Ubiquitous Networks

Introduction to Sensor Networks

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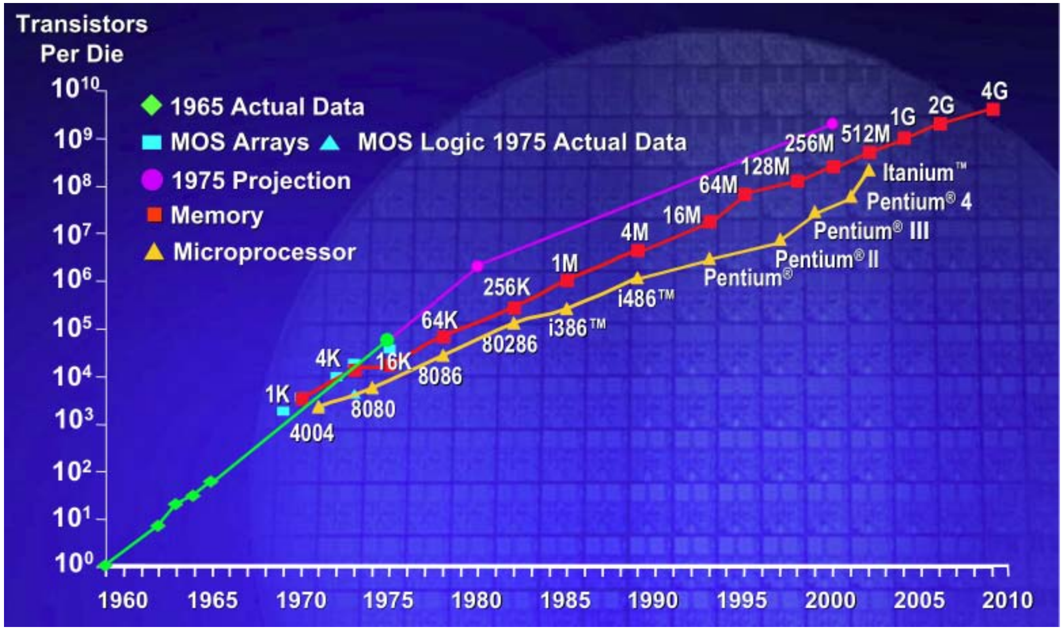
New Generation of Computing Devices

Moore's law

- # of transistors per chip doubles every 1~2 years



Source: Intel Corporation

Bell's law

- New computing class appears every 10 years
  - 1960's mainframe
  - 1970's minicomputer
  - 1980's workstation/PC
  - 1990's PC/mobile phones
  - 2000's PDA/mobile phones
  - 2010's smart phones
  - 2020's wearable sensors

Computing Generations and Industry

IBM System/360

IBM, Unisys, HP(Tandem), Fujitsu, Hitachi, NEC

IBM zEnterprise

DEC PDP-11

DEC, Data General, Apollo, HP

SUN SparcStation 10

SUN, HP, DEC, SGI, Intel

IBM PC AT

MS, Intel, Dell, HP, Compaq, Apple, Motorolla

DELL PC

Palm Pilot

Palm, Compaq, Apple

Apple iPhone

Apple, Google

Samsung Gallaxy II

What is Wireless Sensor Networks?

Definition

- A wireless sensor network (WSN) consists of *spatially distributed autonomous sensors* to *cooperatively monitor physical or environmental conditions*, such as temperature, sound, vibration, pressure, motion or pollutants.

Application

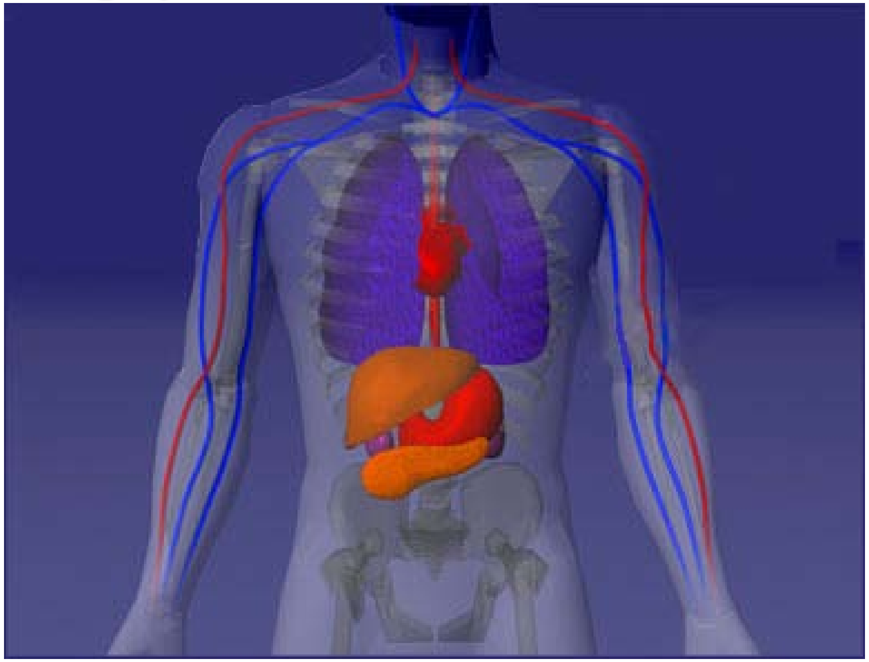
- The development of wireless sensor networks was *motivated by military applications* such as battlefield surveillance and are *now used in many industrial and civilian application areas*

