Energy-aware Reconfiguration of Sensor Nodes

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Sensor Nodes

- Run-time of several years
- Rely on battery power
  - recharge or exchange of power source often not possible
- BTnode (ETH Zürich)
  - Atmel ATmega128 (8 MHz)
  - 128 KB flash memory
  - 4 KB RAM
  - low-power radio ChipCon CC1000, Bluetooth
  - 2 AA batteries (each 1500 mAh)

Outline

- Approaches to Energy Management
- Energy-aware Sensor Nodes
  - Run-time Energy Accounting
  - Battery Lifetime Estimation
- Energy Management Through Reconfiguration
  - Application Upload
  - Multiple Pre-installed Applications
- Conclusion

Approaches to Energy Management

```
loop
    val ← readSensor()

    sendPacket(val)

    sleep(sleepPeriod)
end loop
```

- Estimate & control energy before deployment
  - detailed energy models
  - simulation sufficient for estimation of run-time (e.g., `PowerTossim` for Mica2 motes, `AEON`)
- *sleepPeriod* determines energy consumption and run-time

Nondeterministic Applications

```
loop
    val ← readSensor()
    if  val ≥ threshold  then
        sendPacket(val)
    end if
    sleep(sleepPeriod)
end loop
```

- Energy consumption?
  - worst/average-case estimation
  - redundancy
  - “trial-and-error” (deploy, test, collect, re-program)

Alternative: adaptive, on-line power management

Energy-Aware Sensor Nodes

- Adaptive power management requires information on
  - energy consumption
  - remaining power supply
- Run-time energy estimation
  - hardware with deterministic behavior (no caches ...)
  - fine-grained control over operating modes
  - power consumption of components & modes well documented

Energy Accounting: Microcontroller

- ATmega 128L

instruction	power
lds	31.0 mW
nop	29.7 mW
xor	29.5 mW
fmul	29.0 mW

mode	power
idle	14.28 mW
power save	0.79 µW
power down	0.71 µW

- active mode: count number of cycles
- sleep modes: measure time with externally clocked timer

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  - active mode: count number of cycles
  - sleep modes: measure time with externally clocked timer

- Implementation (TinyOS)
  - modified scheduler
  - code size: 470–988 bytes
  - run time overhead < 5 %

Energy Accounting: Communication

- ChipCon radio

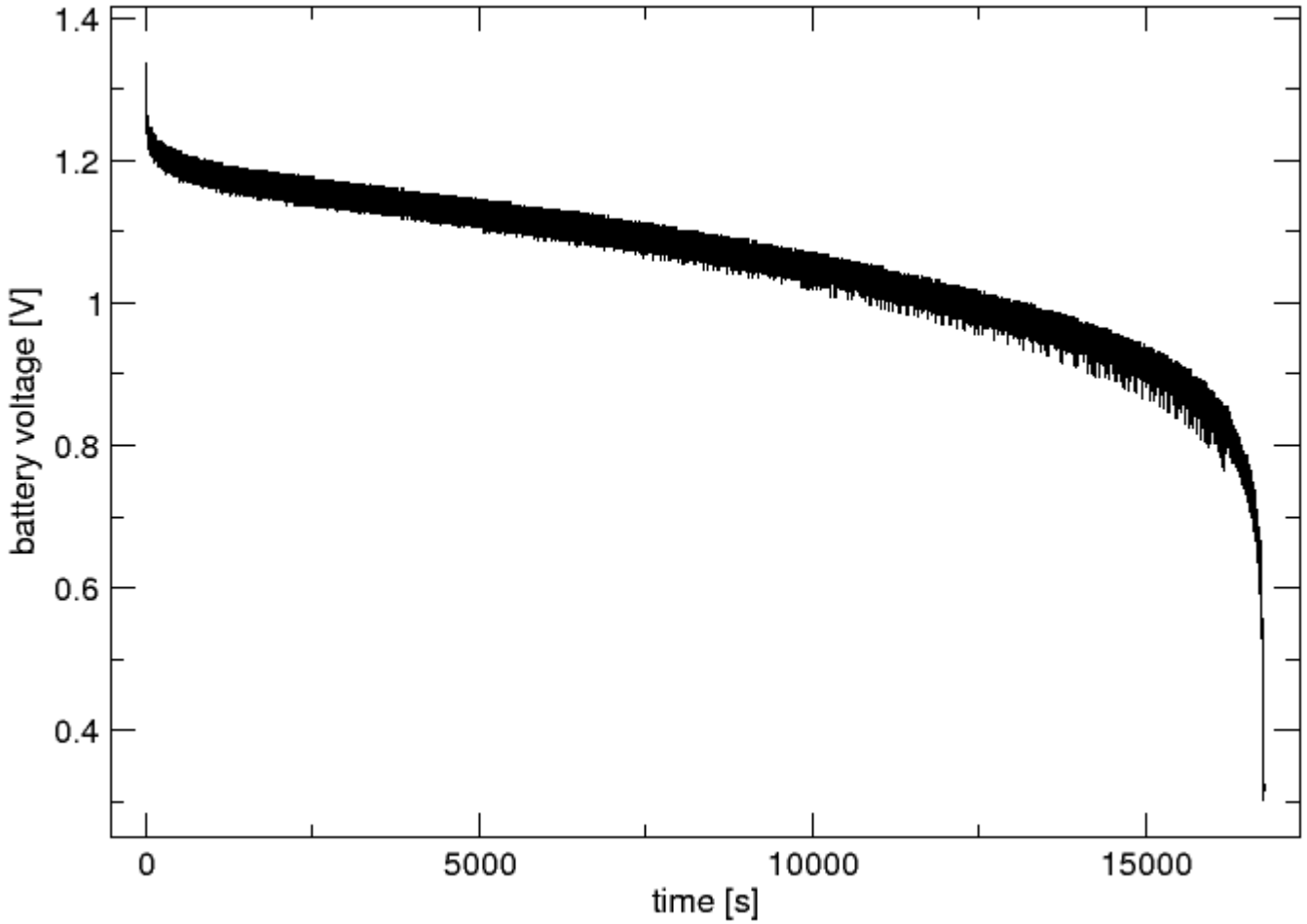
mode	power
receive	28.8 mW
send	26.4–80.7 mW

