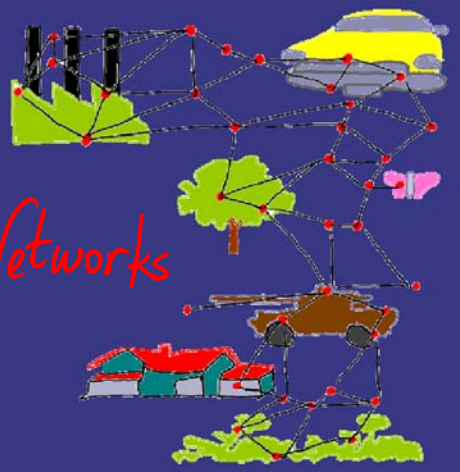
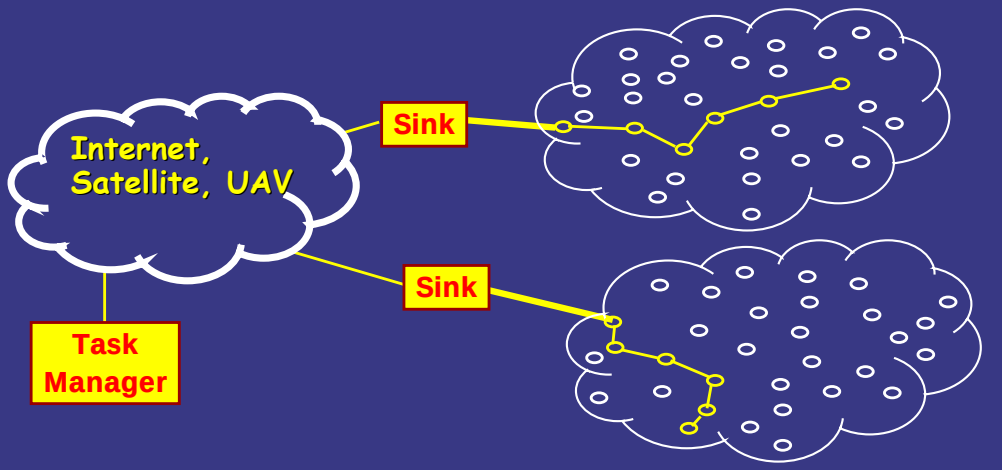
CmpE 58C Wireless Sensor Networks



Introduction

Sensor Networks Architecture



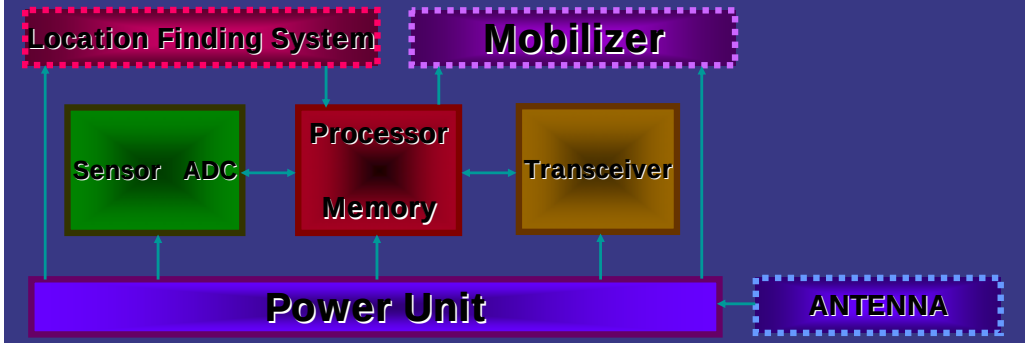
Characteristics of WSNs

- Very large number of nodes, often in the order of thousands
- Nodes need to be close to each other
- Densities as high as 20 nodes/m^3
- Asymmetric flow of information, from sensor nodes to sink
- Communications are triggered by queries or events
- Limited amount of energy (in many applications it is impossible to replace or recharge)
- Mostly static topology
- Low cost, size, and weight per node
- Prone to failures
- More use of broadcast communications instead of point-to-point
- Nodes do not have a global ID such as an IP address
- The security, both on physical and communication level, is more limited than in classical wireless networks

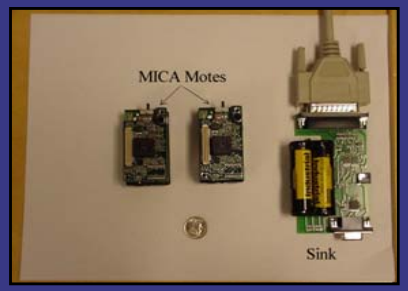
Differences from Ad-Hoc Networks

- Number of sensor nodes can be several orders of magnitude higher
- Sensor nodes are densely deployed and are prone to failures
- The topology of a sensor network may change frequently due to node failure and node mobility
- Sensor nodes are limited in power, computational capacities, and memory
- May not have global ID like IP address
- Need tight integration with sensing tasks

