Wake on Wireless
(Mobicom ’02)

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Authors:
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Motivation:

Wanted a single handheld computing device that is capable of both voice and data processing and communications...

...wanted a Universal CoMunicator

PDA + WiFi → UCoM
The Energy Consumption Problem

A big obstacle in deploying WLAN-based VoIP devices is battery lifetime

• Battery capacity doubles in energy density every 35 years [Pow95]
• Battery lifetime determines total useful operating lifetime between recharges
Managing Power: Basics

Definitions:

- **Active Power** – Power required to perform specified operations on the device
- **Idle Power** – Power required to keep the device turned on (in low power mode), ready to react to

The PocketPC expends energy in idle state most of the time

Idle power consumption is as large as receive power [Fee01]

To increase battery lifetime:

- Reduce active power
- Reduce idle power
Measuring $I_{Avg}$ of popular IEEE 802.11b NICs

<table>
<thead>
<tr>
<th>Chipset</th>
<th>Sleep (mA)</th>
<th>Idle (mA)</th>
<th>Receive (mA)</th>
<th>Transmit (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORiNOCO PC Gold</td>
<td>12</td>
<td>161</td>
<td>190</td>
<td>280</td>
</tr>
<tr>
<td>Cisco AIR-PCM350</td>
<td>9</td>
<td>216</td>
<td>260</td>
<td>375</td>
</tr>
</tbody>
</table>

Cisco Aironet – PSM ~80mA (390mW)
Power Consumed during PS Mode

Power consumed by Orinoco Gold during Power Save Mode

\[ E_{\text{cycle}}(n,t) = 0.060nt + 3300, \ 0 =< n =< 65535 \]

\[ N = \text{listen interval}, \ t = \text{beacon period} \]

Power consumed by Cisco AIR-PCM350 during Power Save Mode

\[ E_{\text{cycle}}(n,t) = 0.045nt + 24200, \ 0 =< n =< 65535 \]

Cisco Aironet – PSM ~80mA (Measured)
Standby Lifetime of an 802.11 iPAQ & a Cell Phone
Reducing Idle Power

The Problem
To receive a phone call the device and the wireless NIC has to be in a “listening” state i.e. they have to be on.

Wake-on-Wireless
When not in use, turn the wireless NIC and the device off.
Create a separate low-power control channel.
Use this channel to “wake-up” device when necessary.

Proof of Concept & Implementation
Add a low power RF transceiver to the 802.11 enabled handheld device
Proof of Concept
System Design and Implementation
Hardware Components

A low-power RF transceiver added to the handheld
- “MiniBrick” or “Mbrick”

A low-power RF transceiver added to the infrastructure
- “SmartBrick” or “Sbrick”

Requirements:
- Sbrick has to be connected to a network
- Sbrick talks to an Mbrick using a defined protocol
- Sbrick connected to a networked computer
Software Components

Proxy:
- Listens for registration requests on LPC
- Sends POWER_ON msg to wake-up UCOM client

Presence Server
(Location at IP-Level)

Location Server
(Geographic locations)

Brick Server
(Keep track of registered Proxies / Clients)
Call Setup

UCoM Client (Bob) 

Register as Client 
OK, inform Client of Registered buddies 
Server update's Client's Buddy List 

Bob calls Alice 
“Call Alice” 

UCoM Server 

Proxy informs Server of Alice’s Presence 

UCoM Proxy 

MiniBrick Registers “Alice” with Proxy 

UCoM Client (Alice) 

Ring 

Device ON 

AUTONOMOUS
The MiniBrick PCB

Modular design allows removal of components
Radio Power Consumption

Radio:
- RFM TR 1000 ASH
- Modulation: ASK
- Voltage: 3V
- Range: 30 feet (approx) vs 332ft (spec)!

Comparing against 802.11 and BT Radios

<table>
<thead>
<tr>
<th>Chipset</th>
<th>Receive (mW)</th>
<th>Transmit (mW)</th>
<th>Standby (mW)</th>
<th>Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersil PRISM 2 (802.11b)</td>
<td>400</td>
<td>1000</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>Silicon Wave SiW1502 (BT)</td>
<td>160</td>
<td>140</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>RFM TR1000</td>
<td>14</td>
<td>36</td>
<td>0.015</td>
<td>0.115</td>
</tr>
</tbody>
</table>
MiniBrick Power Consumption

<table>
<thead>
<tr>
<th>Mode</th>
<th>Power Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit</td>
<td>39 mW</td>
</tr>
<tr>
<td>Receive</td>
<td>16 mW</td>
</tr>
<tr>
<td>Standby</td>
<td>7.8 mW</td>
</tr>
</tbody>
</table>

Theses numbers include the power consumption by the PIC Microcontroller and the RFM TR1000
MiniBrick Operating Mode

<table>
<thead>
<tr>
<th>PREAMBLE</th>
<th>DEST_TYPE</th>
<th>DEST_ID</th>
<th>SRC_TYPE</th>
<th>SRC_ID</th>
<th>DATA_SIZE</th>
<th>DATA</th>
<th>CRC</th>
</tr>
</thead>
</table>

Autonomous Mode (iPAQ off / MiniBrick ON)

- SETUP MINIBRICK
- TRANSMIT (8 ms)
- RECEIVE (20 ms)
- SLEEP (300 ms)
- IPQA STILL ON?
- IPAQ TURNED OFF
- RECEIVED WAKEUP FROM PROXY?
- NO MESSAGE

Data field not used P-to-P (No real MAC)

