ETH Swiss Federal Institute of Technology

Computer Engineering and Networks Laboratory TIK

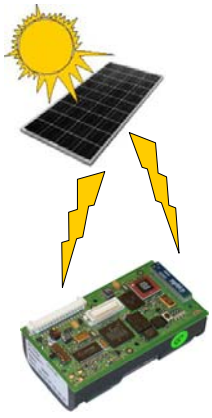
Power Management for Solar-Driven Sensor Nodes

Clemens Moser

(joint work with D. Brunelli, L. Thiele and L. Benini)

Outline

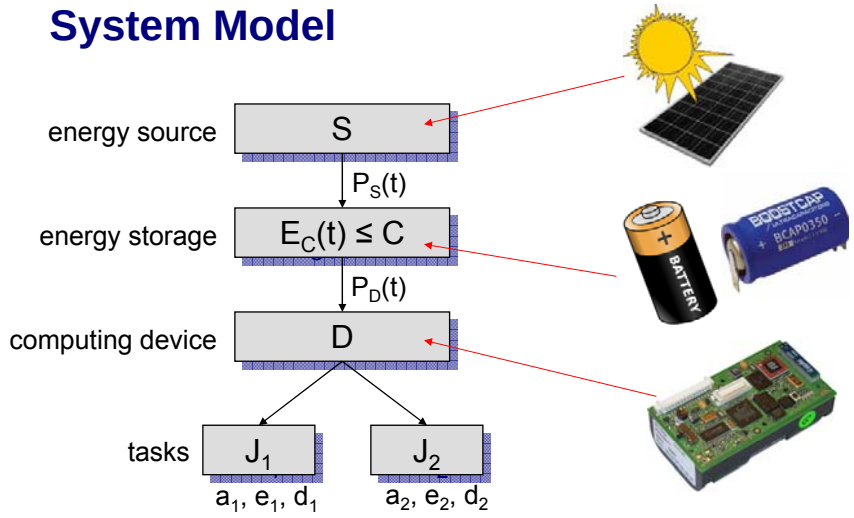
- System Model
- Problem Statement
- Lazy Scheduling
- Admittance Test
- Simulation
- Conclusion



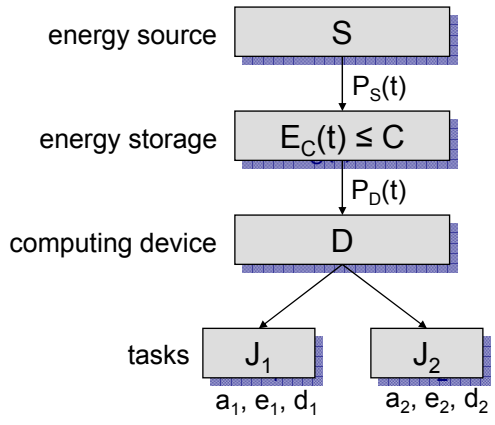
[1] C. Moser, D. Brunelli, L. Thiele, and L. Benini, “Real-time scheduling with regenerative energy.”, In *The 18th Euromicro Conference on Real-Time Systems (ECRTS 2006),* July 2006.

[2] C. Moser, D. Brunelli, L. Thiele, and L. Benini, “Lazy scheduling for energy harvesting sensor nodes.”, In *The Fifth IFIP Conference on Distributed and Parallel Embedded Systems (DIPES 2006)*, October 2006.

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 $0 \le P_D(t) \le P_{max}$
- therefore, needs time $w_i \ge \frac{e_i}{P_{max}}$

Problem Statement

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

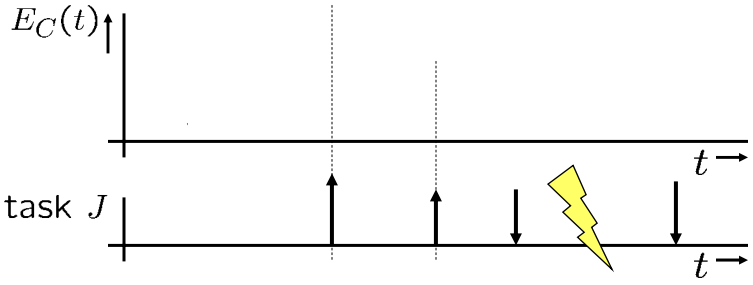
  If the task set is schedulable, it determines a feasible schedule.

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

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

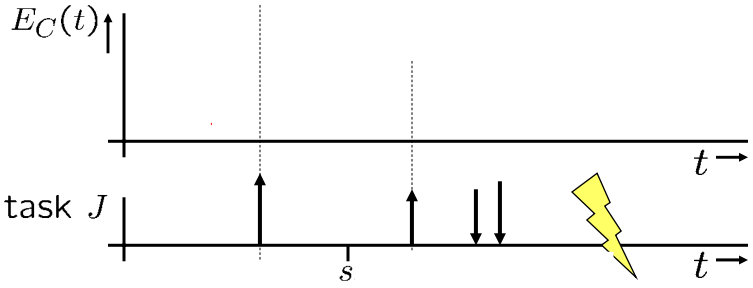
Nothing known so far …

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

$$s_i = \max\{s_i', s_i^*\}$$

$$s_i^* = d_i - \frac{E_C(a_i) + E_S(a_i, d_i)}{P_{max}}$$

$$E_S(a_i, s_i') - C = E_S(a_i, d_i) + (s_i' - d_i)P_{max}$$

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

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

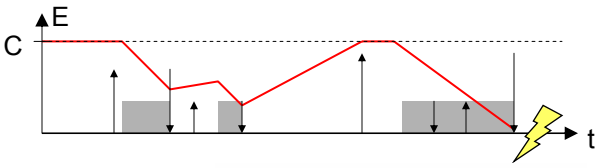
Optimality of Lazy Scheduling Algorithm

Theorem:

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

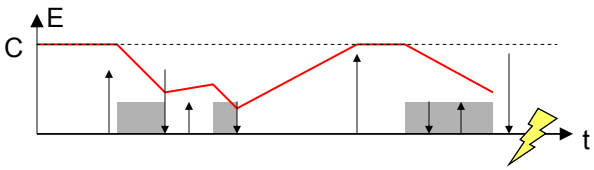
Sketch of Proof

Energy-Constrained



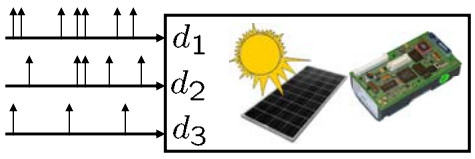
$$\Delta: \quad \text{with} \quad C + E_S < \sum_{\Delta} e_i$$

Time-Constrained



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

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 $[\epsilon^l(\Delta), \epsilon^u(\Delta)]$

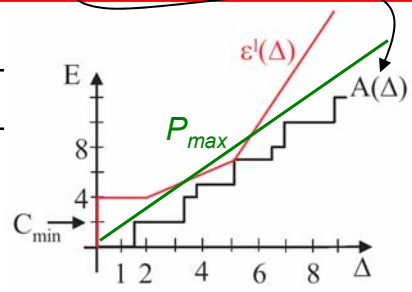
Admittance Test

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

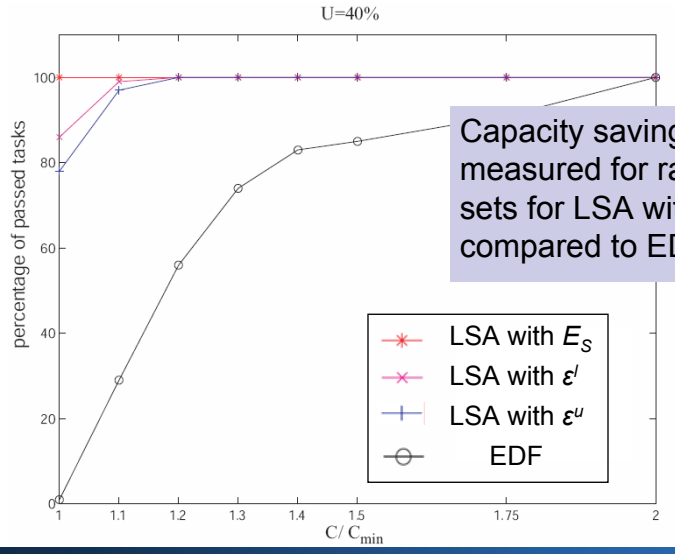
$$\forall \Delta : \sum_{i \in \mathbf{I}} e_i \alpha_i(\Delta - d_i) \leq \min\{\epsilon^l(\Delta) + C, P_{max}\Delta\}$$

Proof: T
[L

work calculus
ne calculus.



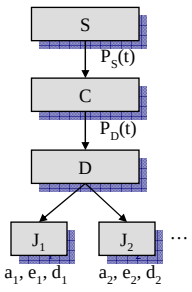
Simulation Results



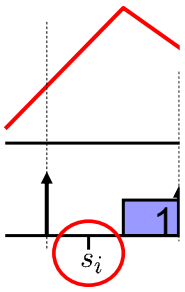
Capacity savings of ~40% measured for random task sets for LSA with $\varepsilon^l(\Delta)$ compared to EDF

Conclusions

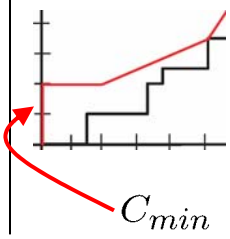
Scheduling Scenario



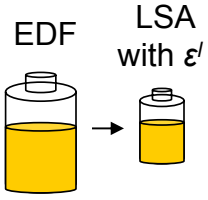
Optimal Lazy Scheduling



Admittance Test

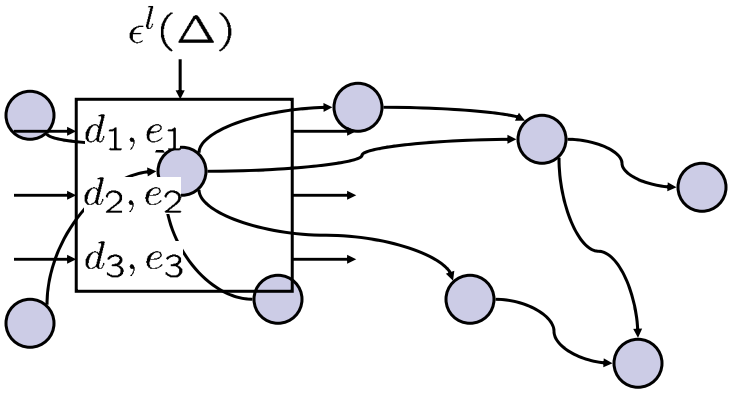


Simulation Results



The Big Picture

- **Modular Real-Time Analysis**



The Big Picture

- **Modular Real-Time Analysis**