Sensor Networks and Telemetry

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Outline

- Overview of sensor networks and applications
- Field deployment examples
- Sensors and data acquisition
- Wired and wireless networks
- Power consumption and energy sources

Overview of Sensor Networks and Applications

- Sensors
- Wireless Networks
- Real-Time Data Management and Analysis
- Visualization

Sensors

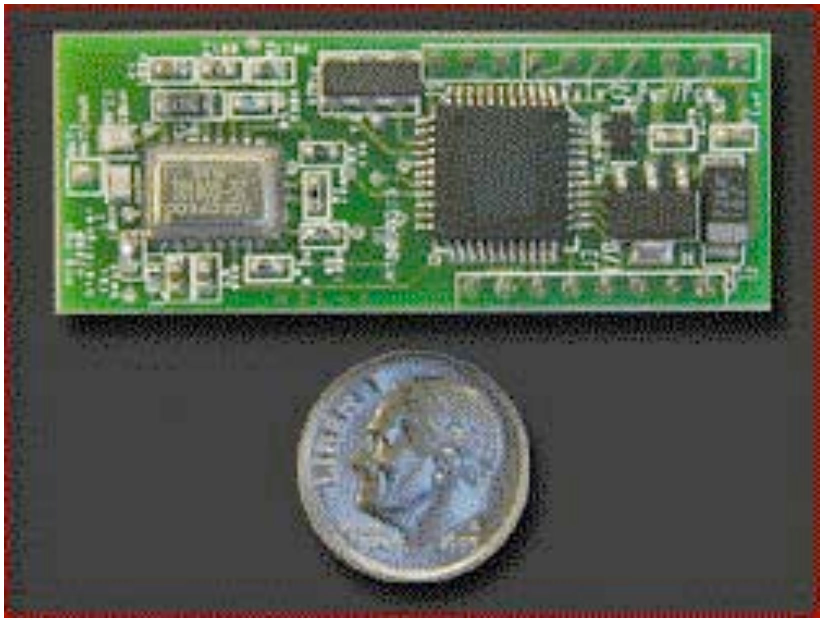
Sensors for Environment and Civil Infrastructure

• Chemical • Biological • Light/Radiation • Temperature • Humidity/Moisture	• Occupancy/Motion • Position/Displacement • Velocity/Acceleration • Force/Strain • Pressure/Flow
• Atmospheric • Terrestrial • Oceanographic	• Ecology • Hydrology • Seismology

Sensor and Signal Conditioning Issues

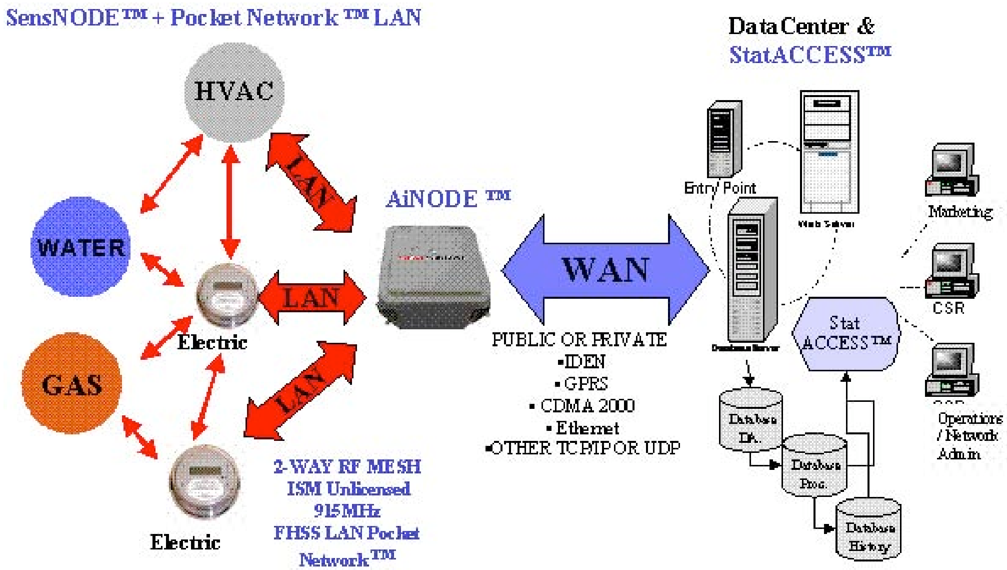
- Low power consumption (long-term deployments)
- Power sources (e.g. batteries, solar power, wind, …)
- Synchronization between multiple spatially separated sensors
- Data buffering
- Preprocessing prior to transmission
    - Triggered data collection (e.g. earthquakes, ...)
    - Data compression (e.g. reduced basis set, covariance matrices, …)
    - Event detection (e.g. intruder alert, …)
- Transmission Quality of Service
    - Error detection/correction and timely delivery

Wireless Networks



StatSignal iModule RF Transceiver operating at 915 MHz provides short-range (~300 m) wireless networking for building systems, utility meter readings, vending machines, e-parking, copy machines, etc.

http://www.statsignal.com



The end metering devices communicate to and through one another, forming the RF Mesh Local Area Pocket Network.

SensNODES - The end nodes of the system which integrate the iModule with the measurement or control devices.

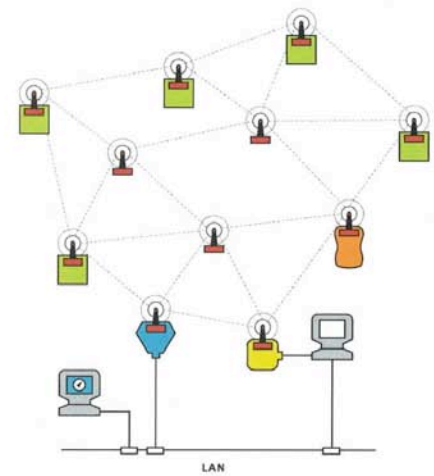
AiNODE - The data collector or site controller that acts as the bridge between the Pocket Network and the Wide Area Network (WAN) that transports the data to the Data Center.

EmberNet Node

v1.0 – 900 MHz

Specification Sheet

The Core Component of EmberNet™ Wireless Sensing and Control Networks



The EmberNet Node is the primary building block of EmberNet networks and Ember Enabled products.

The EmberNet Node is an embedded wireless networking peripheral that gives any processor, from PIC® to Pentium®, the ability to communicate in a wireless mesh network. The primary building block of Ember Enabled™ products and EmberNet networks, this wireless communications module acts as an embedded router. The EmberNet Node has been specifically designed to be embedded into a wide variety of sensing and control devices and can be used alone as a repeater to extend network range and reliability.

Suitable for challenging RF environments like those found in industrial, building automation, or defense applications, the EmberNet Node uses a direct sequence spread spectrum radio, with twelve independent channels and multiple power modes. The EmberNet Node provides hardware-based encryption using the Advanced Encryption Standard (AES) and communicates seamlessly with EmberNet Gateways, EmberNet Serial Nodes, and other Ember Enabled devices using the EmberNet Protocol Stack.

