Organic Computing

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Hardware-Software-Co-Design

Sensor Networks

Outline

- Introduction
- Application
- Challenges
- Architecture
- Focus on
  - Energy efficiency
  - Localization
  - Deployment (….?)
  - Routing
- Enabling technologies
  - The MICA Platform
  - Zigbee
  - TinyOS

Sensor networks - Introduction

- The deployment of small, inexpensive, low-power, distributed devices, capable of local processing and wireless communication, is a reality
- Such nodes are called as sensor nodes
  - Each sensor node is capable of only a limited amount of processing
  - When coordinated many sensor nodes can be used to measure a given physical environment in great detail
- A sensor network can be described as a collection of sensor nodes which co-ordinate to perform some specific action
- Unlike traditional networks, sensor networks depend on dense deployment and co-ordination to carry out their tasks

Sensor networks - Introduction

- Previous sensor networks consisted of small number of sensor nodes, wired to a central processing station
- Nowadays, the focus is more on wireless, distributed sensing and processing
- Why distributed, wireless sensing and communication?
  - When the exact location of a particular phenomenon is unknown
  - Overcome environmental obstacles like obstructions and line of sight constraints
  - Communication is a major consumer of energy
  - A centralized system would mean communication over long distances (more energy consumption)
  - Minimize communication by processing locally as much information as possible

Sensor networks - Introduction

- No infrastructure for either energy or communication in the environment to be monitored
  - Sensor nodes must survive on small, finite sources of energy and
  - Communicate through a wireless communication channel

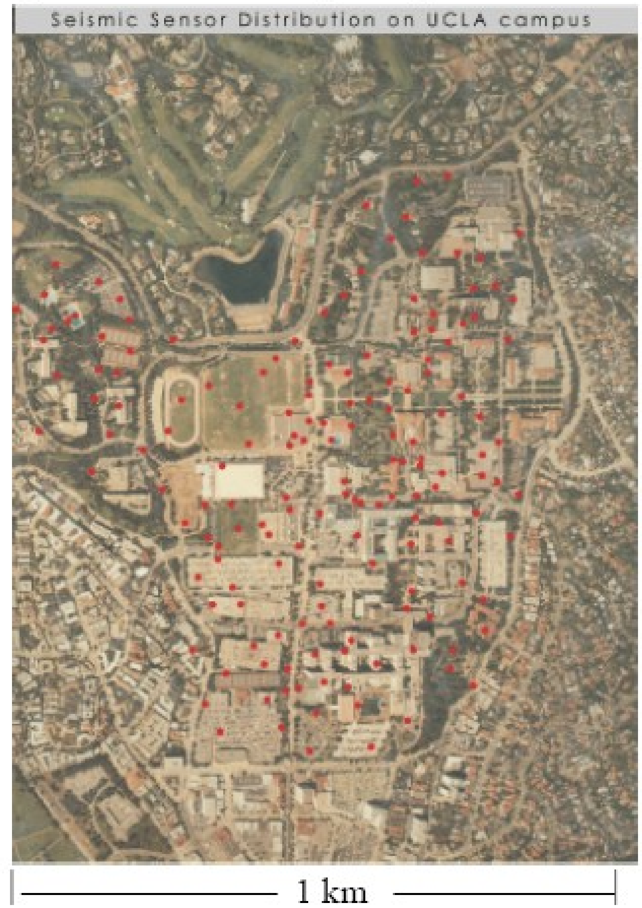
Sensor networks - Application

- environmental monitoring
  - Air
  - Soil and water,
  - Habitat monitoring (determining the plant and animal species population and behavior),
  - Seismic detection,
  - Military surveillance,
  - Inventory tracking,
  - Smart spaces etc

- Due to the pervasive nature of micro-sensors, sensor networks have the potential to revolutionize the very way we understand and construct complex physical system

Sensor networks – Field of experiment

- 38 strong-motion seismometers in 17-story steel-frame Factor Building.
- 100 free-field seismometers in UCLA campus ground at 100-m spacing



Source: D. Estrin, UCLA

Sensor networks - Challenges

- Ad hoc deployment
  - On deployment in region without infrastructure to the nodes must be able identify its connectivity and distribution
- Unattended operation
  - No human intervention after deployment: self reconfiguration on changes
- Untethered
  - Finite source of energy must be optimally used for processing and communication
- Dynamic changes
  - Adaptation to changing connectivity (addition of nodes, failure of nodes etc.) as well as changing environmental stimuli.
- lifetime and system robustness more important than the throughput