Sensor Node Hardware



What We Have in NETLAB

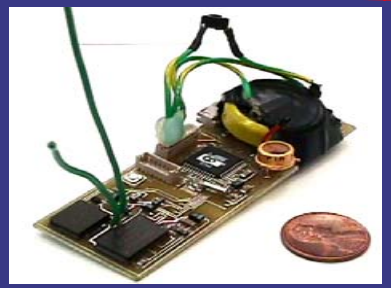


Sensor Node Features

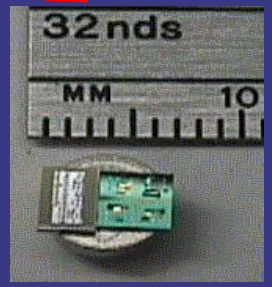
Processor/Radio Board	MPR300CB
Speed	4 MHz
Flash	128K bytes
SRAM	4K bytes
EEPROM	4K bytes
Radio Frequency	916MHz or 433MHz (ISM Bands)
Data Rate	40 kbits/sec (max)
Power	0.75 mW
Radio Range	100 feet
Power	2 x AA batteries; Solar Energy

Examples of Sensor Nodes

UCLA: WINS



UC Berkeley: Dust

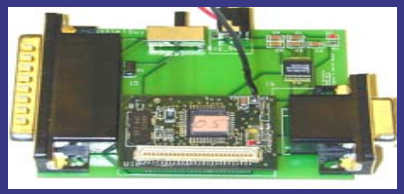


Smart Dust

Rockwell WINS

JPL Sensor Webs

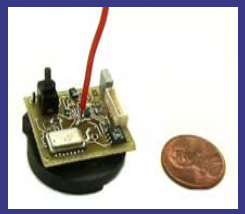
Examples of Sensor Nodes



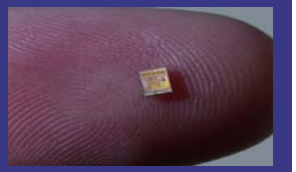
Rene Mote

Dot Mote

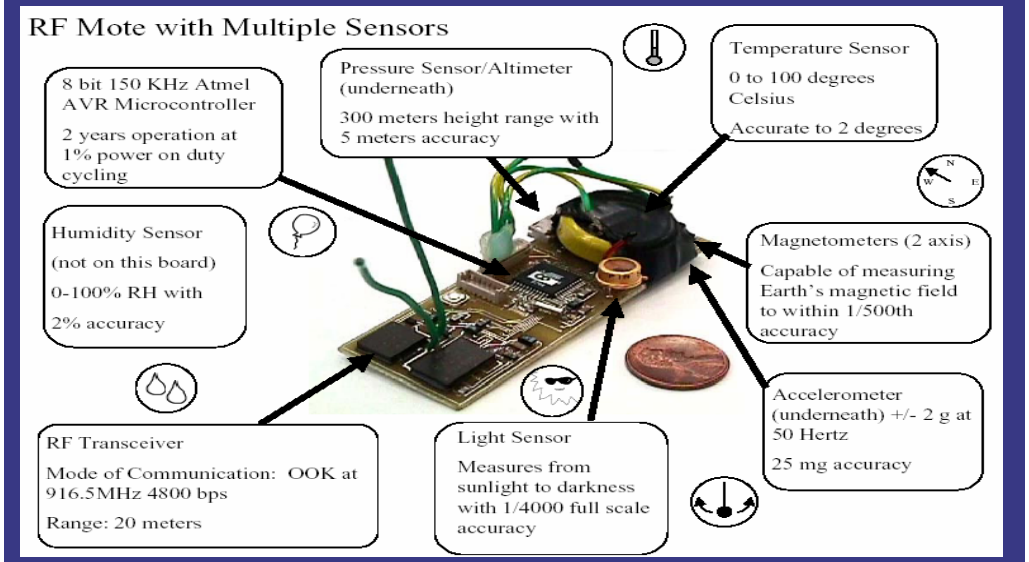
MICA Mote



weC Mote



Berkeley Motes



Sensor Node Evolution

Mote Type	weC	Rene	Rene2	Dot	Mica
Date	Sep-99	Oct-00	Jun-01	Aug-01	Feb-02

Microcontroller (4MHz)

Type	AT90LS8535	ATMega163	ATMega103/128
Flash Mem. (Kb)	8	16	128
RAM (Kb)	0.5	1	4

Communication

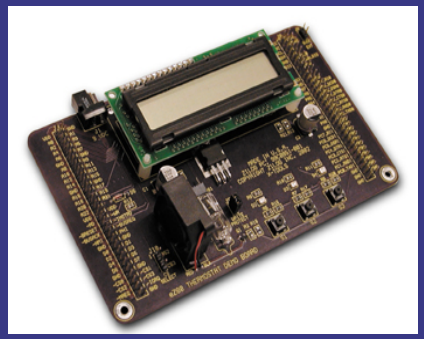
Radio	RFM	TR1000
Rate (kbps)	10	10/40

Telos by MOTEIV.com

- Single board philosophy
  - Robustness, Ease of use, Lower Cost
  - Integrated Humidity & Temperature sensor
- First platform to use 802.15.4
  - CC2420 radio, 2.4 GHz, 250 kbps
  - 3x RX power consumption of CC1000
  - Same TX power as CC1000
- Motorola HCS08 processor
  - Lower power consumption, 1.8V operation, faster wakeup time
  - 40 MHz CPU clock, 10K RAM; 48K Flash
  - 50m indoor; 125m outdoor ranges
- Package
  - Integrated onboard antenna
  - Everything USB & Ethernet based
  - 2 AA batteries
  - Weatherproof packaging

Zylog's eZ80

- Provides a way to Internet-enabled process control and monitoring applications.
- Temperature sensor, water leak detector, and many more applications
- Metro IPWorks™ software stack embedded
- Enables users to access Webserver data and files from anywhere in the world.