The EmberNet Node

http://www.ember.com

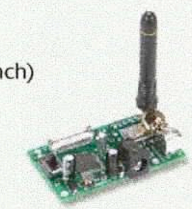
System Components

Endpoints

- Ultra-low-power: <50 microamps at 3 volts
- Very small: 2.3 x 1.8 x 0.3 cm (0.9 x 0.7 x 0.1 inch)
- Analog input channels, 8-, 10-, or 12-bit
- Analog output channels, 8-, 10-, or 12-bit
- PWM output channels
- Digital I/O channels, parallel or serial
- Sample rates up to 10 Hz
- Data rate up to 500 kbps
- Integrated wireless transceiver using license-free bands
- Internal antenna for smallest size or whip antenna for greater range

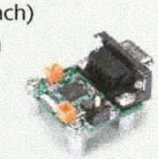
Routers

- Extend network coverage area
- Add fault tolerance
- Low-power: <2 mA at 3 volts
- Compact: 5.6 x 3.3 cm (2.2 x 1.3 inch)
- Integrated wireless transceiver
- Internal antenna for smallest size or whip antenna for greater range
- Data rate up to 500 kbps
- Routers can include same analog and digital interfaces as Endpoints



Gateways

- Low power: RS-232 version can be powered from PC serial port
- Compact: RS-232 version is 3.8 x 3.3 x 1.5 cm (1.5 x 1.3 x 0.6 inch)
- Other versions interface to system via Ethernet, 802.11, GSM, etc.
- Integrated wireless transceiver using license-free bands
- Internal or whip antenna
- Data rate up to 500 kbps

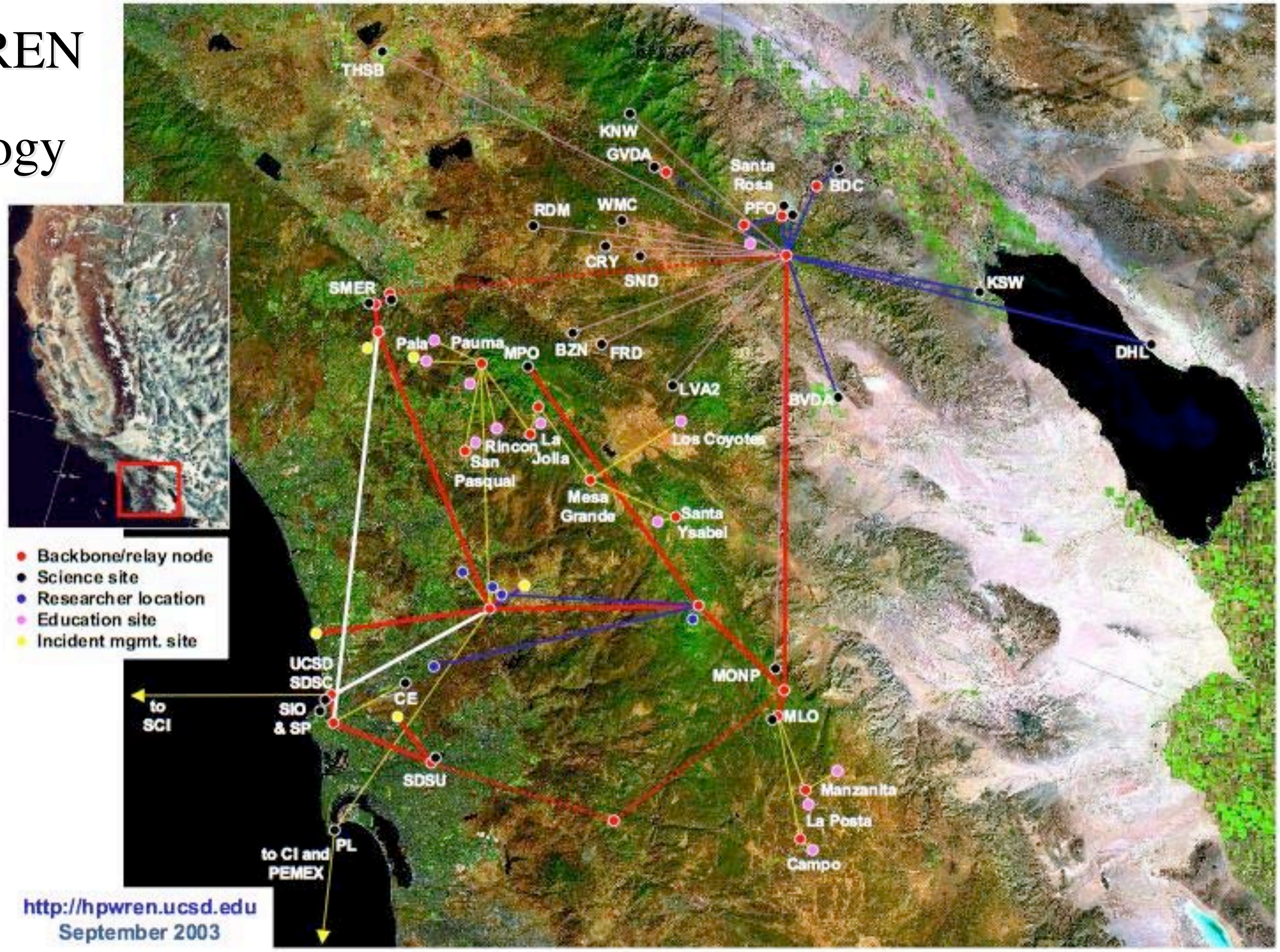


http://www.ember.com

Overview of Sensor Networks and Applications

HPWREN

Topology



Real-Time Data Management and Analysis

Real-Time Data Management

Virtual Object Ring Buffers (VORB)

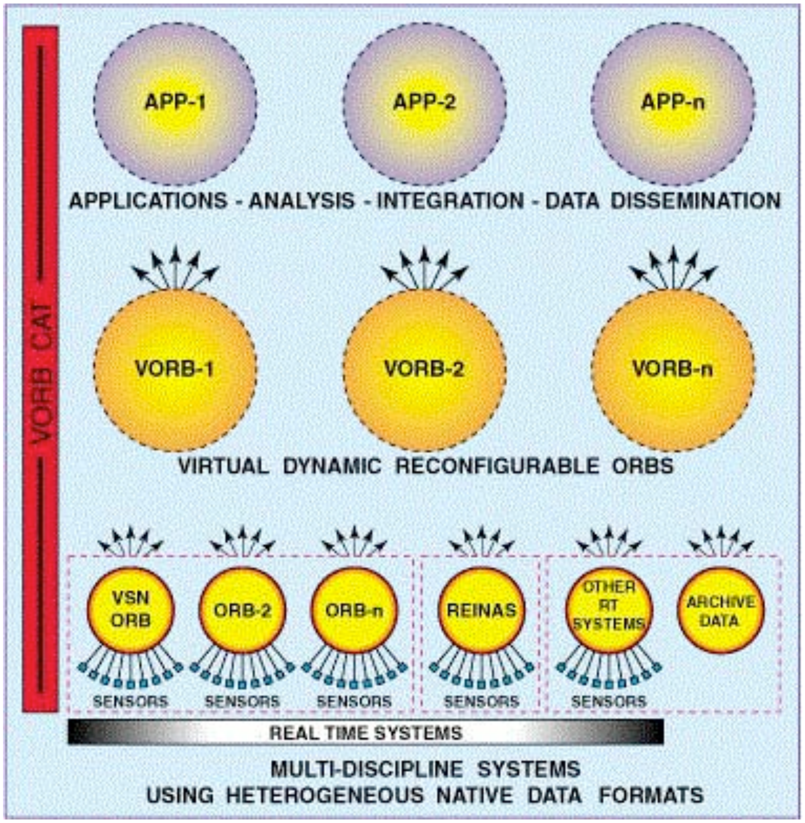
Motivation

- How can I acquire my RT data?
- How can I discover/access my RT data?
- How can I share/integrate the data?
- Can I integrate dynamically?
- Can I share with other disciplines?
- Can I integrate seamlessly with data from other disciplines?
- Can I integrate with static data?

