
Chulsung Park and Pai H. Chou – University of California, Irvine

IEEE SECON 2006

Presenter: Nikos Larisis
Contents

Order of matters addressed

• Introduction

• System overview

• Operation analysis

• Experimental evaluation

• Conclusion

• Questions
Introduction

Back, back, background theory

- Empedocles (Ἐμπεδοκλῆς)
Introduction

Back, back, background theory

- Empedocles (Ἐμπεδοκλῆς) (490 - 430 BC)

- pre-Socratic philosopher from Agrigentum (Sicily).
- Originator of the cosmogenic theory of the four classical elements.

*fire, air, water, earth*

(πῦρ, ἀἷρ, ὕδωρ, γῆ)
Introduction

Background theory

• Energy harvesting
  • Definition
  • Motivation
  • Devices/Sources
    • Thermoelectric generator (πυρ)
    • Micro wind turbine (αήρ)
    • “Eels” (ύδωρ)
    • Tidal power generator (γη)
Introduction

Background theory

• Beyond Empedocles scope...
  • Photovoltaic (*solar power*)
  • Piezoelectric devices (*pressure, vibration*)
  • Electromagnetic generator (*EM movement*)
  • p-RFID (*ambient radiation*)
  • many more beyond our scope...
Introduction

The “WSN case”

• Importance
• Reducing energy
• Energy systems
Introduction

The “WSN case”

• Importance
• Reducing energy
• Energy systems
• AmbiMax
System overview

Introduction

- Novel notion
  - Maximum Power Point tracking
  - Autonomy of harvesting control
  - Expandability
System overview

Introduction

• Architecture
  • EH subsystem
  • RCA subsystem
  • CC subsystem

• Powering principle
System overview

Ambient power sources

- Solar panel

  Solar World’s solar module (4-40-100) with max: Vout=4V, Iout=100mA
System overview

Ambient power sources

- Wind generator

  Wind Generator with Rotor Speed Sensor

- Joiniff’s wind generator:
  500 mW @ 2000 rpm
A. Energy harvesting subsystem

- Ambient power source
- PWM switching regulator
  - Charge even if $V_{\text{cap}} > V_{\text{oc}}$ until battery fully charged
  - Emulates diode function preventing....(?)

![Output waveform](image)
Operation analysis

A. Energy harvesting subsystem

- MPPT circuitry

1. *PWM switching regulator* – detects the MPP
2. *Comparator* – controls the operation of the regulator

   if $V_{ambi} < V_{sensor} - V_{hysterisis}$ then regulator=OFF
   if $V_{ambi} > V_{sensor} + V_{hysterisis}$ then regulator=ON
Operation analysis

B. Reservoir capacitor array subsystem

- Composition
- Benefits
  - volatile ambient power
  - main advantage (?)
  - avoid battery aging
Operation analysis

C. Control and charger subsystem

• Destination

I. Powering (*threshold detector*)

if $V_{RCA} > V_{th}$ then $E=\text{RCA}$

if $V_{RCA} < V_{th}$ then $E=\text{battery}$

II. Charging (*window comparator*)

when $V_{RCA} > V_{th1}$ && $V_{bat} < \text{FULL}$

($V_{th} = 2.7V$, $V_{th1} = 3.4V$)
Experimental evaluation

A. Experimental setup

1. Indoors
Experimental evaluation

A. Experimental setup

2. Outdoors

<table>
<thead>
<tr>
<th>WSN</th>
<th>Lifetime &gt; 1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power Consumption &lt; 200 mW</td>
</tr>
<tr>
<td></td>
<td>Regulator: Switching or Linear, 3~4V output</td>
</tr>
<tr>
<td></td>
<td>Battery: One cell Li-Ion/Polymer or Two AA type</td>
</tr>
<tr>
<td>Sunlight</td>
<td>at least 6 hours a day, higher than 800 Lumens</td>
</tr>
<tr>
<td>Wind</td>
<td>avg. 10 mps at least 6 hours</td>
</tr>
</tbody>
</table>

Eco Wireless Sensor Node

Top View
Experimental evaluation

B. Solar harvesting efficiency

**AmbiMax vs Prometheus**

- How much time until $V_{cap} = 3V$
- How much energy harvested for $\Delta t = 20\text{ sec}$

<table>
<thead>
<tr>
<th></th>
<th>Time</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>AmbiMax</td>
<td>0.4 secs</td>
<td>1318.3 J</td>
</tr>
<tr>
<td>Prometheus</td>
<td>5 secs</td>
<td>433.8 J</td>
</tr>
</tbody>
</table>
Experimental evaluation

C. Experimental data on Eco nodes
Conclusion

Pro et contra

+ analog circuitry (autonomy/liberate MCU)
+ multi-supply harvesting
+ MPPT
+ outperforming the “classics”
+ comparing in practice the rivals

- outdoor measurement
- hardware failures/inconsistencies
- cost vs form factor