Sensor Network Features

- APPLICATIONS:
  - Military, Environmental, Health, Home, Space exploration, Chemical Processing, Volcanoes, Mining, Disaster relief….
- SENSOR TYPES:
  - Seismic, Low sampling rate, Magnetic, Thermal, Visual, Infrared, Acoustic, Radar…
- SENSOR TASKS:
  - Temperature, Humidity, Vehicular movement, Lightning condition, Pressure, Soil makeup, Noise levels, Presence or absence of certain types of objects, Mechanical stress levels on attached objects, Current characteristics (speed, direction, size) of an object …

Military Applications:

Command, Control, Communications, Computing, Intelligence, Surveillance, Reconnaissance, Targeting (C4ISRT)

- Monitoring friendly forces, equipment and ammunition
- Battlefield surveillance
- Reconnaissance of opposing forces and terrain
- Targeting
- Battle damage assessment
- Nuclear, Biological and Chemical (NBC) attack detection and reconnaissance

Further Military Applications

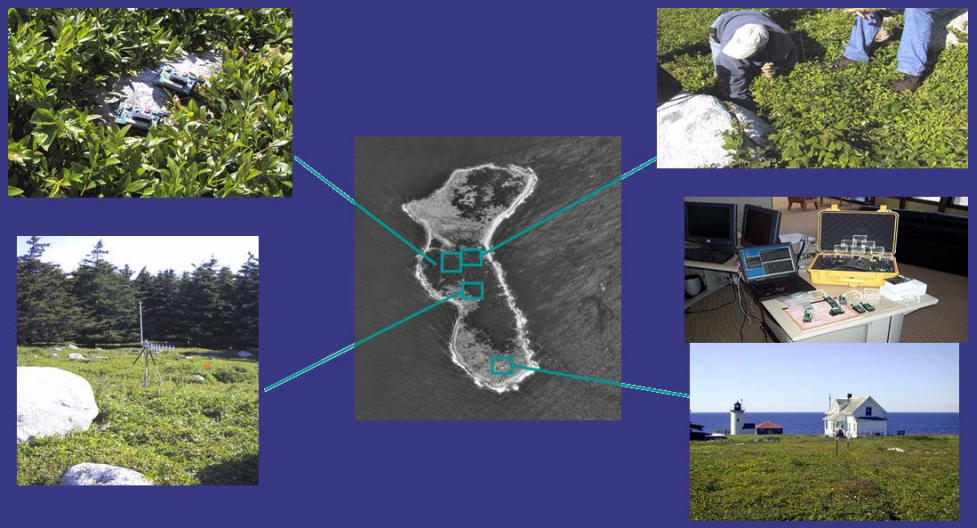
- Intrusion detection (mine fields)
- Detection of firing gun (small arms) location
- Chemical (biological) attack detection
- Targeting and target tracking systems
- Enhanced navigation systems
- Battle damage assessment system
- Enhanced logistics systems

Environmental Applications

- Tracking the movements of birds, small animals, and insects
- Monitoring environmental conditions that affect crops and livestock
- Irrigation
- Earth monitoring and planetary exploration
- Chemical/biological detection
- Biological, Earth, and environmental monitoring in marine, soil, and atmospheric contexts
- Meteorological or geophysical research
- Pollution study
- Precision agriculture
- Biocomplexity mapping of the environment
- Flood detection, and Forest fire detection.

Habitat Monitoring

http://www.greatduckisland.net Great Duck Island in Maine

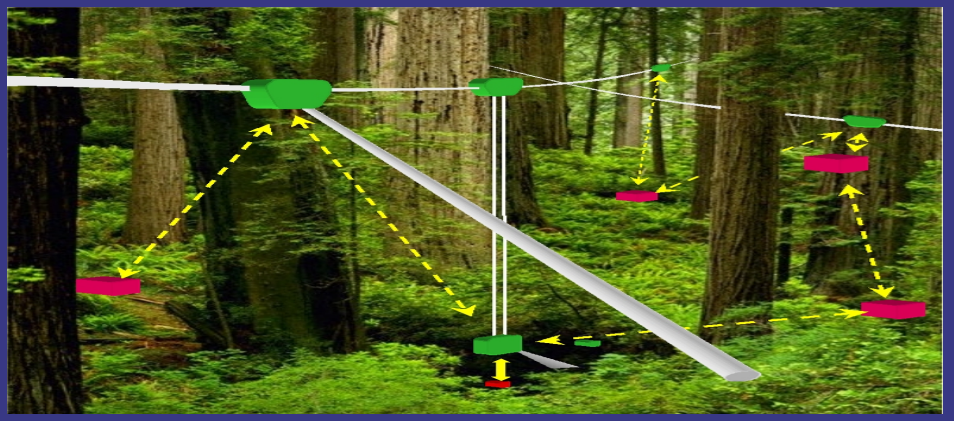


Habitat Monitoring

- Approx. 200 nodes including MICA, MICA2, burrow nodes (with IR) and weather station nodes
- Motes detect light, barometric pressure, relative humidity, and temperature conditions.
- An infrared heat sensor detects whether the nest is occupied by a seabird, and whether the bird has company.
- Motes within the burrows send readings out to a single gateway sensor above ground, which then wirelessly relays collected information to a laptop computer at a lighthouse (~350 feet).
- The laptop, also powered by photovoltaic cells, connects to the Internet via satellite.
- Computer at base-station logs data and maintains database

