

Maximizing system lifetime by battery scheduling

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Quasimodo

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introduction

- mobile devices depend on batteries for their power

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- battery capacity is limited



~ 8.4 kJ



~ 1171 kJ

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 - ▶ battery capacity
 - ▶ level of discharge current
 - ▶ usage pattern

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- **what is the best way to schedule the batteries over the load?**

introduction

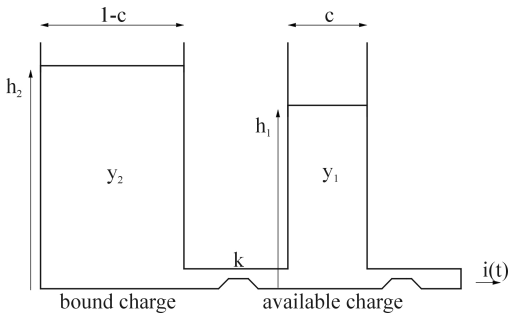
- battery lifetime depends on:
 - ▶ battery capacity
 - ▶ level of discharge current
 - ▶ usage pattern
- in a multiple battery system the usage pattern can be influenced by battery scheduling
- **what is the best way to schedule the batteries over the load?**
- approach: priced-timed automata battery scheduling model

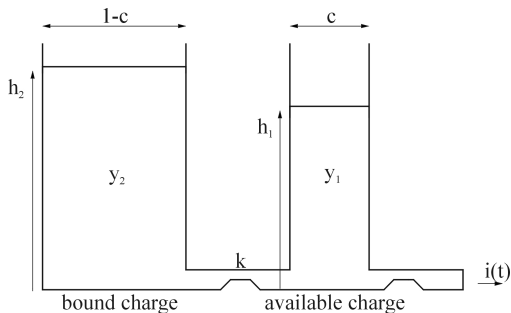
non-linear battery properties

- rate capacity effect
capacity drops for high discharge currents
- recovery effect
battery can regain some of its lost capacity during idle periods

Kinetic Battery Model (KiBaM)

- Manwell and McGowan (1993)
- battery charge is divided over two wells
 - ▶ available-charge well
 - ▶ bound-charge well
- two differential equations describe evolution



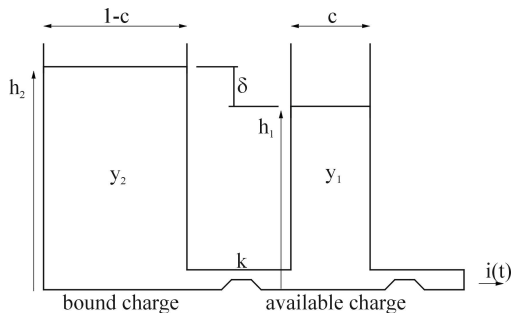


$$\frac{dy_1}{dt} = -i(t) + k(h_2 - h_1)$$

$$\frac{dy_2}{dt} = -k(h_2 - h_1)$$

$$h_1 = \frac{y_1}{c}, \quad h_2 = \frac{y_2}{1-c}$$

KiBaM transformed

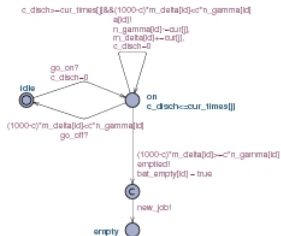


$$\gamma = y_1 + y_2, \quad \delta = h_2 - h_1$$

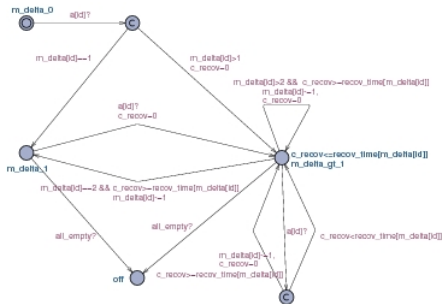
$$\frac{d\gamma}{dt} = -i(t)$$

$$\frac{d\delta}{dt} = \frac{i(t)}{c} - \frac{k}{c(1-c)}\delta$$

timed automata KiBaM



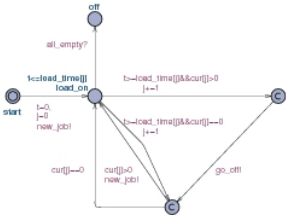
total charge



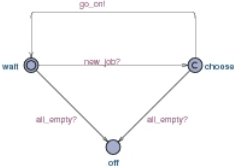
height difference

- discretized version of the KiBaM modeled in two automata
- battery empty first time available charge is zero