Source: Arcot Rajasekar - http://roadnet.ucsd.edu

Real-Time Data Acquisition Requirements

- Data Acquisition
- Data Communications
- Data and Information Buffering
- Data and Information Flow
- Automated Data Processing
- Automated Data and Information Archiving
- Real-Time Data and Information Integration, Distribution and Sharing
- Real-Time System Monitoring and Control
- Real-Time Graphical User Interfaces



Source: Arcot Rajasekar - http://roadnet.ucsd.edu

Visualization

Data and Information Visualization

http://siovizcenter.ucsd.edu

References

Journal Literature

• "Special issue on sensor networks and applications," Proc. IEEE (August 2003).

• I. Akyildiz et al., "A survey on sensor networks," IEEE Communications Magazine, pp. 102-114 (August 2002).

• S. Kumar, F. Zhao, and D. Shepherd, "Collaborative signal and information processing in microsensor networks," IEEE Signal Processing Magazine 19(2), pp. 13-85 (March 2002).

Overview of Sensor Networks and Applications

sensors

YOUR TECHNICAL RESOURCE FOR SENSING, COMMUNICATIONS, AND CONTROL

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www.sensorsmag.com

contents

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http://www.sensorsmag.com

Field Deployments

Wireless Networking

- High Performance Wireless Research and Education Network (HPWREN)
    - PI’s: Hans-Werner Braun (SDSC) and Frank Vernon (SIO)
    - NSF Advance Networking Infrastructure and Research (ANI-0087344)
    - http://hpwren.ucsd.edu

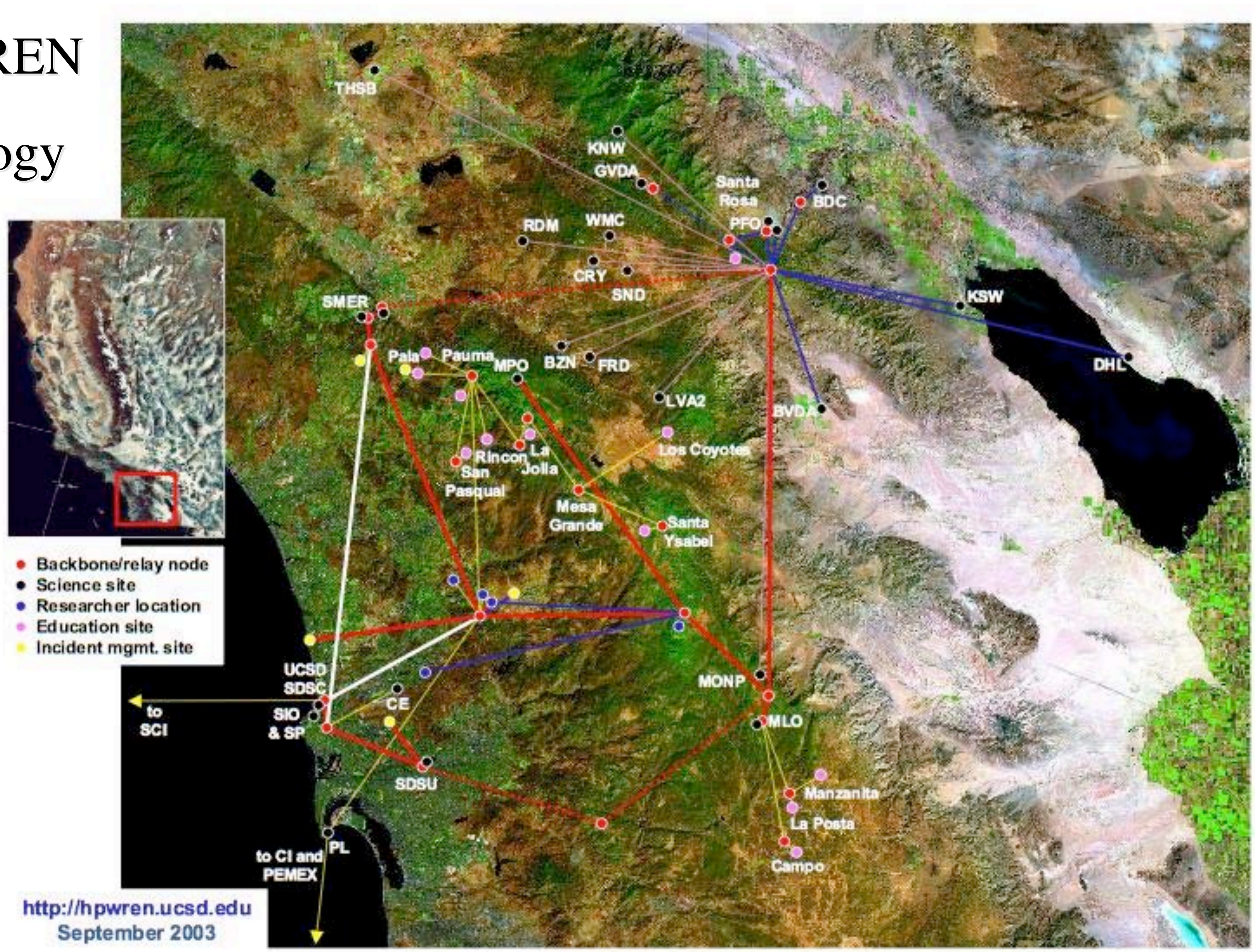
- Real-time Observatories Applications and Data management Network (ROADNet)
    - PI’s: John Orcutt (SIO), Frank Vernon (SIO), Hans-Werner Braun (SDSC), and Arcot Rajasekar (SDSC)
    - NSF Ocean Sciences and CISE (OCE-0121726)
    - http://roadnet.ucsd.edu

High Performance Wireless Research and Education Network (HPWREN)