Ecosystems, Biocomplexity

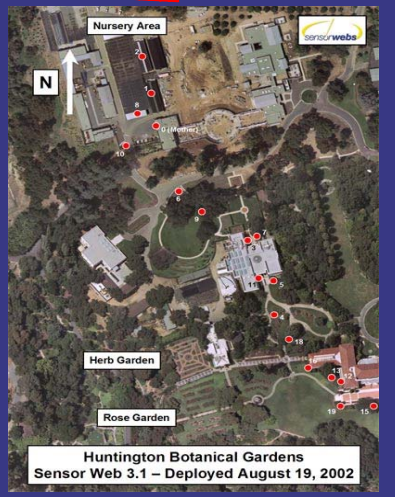
- Ecosystems infused with chemical, physical, acoustic, image sensors to track global change parameters



Huntington Botanical Gardens

Sensor Web 3.1 http://sensorwebs.jpl.nasa.gov

- Each pod measures light levels, air temperature and humidity, with optional measurements of soil temperature and soil moisture
- E.g., correlating soil conditions with local light and temperature, it is possible to deduce the effects of rain in the specific area



Huntington Botanical Gardens

Sensor Web pod 15 at Huntington Botanical Gardens is covered in mud from nearby watering and has had an antenna chewed on by a small animal.

- Dry conditions detected by a Sensor Web could automatically turn on sprinklers.
- If pods used sensors that measure barometric pressure, the web could analyze light and barometric pressure levels to predict that rain was imminent, deciding not to use the sprinklers after all.
- Two plants of the same kind and age need different amounts of water because of soil conditions.

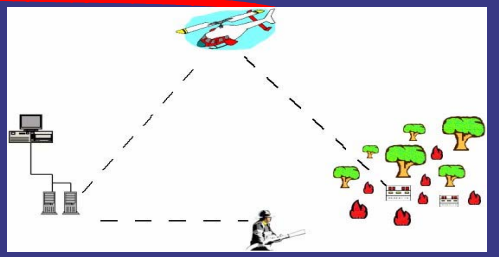
Forest Fire Detection: Firebug

http://firebug.sourceforge.net

- Design and Construction of a Wildfire Instrumentation System using Networked Sensors
- Network of GPS-enabled, wireless thermal sensors
- FireBug network self-organizes into edge-hub configurations
- Hub motes act as base stations

Firebug

- Firebug - mote/fireboard pair
- Mote - Crossbow MICA board
- Fireboard - Crossbow MTS420CA
  - Temperature and humidity sensor.
  - Barometric pressure sensor.
  - GPS unit.
  - Accelerometer
  - Light Intensity Sensor



Observation and Forecasting System for the Columbia River

Health Applications

- Providing interfaces for the disabled
- Integrated patient monitoring
- Diagnostics
- Telemonitoring of human physiological data
- Tracking and monitoring doctors and patients inside a hospital, and
- Drug administration in hospitals

CodeBlue: WSNs for Medical Care

http://www.eecs.harvard.edu/~mdw/proj/codeblue

- NSF, NIH, U.S. Army, Sun Microsystems and Microsoft Corporation
- Motivation - Vital sign data poorly integrated with pre-hospital and hospital-based patient care records

CodeBlue: WSNs for Medical Care

Hardware

- Small wearable sensors
- Wireless pulse oximeter / 2-lead EKG
- Based on the Mica2, MicaZ, and Telos sensor node platforms
- Custom sensor board with pulse oximeter or EKG circuitry
- Pluto mote
  - scaled-down version of the Telos
  - rechargeable Li-ion battery
  - small USB connector
  - 3-axis accelerometer

CodeBlue: WSNs for Medical Care

- CodeBlue - scalable software infrastructure for wireless medical devices
  - Routing, Naming, Discovery, and Security
  - MoteTrack - tracking the location of individual patient devices indoors and outdoors
- Heart rate (HR), oxygen saturation (SpO2), EKG data monitored
- Relayed over a short-range (100m)
- Receiving devices - PDAs, laptops, or ambulance-based terminals
- Data can be displayed in real time and integrated into the developing pre-hospital patient care record
- Can be programmed to process the vital sign data (and provide alerts)