Sensor networks - Architecture

- A sensor node usually consists of four sub-systems
  - a computing subsystem
  - a communication subsystem
  - a sensing subsystem
  - a power supply subsystem
- Computing subsystem
  - Microprocessor (microcontroller unit, MCU) responsible for the control of the sensors and execution of communication protocols
  - Usually operate under various operating modes for power management purposes
  - Switching between operating modes involves consumption of power

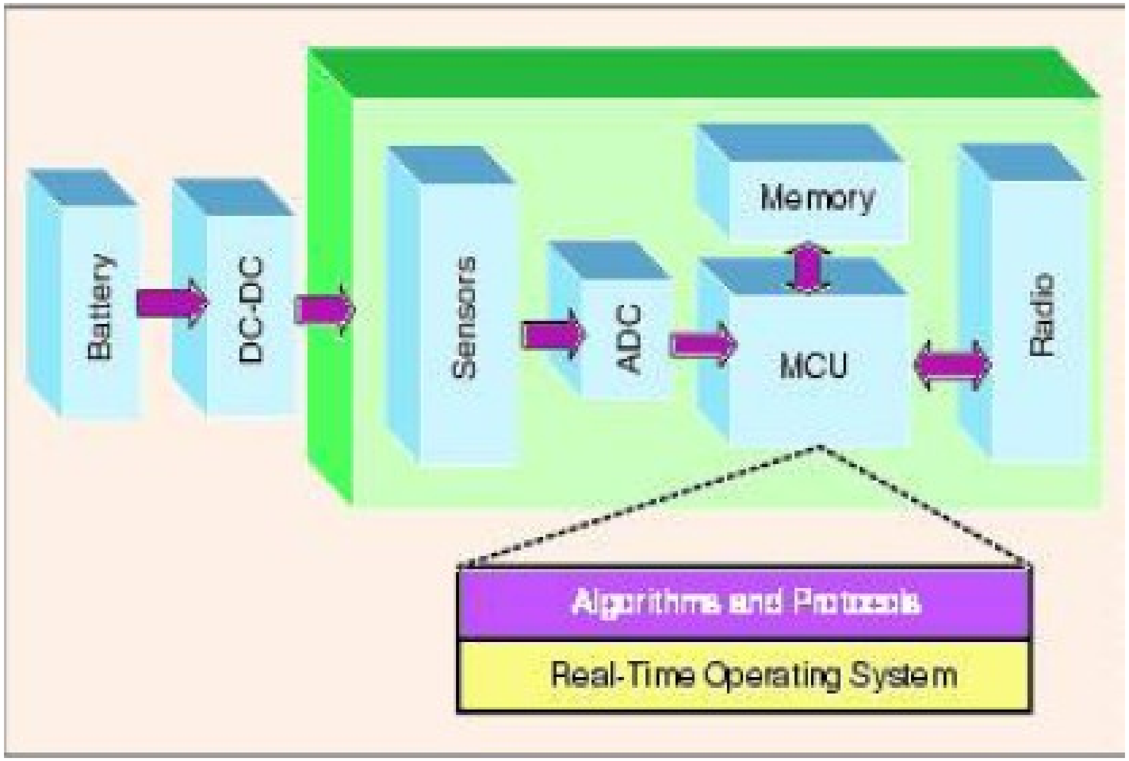
Sensor networks - Architecture

- Communication subsystem
  - It consists of a short range radio which is used to communicate with neighboring nodes and the outside world
  - Radios can operate under the Transmit, Receive, Idle and Sleep modes
  - It is important to completely shut down the radio rather than put it in the Idle mode when it is not transmitting or receiving because of the high power consumed in this mode
- Sensing subsystem
  - It consists of a group of sensors and actuators that link the node to the outside world
  - Energy consumption can be reduced by using low power components and saving power at the cost of performance which is not required

Sensor networks - Architecture

- Power supply subsystem
  - It consists of a battery which supplies power to the node
  - The amount of power drawn from a battery should be checked
    - If high current is drawn from a battery for a long time, the battery will die even though it could have gone on for a longer time
  - The lifetime of a battery can be increased by reducing the current drastically or even turning it off often

Sensor networks - Architecture



System architecture of a typical wireless sensor node

Sensor networks - Localization

- Deployment of nodes into unplanned infrastructure
  - no *a priori* knowledge of location

- The problem of estimating spatial-coordinates of the node is referred to as localization

- Why not GPS (Global Positioning System) ?
  - GPS can work only outdoors
  - GPS receivers are expensive
    - Not suitable in the construction of small cheap sensor nodes
  - cannot work in the presence of any obstruction like dense foliage etc

- Sensor nodes need other means of
  - establishing their positions and
  - organizing themselves into a coordinate system without relying on an existing infrastructure

