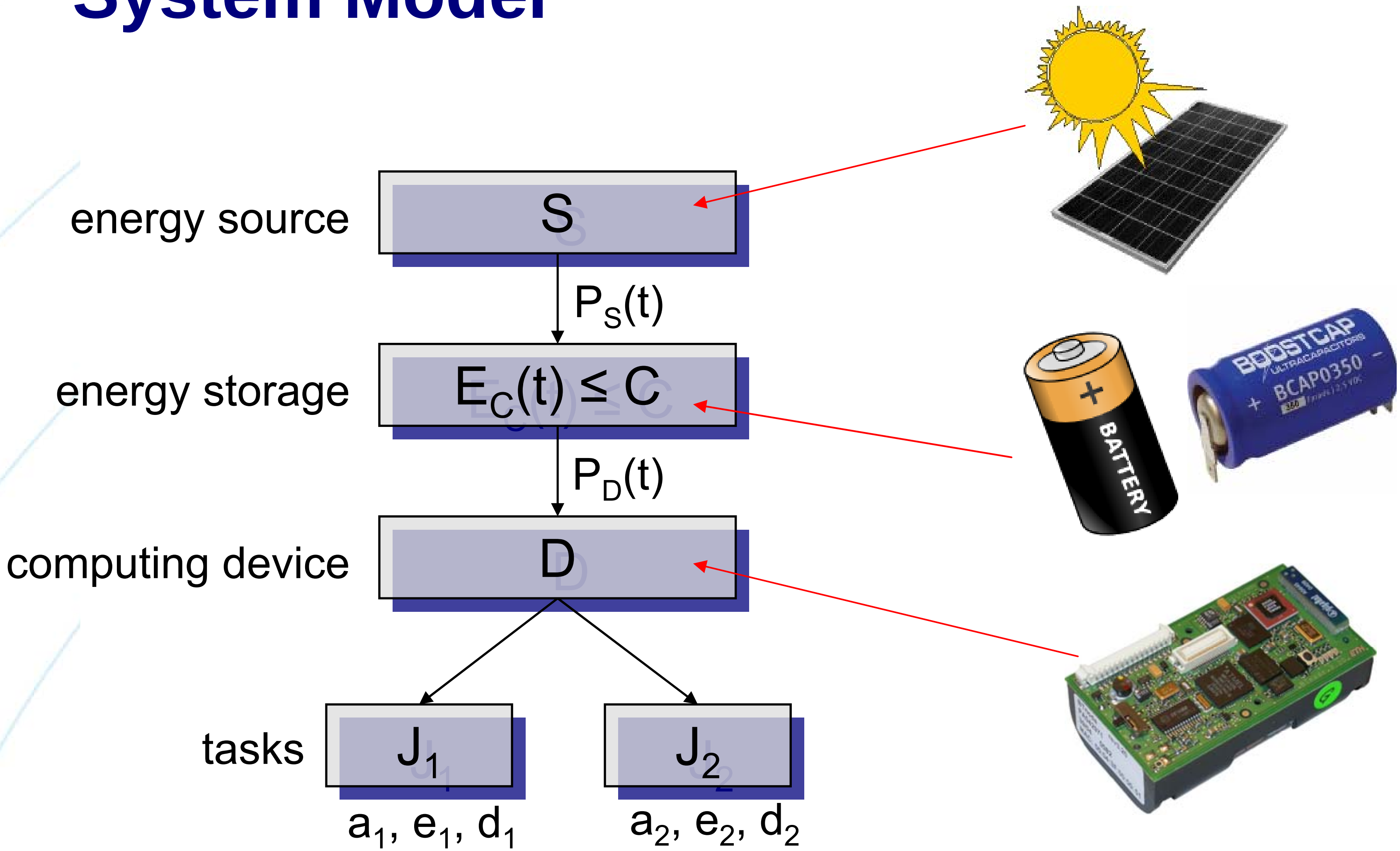
Motivation

[Heliomote: Srivastava]