CodeBlue: WSNs for Medical Care

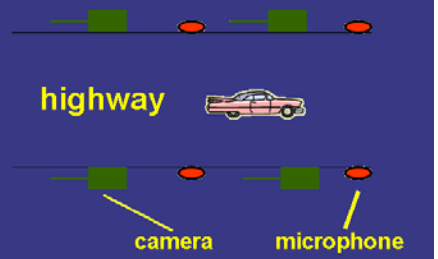
- Research focuses on the following areas:
  - Integration of medical sensors with low-power wireless networks
  - Wireless ad-hoc routing protocols for critical care; security, robustness, prioritization
  - Hardware architectures for ultra-low-power sensing, computation, and communication
  - Interoperation with hospital information systems; privacy and reliability issues
  - 3D location tracking using radio signal information
  - Adaptive resource management, congestion control, and bandwidth allocation in wireless networks

Further Applications

- Monitoring product quality
- Factory Floor Automation
- Constructing smart homes
- Constructing office spaces
- Interactive toys
- Monitor disaster areas
- Smart spaces
- Machine diagnosis
- Interactive museums
- Managing inventory control
- Environmental control in office buildings

Smart Roads

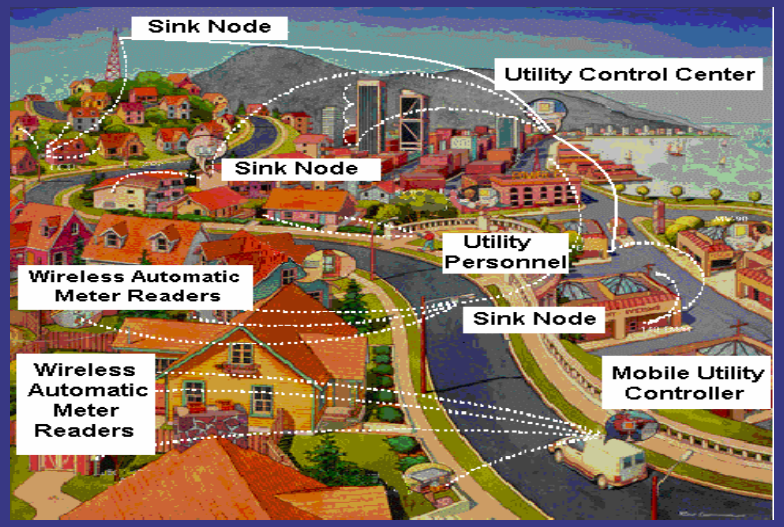
- Traffic monitoring, accident detection, recovery assistance
- Finding out empty parking lots in a city, without asking a server (car-to-car communication)
- Detecting and monitoring car thefts
- Vehicle tracking and detection
- Parking lots detection



Disaster Relief Operations

- Drop sensor nodes from an aircraft over a WILDFIRE
  - Each node measures temperature
  - Derive a "temperature map"
- Schools detect airborn toxins at low concentrations, trace contaminant transport to source
- Earthquake-rubbled building infiltrated with robots and sensors: locate survivors, evaluate structural damage

Wireless Automatic Meter Reading (WAMR) Systems for Power Utilities

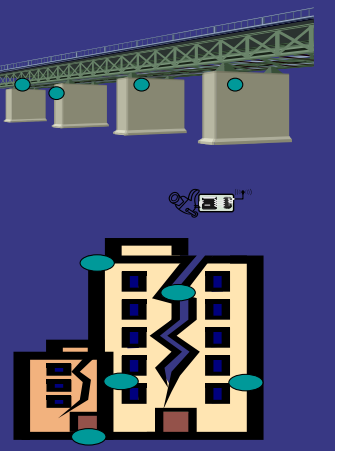


Wireless Automatic Meter Reading (WAMR) Systems

- Automatic meter reading functionalities:
  - Real-time energy consumption statistics
  - Effective billing management
- Telemetry functionalities:
  - Remote control of equipment
- Dynamic configuration functionality:
  - Self-configuration of the network in case of route failures
- Status monitoring functionality:
  - Monitoring the status of the metering devices

Buildings (or Bridges)

- High-rise buildings self-detect structural faults
- Reduce energy wastage by proper humidity, ventilation, air conditioning (HVAC) control
- Needs measurements about room occupancy, temperature, air flow, …
- Monitor mechanical stress after earthquakes



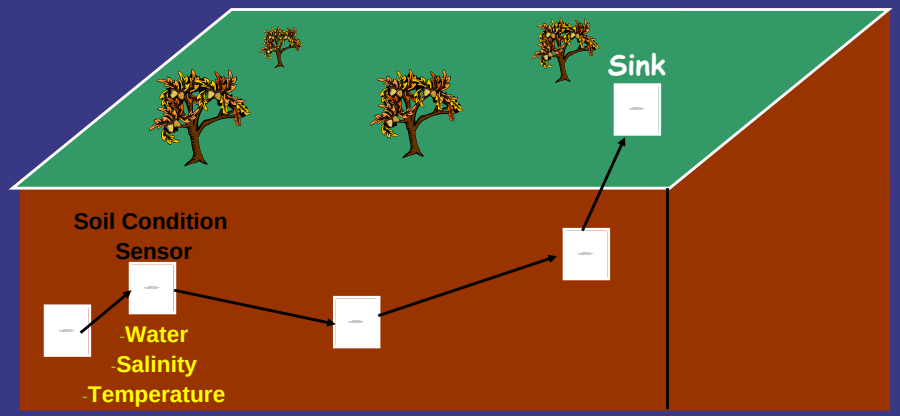
More Applications

- Facility Management
  - Intrusion detection into industrial sites
  - Control of leakages in chemical plants, …
- Machine surveillance and preventive maintenance
  - Embed sensing/control functions into places no cable has gone before
  - E.g., tire pressure monitoring