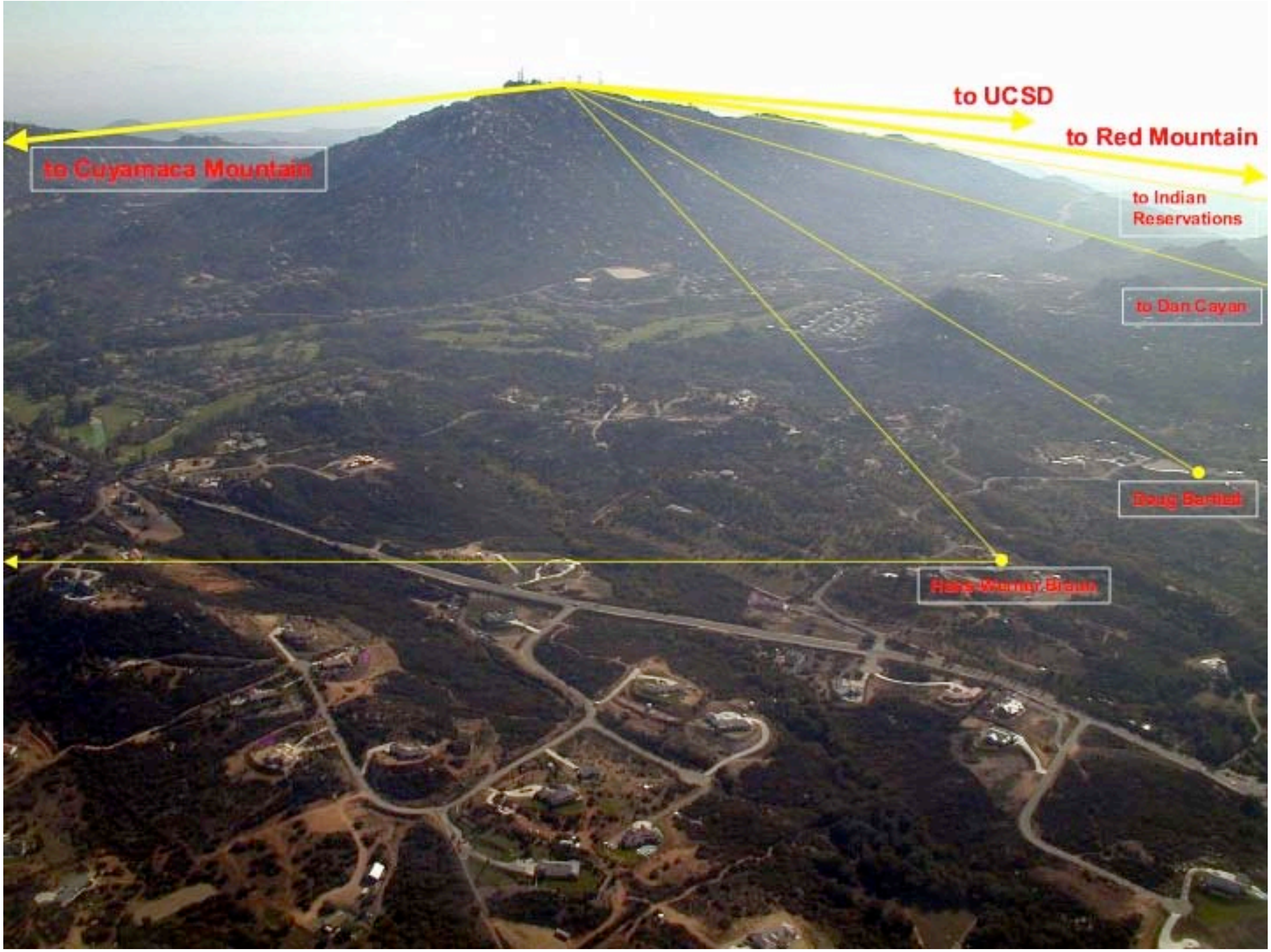
Field Deployments

HPWREN

Topology

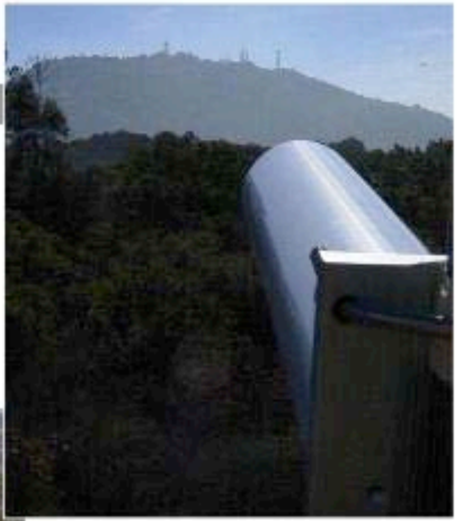


Field Deployments



Field Deployments

Researchers in the field



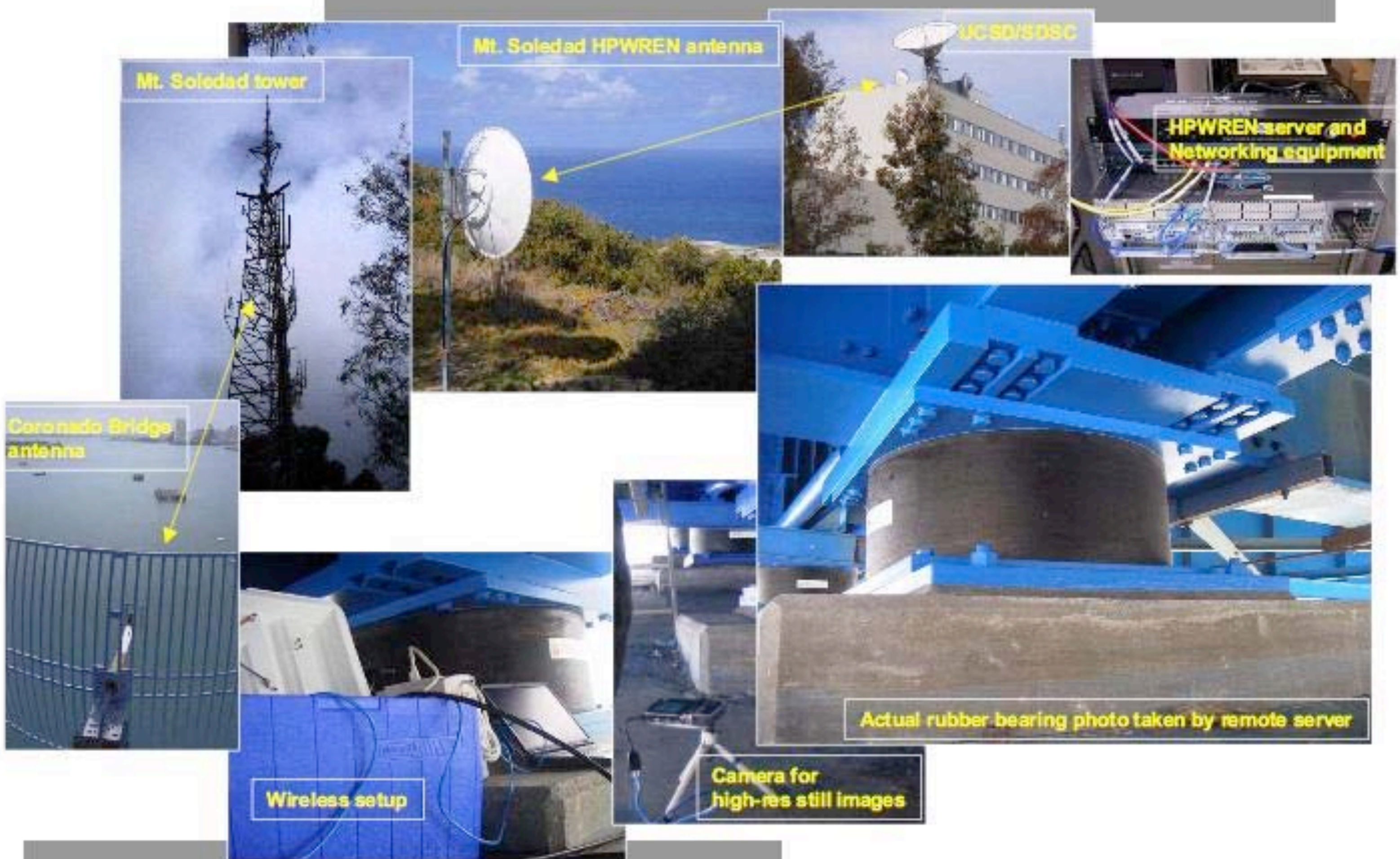
- antenna mounted on tripod
- connected to laptop PCMCIA card
- no external power or equipment