68bit Msg Sent 10 Times
Integrating MiniBrick & iPAQ

MiniBrick turns on the iPAQ by toggling the **Data Carrier Detect** (DCD) line on serial port.
## Power Consumption of the UCoM Device

<table>
<thead>
<tr>
<th>iPAQ Mode</th>
<th>MiniBrick Mode</th>
<th>Power Consumed (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTIVE</td>
<td>Off</td>
<td>2.92</td>
</tr>
<tr>
<td>ATTEMPT</td>
<td>Off</td>
<td>2.92</td>
</tr>
<tr>
<td>STANDBY</td>
<td>Autonomous</td>
<td>0.12</td>
</tr>
</tbody>
</table>

ACTIVE – during actual conversation
ATTEMPT – when device is attempting a call
STANDBY – when device is completely OFF (Minibrick ON & iPAQ sleep)
The SmartBrick

Powered from Serial port
System Performance
Results: Standby Time?

The Idle power consumption in PDAs range from 100 to 200 mW [Fee01]

The Idle power consumption for iPAQ H3650 is 112 mW

115% improvement in battery lifetime over PS mode with lower latency
How do we do for real users?

Cellular Phone Usage Profile
From one month’s cell phone bills of two real users

**Alice**
82 minutes talk time
(798 minutes / month)

**Bob**
35 minutes talk time
(562 minutes / month)
Battery Lifetime for real users

With .11 PS both Alice and Bob will have to perform midday recharge for all days profiled.

<table>
<thead>
<tr>
<th></th>
<th>Alice</th>
<th>Bob</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain over 802.11b PS</td>
<td>&gt; 40%</td>
<td>&gt; 27%</td>
</tr>
<tr>
<td>Gain over 802.11b CAM</td>
<td>&gt; 180%</td>
<td>&gt; 180%</td>
</tr>
</tbody>
</table>
A comparison with alternative strategies
## Power Consumption Measurement: Methodology and Results – PC cards

<table>
<thead>
<tr>
<th></th>
<th>RFM TR1000</th>
<th>Xircom BT PC card</th>
<th>OriNOCO Silver 802.11b</th>
<th>Air-PCM340 802.11b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idle (mW)</td>
<td>N/A</td>
<td>140</td>
<td>840</td>
<td>1029</td>
</tr>
<tr>
<td>Xmit (mW)</td>
<td>16</td>
<td>250</td>
<td>946</td>
<td>1329</td>
</tr>
<tr>
<td>Receive (mW)</td>
<td>19</td>
<td>263</td>
<td>916</td>
<td>1203</td>
</tr>
<tr>
<td>Sleep (mW)</td>
<td>7.8</td>
<td>140</td>
<td>15</td>
<td>74</td>
</tr>
<tr>
<td>Raw Data Rate</td>
<td>115.2 Kbps</td>
<td>1 Mbps</td>
<td>11 Mbps</td>
<td>11 Mbps</td>
</tr>
</tbody>
</table>
Power Consumption Measurement: Methodology and Results – Cell Phones

<table>
<thead>
<tr>
<th>Mode</th>
<th>High (mW)</th>
<th>Low (mW)</th>
<th>Average (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standby (weak signal)</td>
<td>156</td>
<td>84</td>
<td>125</td>
</tr>
<tr>
<td>Standby (strong signal)</td>
<td>26</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>Ringing</td>
<td>1676</td>
<td>1440</td>
<td>1582</td>
</tr>
<tr>
<td>Talking</td>
<td>1612</td>
<td>1032</td>
<td>1254</td>
</tr>
<tr>
<td>Call Attempt</td>
<td>704</td>
<td>884</td>
<td>696</td>
</tr>
</tbody>
</table>
Lifetime with various technologies

**Alice**

New BT radios (v1.2)
80mW Active
8-20mW Low Power-Idle

**Bob**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Energy Used (Wh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11b CAM</td>
<td>7600</td>
</tr>
<tr>
<td>802.11b PSP</td>
<td>7600</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>6340</td>
</tr>
<tr>
<td>With LPC</td>
<td>3390</td>
</tr>
<tr>
<td>IPAQ+ with LPC</td>
<td>2830</td>
</tr>
<tr>
<td>Cell Phone</td>
<td>1720</td>
</tr>
</tbody>
</table>
Summarizing
The UCoM Device
What did WoW achieve?

Started with

- iPAQ H3650 that consumes 112 mW even when it is “off”
  - Total standby lifetime: 35 hours
- iPAQ H3650 with Cisco AIR-PCM340 802.11b in PS mode
  - Total standby lifetime: 14.5 hours
    - Compare with Motorola v60t cell phone with 44.5 hours standby time

Accomplished

- Standby life-time of a unmodified iPAQ with 802.11b and LPC went to over 30 hours -- an improvement of 115% (in addition to lower latency wake-on-wireless capability)
- For a typical user with 82 min./day use – we see an improvement of over 40% or a battery lifetime of over 20 hour

Important note

- Technique is not limited to iPAQ
- Technique is not limited to LPR, can use BT or 802.15.4 as trigger
Discussion

• Latency to do Wake-on-Wireless?
  “We haven’t measured it – but estimate 5-10s)” !!
• Bar for deployment extremely high
  – 30ft radio ranges (can improve – On-Demand-Paging)
  – Need to add custom radios & a LOT of infrastructure
• Low Power MAC quite simplistic.
  – What happens to power consumption when a real MAC is used?
• Description of the various system components brief…
  – What are the various packet fields used for?
  – Why is the location server needed?
  – What modifications are needed to the VoIP protocols to make this all work?