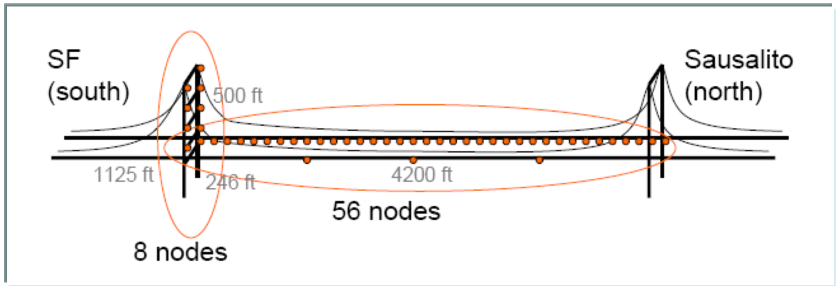
Design

- Low-power *microcontroller* with limited memory & storage
- Low-power low data-rate *RF receiver*
- *Sensors* (temperature, GPS, camera, etc.) & *Actuators* (robots, speaker)
- *Battery*

Vision: Embed the World

- Embed numerous sensing nodes to monitor and interact with physical world.





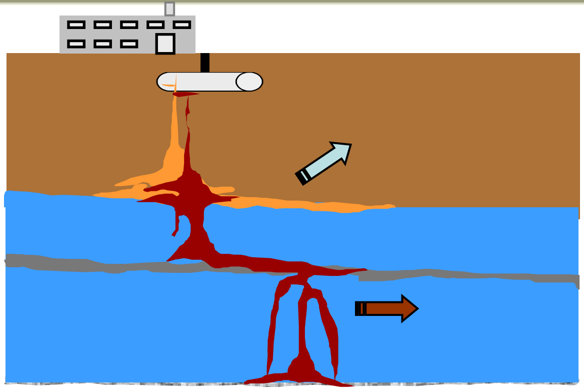
- Network these devices so that they can execute more complex task.

Embedded Networked Sensing Applications

Seismic Structure response

- Micro-sensors, on-board processing, wireless interfaces feasible at very small scale--can monitor phenomena "up close"
- Enables spatially and temporally dense environmental monitoring

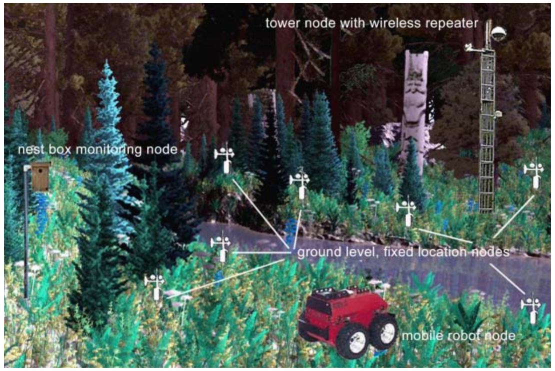
Embedded Networked Sensing will reveal previously unobservable phenomena