Underground Wireless Sensor Networks

- Applications:
  - Soil condition monitoring
  - Well/Aquifer monitoring
  - Voice communication within underground environments (e.g., caves, mines)
  - Earthquake monitoring
  - Golf Courses
  - Locating people in a collapsed building
  - Monitoring structural health (sensors within beams)

Example: Soil Monitoring



Research Challenges

- Extremely Lossy Environment
- Dynamic Channel Environment
- Power Constraints
- Low data rate

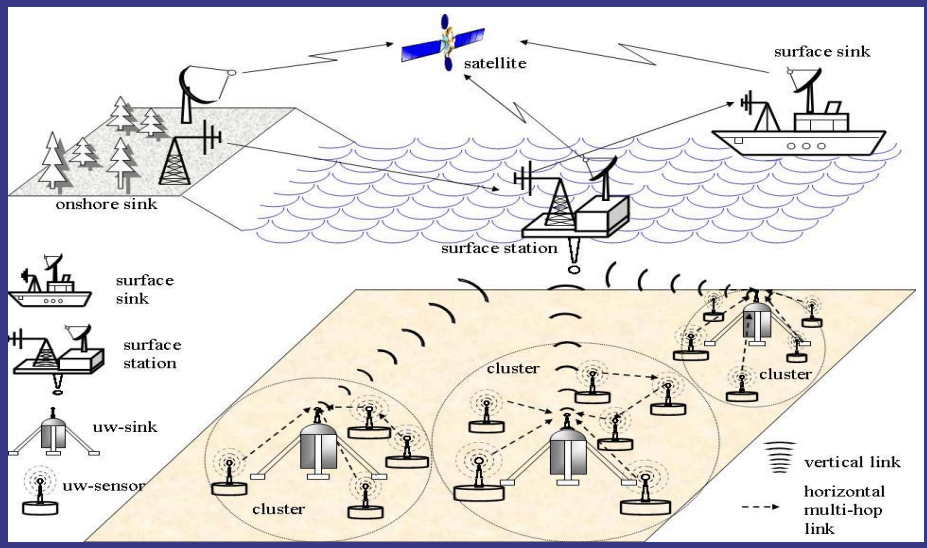
Underwater Sensor Networks

Recommended Reading: I.F. Akyildiz, D. Pompili, T. Melodia, "Underwater Acoustic Sensor Networks: Research Challenges"

- Applications:
  - Ocean Sampling Networks
  - Pollution Monitoring and other environmental monitoring (chemical, biological)
  - Buoys alert swimmers to dangerous bacterial levels
  - Disaster Prevention
  - Assisted Navigation
  - Distributed Tactical Surveillance
  - Mine Reconnaissance

Underwater Sensor Networks

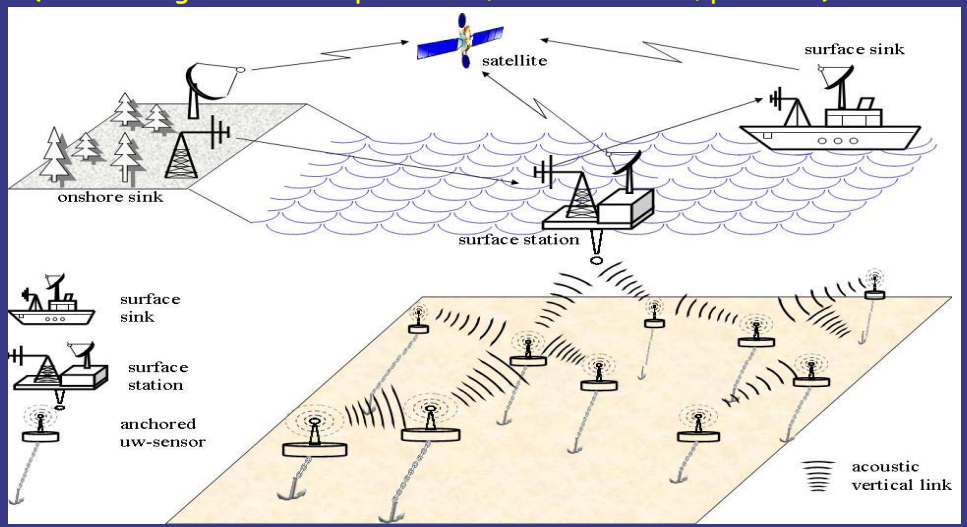
2D Architecture for Ocean Bottom Monitoring