high performance wireless research and education network

Coronado Bridge

Field Deployments

Coronado bridge communications test, April 2002



high performance wireless research and education network

Field Deployments

Coronado Bridge

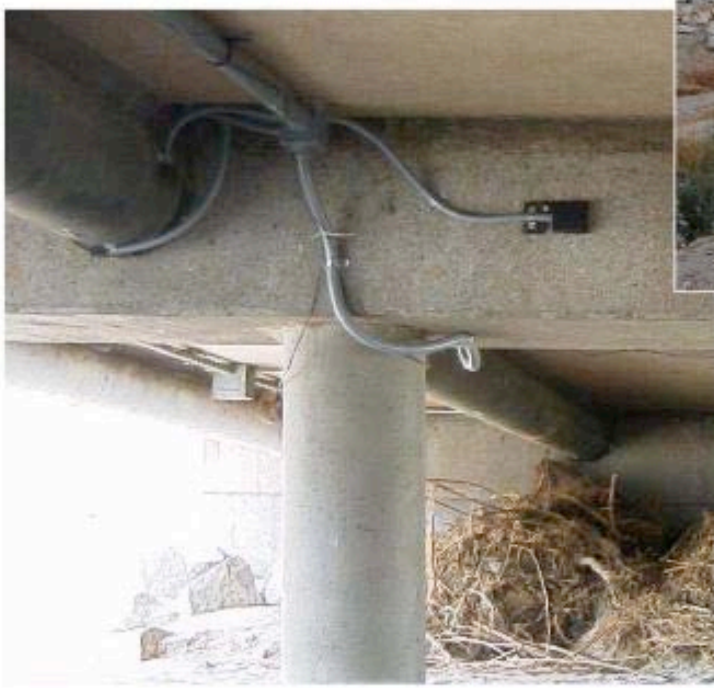
April 2002

Kings Stormwater Bridge

Field Deployments

Kings Stormwater Bridge

Bridge connection near Salton Sea
Nov 2002



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Anza Seismic Sensors

Field Deployments

Example earthquake sensors in the desert

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Field Deployments

Earthquake sensor and data collector on Toro Peak

http://epicenter.ucsd.edu/ANZA/

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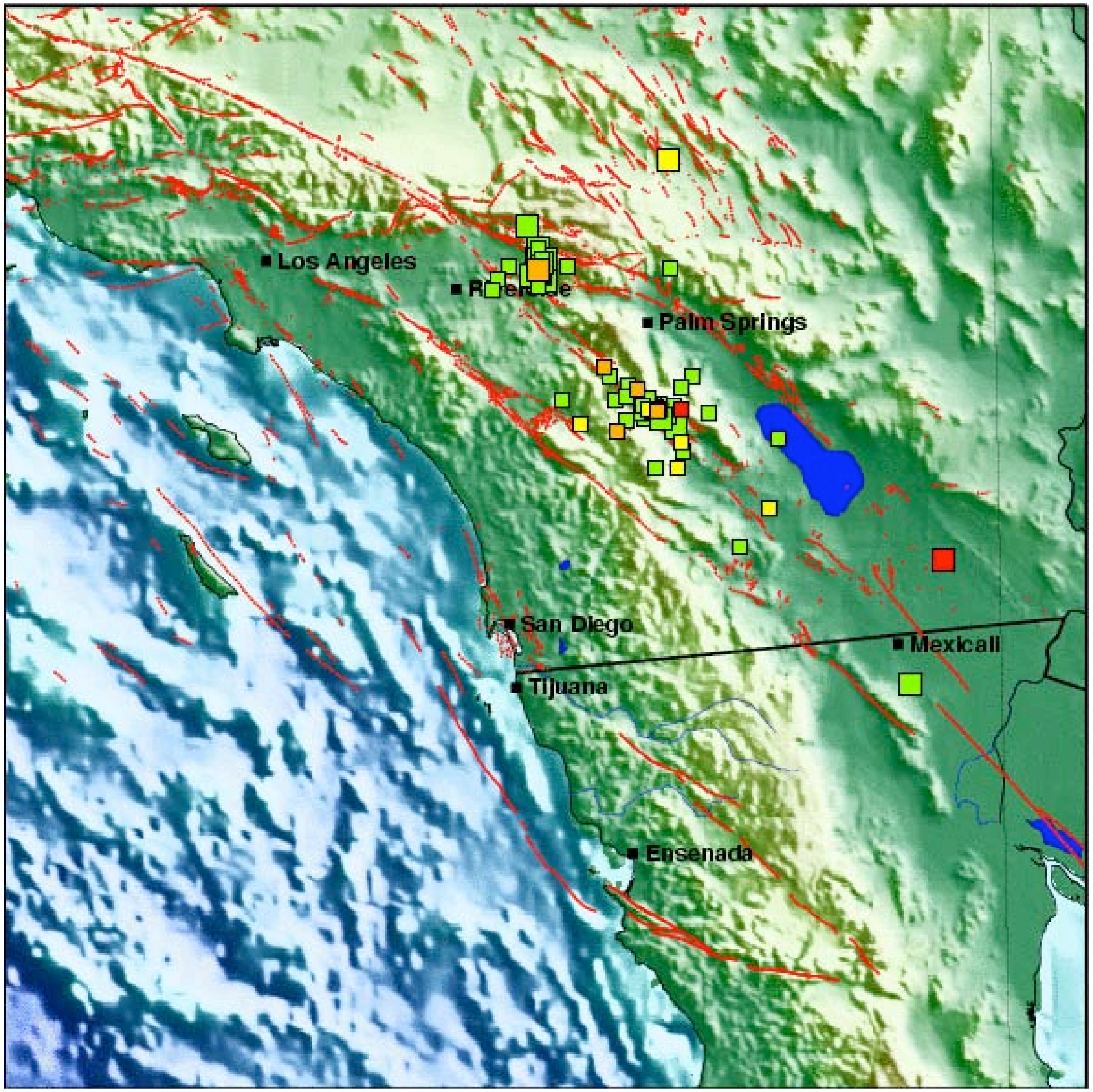
Field Deployments