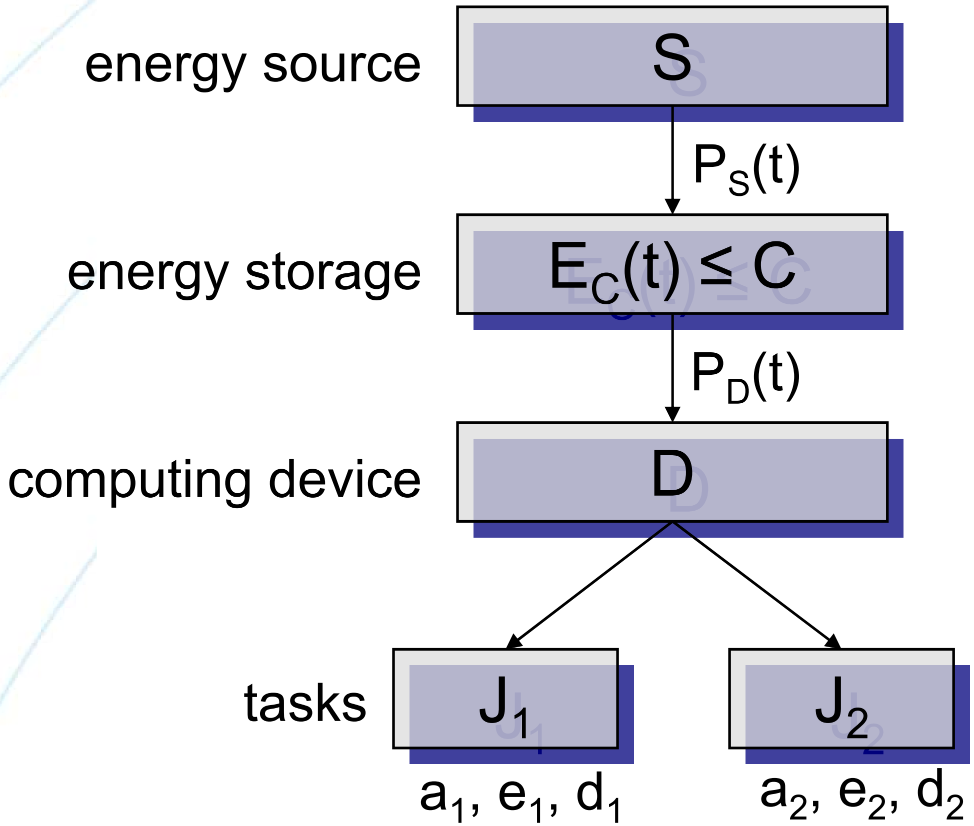
[Prometheus: Culler]



System Model



System Model



Task J_i

- can be preempted
- arrives at time a_i
- has deadline d_i
- needs total energy e_i to complete
- can consume power $0 \leq P_D(t) \leq P_{max}$
- therefore, needs time $w_i \geq \frac{e_i}{P_{max}}$

Problem Statement

- Determine an ***optimal on-line scheduling*** algorithm:

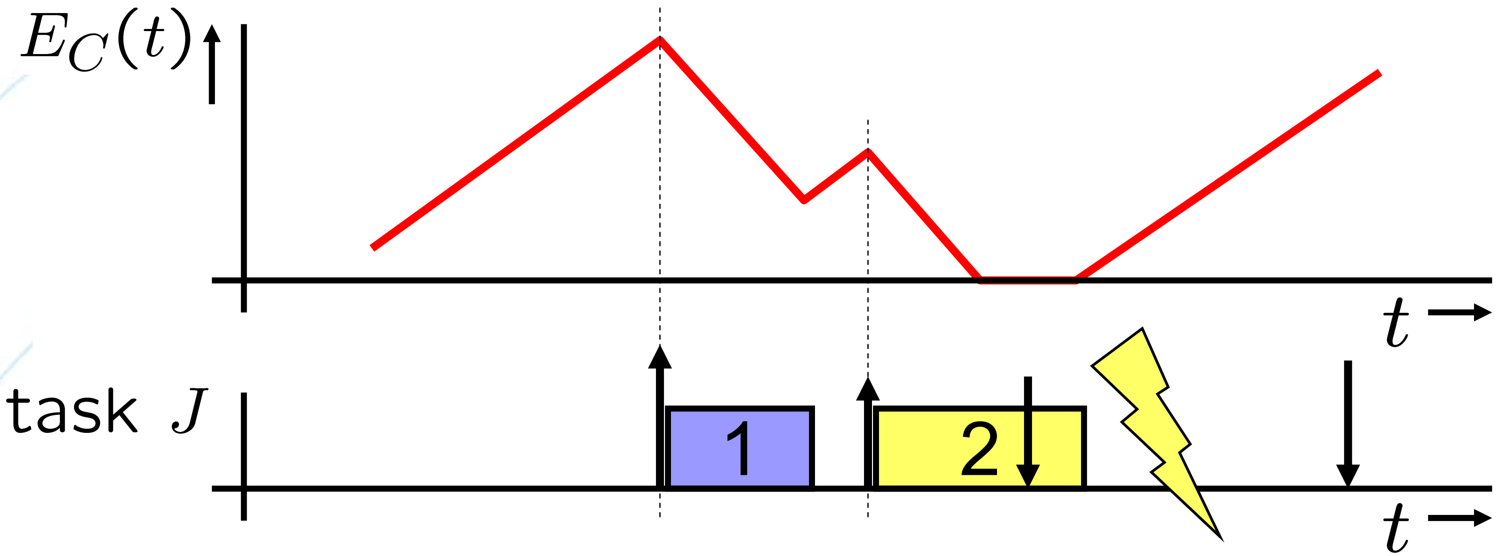
  If the task set is schedulable, it determines a feasible schedule.