  - measure time the radio is turned on (receiving/sending)
  - or: count number of packets sent

- Bluetooth
  - less suited for energy accounting as Bluetooth chip hides low-level functionality
  - several low-power idle modes (hold, sniff, park)

Estimating Battery Lifetime

- A/D converter to read battery voltage



Estimating Battery Lifetime

- First approach: generic battery model
  - but: hard to derive
- Second approach: regression fitting

$$f(x) = a_6 e^{a_5 x} + a_4 e^{a_3 x} + a_2 x^2 + a_1 x + a_0$$

  - but: erratic readings of A/D converter on BTnode
- Third approach:
  store tables describing discharge characteristics on node
  - several discharge curves for different temperature ranges

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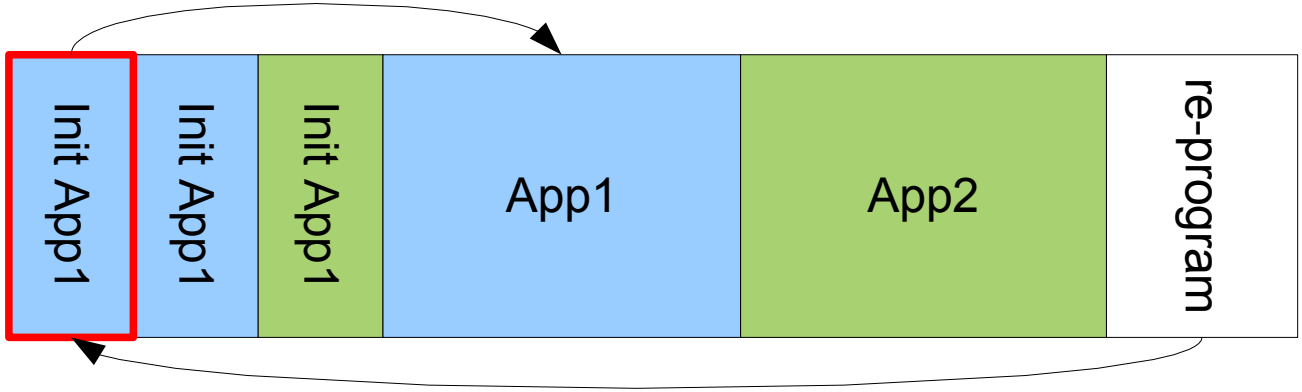
Reconfiguration: Application Upload

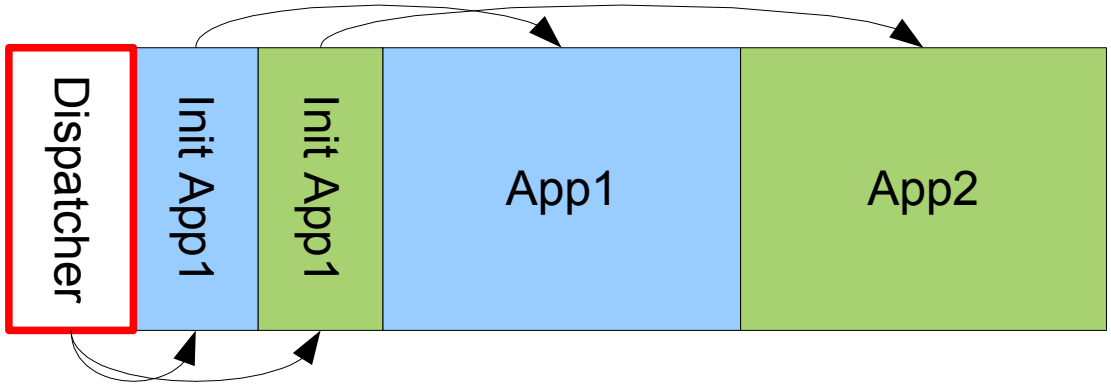
- Update nodes via communication link
- Replace (parts of) application
  - exchange complete binary (`Xnp`)
  - or single modules/components (`Contiki`, `SOS`, `Maté`)
  - overhead due to interaction between dynamically loaded modules (6% for `SOS`, 11% for `Maté`)
- Example
  - install new application (16.5 kB)
  - overhead of transmission:
    Bluetooth: 18.9 s, 2 J, ChipCon: 13.8 s, 1.6 J
  - overhead of programming: 1.3 s, 100 mJ

Multiple Pre-installed Applications



- Interrupt table and initialization code in first page of program memory (flash)
- Implementation
  - overwrite this page and reset BTnode
  - overhead: 20 ms, 1–2 mJ
  - code size: 1274 byte + flash page (256 bytes)

Dispatcher



- Avoid writing to flash memory
- Implementation
  - interrupt dispatcher (id of current application stored in RAM)
  - code size: 334 byte (including flash page for dispatcher)
  - run-time overhead at each interrupt due to additional level of indirection (56 cycles)

Conclusion

- Transfer concepts of adaptive power management to sensor nodes
  - extremely limited resources
  - avoid additional energy overhead
- Make sensor nodes energy-aware
  - on-line energy accounting
  - battery lifetime estimation
- Control energy consumption during runtime
  - reconfiguration through application upload
  - multiple pre-installed applications