Contaminant Transport

Marine Microorganisms

Ecosystems, Biocomplexity

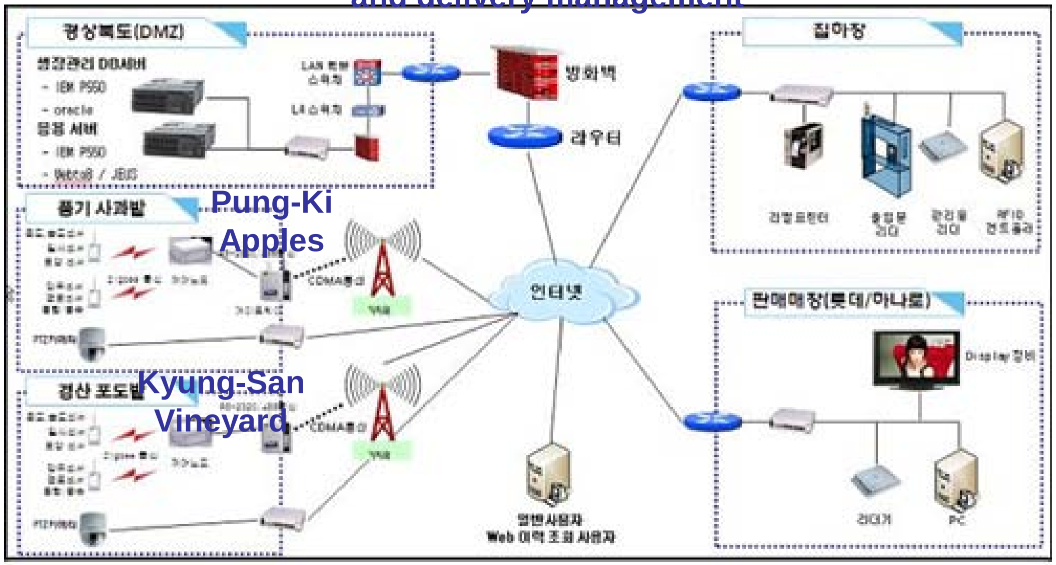


Agricultural Applications

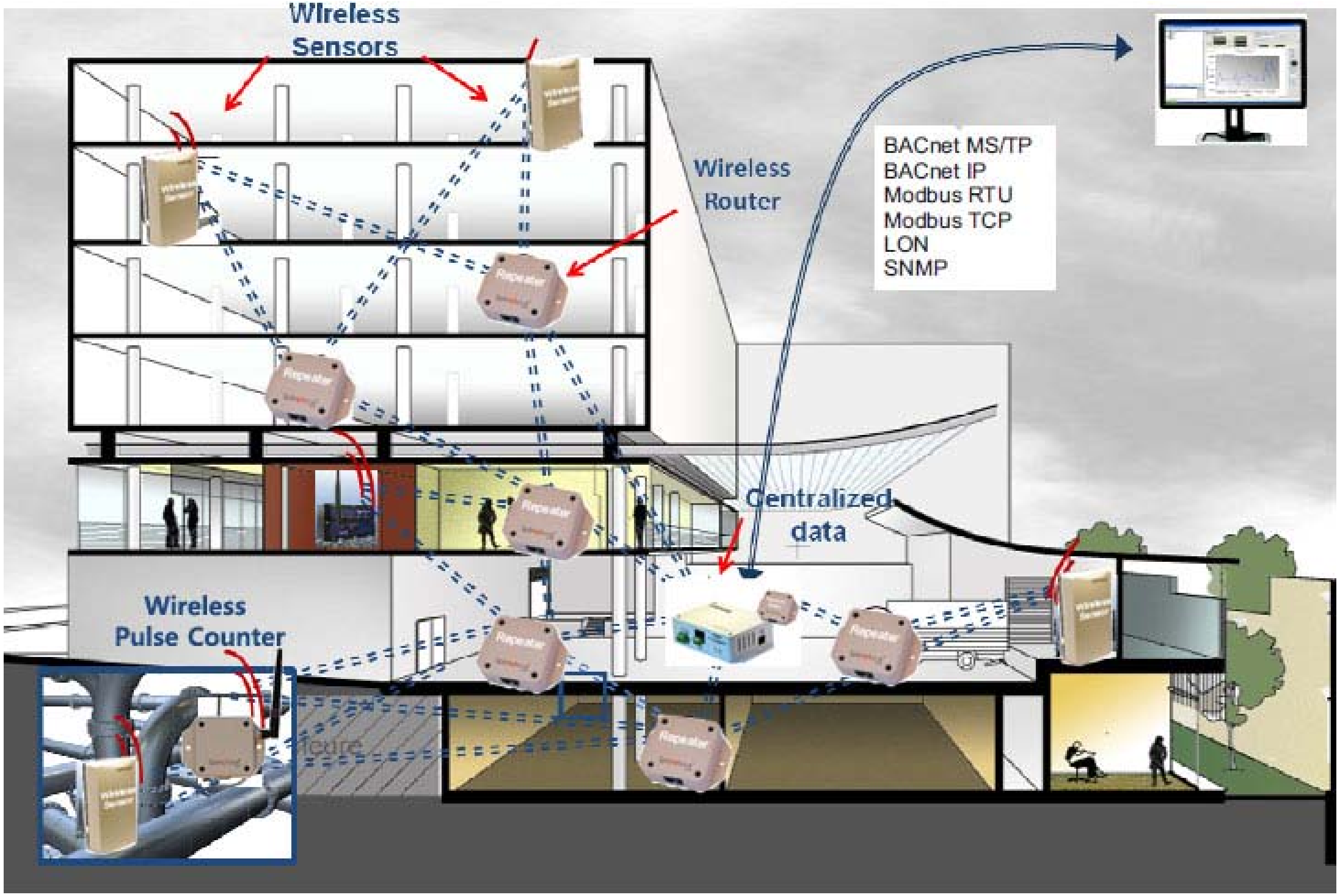
Kyung-San Vineyard greenhouse

Growth, quality improvement, distribution history, purchase and delivery management