- Construct an ***admittance test***:

  Determine, whether a set of event streams with a given characteristic is schedulable.

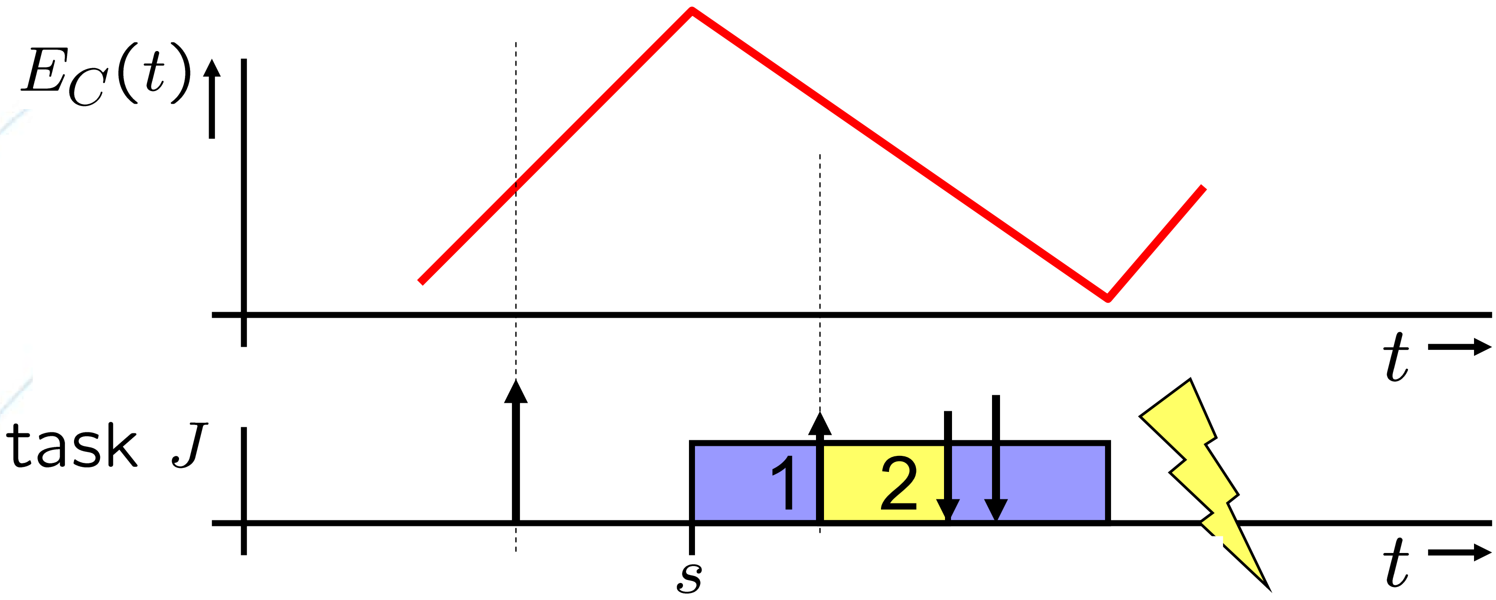
Nothing known so far …

Problem Statement - EDF



Greedy scheduling is not suited.

