Wireless sensor Networks

Waltenegus Dargie
Chair for Computer Networks
http://z2.inf.tu-dresden.de/dargie/class.htm
Motivation

- Environment monitoring
  - Forest fire detection, wild life, passive observation
- Health
  - Tele-monitoring of patients as well as medical personnel
- Inventory, asset tracking and supply chain management
- Manufacturing
- Home automation
- Traffic control
- Disabled and elderly assistance
- Intrusion detection
- Precision agriculture
- Military
  - Monitoring, surveillance, reconnaissance of opposing forces and terrains, targeting, damage assessment, nuclear, biological, and chemical attack detection
A Sensor Node

- Integrates one or more sensors.
- Locally processes and stores sensed data and communicates with other nodes via a wireless link.
A Sensor Node

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A Sensor Node

- Parallel interface for programming and debugging
- Vibration sensor
- Infrared receiver
- Serial interface for data in- and output
- User mode button
- Cell phone connector to trigger SMS messages (not displayed)
- Infrared sender diode
- Light, temperature and movement sensor
- External power source
- Red/yellow/green LEDs
- Battery box for 3 AA batteries - other version of the ESB are powered only by a solar cell
- On/off switch for battery power (has no influence on external power)

Texas Instruments MSP430 system on a chip with 8 MHz RISC CPU, 64kB memory, AD/DA converter

Piezoelectric buzzer

Antenna

TR1001 low-power radio transceiver operation at 868.35 Mhz at max. 115.2k baud data rate
Sensors

- Passive and omnidirectional
  - temperature, humidity, Light, vibration, microphone, mechanical stress or tension, blood pressure, blood flow, oxygen, heart rate, respiratory rate, chemical (soil makeup), smock detector;

- Passive and narrow beam
  - Camera

- Active
  - Seismic sensors, radar
Design Issues

- Cost
- Lifetime (when almost always on, when almost always off)
- Performance:
  - Speed (in ops/sec, in ops/joule)
  - Communication range and frequency
  - Memory (size, latency)
- Concurrent operation (sensing, processing, transmission, and receiving)
- Reliability, security, size, packaging
Design Issues

- **Sampling rate**: (1Hz or lower to 5KHz or higher)
- **Signal resolution:**
  - ADC bits: 8, 10, 12, 16, 20 bit (cost matters)
  - Sensitivity, drift, offset
- **Sensor calibration or reset frequency**
- **Interference, cross-talk**
Design Issues

- **Microcontroller:**
  - Microprocessors, microcontrollers, FPGAs, and ASICs: flexibility versus energy efficiency
  - Architecture
    - von Neumann architecture (same address and data bus)
    - typical 4 bit, 8 bit, 16 bit or 32 bit architectures
    - speed 4 MHz-400MHz with 10-300 or more MIPS
  - Power management vs. Latency
    - fully active: 1 to 50 mW
    - sleep (memory standby, interrupts active, clocks active, cpu off)
    - sleep (memory retained, interrupts active, clocks active, cpu off)
    - sleep (memory retained, interrupts active, clocks off, cpu off) 5uW
Design Issues

- **Memory**:
  - Speed, capacity, price, power consumption, memory protection
  - **SRAM**: typical 0.5KB-64MB
    - Typical power consumption
      - retained: \(~100\mu A\); read/write: \(~10mA\) if separate chip
      - retained: 2-100 \(\mu A\), read/write: \(~5mA\) if in core
  - **DRAM**: high power consumption in retained mode
  - **EEPROM**: 4KB-512KB, often used as program store
  - **Flash**: 256KB-1GB or beyond
    - Typical power consumption
      - retained: negligible; read/write: \(~7/20mA\)
      - erase operation is expensive
    - Large flashes are outside of core
Design Issues

- **Peripheral interfaces:**
  - Sensors, actuators, I/O, power
  - Analog and digital
  - Multiple busses with bridges between them
  - SPI: Serial Peripheral Interface
  - UART: Serial communication
  - USB
  - PCI
Design Issues

- Interrupts:
  - Asynchronous breaks in program execution
    - Press of a button; expiration of a timer; completion of sensing data collection, DMA transfer, transmission event, ...
  - When interrupt occurs, processor transitions to the corresponding interrupt handler to service interrupt and then resumes execution
  - Multiple priority levels
Design Issues

- **Power supply:**
  - Chemical batteries, fuel cells, nuclear batteries (tritium), nuclear batteries (polonium)
  - Voltage regulation
    - Typical ranges: 1.8V, 3.3V, 5V
    - Multiple voltage levels for various subsystem
- **Charging, harvesting, scavenging**
  - solar, wind, vibration, heat
Design Issues