USN-based remote chrysanthemum production system



Building Management System



Energy Monitoring and Management

USN Applications

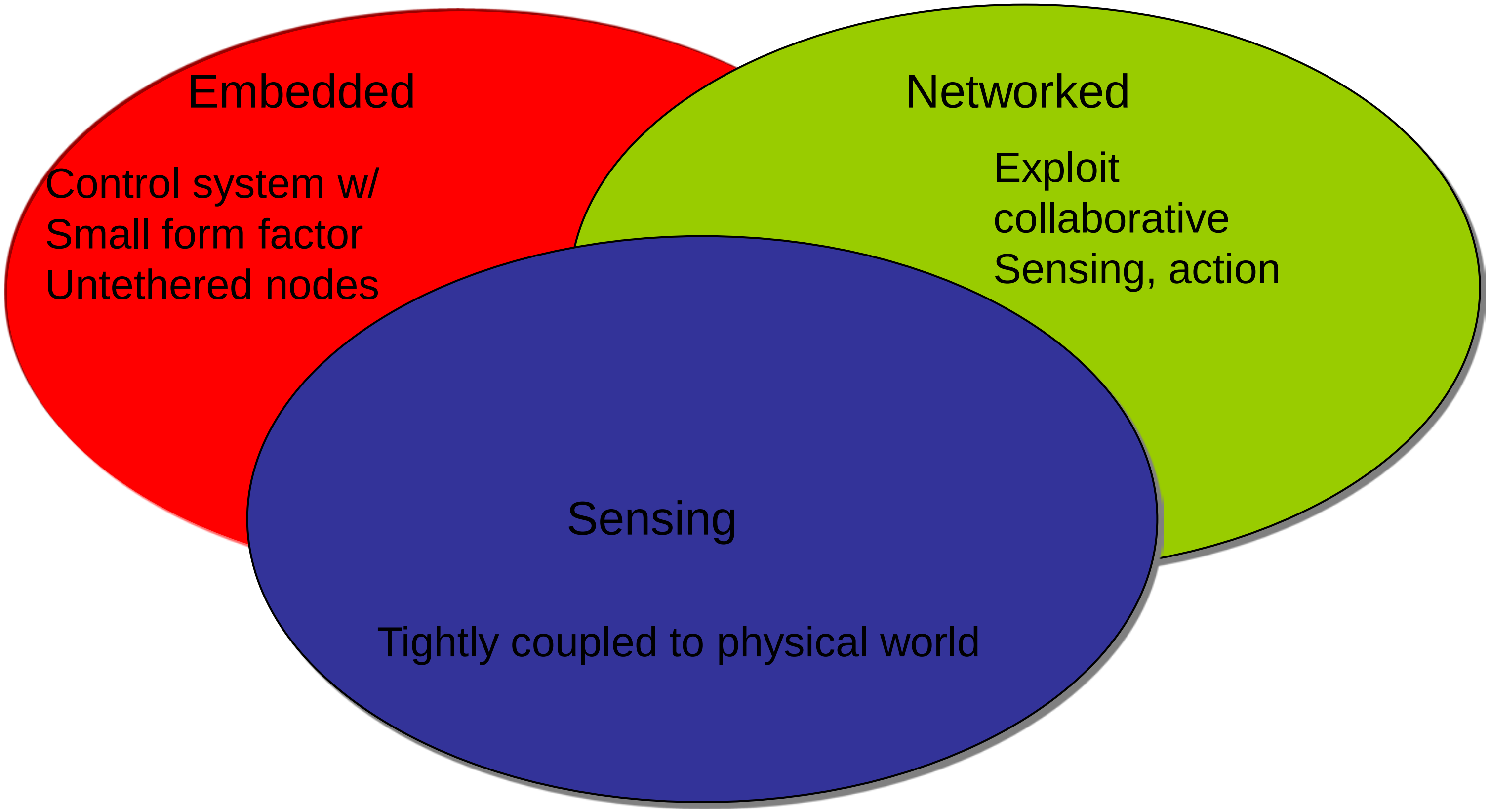
Applications of Sensor Networks

- **Military applications**
  - Battlefield surveillance and monitoring
  - Detection of attack by weapons of mass production such as chemical, biological, nuclear weapons
- **Environmental applications**
  - Forest fire detection, glacier/alpine/coastal erosion (ASTEC) monitoring
  - Flood detection, water/waste monitoring
  - Habitat monitoring of animals
  - Structural monitoring
  - Seismic observation
- **Healthcare applications**
  - Patient diagnosis and monitoring
- **Commercial applications**
  - Smart home, smart office, smart building, smart grid, intrusion detection, smart toys
  - Agricultural, fisheries, factories, supermarkets, schools, amusement parks
  - Internet data centers(IDC), Inventory control system, machine health monitoring

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

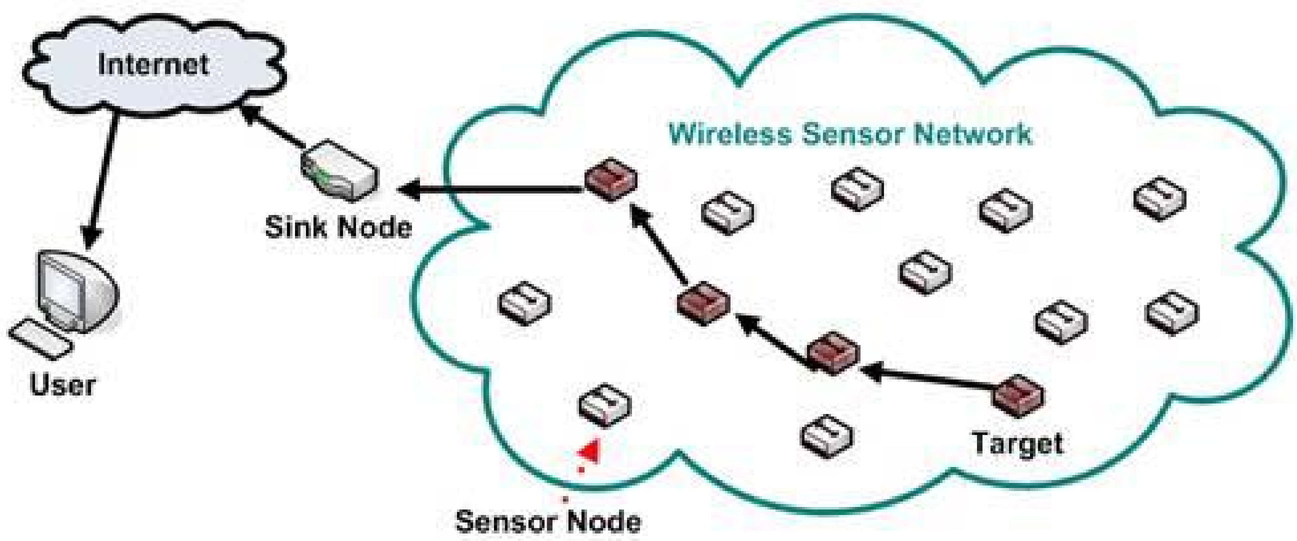
MEMS

- **Micro-Electro-Mechanical Systems (MEMS)**
  - The integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology.
  - While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes),
  - The micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices.