Underwater Sensor Networks

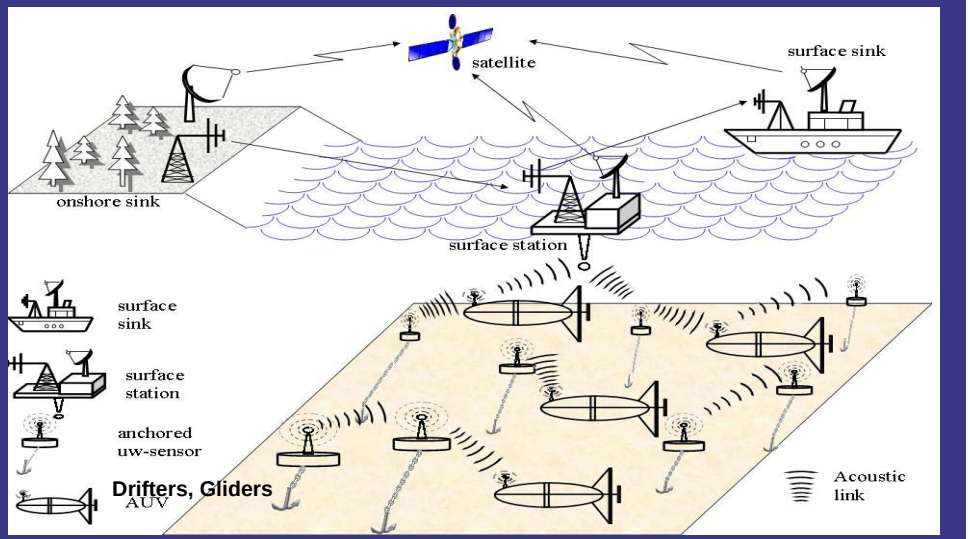
3D Static Architecture for Ocean Column Monitoring

For surveillance applications or monitoring of ocean phenomena (ocean bio-geo-chemical processes, water streams, pollution)



Underwater Sensor Networks

3D DYNAMIC Architecture using AUVs



Ocean Sampling Sensors

Spread Spectrum Modem

http://www.dspcomm.com/

Precision Marine Geodetic Systems

http://www.link-quest.com

Acoustic Transponders

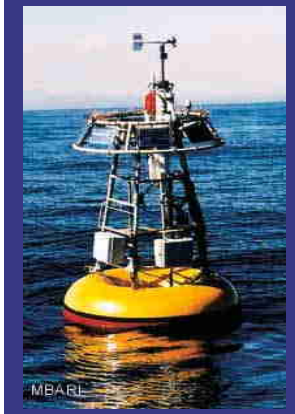
http://www.link-quest.com

Terrestrial vs. Underwater Sensors

Terrestrial Wireless Sensor	Mica Mote MPR300CB
Speed	4 MHz
Flash	128K bytes
Radio Frequency	916MHz or 433MHz (ISM Bands)
Data Rate	40 kbits/s (max)
Transmit Power	0.75 mW
Radio Range	100 feet
Power	2 x AA batteries

Underwater Acoustic Modem	Short-range	Medium-range
Acoustic Frequency	27- 45 kHz	54-89 kHz
Data Rate	7 kbit/s	14 kbit/s
Transmit Power	1 W	6 W
Receive Power	0.75 W	1 W
Sleep Power	8 mW	12 mW
Radio Range	1000 feet	3000 feet

Ocean Sampling Sensors



Point measurements in upper water column 10 and 25 mi off Moss Landing

http://www.mbari.org/aosn/

Drift buoy: Path followed by surface currents

http://www.mbari.org/aosn/

Surface station

http://www.link-quest.com

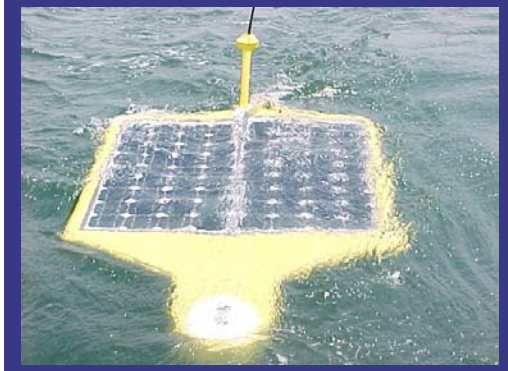
Autonomuos Underwater Vehicles (AUVs)

CARIBOU by **Bluefin Robotics Corporation**

Equipped with state-of-the-art sensors (side-scan sonar and sub-bottom profiler), and can collect high-quality data for:

- Archaeological remote sensing
- Multi-static acoustic modeling
- Fisheries resource studies and
- Development of concurrent mapping and localization techniques.

Autonomuos Underwater Vehicles (AUVs)



Solar recharged AUV

http://www.mbari.org/aosn

Phantom HD2 ROV

http://www.link-quest.com

Research Challenges for UW Sensor Networks

- Available bandwidth is severely limited
- UW channel is severely impaired (in particular due to multi-path and fading)
- Very long (5 orders of magnitude higher than in RF terrestrial channels) and extremely variable propagation delays
- Very high bit error rates and temporary losses of connectivity (SHADOW ZONES)
- Battery power is limited and usually batteries cannot be recharged; no solar energy!!
- Very prone to failures because of fouling, corrosion, etc.

Basic Principles for Sensor Networks

- Principle 1: Simple Nodes, Powerful Networks!
- Principle 2: There is no single wireless sensor market. There are several wireless sensor markets.
- Principle 3: Low duty cycle makes for long battery life
- Principle 4: Frequency constrained by area, range, spectrum
- Principle 5: Optimize bit rate for minimum total receive power (fixed + dynamic)
- Principle 6: Short range link, long range network.
- Principle 7: Location! Location! Location!