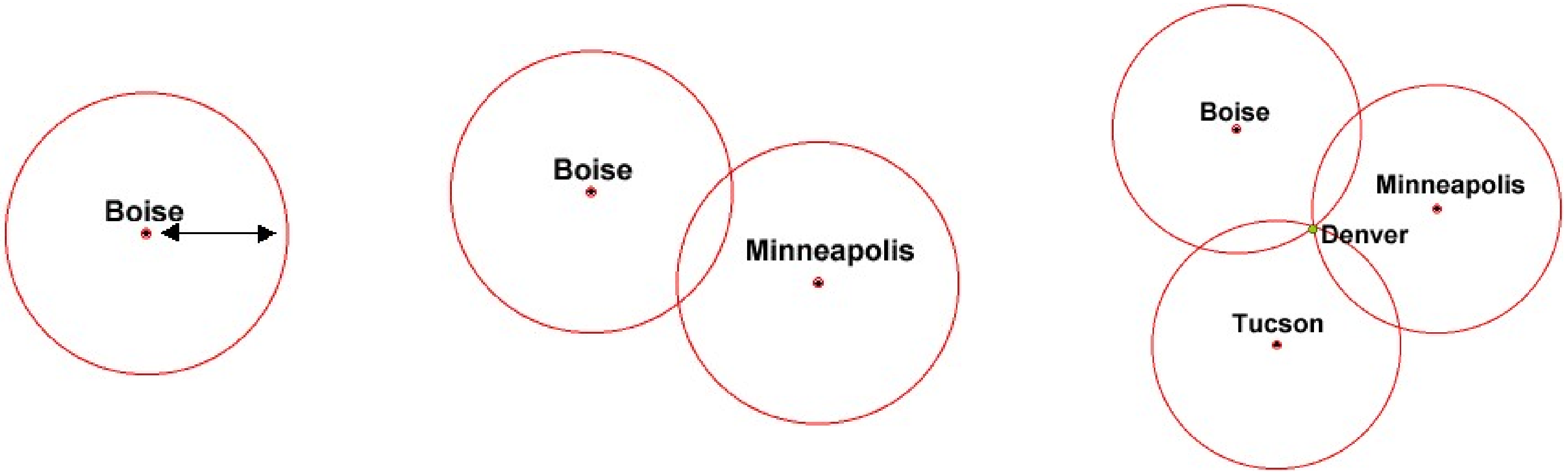
Sensor networks - Localization

- Trilateration/multilateration techniques mostly used
- Hierarchical organization
  - More complex nodes (already knowing their location) on the higher level
  - Complex node then act as beacons by transmitting their position periodically
  - Nodes which have not yet inferred their position use the information from beacons to calculate its own position
- *Proximity-based localization*
  - Each node calculate its position as the centroid of all the locations it has obtained

Sensor networks - Localization

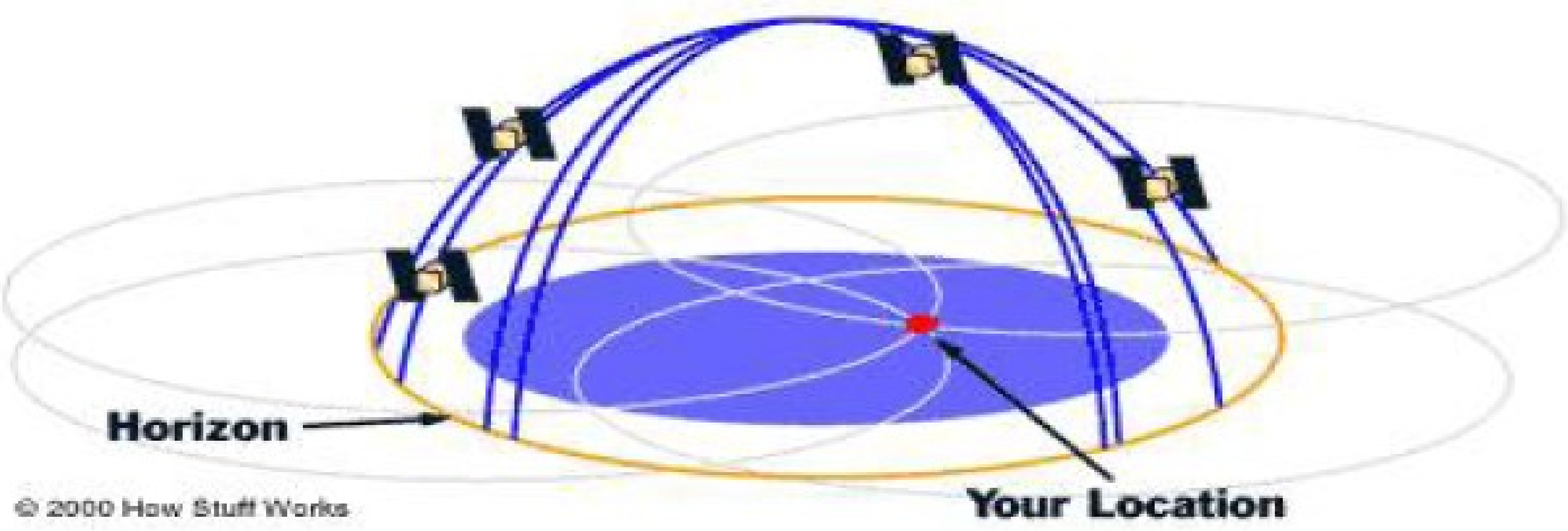
- Possible that all nodes do not have access to the beacons
  - Iterative Multilateration: nodes which have obtained their position through proximity based localization themselves act as beacons to the other nodes
    - iterative multilateration leads to accumulation of localization error