Southern California
Earthquake Data
(June 2005)



http://eqinfo.ucsd.edu

Mount Laguna Environmental Sensors

Field Deployments

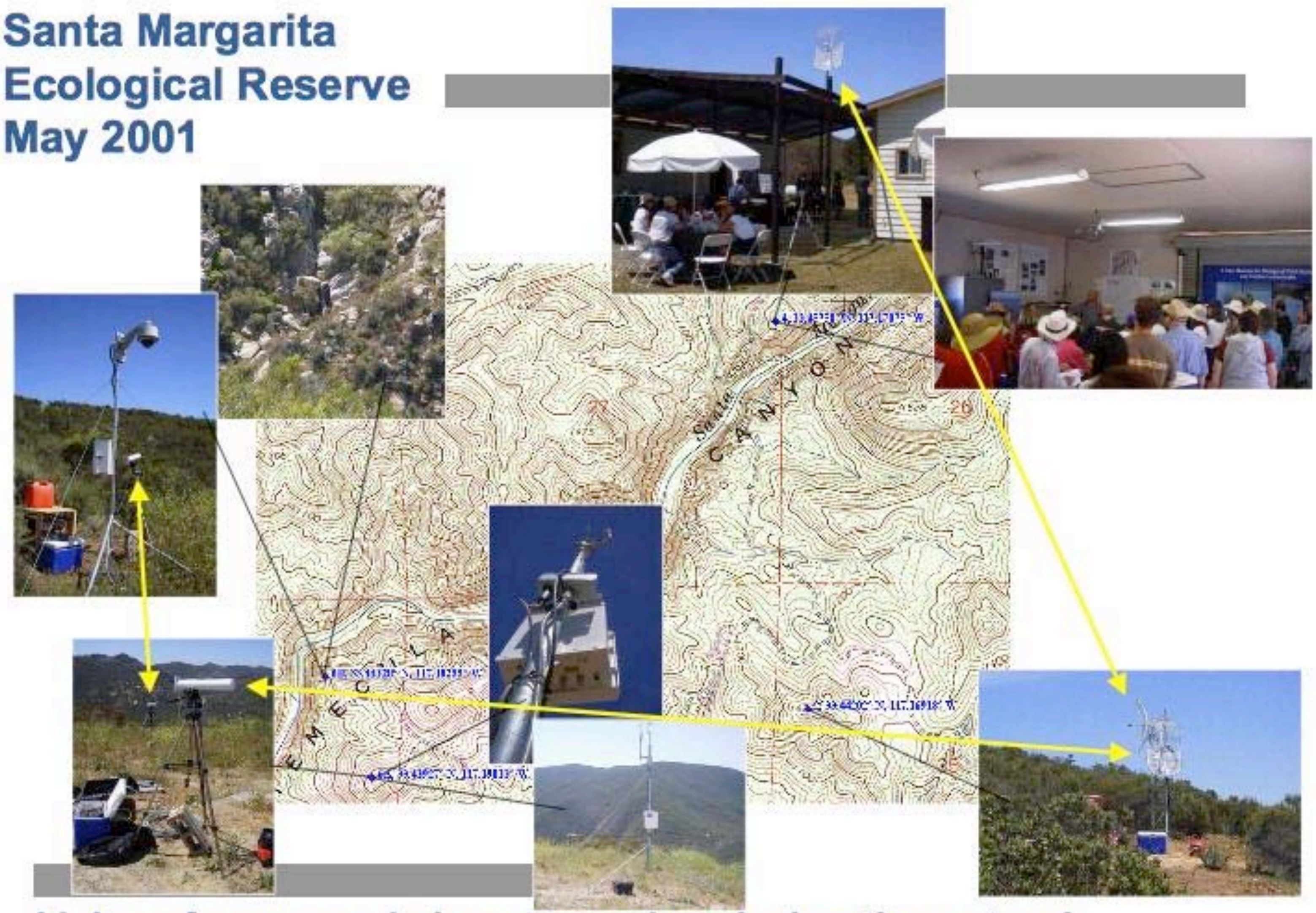
Mount Laguna sensor instrumentation

high performance wireless research and education network

Santa Margarita Ecological Reserve

Field Deployments

Santa Margarita Ecological Reserve May 2001



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Field Deployments

MARINE PHYSICAL LABORATORY

Field Deployments

Ecology Experiment at SMER

Ships

Field Deployments

SeaTel C-Band antenna radome
mounted on the R/V Revelle (~64 kbps)

http://hiseasnet.ucsd.edu

Sensors and Data Acquisition

Sensor Characterization

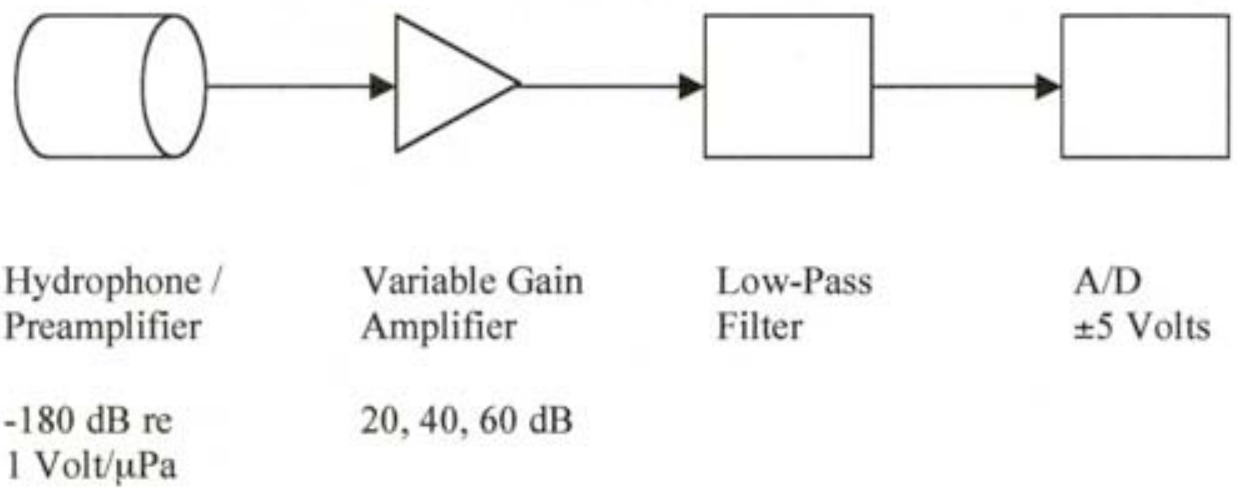
- Power consumption along with specific voltage/current requirements.
- Output (e.g. analog voltage and range, digital and number of bits, etc.).
- Resolution, accuracy, time constant (i.e. how rapidly the sensor responds), drift, and hysteresis characteristics.
- Typical calibration characteristics (i.e. how do you go back to physical input units from the sensor output units?).
- Theory of operation (i.e. physics behind the sensor).
- Range of sensor input values expected in the application and corresponding range of anticipated sensor output values.
- Signal conditioning requirements prior to A/D conversion based on anticipated range of sensor output values.
- Required sampling rate (fs) and minimum number of A/D bits per sample.

