Technische Universität Braunschweig

Institute of Operating Systems and Computer Networks

Paint it Black – Increase WSN Energy Efficiency with the Right Housing

RealWSN 2015

Ulf Kulau, Sebastian Schildt, Stephan Rottmann and Lars Wolf,
November 1, 2015
Technische Universität Braunschweig, IBR

Introduction

Many WSNs in challenging areas of application

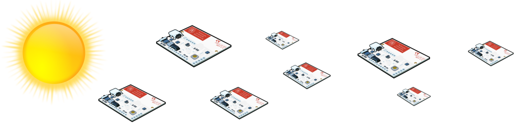
- Harsh environmental conditions
  $\rightarrow$ Reliability of nodes decreases
- Bad maintainability
  $\rightarrow$ Constrained energy resources (e.g. batteries)




Temperature vs. Reliability vs. Energy Efficiency

The crux: Higher temperatures...

1. might disturb wireless communication [1, 2, 3]



Boano et.al., *The Impact of Temperature on Outdoor Industrial Sensornet Applications*,IEEE Industrial Informatics, 2010

Boano et.al., *Hot Packets: A Systematic Evaluation of the Effect of Temperature on Low Power Wireless Transceivers*, ExtremeCom 2013

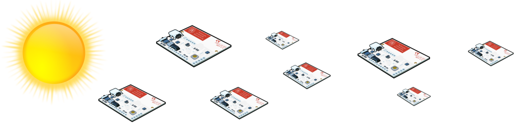
Schmidt et.al., *If You Can't Take The Heat: Temperature Effects On Low-Power Wireless Networks And How To Mitigate Them*, EWSN 2015

Temperature vs. Reliability vs. Energy Efficiency

The crux: Higher temperatures...

1. might disturb wireless communication [1, 2, 3]
2. lead to *increased energy efficiency*

→ Q: How does temperature affect the energy efficiency of a node?



Boano et.al., *The Impact of Temperature on Outdoor Industrial Sensornet Applications*,IEEE Industrial Informatics, 2010

Boano et.al., *Hot Packets: A Systematic Evaluation of the Effect of Temperature on Low Power Wireless Transceivers*, ExtremeCom 2013

Schmidt et.al., *If You Can't Take The Heat: Temperature Effects On Low-Power Wireless Networks And How To Mitigate Them*, EWSN 2015

Undervolting – Basics

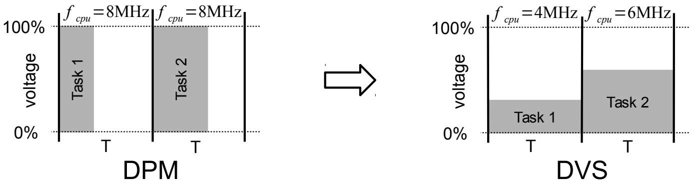
Voltage Scaling increases energy efficiency significantly

- Dynamic power dissipation of CMOS $p_{dyn} = C_L \cdot f_{cpu} \cdot V^2$

Undervolting – Basics

Voltage Scaling increases energy efficiency significantly

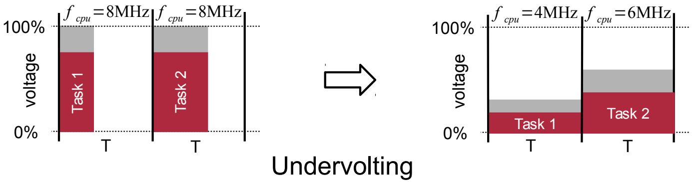
- Dynamic power dissipation of CMOS $p_{dyn} = C_L \cdot f_{cpu} \cdot V^2$
- DVS: Adapting f_{cpu} to current workload *and* scale $V(f_{cpu})$



Undervolting – Basics

Voltage Scaling increases energy efficiency significantly

- Dynamic power dissipation of CMOS $p_{dyn} = C_L \cdot f_{cpu} \cdot V^2$
- DVS: Adapting f_{cpu} to current workload *and* scale $V(f_{cpu})$
- Undervolting: Violate specifications $V(f_{cpu}) \rightarrow V(f_{cpu}) - \Delta V$



Undervolting – Legitimation

Temperature dependency of CMOS gates

- Specification of $V(f_{cpu})$ is given in data sheets
- Specification does *not* include the temperature $V(f_{cpu}, \underline{T})$
  - Threshold Voltage V_{th} of CMOS is temperature-dependent

$$V_{th}(T) = V_{th0} + \alpha \cdot (T - T_0)$$

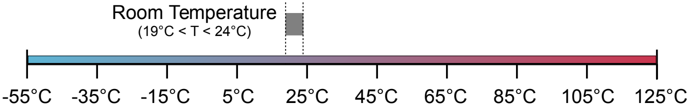
Undervolting – Legitimation

Temperature dependency of CMOS gates

- Specification of $V(f_{cpu})$ is given in data sheets
- Specification does *not* include the temperature $V(f_{cpu}, \underline{T})$
  - Threshold Voltage V_{th} of CMOS is temperature-dependent

$$V_{th}(T) = V_{th0} + \alpha \cdot (T - T_0)$$

MCUs cover a widespread temperature range with a fixed $V(f_{cpu})$



$\rightarrow$ MCUs must be able to run below $V(f_{cpu})$ (under *normal* conditions)