- 2-D Trilateration



Sensor networks - Localization

- 3-D Trilateration



Sensor networks – Placement techniques

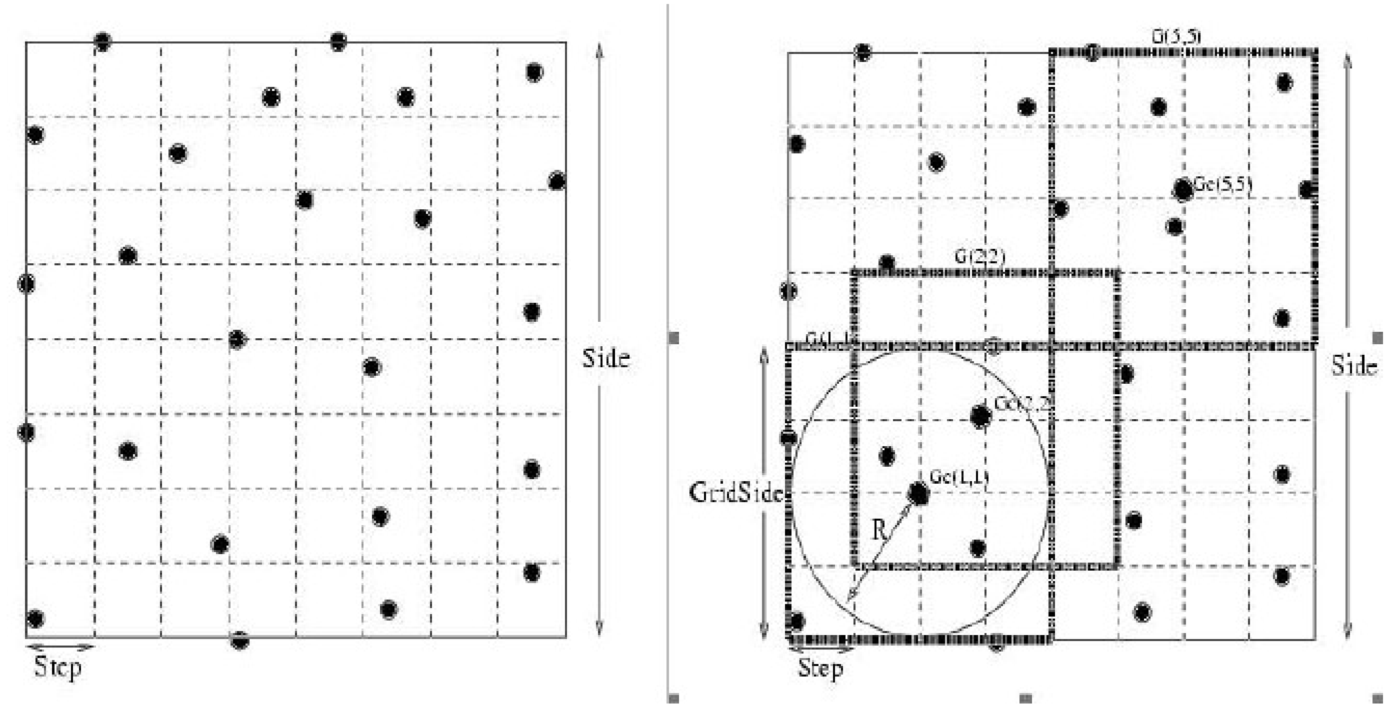
- Uniform beacon placement and Very dense beacon placement are not sufficient
  - With airdropped beacons over a hill, the heavier beacons would roll down the hill while the lighter sensor nodes would remain atop
  - Uniform placement does not necessarily ensure visibility
- Cost/power might be a major consideration for dense placement
- Mostly, problems arise due to the unpredictable nature of environmental conditions
  - Nodes need to be able to adapt to environmental changes
  - incremental beacon placement based on empirical adaptation
    - placement is adjusted through adding more beacons rather than complete re-deployment
    - additional deployment decisions are made by local measurements rather than complete off-line analysis of the whole model