Sensor Network

Sensor networks

- Sensors are usually scattered in a field.
- Sensors collect and route data toward the sink
- Sensors relay on each other for multi-hop communication
- Sink communicates to a user through Internet



Sensor Node

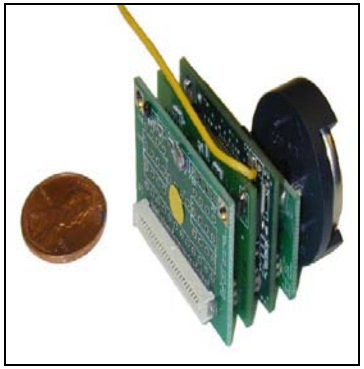
- **Consists of 3 subsystems**
  - Sensor
    - Monitor a variety of environmental conditions such as
      - Temperature, humidity, pressure, sound, motion, ..
    - Different types of sensors
      - Passive elements
        - Seismic, thermal, acoustic, humidity, infrared sensors, 3D accelerators, light
      - Passive arrays
        - Image, biochemical
      - Active sensors
        - Radar, sonar, microphones
        - High energy, in contrast to passive elements
  - Processor
    - Performs local computations on the sensed data
  - Communication
    - Exchanges messages with neighboring sensor nodes

Sensor Node Development

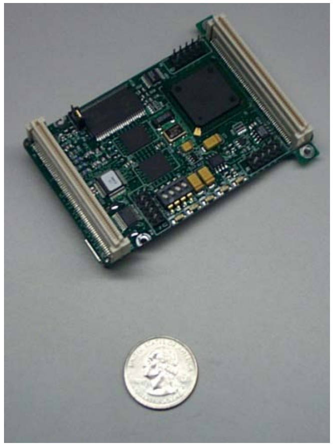
LWIM III
UCLA, 1996
Geophone, RFM radio, star network

AWAIRS I
UCLA/RSC 1998
Geophone, DS/SS Radio, strongARM, Multi-hop networks

UCB Mote, 2000
4 MHz, 4K RAM
512K EEPROM,
128K code,
CSMA
half-duplex RFM radio



WINS NG 2.0
Sensoria, 2001
Node development platform; multi-sensor, dual radio, Linux on SH4, Preprocessor, GPS



Processor

Sensor Node Development

Sun SPOT

Sun, 2008

Everything Java (Java drivers)

IPv6/LoPAN, AODV

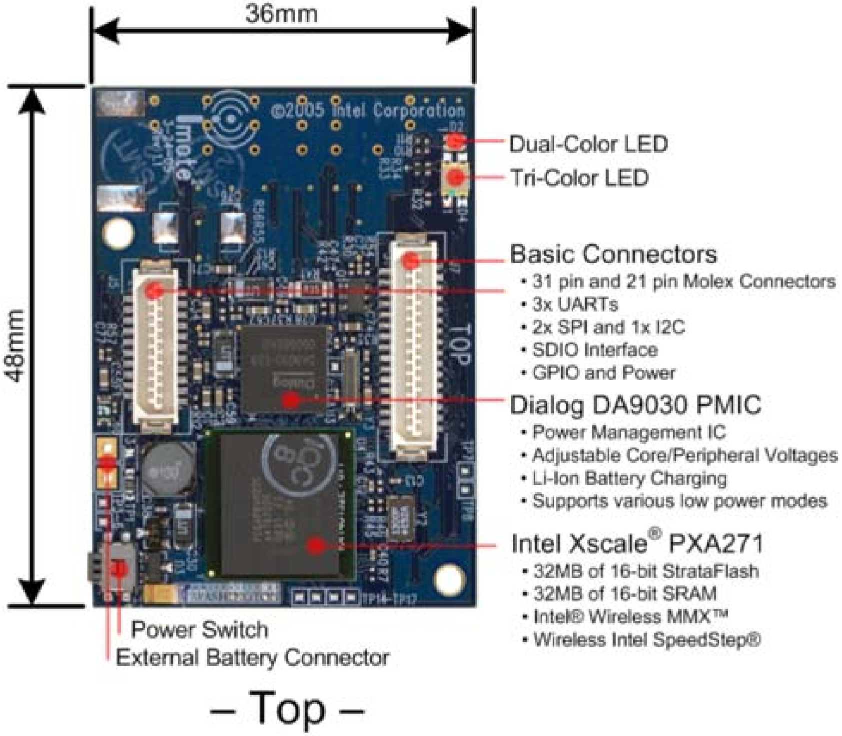
Intel/Crossbow iMote2, 2007

Xscale processor

32MB Flash, 32MB SRAM

802.15.4 radio (CC2420)

Linux kernel + JFFS2 flash file system



Source: Intel Corporation

Physical Size

AWACS

(Airborne Warning and Control System)