Problem Statement - ALAP



ALAP does not work either.

And what happens if the energy storage is full?

Lazy Scheduling Algorithm

optimal starting time s_i

$$s_i = d_i - \frac{\min\left(E_C(a_i) + E_S(a_i, d_i), C + E_S(s_i, d_i)\right)}{P_{max}}$$

Rule 1: All tasks with $s_i \le t$ are processed with EDF scheduling using P_{max}.

Rule 2: If there is no task with $s_i \le t$ and the energy storage is full, all incoming power $P_S(t)$ is assigned to the task with the currently earliest deadline.

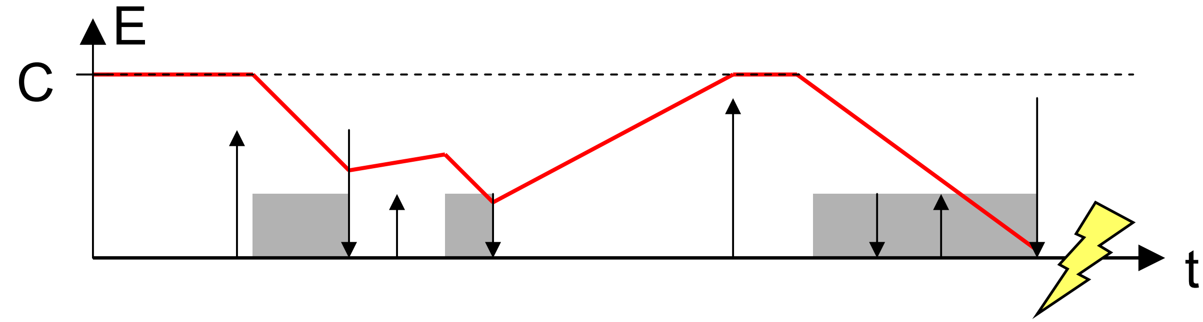
Optimality of Lazy Scheduling Algorithm

Theorem:

If the Lazy Scheduling Algorithm LSA cannot schedule a given set of tasks, then no other scheduling algorithm can schedule it.

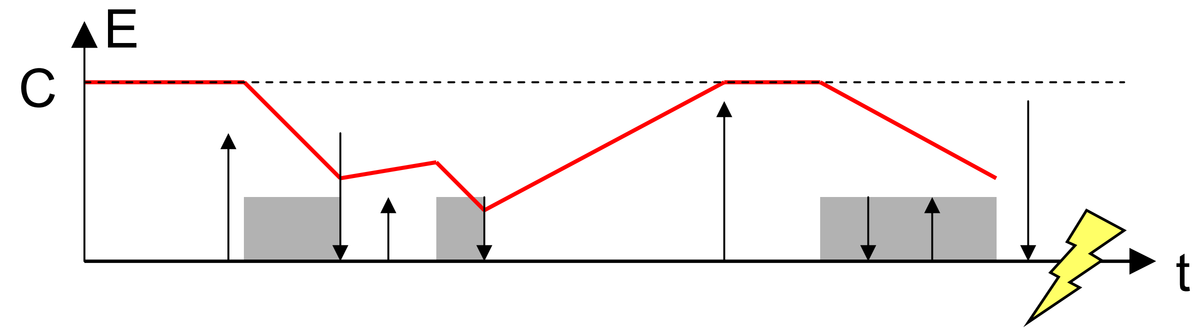
Sketch of Proof

Energy-Constrained



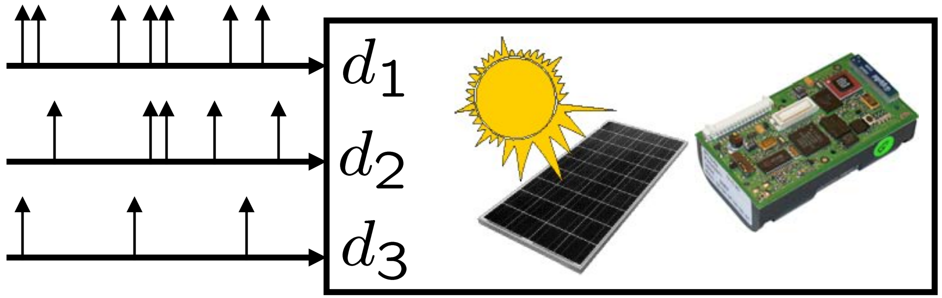
$$\Delta : \quad \text{with } C + E_S(\Delta) < \sum_{\Delta} e_i$$