Sensor networks – Placement techniques

- Random deployment
  - As the name suggests, any random location is chosen as a suitable candidate
- Max deployment
  - The terrain is divided into step*step squares
  - The localization error is calculated at each square corner
  - A beacon is added at the point which has the maximum localization error
  - Simple approach, but influenced by propagation effects

Sensor networks – Placement techniques

- Grid deployment
  - Compute the cumulative localization error over each grid for several overlapping grids
  - A new beacon is added at the center of the grid which has the maximum cumulative localization error



Sensor networks – Routing

- The energy constraint limits the use of conventional routing protocols
  - Usually the flooding technique is used
    - A node stores the data item it receives and then sends copies of the data item to all its neighbors
  - Implosion: nodes get multiple copies of the same data item
  - Resource management : nodes are not resource-aware. They continue with their activities regardless of the energy available to them at a given time
- Proactive and reactive protocols better adapted
  - SPIN-PP: adapted to point to point communication
  - SPIN-EC: SPIN-PP with energy-conservation heuristic
  - SPIN-BC: adapted to broadcast network
  - SPIN-RL: intelligent SPIN-BC

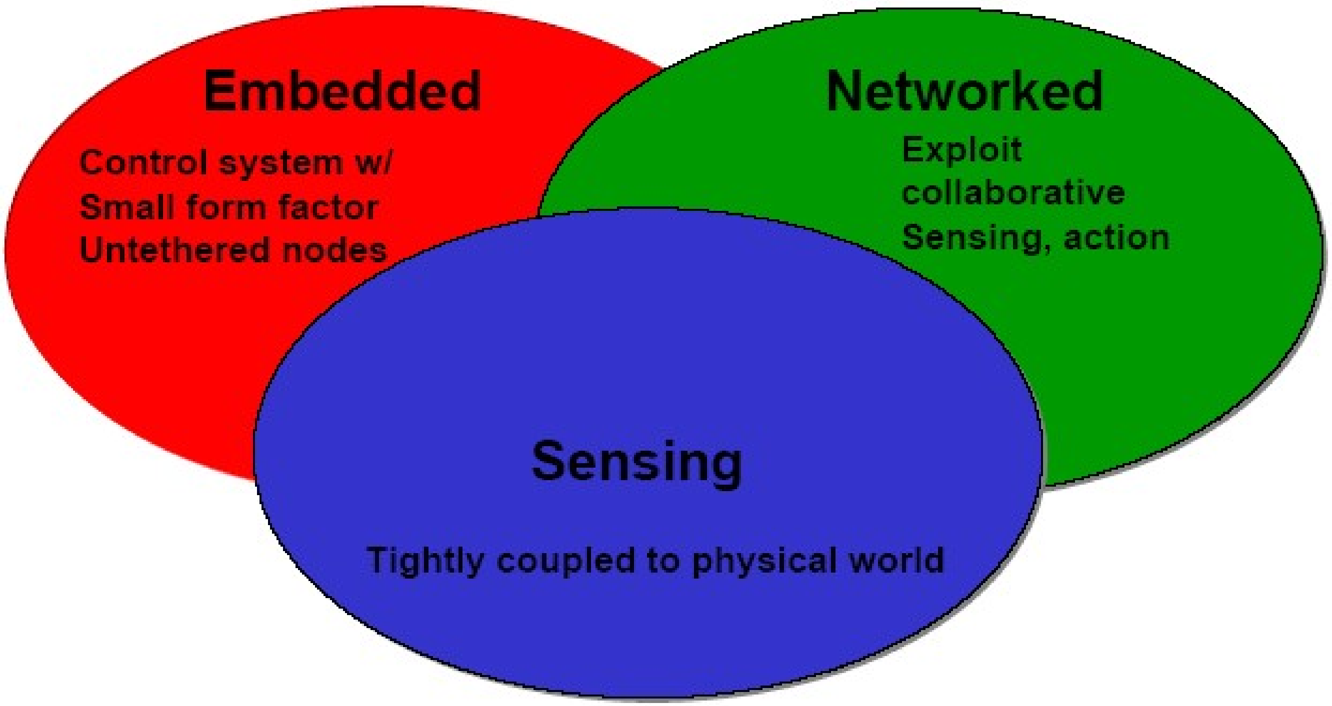
Sensor networks – Routing

- Energy aware routing
  - Occasionally use of sub-optimal paths to increase the lifetime of the network
  - A set of good paths are maintained and chosen by means of a probability
    - probability depends on the energy consumption of a path
  - Three phases:
    - **Setup**
      - Builds the routing table between the source and the destination. Routes and costs are considered
      - The high-cost paths are discarded and the others are added to the forwarding table
    - **Data Communication**
      - Data is sent from the source to the destination using one of the neighbors in the forwarding
    - **Route maintenance**:
      - Localized flooding is performed from the destination to keep the paths alive