- **Communications:**
  - Interface: bit, byte, packet level
  - Data rate
  - Transmission range: maximum transmission power, antenna directivity, attenuation, acceptable bit error rate (proportional to $E_b/N_0$)
  - Power consumption, startup time
  - Carrier frequency and multiple channels
  - Modulation
  - Energy efficiency: joules/bit/m
  - Signal propagation and interference characteristics
  - Power efficiency: the percentage of consumed power which is radiated
  - Power consumption during sending and receiving data as well as during idly listening to the arrival of message
  - Receiver sensitivity and Out of band emission
  - Carrier sense and RSSI
  - Frequency stability
  - Operation voltage range
  - Time and energy consumption to change between different states
  - Transmission power control
Design Issues

• Active, idle and sleeping modes
Design Issues

\( P_{\text{active}}, P_{\text{sleep}}; \)
\( t_1 = \text{the time at which a decision whether or not a component is} \)
\( \text{to be put into sleep mode is made}; \)
\( \tau_{\text{down}} = \text{sleeping time}; t_{\text{event}} = \text{the time at which an event} \)
\( \text{arrives: timer expires, a sensor reports interesting} \)
\( \text{phenomenon, or a message is received}; \)
\( E_{\text{active}} = P_{\text{active}}(t_{\text{event}} - t_1); \)
\( P_{\text{ave}} = (P_{\text{active}} + P_{\text{sleep}})/2: \text{the average power consumption during} \)
\( \text{the transition from an active into a sleeping mode and vise} \)
\( \text{vera} \)
\( E_{\text{sleep}} = \tau_{\text{down}}(P_{\text{active}} + P_{\text{sleep}})/2 + (t_{\text{event}} - t_1 - \tau_{\text{down}})P_{\text{sleep}}; \)
\( E_{\text{saved}} = (t_{\text{event}} - t_1)P_{\text{active}} - (\tau_{\text{down}} (P_{\text{active}} + P_{\text{sleep}})/2 + (t_{\text{event}} - t_1 - \tau_{\text{down}})P_{\text{sleep}}; \)
\( E_{\text{overhead}} = \tau_{\text{up}}(P_{\text{active}} + P_{\text{sleep}})/2 \)
Design Issues

• Switching to a sleeping mode is beneficial if the time to the next event is sufficiently large, i.e.,

\[
(t_{\text{event}} - t_1) > \frac{1}{2} \left( \tau_{\text{down}} + \frac{P_{\text{active}} + P_{\text{sleep}}}{P_{\text{active}} - P_{\text{sleep}}} \tau_{\text{up}} \right)
\]
Design Issues

• Modelling energy consumption during transmission
  – Transmission power, $P_{tx}$, energy per bit over noise, bandwidth efficiency, distance of transmission, and path loss
  – Power amplifier, $P_{amp}$, baseband processors ($P_{txElec}$)

$$P_{amp} = \alpha_{amp} + \beta_{amp} P_{tx}$$

• Where $\alpha_{amp}$ and $\beta_{amp}$ are constants which depend on process technology and amplifier characteristics
The energy to transmit a packet $n$-bits long depends on:
- The nominal bit Rate, $R$
- Coding rate, $R_{code}$
- Total consumed power during transmission

\[
E_{tx}(n, R_{code}, P_{amp}) = T_{start} P_{start} + \frac{n}{RR_{code}} (P_{txElec} + P_{amp})
\]
Design Issues

- Modelling energy consumption during reception
  - Preamplifier
  - Decoding electronic

\[ E_{\text{recd}} = T_{\text{start}} P_{\text{start}} + \frac{n}{R R_{\text{code}}} (P_{\text{rxElec}} + nP_{\text{E_{decBit}}}) \]
## Design Issues

### Overview

<table>
<thead>
<tr>
<th>Technology</th>
<th>Data Rate</th>
<th>Tx Current</th>
<th>Energy per bit</th>
<th>Idle Current</th>
<th>Startup time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mote</td>
<td>76.8 Kbps</td>
<td>10 mA</td>
<td>430 nJ/bit</td>
<td>7 mA</td>
<td>Low</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>1 Mbps</td>
<td>45 mA</td>
<td>149 nJ/bit</td>
<td>22 mA</td>
<td>Medium</td>
</tr>
<tr>
<td>802.11</td>
<td>11 Mbps</td>
<td>300 mA</td>
<td>90 nJ/bit</td>
<td>160 mA</td>
<td>High</td>
</tr>
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