Time-Constrained



$$\Delta : \quad \text{with } \Delta < \frac{\sum_{\Delta} e_i}{P_{max}}$$

Admittance Test



Is the scheduling of the event streams feasible with LSA ?

Abstraction

Event stream: delay requirement d
energy request per event e
arrival curve $\alpha(\Delta)$

Energy source: energy variability $[\epsilon^l(\Delta), \epsilon^u(\Delta)]$

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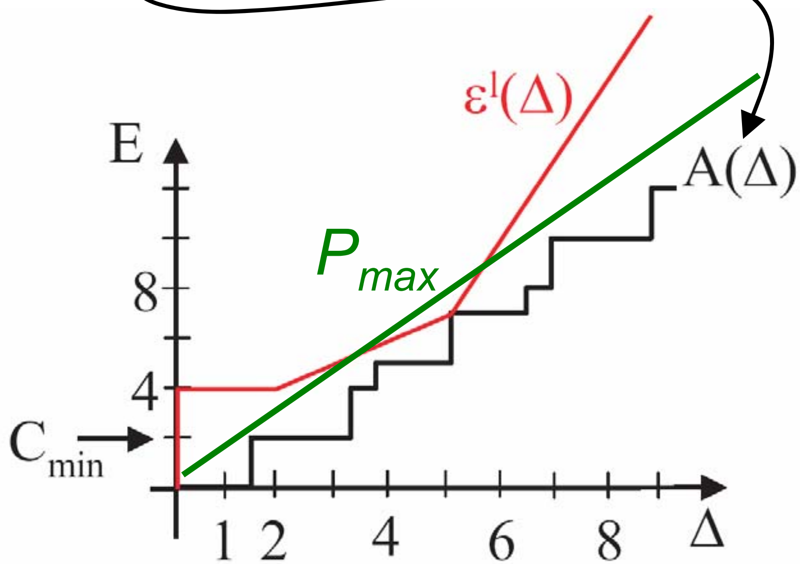
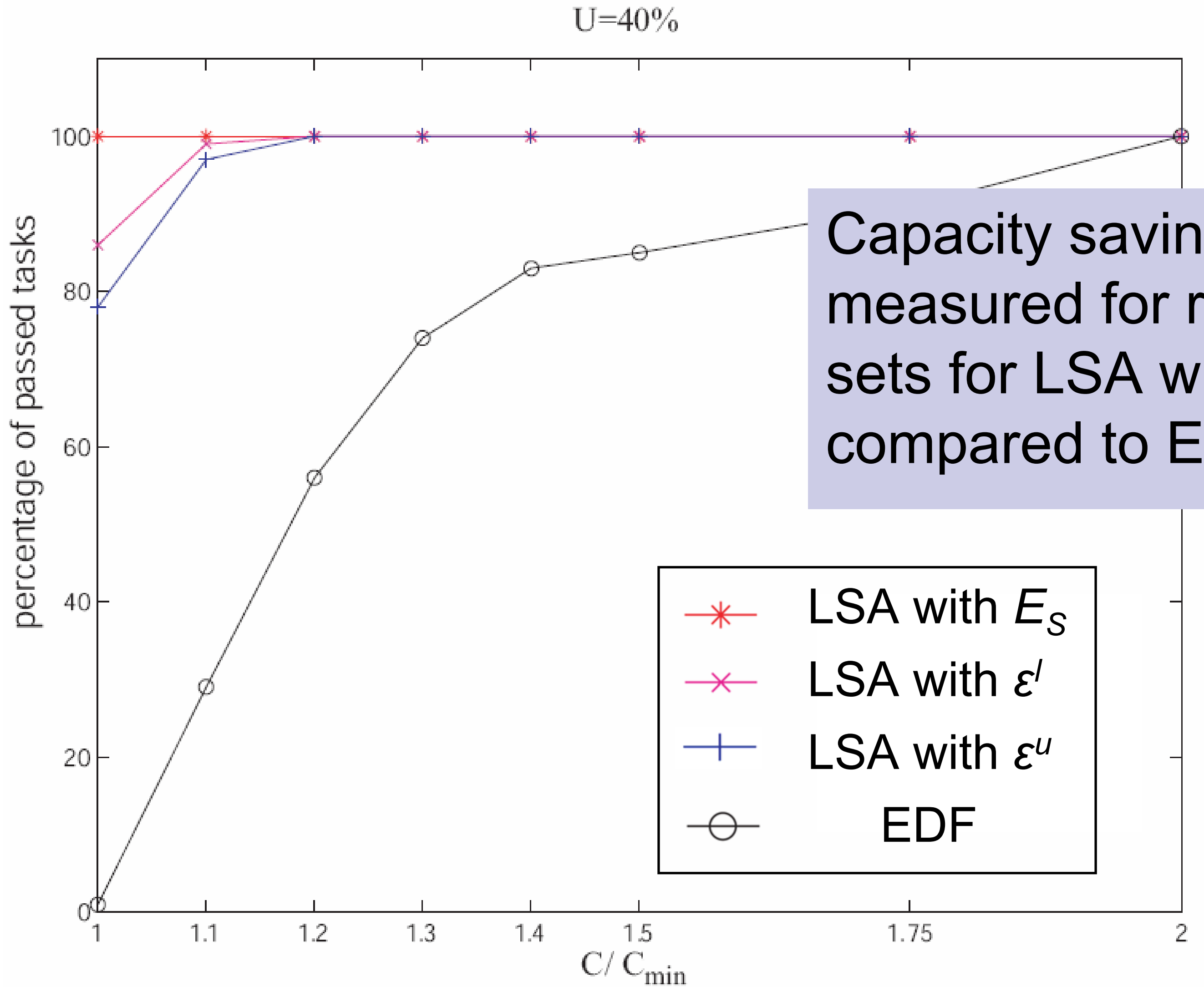
Admittance Test