Structuring WSN Application Types

- Interaction Patterns between sources and sinks classify application types
- Event Detection: Nodes locally detect events (maybe jointly with nearby neighbors), report these events to interested sinks
- Periodic measurement
- Function Approximation: Use sensor network to approximate a function of space and/or time (e.g., temperature map)
- Edge Detection: Find edges (or other structures) in such a function (e.g., where is the zero degree border line?)
- Tracking: Report (or at least, know) position of an observed intruder ("pink elephant")

Deployment Options for WSNs

- Dropped from aircraft ! *Random deployment*
  - Usually uniform random distribution for nodes over finite area is assumed
- Well Planned, Fixed ! *Regular deployment*
  - E.g., in preventive maintenance or similar
  - Not necessarily geometric structure, but that is often a convenient assumption
- *Mobile* Sensor Nodes
  - Can move to compensate for deployment shortcomings
  - Can be passively moved around by some external force (wind, water)
  - Can actively seek out "interesting" areas

Maintenance Options

- Feasible and/or practical to maintain sensor nodes?
  - E.g., to replace batteries?
  - Or: unattended operation?
  - Impossible but not relevant? Mission lifetime might be very small
- Energy supply?
  - Limited from point of deployment?
  - Some form of recharging, energy scavenging from environment?
    - E.g., solar cells

Manufacturers of Sensor Nodes

- Millenial Net (www.millenial.com)
  - iBean sensor nodes
- Ember (www.ember.com)
  - Integrated IEEE 802.15.4 stack and radio on a single chip
- Crossbow (www.xbow.com)
  - Mica2 mote, Micaz, Dot mote and Stargate Platform
- Intel Research
  - Stargate, iMote
- Dust Inc
  - Smart Dust
- Cogent Computer (www.cogcomp.com)
  - XYZ Node (CSB502) in collaboration with ENALAB@Yale
- Mote iv – Telos Mote
- Sensoria Corporation (www.sensoria.com)
  - WINS NG Nodes

Manufacturers of Sensor Nodes

- *XSILOGY Solutions* is a company which provides wireless sensor network solutions for various commercial applications such as tank inventory management, stream distribution systems, commercial buildings, environmental monitoring, homeland defense etc.
  http://www.xsilogy.com/home/main/index.html
- *In-Q-Tel* provides distributed data collection solutions with sensor network deployment.
  http://www.in-q-tel.com/tech/dd.html
- *ENSCO Inc.* invests in wireless sensor networks for meteorological applications.
  http://www.ensco.com/products/homeland/msis/msis_rnd.htm
- *EMBER* provides wireless sensor network solutions for industrial automation, defense, and building automation.
  http://www.ember.com

Manufacturers of Sensor Nodes

- H900 Wireless SensorNet System(TM), the first commercially available end-to-end, low-power, bi-directional, wireless mesh networking system for commercial sensors and controls is developed by the company called Sensicast Systems. The company targets wide range of commercial applications from energy to homeland security.
  http://www.sensicast.com
- The Sensor-based Perimeter Security product is introduced by a company called SOFLINX Corp. (a wireless sensor network software company)
  http://www.soflinx.com
- XYZ On A Chip: Integrated Wireless Sensor Networks for the Control of the Indoor Environment In Buildings is another commercial application project currently performed by Berkeley.
  http://www.cbe.berkeley.edu/research/briefs-wirelessxyz.htm

Manufacturers of Sensor Nodes

- The Crossbow wireless sensor products and its environmental monitoring and other related industrial applications of such as surveillance, bridges, structures, air quality/food quality, industrial automation, process control are introduced.
  http://www.xbow.com
- Japan's Omron Corp has two wireless sensor projects in the US that it hopes to commercialize in the near future. Omron's Hagoromo Wireless Web Sensor project consists of wireless nodes equipped with various sensing abilities for providing security for major cargo-shipping ports around the world.
  http://www.omron.com

Manufacturers of Sensor Nodes

- Millennial Net builds wireless networks combining sensor interface endpoints
  and routers with gateways for industrial and building automation, security, and telemetry http://www.millennial.net
- CSEM provides sensing and actuation solutions
  http://www.csem.ch/fs/acuating.htm
- Dust Inc. develops the next-generation hardware and software for wireless
  sensor networks http://www.dust-inc.com
- Integration Associates designs sensors used in medical, automotive, industrial, and military applications to cost-effective designs for handheld consumer appliances, barcode readers, and wireless computer input devices
  http://www.integration.com

Manufacturers of Sensor Nodes

- Melexis produces advanced integrated semiconductors, sensor ICs, and programmable sensor IC systems.
  http://www.melexis.com
- ZMD designs, manufactures and markets high performance, low power mixed signal ASIC and ASSP solutions for wireless and sensor integrated circuits.
  http://www.zmd.biz
- Chipcon produces low-cost and low-power single-chip 2.4 GHz ISM band transceiver design for sensors.
  http://www.chipcon.com
- ZigBee Alliance develops a standard for wireless low-power, low-rate devices. http://www.zigbee.com