LWIM III

AWAIRS I

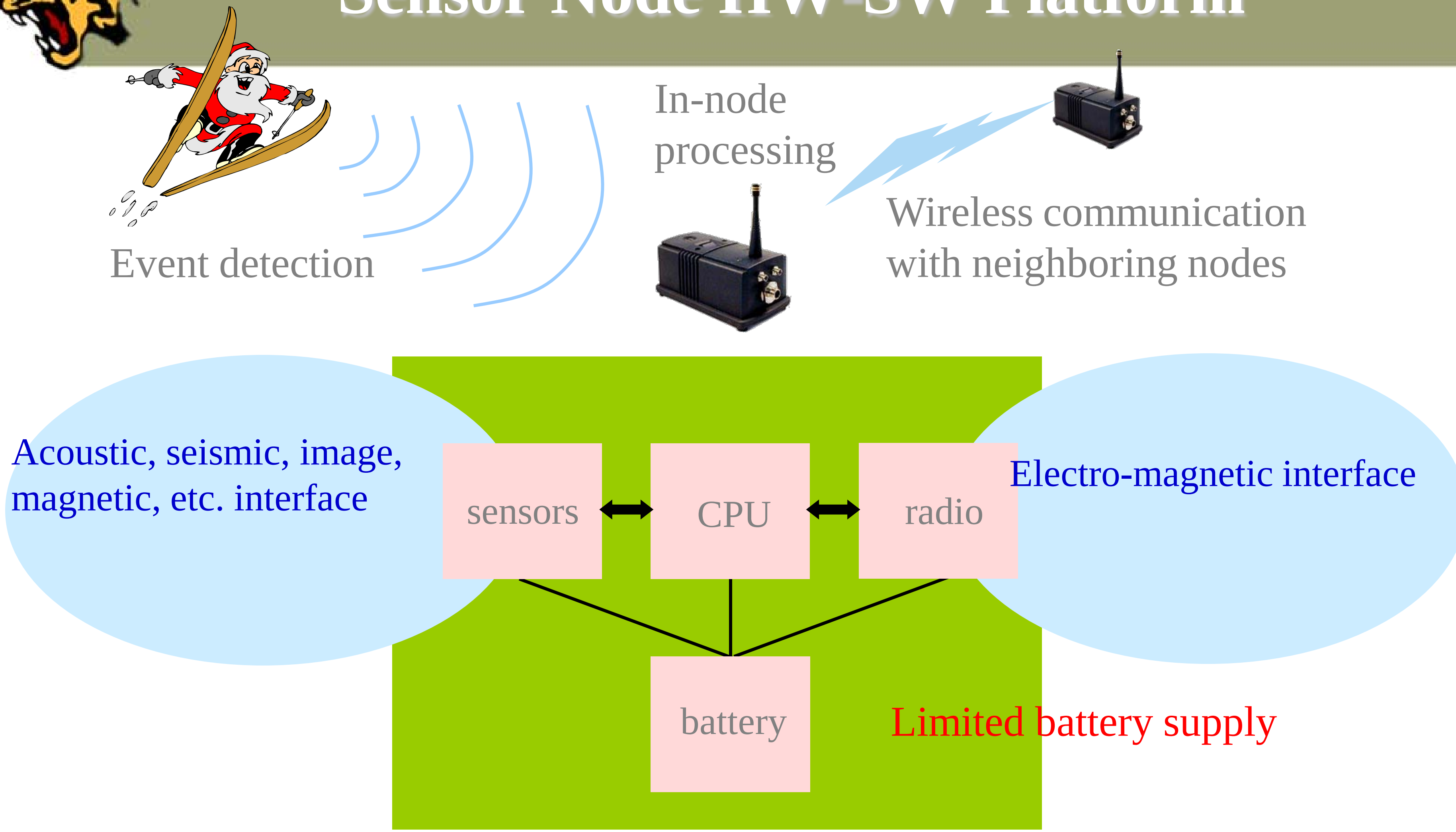
WINS

NG 2.0

Berkley

Motes

Sensor Node HW-SW Platform



Energy efficiency is the crucial h/w and s/w design criterion

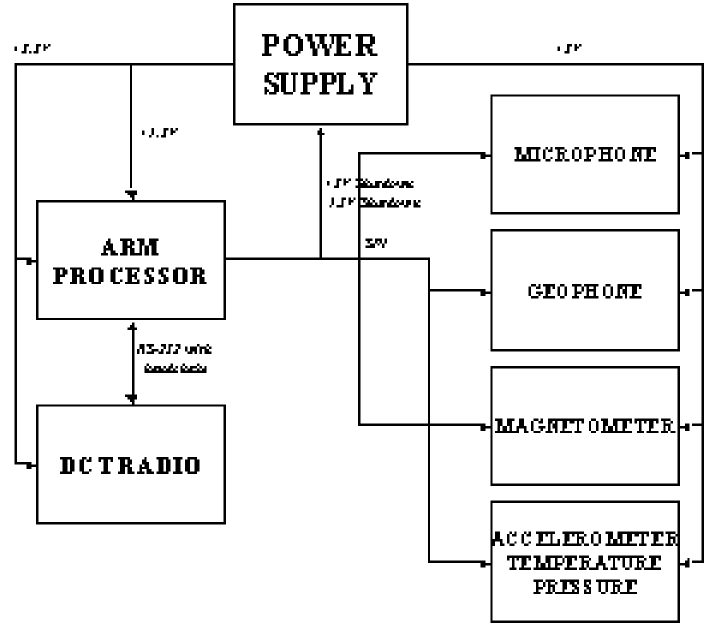
Sensor Node Platforms

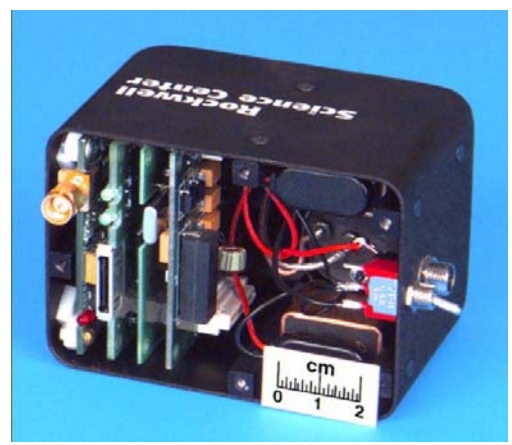
- Rockwell WINS & Hidra
- Sensoria WINS
- UCLA’s iBadge
- UCLA’s Medusa MK-II
- Berkeley’s Motes
- Berkeley Piconodes
- MIT’s μAMPs
- Intel’s iMote
- Sun’s SPOT
- And many more…