Short Demo

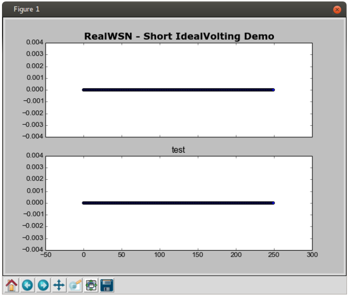
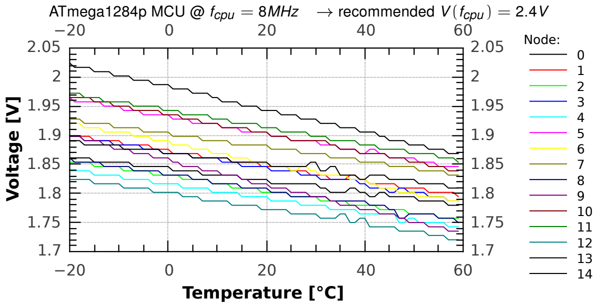


Figure 1
RealWSN - Short IdealVolting Demo
0.004
0.003
0.002
0.001
0.000
−0.001
−0.002
−0.003
−0.004
test
0.004
0.003
0.002
0.001
0.000
−0.001
−0.002
−0.003
−0.004
−50
0
50
100
150
200
250
300

First Results – Temperature Dependency

Measurement of $v(T)$ in a climatic chamber

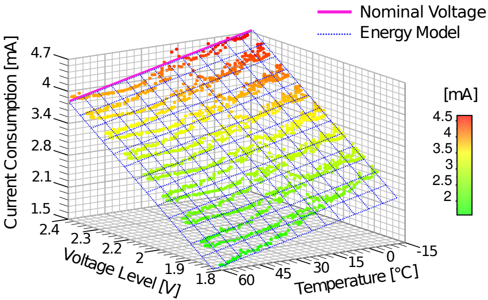
- Higher temperatures allow lower voltage levels
- Heterogeneity due to manufacturing and temperatures



First Results – Energy Model

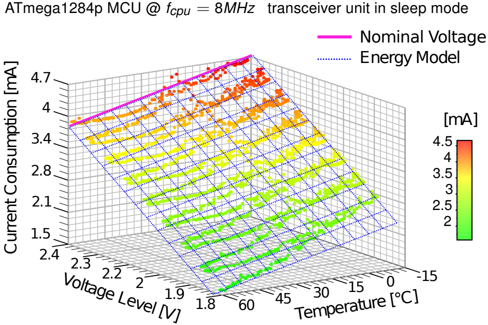
Measurement of $I_{cc}(v, T)$ in a climatic chamber

ATmega1284p MCU @ $f_{cpu} = 8MHz$ transceiver unit in sleep mode



First Results – Energy Model

Measurement of $I_{cc}(v, T)$ in a climatic chamber



- Derivation of an energy model $I_{cc}(v, T) = p + s \cdot T + t \cdot v$

least squares method leads to $p = -4.558[mA]$, $s = -11.976[\mu AK^{-1}]$ and $t = 3.770[mAV^{-1}]$

Experiment

Idea: Quantify the energy saving potential of housings

1. Measurement of thermal characteristics of different housings
2. Simulate the energy consumption by using $v(T)$ and $I_{cc}(v, T)$

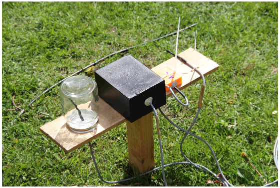
Experiment

Idea: Quantify the energy saving potential of housings

1. Measurement of thermal characteristics of different housings
2. Simulate the energy consumption by using $v(T)$ and $I_{cc}(v, T)$

Setup: Four different housings at different locations

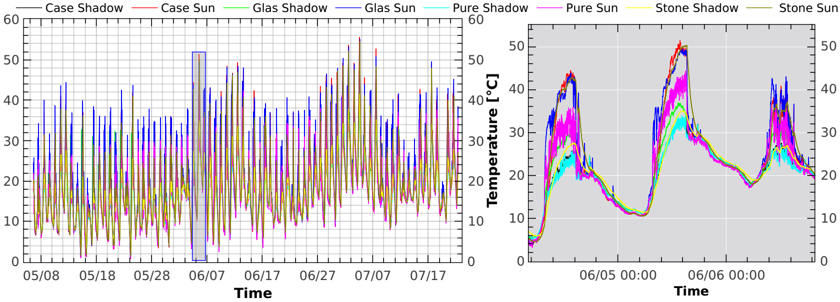
- Housings – Unpacked (pure), Plastic (case), Transparent (glass), Stone
- Locations – Direct sunlight (☼) and shadow (●)



Experimental Results – Temperature profile

Long-term temperature measurement in northern Germany[a]