References

• Jacob Fraden. *Handbook of Modern Sensors: Physics, Designs, and Applications*. Springer, 3rd ed. (2004) (ISBN 0-387-00750-4).

• Ramon Pallas-Areny and John G. Webster. *Sensors and Signal Conditioning*. Wiley, 2nd ed. (2001) (ISBN 0-471-33232-1).

Underwater Acoustic Data Acquisition System



Sources of Noise at A/D Output

- Environmental (ambient) noise
- Preamplifier noise
- A/D quantization noise

Considerations

- Largest expected signal level sets upper limit on system gain (amplifier or A/D clipping)
- Smallest ambient noise level should be larger than preamplifier and A/D quantization noise levels

Sensor Input Level Not Always Encoded in Amplitude of Sensor Output

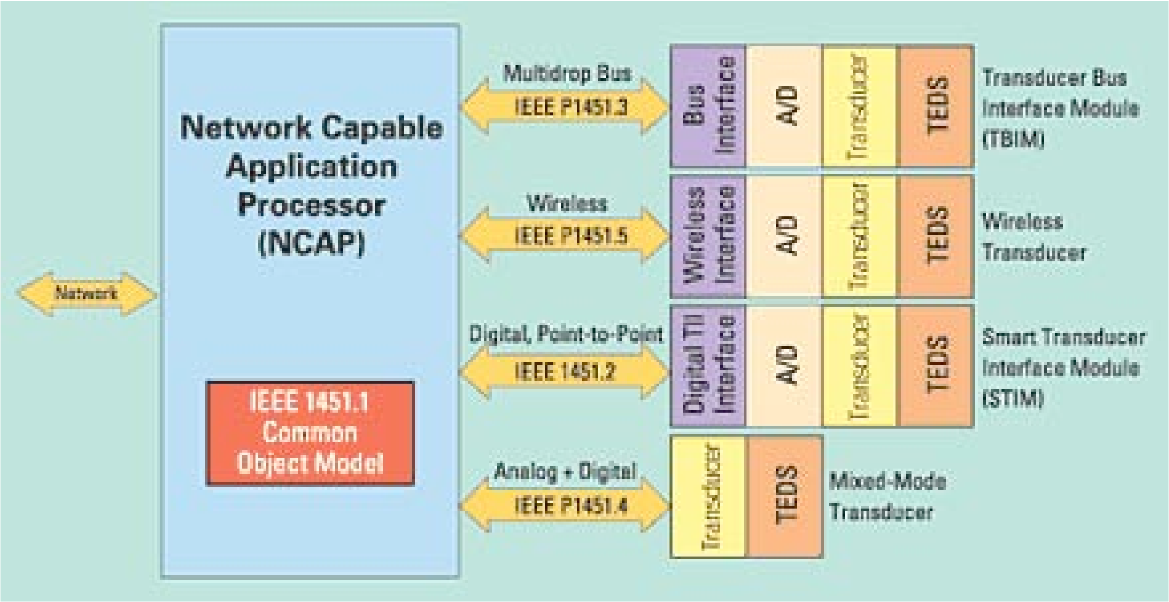
- Serial digital data stream - A/D included in sensor
- Pulse width modulation (PWM)
- Frequency of sinusoid or square wave output

Microcontrollers

- Embedded in a wide range of sensor and control systems
- Inexpensive, low power, and integrated with some I/O functionality
- Programming support tools are critical for effective software development - compilers, debuggers, and in most cases some form of higher-level language support beyond just assembly-level language (e.g. BASIC and/or C)

Smart Sensors (IEEE 1451)

- IEEE 1451 is a complementary family of standards for smart transducer (sensor and actuator) interfaces
- IEEE 1451.2-1997 introduced the concept of the Transducer Electronic Data Sheet (TEDS) which included transducer calibration data
- Also divided the smart transducer into two parts - the Smart Transducer Interface Module (STIM) and the Network Capable Application Processor (NCAP)



Sensors Magazine (December, 2002, pp. 14-19)

Wired and Wireless Networks

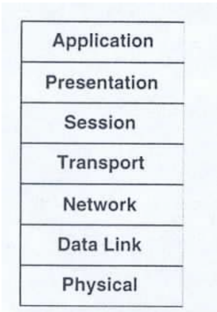
Protocol

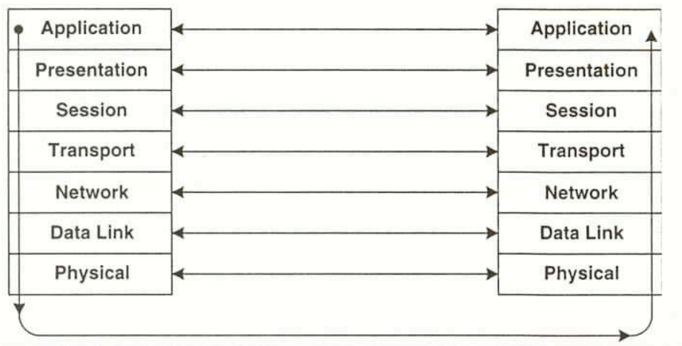
- Protocol defines a message structure that devices recognize and use for communication
- Describes the process a controller uses to request access to another device, how it will respond to requests from other devices, and how errors will be detected and reported
- Establishes a common format for the layout and contents of message fields - device addresses, actions to be taken, and data or other information in message

Network Standards

- Open Systems Interconnection (OSI) networking protocol suite standardization effort began in mid-1970's
- Details of the internal operation of any given layer are irrelevant as long as each layer provides a certain set of well-defined services to the layer above it just as each layer depends on a different set of well-defined services that are exposed by the layer below it
- Each layer is communicating with a peer process at the same layer on another machine using the services provided by the layers below it in the stack - logically, the interaction is as if peers were communicating directly
- OSI Reference Model consists of 7 abstract layers of a protocol stack that divides sending/receiving data over a network into layers each with its own well-defined functions
- Protocol stack manifests itself as a nested series of headers that are prefixed to data that is passed down from the layer above - headers are treated as if they are data to the layers below