- Different points in (cost, power, functionality, form factor) space

Rockwell WINS and Hidra Nodes

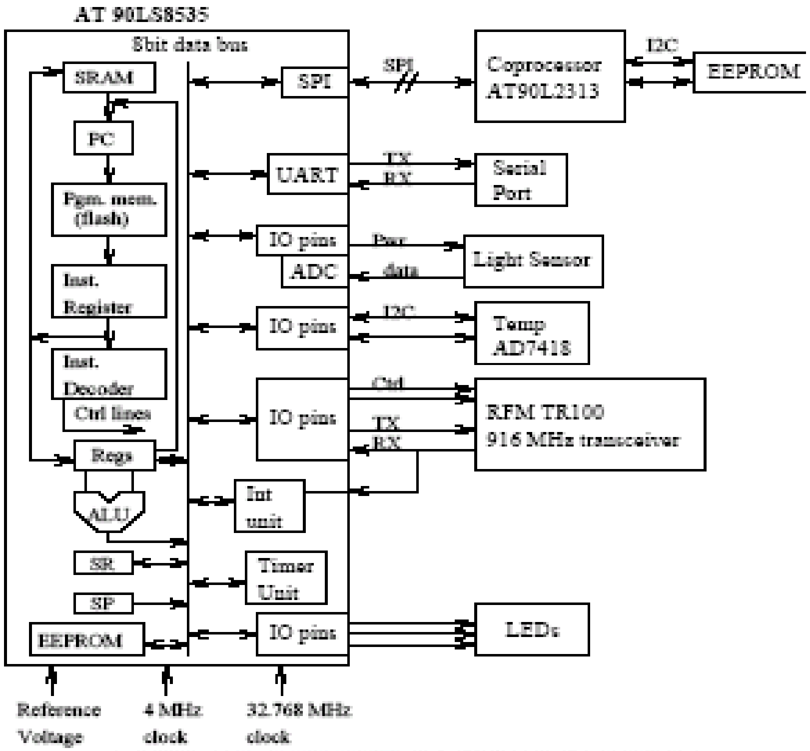
- **Consists of 2”x2” boards in a 3.5”x3.5”x3” enclosure**
  - StrongARM 1100 processor @ 133 MHz
    - 4MB Flash, 1MB SRAM
  - Various sensors
    - Seismic (geophone)
    - Acoustic
    - magnetometer,
    - accelerometer, temperature, pressure
  - RF communications
    - Connexant’s RDSSS9M Radio @ 100 kbps, 1-100 mW, 40 channels
  - eCos RTOS
- **Commercial version: Hidra**
  - μC/OS-II
  - TDMA MACwith multihop routing
- **http://wins.rsc.rockwell.com/**

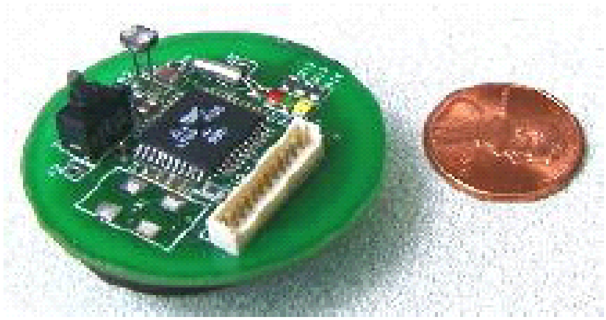




UC Berkeley Motes

- **Processing**
  - ATMEL 8b processor with 16b addresses running at 4MHz. 8KB FLASH as the program memory and 512B of SRAM as the data memory, timers
  - Three sleep modes: Idle, Power down, Power save
- **Communication**
  - RF transceiver, laser module, or a corner cube reflector
    - 916.5MHz transceiver up to 19.2Kbps
- **Sensors**
  - Temperature, light, humidity, pressure, 3 axis magnetometers, 3 axis accelerometers
- **TinyOS**





The Mote Family

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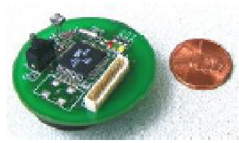
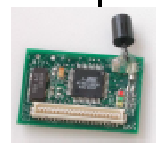
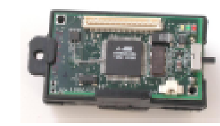
</td><td colspan="2">rene2 rene2
</td><td>dot
</td><td>mica
</td></tr>
<tr><td>Date</td><td>9/99</td><td>10/00</td><td>6/01</td><td>8/01</td><td>2/02</td></tr>
<tr><td colspan="6">Microcontroller</td></tr>
<tr><td>Type</td><td colspan="2">AT90LS8535</td><td colspan="2">ATMega163</td><td>ATMega103</td></tr>
<tr><td>Prog. mem. (KB)</td><td colspan="2">8</td><td colspan="2">16</td><td>128</td></tr>
<tr><td>RAM (KB)</td><td colspan="2">0.5</td><td colspan="2">1</td><td>4</td></tr>
<tr><td colspan="6">Nonvolatile storage</td></tr>
<tr><td>Chip</td><td colspan="4">24LC256</td><td>AT45DB041B</td></tr>
<tr><td>Connection type</td><td colspan="4">I2C</td><td>SPI</td></tr>
<tr><td>Size (KB)</td><td colspan="4">32</td><td>512</td></tr>
<tr><td colspan="6">Default Power source</td></tr>
<tr><td>Type</td><td>Li</td><td colspan="2">Alk</td><td>Li</td><td>Alk</td></tr>
<tr><td>Size</td><td>CR2450</td><td colspan="2">2xAA</td><td>CR2032</td><td>2xAA</td></tr>
<tr><td>Capacity (mAh)</td><td>575</td><td colspan="2">2850</td><td>225</td><td>2850</td></tr>
<tr><td colspan="6">Communication</td></tr>
<tr><td>Radio</td><td colspan="5">RFM TR1000</td></tr>
<tr><td>Rate (Kbps)</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10/40</td></tr>
<tr><td>Modulation type</td><td colspan="4">OOK</td><td>OOK/ASK</td></tr>
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Crossbow MiCA Series