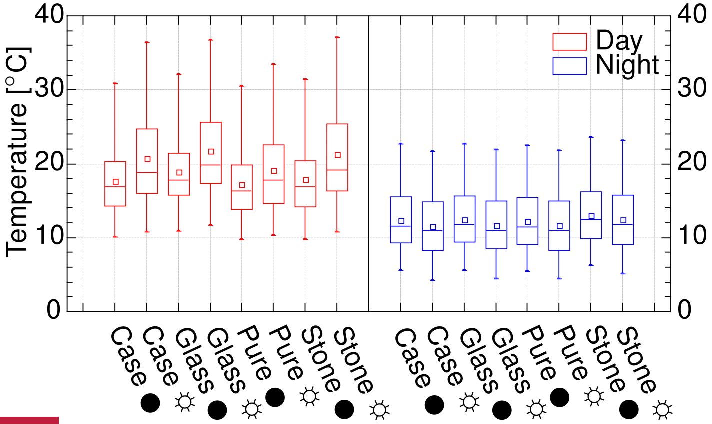
[a] → Online: `www.ibr.cs.tu-bs.de/users/kulau/PotatoNet-heat.html`



Experimental Results – Characteristics

Thermal characteristics during day and night

→ Average temperature – remarkable difference during daytime



Experimental Results – Energy Consumption

Energy Consumption [J] (dawn to dusk)

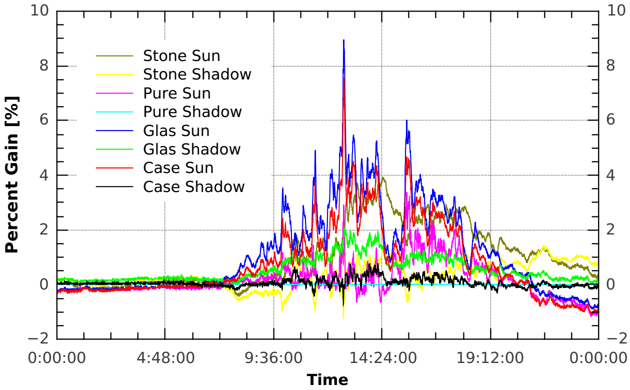
→ Housing and location influences the energy efficiency

	Undervolted		Nominal Voltage	
	hot day	cold day	hot day	cold day
Case ●	323.76	376.83	852.46	902.86
Case ☼	313.07	374.58	843.63	901.05
Glass ●	320.99	374.26	850.17	900.90
Glass ☼	312.73	372.04	843.27	899.10
Pure ●	325.06	377.99	853.54	903.80
Pure ☼	318.94	376.02	848.44	902.32
Stone ●	322.68	377.95	851.67	903.87
Stone ☼	312.05	374.87	842.79	901.38

Experimental Results – Exemplary Day

Gain in energy efficiency (baseline = pure shadow)

→ Significant differences between location and housings



Summary

WSNs in harsh environments:

- Potential for increased energy efficiency
  - Undervolting in WSNs $\rightarrow$ Temperature dependent voltage level

Summary

WSNs in harsh environments:

- Potential for increased energy efficiency
  - Undervolting in WSNs $\rightarrow$ Temperature dependent voltage level

Preliminary studies:

- Individual characteristics of $v(T)$
- Derivation of an energy model $I_{cc}(v, T)$

Summary

WSNs in harsh environments:

- Potential for increased energy efficiency
  - Undervolting in WSNs $\rightarrow$ Temperature dependent voltage level

Preliminary studies:

- Individual characteristics of $v(T)$
- Derivation of an energy model $I_{cc}(v, T)$

Experiment: Thermal characteristics of housings

- Energy savings...
  - $\approx$ 4% between housings (single day)
  - $\approx$ 20% between cold $\Leftrightarrow$ hot days

Summary

WSNs in harsh environments:

- Potential for increased energy efficiency
  - Undervolting in WSNs → Temperature dependent voltage level

Preliminary studies:

- Individual characteristics of $v(T)$
- Derivation of an energy model $I_{cc}(v, T)$

Experiment: Thermal characteristics of housings

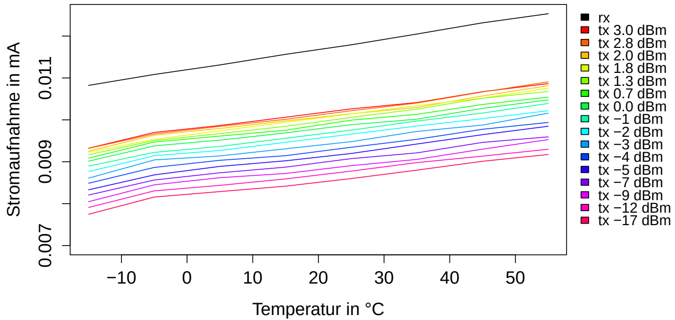
- Energy savings...
  - $\approx 4\%$ between housings (single day)
  - $\approx 20\%$ between cold ⇔ hot days

Thank you for your attention! Questions?

Ulf Kulau

kulau@ibr.cs.tu-bs.de

Backup – Transceiver vs. Temperature



Backup – Protocols