Cluster 2

Real-Time Scheduling for Energy Harvesting Sensor Nodes

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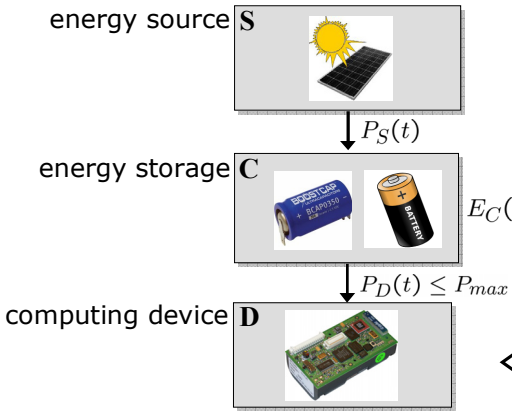
System Model

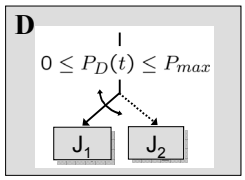


Application Model

Task J_i (a_i, e_i, d_i)

- … can be preempted
- … has arrival time a_i and deadline d_i
- … needs total energy e_i to complete
- … starting at time s_i will finish at time $f_i = \min\left\{t : e_i = \int_{s_i}^{t} P_D(t)\mathrm{d}t\right\}$

Scheduling scenario



- only one task can be processed at the same time
- at any point in time t the scheduler decides which amount of power $0 \leq P_D(t) \leq P_{max}$ is assigned to a selected task

Problem Statement:

1. **Construct an *optimal on-line scheduling* algorithm:**

   If the task set is schedulable with the energy generated by a given energy source, an optimal algorithm determines a feasible schedule.

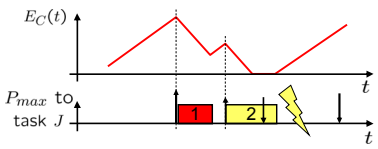
2. **Construct an *admittance test* :**

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

Naive approaches fail .....

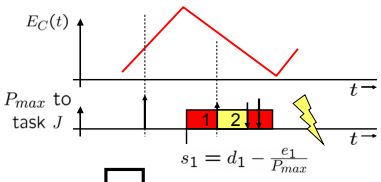
Scenario I: scheduling with Earliest Deadline First (EDF) algorithm

Result: Greedy scheduling is not suited.



Scenario II: scheduling based on As-Late-As-Possible (ALAP) principle

Result: ALAP does not work either.



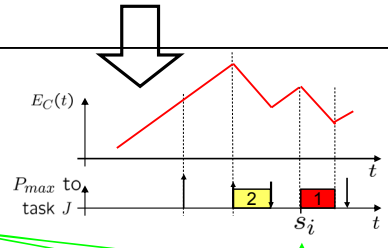
Result 1: Optimal Lazy Scheduling Algorithm (LSA)

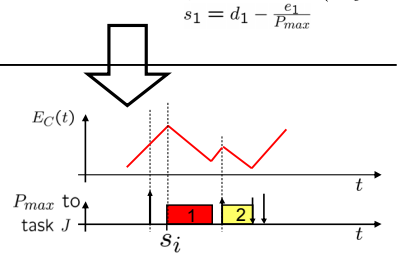
optimal starting time s_i

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

Rule 1: All tasks with $s_i \leq t$ 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.





Theorem 1 (Optimality of LSA)

Assume a system (C, P_{max}) is driven by an energy source E_S. If LSA cannot schedule a given task set, then no other scheduling algorithm is able to schedule it.

Note:

Lazy Scheduling algorithms are energy-clairvoyant, i.e. the energy $E_S(a_i, d_i)$ has to be known in advance to calculate s_i. Therefore, a practical algorithm has to *predict* the future energy $E_S(a_i, d_i)$.

Result 2: Admittance Test

Event stream model:

- delay requirement d
- energy request per event e
- maximum number $\alpha(\Delta)$ of events observed in any interval Δ

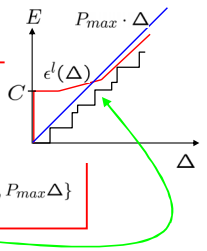
Energy Source Model:

- minimum energy $\epsilon^l(\Delta)$ generated in any interval Δ

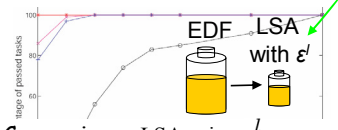
Theorem 2 (Admittance Test):

A given set of event streams J_i, $i \in \mathbf{I}$ is schedulable with initially stored energy $E_C(0) = C$, iff

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



Simulation Results:



Comparison: LSA using ϵ^l as energy predictor versus EDF

Result: capacity savings of ~40% for random task sets for LSA

References:

- C.Moser, D.Brunelli, L.Thiele, L.Benini: Real-Time Scheduling for Energy Harvesting Sensor Nodes. Int. Journal Real-Time Systems, January 2007.
- C.Moser, D.Brunelli, L.Thiele, L.Benini: Lazy Scheduling for Energy Harvesting Sensor Nodes. 5th IFIP Conf. on Distr. and Parallel Embedded Systems DIPES, Portugal, October 2006.
- C.Moser, D.Brunelli, L.Thiele, L.Benini: Real-Time Scheduling with Regenerative Energy. 18th Euromicro Conference on Real-Time Systems ECRTS, Germany, July 2006.

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

EPFL École polytechnique fédérale de Lausanne
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ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich
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