Sensor networks – Enabling technologies

Embed numerous distributed devices to monitor and interact with physical world

Network devices to coordinate and perform higher-level tasks



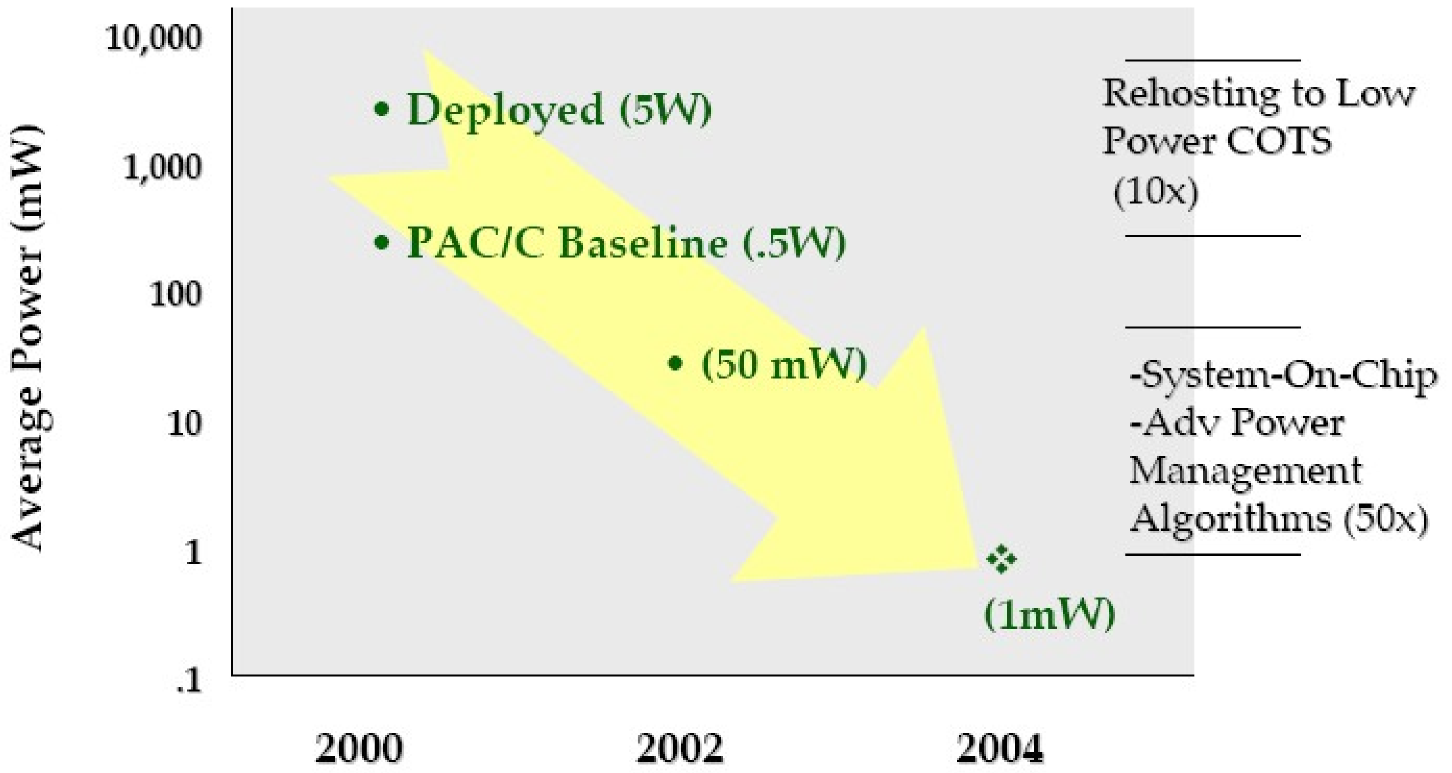
Exploit spatially and temporally dense, in situ, sensing and actuation

Source: D. Estrin, UCLA

Sensor networks – Sensors

- Passive elements
  - Seismic, acoustic, infrared, strain, salinity, humidity, temperature, etc
- Passive arrays
  - Imagers (visible, IR), biochemical
- Active sensors
  - Radar, sonar (High energy, in contrast to passive elements)
- Technology trend
  - Use of IC technology for increased robustness, lower cost, smaller size