A given set of event streams J_i, $i \in \mathbf{I}$ is schedulable with initially stored energy C, iff

$$\forall \Delta : \quad \sum_{i \in \mathbf{I}} e_i \alpha_i(\Delta - d_i) \leq \min\{\epsilon^l(\Delta) + C, P_{max}\Delta\}$$



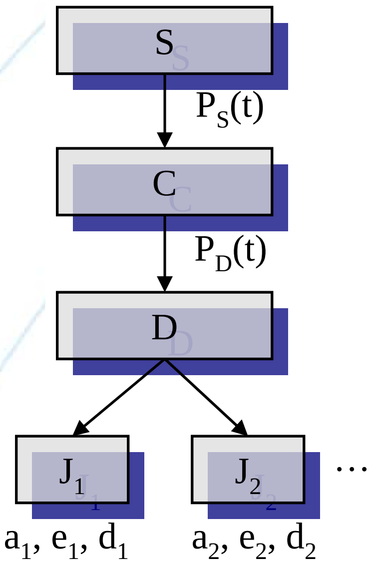
Simulation Results



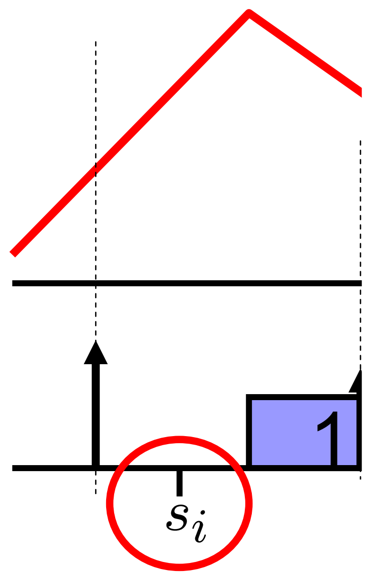
Capacity savings of ~40% measured for random task sets for LSA with $\varepsilon^l(\Delta)$ compared to EDF

