Sensor Networks Hardware

Why Care About Hardware?

Sensor node components:
- Sensing
- Processing
- Communication

Why not use high level abstractions?
1. Hardware improvements made sensor networks possible
2. Application characteristics impact sensor network design, both hardware and software

Hardware trends

- Moore's law
  - Processing, storage
- System on a chip
  - Digital and analog components on a same chip
  - Low power, small form factor
- MEMS technology
  - Low power, small form factor, high performance sensors/actuators
- Energy source
  - Higher density, smaller form factor
  - Do not follow Moore's law

Hardware impact on applications

- Lifetime
  - Depends on energy budget (batteries, energy harvesting)
  - Energy consumption depends on hardware components and on interaction with software
  - Turning off components to save energy
  - Moving boundary between hardware and software components
  - Hardware characteristics impact software design
    - CO-DESIGN
    - CROSS LAYER OPTIMIZATIONS

Hardware impact on applications

- Cost
  - Dictates choice of hardware components, of fabrication method
- Sensed Data
  - Dictates choice of radio, of sensors
- Environment
  - Form factor impacts choice of hardware components, layout

A Case Study: ETH BTNode

http://www.btnode.ethz.ch/
Sensor Node Components

- Processing
  - Microcontroller
  - Memory
- Communication
  - RF transceiver
  - Optical transceiver
- Sensing
  - Sensor Board
- Energy
- Interface

Micro-Controller Unit

- CPU
  - 8 / 16 / 32 bits
  - Compiler support
- Pins in/out (GPIO)
- Serial / UART
  - SCI (to PC)
  - SPI (to radio)
  - I2C (chip to chip com)
- Clock / Timer
  - (external) crystal
- Memory
  - Internal Flash/RAM
  - registers imany for RISC, few for CISC
- Tight coupling
  - Integrated interrupt controller
  - No MMU
- Analog to Digital converter
  - Given resolution at a given frequency

Micro-Controller

- Sleeping modes
  - Turn off different components (CPU, UART, memory, flash)
- CPU wake-up events
  - Woken up on any interrupts
  - Woken up only on timer interrupt

MCU: ETH BTNode

- Atmega1281 MCU
  - 8 bits
  - External crystal
    - 32 kHz (real time)
    - 7 MHz (CPU clock)
  - 4 KB SRAM
  - 4 KB EEPROM
  - 10 bit ADC at 50-200 kHz
- Sleeping modes:
  - Idle: CPU woken up by any signal from UART or clock
  - Power save: CPU only woken up by external clock

Memory

- RAM (Random Access Memory)
  - SRAM
- EEPROM (Electrically Erasable Programmable Read-Only Memory)
  - Programmable 1 byte at a time
- Flash
  - Special type of EEPROM programmable one page at a time

RF Transceiver

- SPI connection to MCU
- Bandwidth
  - 800MHz, 900 MHz, 2.4 GHz
- Digital + Analog
  - Shared channel vs. Separate channels
    - Impact on interferences (or traffic overloading)
    - Oversampling
    - Hardware accelerator
  - Independent clock
- Antenna
  - Onboard vs. external
RF Transciever: ETH BTNode

Ericsson ROK 101 007
- 2.4 GHz radio
- Bluetooth Baseband
  - Frequency hopping Spread Spectrum (separated channels)
  - Internal 15 MHz crystal
  - Packet based interface (IrDa)
  - Bandwidth up to 35 Kbps

Optical Transciever

Sensor Board

- Choosing a sensor
  - Mode
    - Scientific, light, temperature, motion detector...
  - Range of operation
  - Interface
    - Analog (via ADC)
    - Digital (i2c, spi)
  - Power consumption
  - Duty cycling possibilities
  - Consumption when idle, in operation
  - Start-up time
- Precision
  - Accuracy of measurement
  - If ADC is used, accuracy is a combination of sensor measurement and CPU sampling/representation
- Designing a sensor board
  - Connection to MCU
  - Power source
  - Form factor / packaging

Temperature Sensor Board for Dummies

- Thermistor
  - NTC resistor: 10 kΩ
  - Decrease in resistance when subjected to an increase in temperature
- Power source
  - Independent
  - From MCU
- Input to ADC converter
  - Voltage drop (analog input) gives indication of decrease in resistance

Energy

- Joules / Watts / Amperes / Volts
  - Power (P in Watt) = Potential Difference (U in Volts) * Current (I in Ampere)
  - Energy (E in Joule) = Power (P in Watt) * Time (T in sec)
  - 1 W = 1 V * 1 A
  - 1 J = 1 J / sec
- Voltage regulation on a sensor node
  - CMOS has different consumption at different voltages
  - Different components have different voltage needs

Energy Consumption: ETH BTNode

With 5V power source:
- BTNode consumes 46mW in idle mode with radio off
- Bluetooth radio consumes 30mW extra

With 3V power source:
- 24mW power save
- 2 mW external RAM off
- 0.6 mW voltage regulator off
### Energy Consumption: ETH BTNode

- **Back of the envelope calculation**
  - Transmitting 1KiB at 20 meters:
    - 230 mW at 5 KiB/sec
    - 230 (mJ/sec) / 5 = 46 mJ
  - Computing 6 million instructions:
    - 7 MIPS at 50 mW
    - 50 (mJ/sec) * 6 / 7 = 42 mJ

Transmitting 1 KiB ~ Processing 6 mio. instructions

### Batteries

- **Characteristics**
  - Voltage: e.g., 1.2V
  - Charge capacity: 2000 mAh

### Energy Harvesting

- **Solar energy**
  - Energy from the sun: 100 mW/cm²
- **Photo-voltaic cells**: 10-15% efficiency
- **Mechanical energy**
  - Piezo-electrical components
  - Shoe example: 200mW during a walk
- **Temperature/pressure variation**
  - Up to 100 mW
- **Exotic solutions**
  - Biological fuel cells, fat burning, radioactive sources, …

### Interface

- **Programming**
  - Serial (over RS232 or USB)
  - Parallel
- **Debugging**
  - Sensor (in), LED (out)
  - UART
  - BDM
  - JTag

### Berkeley Mote Evolution

http://www.tinyos.net/media.html

### Towards Sensor Nodes On A Chip

- **Digital + Analog components**
- **Digital Design**
  - High level down to gates
- **FPGA support for co-design**
  - Spec Mote
Application Driven Co-Design

Application specific assembly of HW and SW components
• Application requirements
• Energy budget
• HW / SW characteristics:
  – Which HW components?
  – Duty cycling?

Vs.

Generic hardware + Application specific Energy source and SW components

Cross Layer Optimizations:
HW Impact on SW Design

• Processing is orders of magnitude cheaper than transmissions
  – In-network processing
• Radio bandwidth
  – Transmitting a lot fast vs. Transmitting few bits
• Sleeping modes
  – Power consumption in different sleeping states impacts duty cycling
• Separate clocks for radio and MCU
  – Radio vs. MCU driven duty cycling

Summary

• HW Components
  – MCU, Memory, Radio, Antenna, Energy source
• Energy budget is limited
  – Based on source of energy available
  – Local processing cheaper than transmission
  – Duty cycling
    • turn off components to preserve energy
  – Cross Layer Optimizations