Sensor networks – Sensors – power

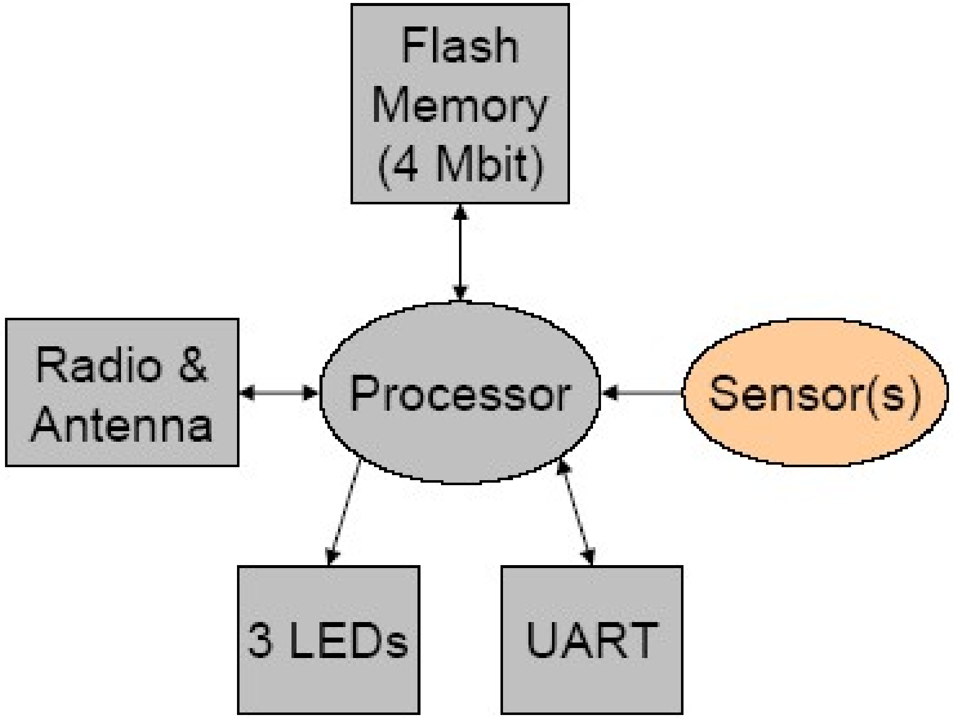


Sensor networks – The MICA Platform

- Designed in EECS at UC Berkeley
- Manufactured/marketed by Crossbow
  - Several thousand produced
  - Used by several hundred research groups
  - About Euro 160/piece
- Variety of available sensors