Conclusions

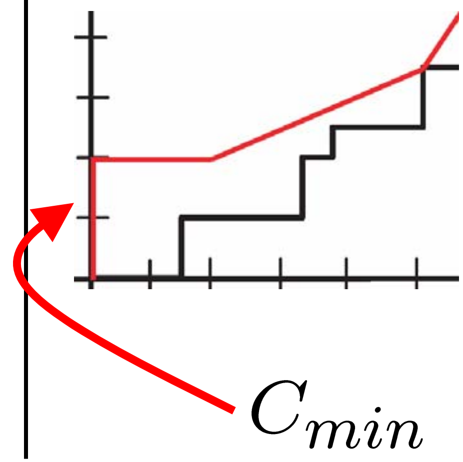
Scheduling Scenario



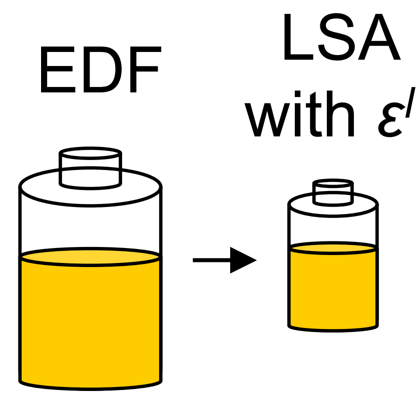
Optimal Lazy Scheduling



Admittance Test



Simulation Results

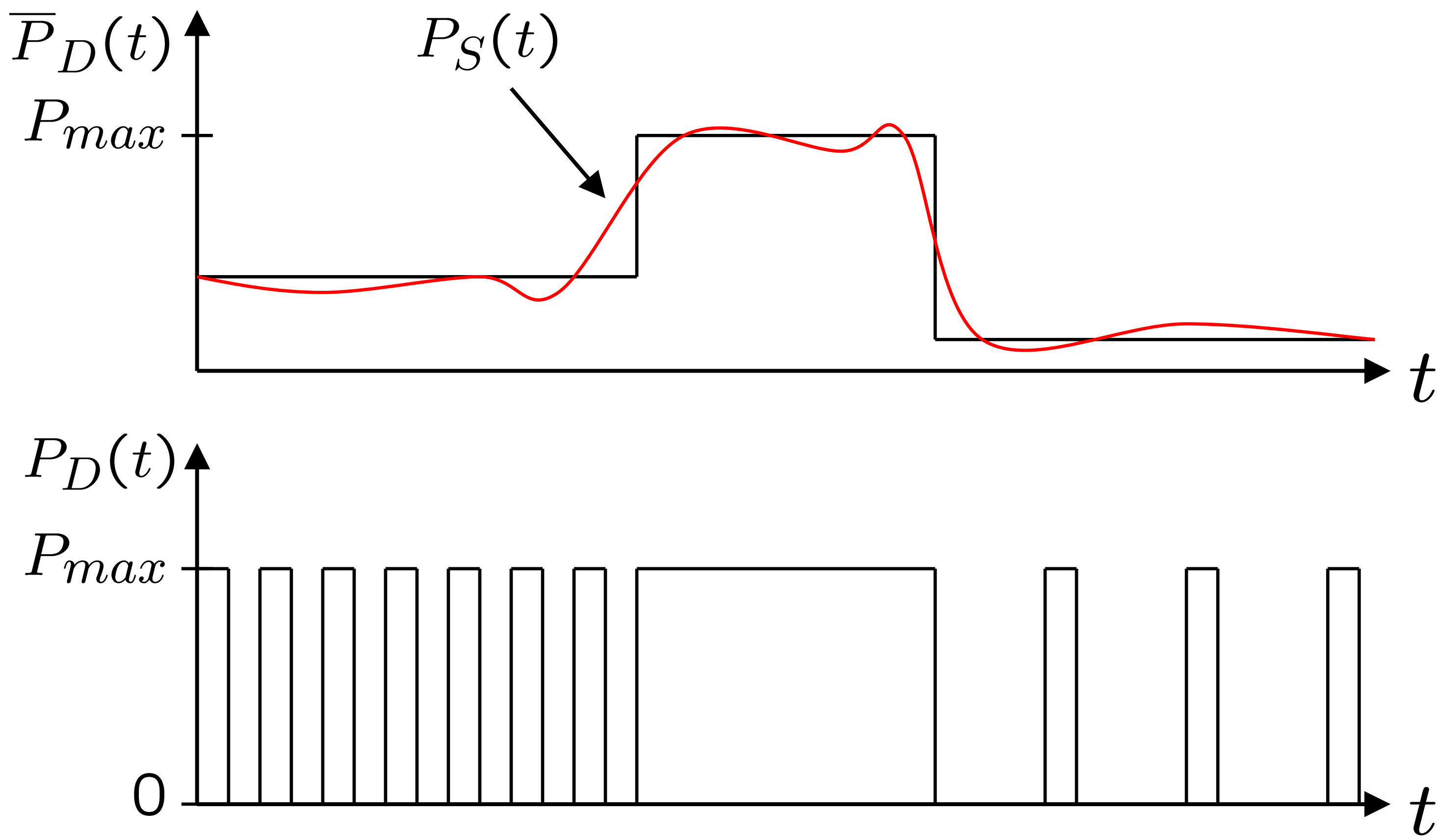


Practical Task Processing (1/3)

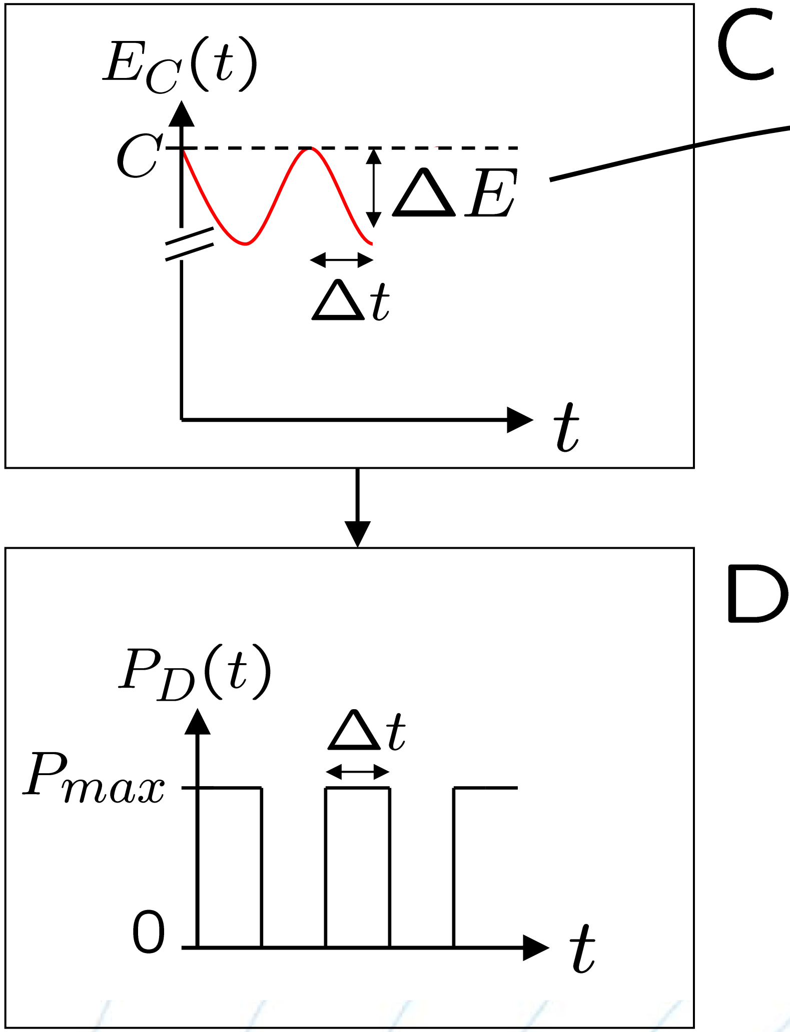
- Task processing with continuous power $P_D = P_S$ in $0 \leq P_D \leq P_{max}$ is only required if the energy storage is full ($E_C(t)=C$).
- In all other situations, tasks are processed with (constant) power $P_D=P_{max}$.

Practical Task Processing (2/3)

Approximating $\overline{P}_D(t) \sim P_S(t)$ by duty cycling



Practical Task Processing (3/3)



$$\Delta E = P_{max} \cdot \Delta t - \epsilon^l(\Delta)$$

$$\boxed{C' = C - \Delta E}$$

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