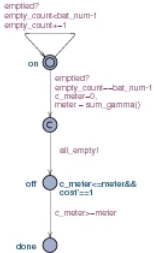
PTA optimal scheduler



load



scheduler



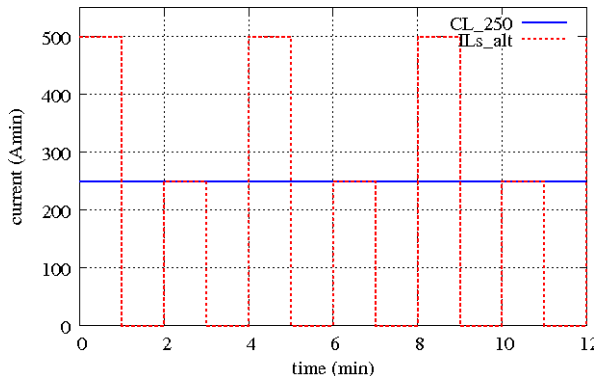
maximum finder

- load defined in 3 arrays
- scheduler nondeterministically chooses one of the batteries
- maximum finder transforms maximum lifetime into minimum cost
- details model in DSN 2009 paper

first results

- two batteries $C = 5.5 \text{ Amin}$
- optimal schedule is computed for 10 regular test loads
- divided into 1 minute epochs
- 0 mA, 250 mA, 500 mA discharge current
- scheduler at start of every epoch with positive current
- optimal lifetimes compared to three simple schedulers:
 - ▶ sequential
 - ▶ round robin
 - ▶ best-of-two

example test loads



- continuous load (CL), 250 mA discharge current
- intermittent load with short idle periods of 1 min (ILs), and discharge currents alternating between 250 mA and 500 mA

results test loads

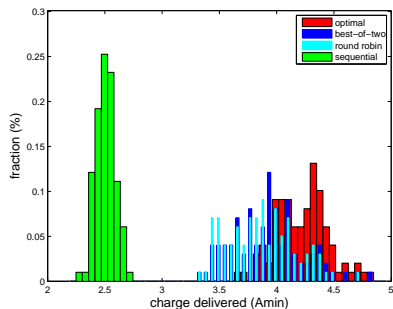
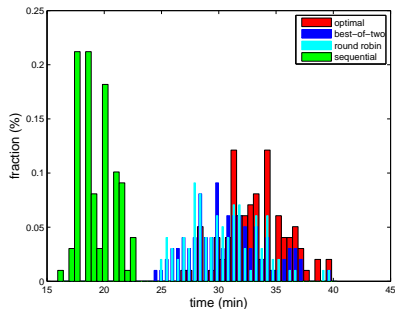
test load	sequential lifetime (min)	round robin lifetime (min)	best-of-two lifetime (min)	optimal lifetime (min)
CL_250	9.12	11.60	11.60	12.04
CL_500	4.10	4.53	4.53	4.58
CL_alt	5.48	6.10	6.12	6.48
ILs_250	22.80	38.96	38.96	40.80
ILs_500	8.60	10.48	10.48	10.48
ILs_alt	12.38	12.82	16.30	16.91
ILs_r1	12.80	16.26	16.26	20.52
ILs_r2	12.24	14.50	14.50	14.54
ILl_250	45.84	76.00	76.00	78.96
ILl_500	12.94	15.96	15.96	18.68

- sequential is worst case
- round robin and best-of-two differ only for alternating test loads
- optimal gives maximum improvement compared to round robin of 32% for ILs_alt

random loads

- periodic on-off
- 250 mA discharge current
- random discharge time, uniform (0.5 min, 1.5 min)
- fixed idle time, 1 min
- 100 loads generated
- two batteries $C = 7.5 \text{ Amin}$

results random loads



- optimal schedule gives average improvement:

- ▶ 70% to sequential
- ▶ 10% to round robin
- ▶ 8% to best-of-two

conclusions & outlook

conclusions

- PTA battery scheduling model works, but only for small batteries
- optimal schedules give considerable lifetime improvements
- practically the optimal schedule is not usable

outlook

- UPPAAL not best suited for this optimization
 - ▶ dedicated C++ program
 - ▶ other approach: optimal control theory
- statistical analysis of optimal schedules
- create better deterministic scheduler

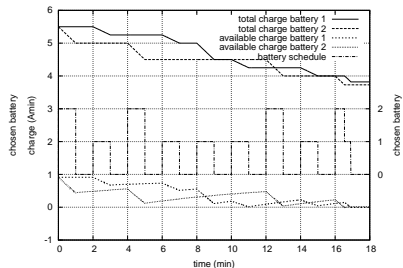
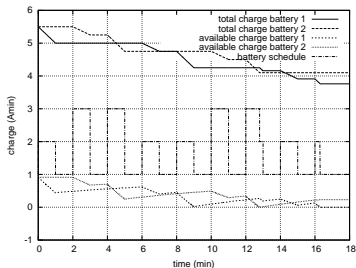
questions?

validation

test load	lifetime KiBaM (min)	lifetime TA-KiBaM (min)	difference %
CL_250	4.53	4.56	0.7
CL_500	2.02	2.04	1.0
CL_alt	2.58	2.60	0.8
ILs_250	10.80	10.84	0.4
ILs_500	4.30	4.32	0.5
ILs_alt	4.80	4.82	0.4
ILs_r1	4.72	4.74	0.4
ILs_r2	4.72	4.74	0.4
ILl_250	21.86	21.88	0.1
ILl_500	6.53	6.56	0.5

- slightly higher lifetimes for TA-KiBaM due to discretization

example schedule



- best-of-two and optimal schedules for ILs_alt test load