MICA2

- 868, 912MHz multi-channel transceiver
- 38.4 kbps data rates
- Embedded sensor networks
- Light, temperature, barometer, acceleration, seismic, acoustic, magnetic sensors
- >1 year battery life on AA batteries
- Atmel ATMEGA128L 8 bit microcontroller
- 128KB program and 512KB data (flash) memories

MICAZ

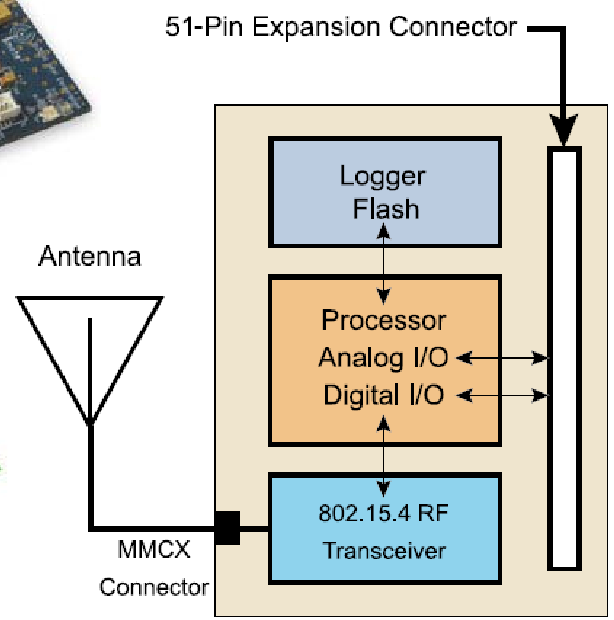
- 2.4 GHz IEEE15.4 compliant
- 250 kbps high data rates
- Same processor and memory as MICA2

IMote2

- 2.4 GHz IEEE15.4 compliant
- Xscale processor up to 416MHz
- DSP coprocessor
- 256KB SRAM, 32MB Flash, 32MB SDRAM

TelosB

- 2.4 GHz IEEE15.4 compliant
- 8MHz TI MSP430 microcontroller
- Open source platform



MPR2400 Block Diagram

Comparison with MANET

- **The number of nodes in a sensor network can be several orders of magnitude larger (more densely deployed)**
  - Need more scalability
- **Limited resources**
  - Limitations in processing, memory, and power
- **More prone to failure**
- **More prone to energy drain**
  - Battery sources are usually not replaceable or rechargeable
- **No unique global identifiers**
- **Data-centric routing vs. address-centric routing**
  - Queries are addressed to nodes which have data satisfying conditions
    - Query may be addressed to nodes “which have recorded a temperature higher than 30° C”
- **More massive data**
  - Need aggregation/fusion before relaying to reduce bandwidth consumption, delay, and power consumption

Issues and Challenges

- **Autonomous setup and maintenance**
  - Sensor nodes are randomly deployed and need to be maintained without any human intervention
- **Infrastructure-less**
  - All routing and maintenance algorithms need to be distributed
- **Energy conscious design**
  - Energy at the nodes should be considered as a major constraint while designing protocols
  - The microcontroller, OS, communication protocols, and application software should be designed to conserve power
- **Global time synchronization**
  - Sensor nodes need to synchronize with each other in a completely distributed manner for communication synchronization, temporal ordering of detected events, elimination of redundant events/messages
- **Dynamic topology due to failures or power-down/up**
- **Real-time and secure communication**

Sensor Network Architecture Goals

- **Maximize the network life time (low energy)**
  - Usually battery operated and they are not easy to recharge or replace
- **Coverage**
  - Two types of coverage region
    - Sensing region: At least a node must exist in a sensing region
    - Communication region: A node must be within the communicating region of another node to be connected to the network
  - How to determine optimal spacing between the communicating node?
    - Too close means collision and increase the number of hops in communication while too far means disconnectivity
- **Performance: minimize latency and increase network bandwidth**
  - Minimize collision among wireless transmission
  - Minimize unnecessary transmissions
    - Minimize redundant data collection by different nodes
    - Minimize redundant messages sent by a single node
- **Cost**
  - Minimize the total number of nodes and the cost of each node
- **Others: scalable to a large number of nodes, fault tolerant**
- **Conflicting goals**
  - Cost vs. availability, Cost vs. performance?

Sensor Network Protocol Stack

Resource constraints call for more tightly integrated layers

Open Question:

Can we define an Internet-like architecture for such application-specific systems??

User Queries, External Database
In-network: Application processing, Data aggregation, Query processing
Data dissemination, storage, caching
Adaptive topology, Geo-Routing
MAC, Time, Location
Phy: comm, sensing, actuation