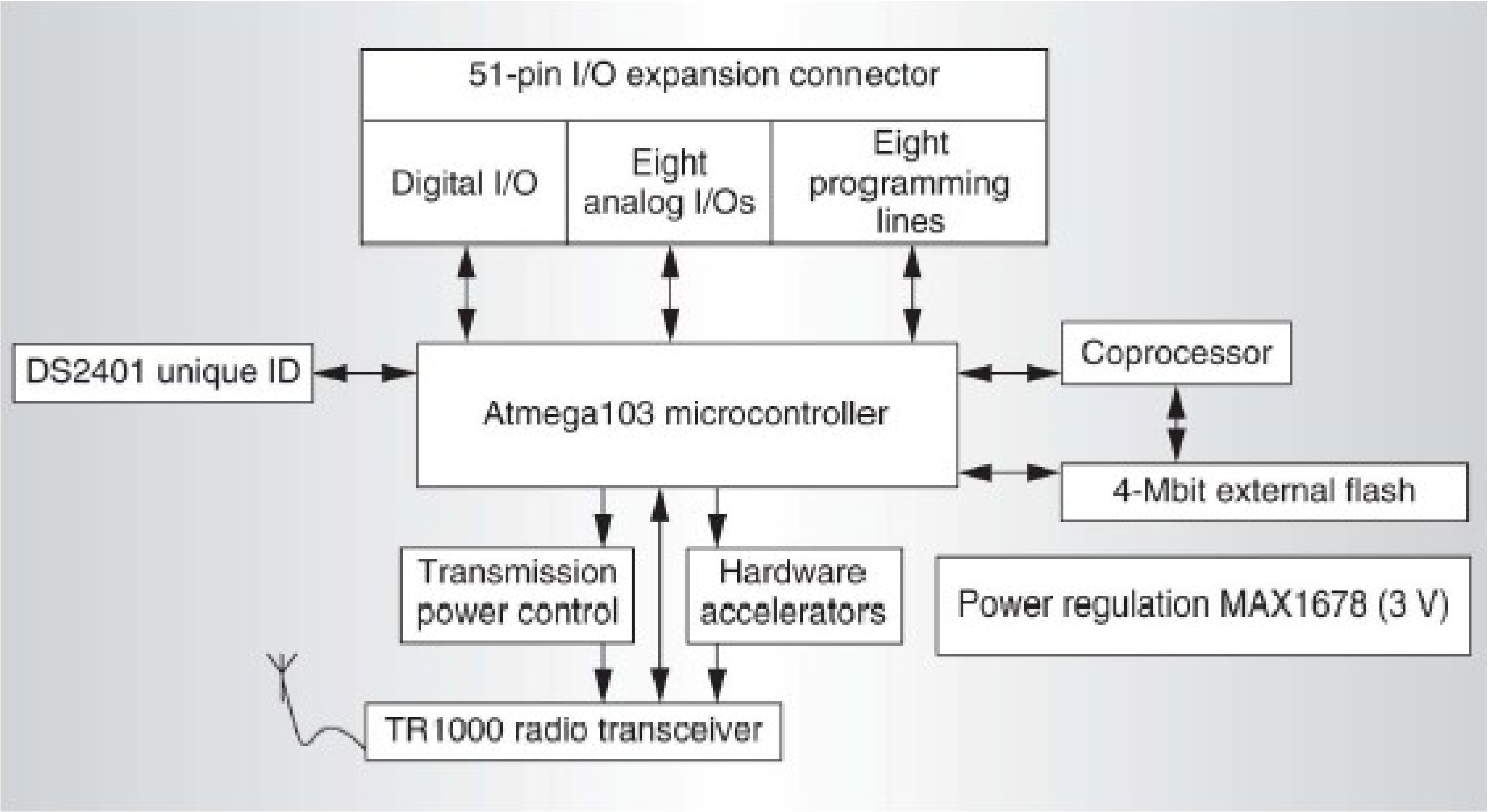
Sensor networks – The MICA Platform

- Division into 6 basic sections
  - all we need for a simple sensor network



Sensor networks – The MICA Platform

- Architecture of MICA(1)



Sensor networks – The MICAz Platform

- Atmel ATmega128L
  - 8 bit microprocessor, ~8MHz
  - 128kB program memory, 4kB SRAM
  - 512kB external flash (data logger)
- ChipconCC2420
  - 802.15.4 (Zigbee)
- 2 AA batteries
  - about 5 days active (15-20 mA)
  - about 20 years sleeping (15-20 µA)
- TinyOS

Sensor networks – The MICA Platform

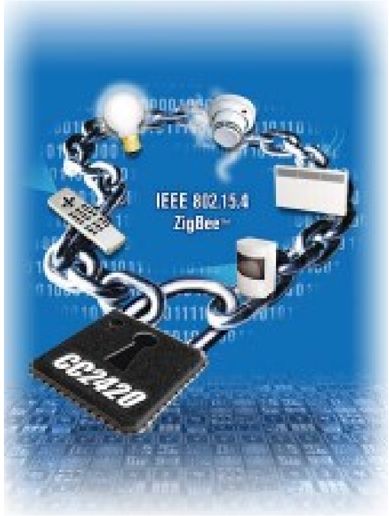
Mica2 power consumption

µC Active	8.0 mA
µC Idle	3.2 mA
ADC Noise Rdctn	1.0 mA
Power-down	103 µA
Power-save	110 µA
Standby	216 µA
Ext. Standby	223 µA
Internal Oscillator	0.93 mA

LEDs (each)	2.2 mA
Sensorboard	0.7 mA
Radio Rx	7.03 mA
Radio Tx (00)	3.72 mA
Radio Tx (03)	5.37 mA
Radio Tx (09)	7.05 mA
Radio Tx (60)	11.57 mA
Radio Tx (FF)	21.48 mA

Sensor networks – 802.15.4 / Zigbee

- standard for low-power wireless monitoring and control
  - 2.4 GHz ISM band (84 channels), 250 kbps data rate
- Chipcon/Ember CC2420: Single-chip transceiver
  - 1.8V supply
    - 19.7 mA receiving
    - 17.4 mA transmiting
  - Easy to integrate: Open source drivers
  - O-QPSK modulation; “plays nice” with 802.11 and Bluetooth



Sensor networks – TinyOS

- Minimal OS designed for Sensor Networks
- Event driven execution
- Widespread usage on motes
  - MICA (ATmega128L)
  - TELOS (TI MSP430)
- Provided simulator: TosSim

Sensor networks – TinyOS

- Language: NesC
  - C-like syntax, but supports TOS concurrency model
  - detects data races at compile time
  - “components” provide & use “interfaces”
    - an interface consists of “commands” and “events”
      - commands are functions implemented by the provider
        - ex: Timer.start()
      - events are implemented by the interface user
        - ex: Timer.fired()