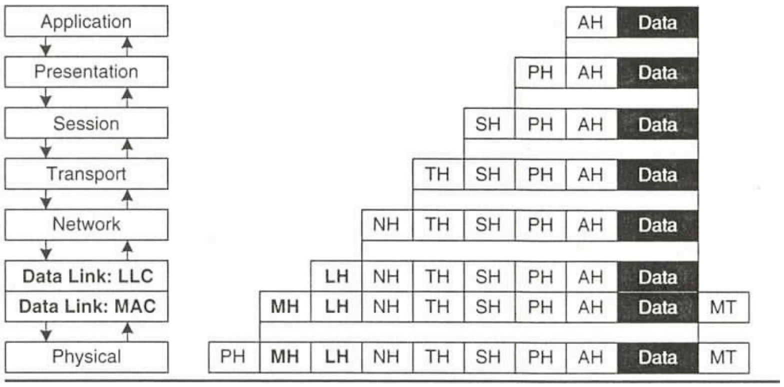
Wired and Wireless Networks





OSI Reference Model

Operation of the layered protocol model

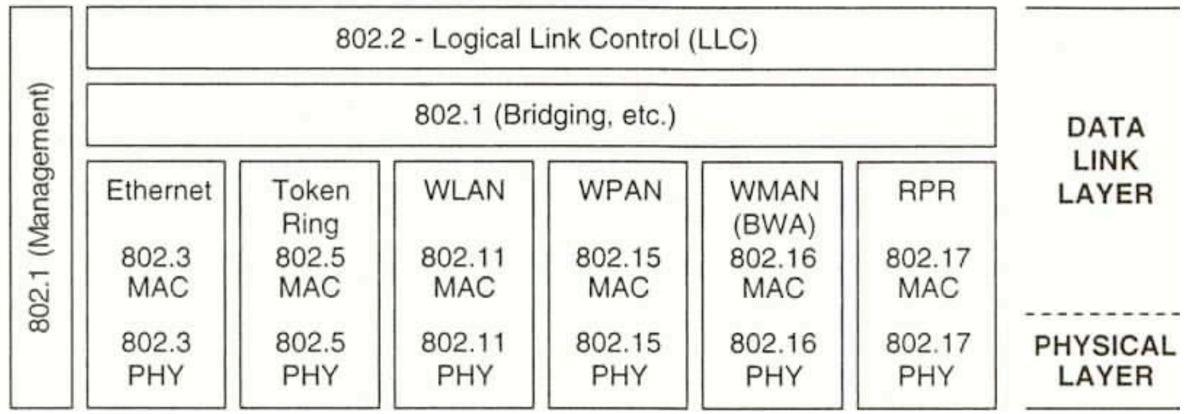


Layered headers in the OSI Reference Model

T. Maufer. *A Field Guide to Wireless LANs*. Prentice-Hall (2004).

Wired and Wireless Networks

Top-level structure of Project IEEE 802



Complete constituents of Project IEEE 802

	802.1	**WG**	**Higher Layer LAN Protocols (e.g., bridging and management)**
(inactive)	802.2	WG	Logical Link Control
	802.3	**WG**	**Ethernet**
(inactive)	802.4	WG	Token Bus
(inactive)	802.5	WG	Token Ring
(inactive)	802.6	WG	Metropolitan Area Network (DQDB/SMDS)
(inactive)	802.7	WG	Fiber Optic
(disbanded)	802.8	TAG	Broadband
(inactive)	802.9	WG	Isochronous LAN
(inactive)	802.10	WG	Security
	802.11	**WG**	**Wireless Local Area Network (WLAN)**
(inactive)	802.12	WG	Demand Priority
<never used>	802.13		
(disbanded)	802.14	WG	Cable Modem
	802.15	**WG**	**Wireless Personal Area Network (WPAN)**
	802.16	**WG**	**Broadband Wireless Access (WMAN; fixed and mobile)**
	802.17	**WG**	**Resilient Packet Ring**
	802.18	**TAG**	**Radio Regulatory**
	802.19	**TAG**	**Coexistence**
	802.20	**WG**	**Mobile Broadband Wireless Access (MBWA)**

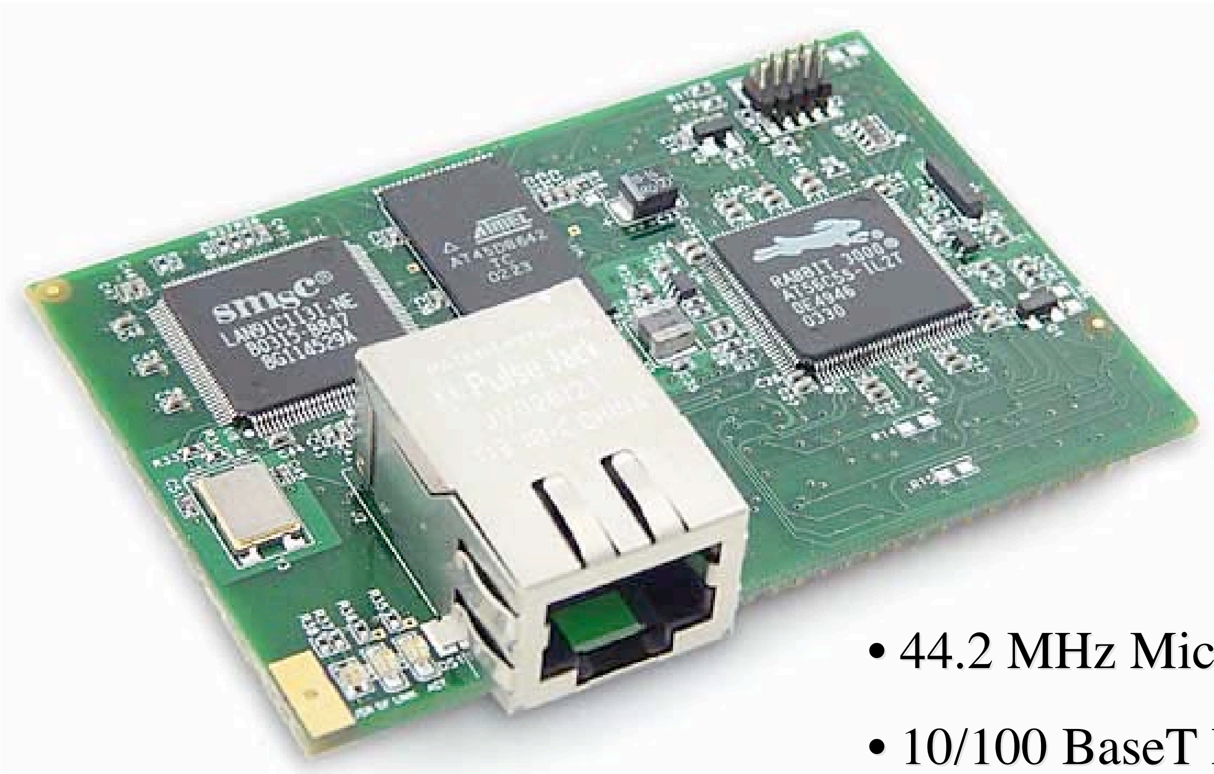
T. Maufer. *A Field Guide to Wireless LANs*. Prentice-Hall (2004).

Ethernet (802.3)

- Developed mid-1970's
- Working example of the more general Carrier Sense Multiple Access with Collision Detect (CSMA/CD) local area networking technology
  - "Carrier Sense" - All nodes can distinguish between and idle and busy link
  - "Collision Detect" - A node listens as it transmits and can detect when a frame it is transmitting has interfered (collided) with a frame transmitted by another node
- Various physical transmission media - e.g. 10BaseT (10 Mb/s, baseband transmission, twisted pair)
- Algorithm that controls access to the shared Ethernet is commonly called the media access control (MAC) and typically is implemented in hardware
- Each host has a unique Ethernet address (6B)
- Ethernet adaptor delivers frames to the host that are addressed to it

Wired and Wireless Networks

Rabbit Semiconductor
RCM3300 RabbitCore



- 44.2 MHz Microprocessor
- 10/100 BaseT Ethernet connectivity
- 8 MB serial flash memory
- Multiple serial ports (including 3 SPI)
- TCP/IP stack, web server
- C development environment

http://www.rabbitsemiconductor.com

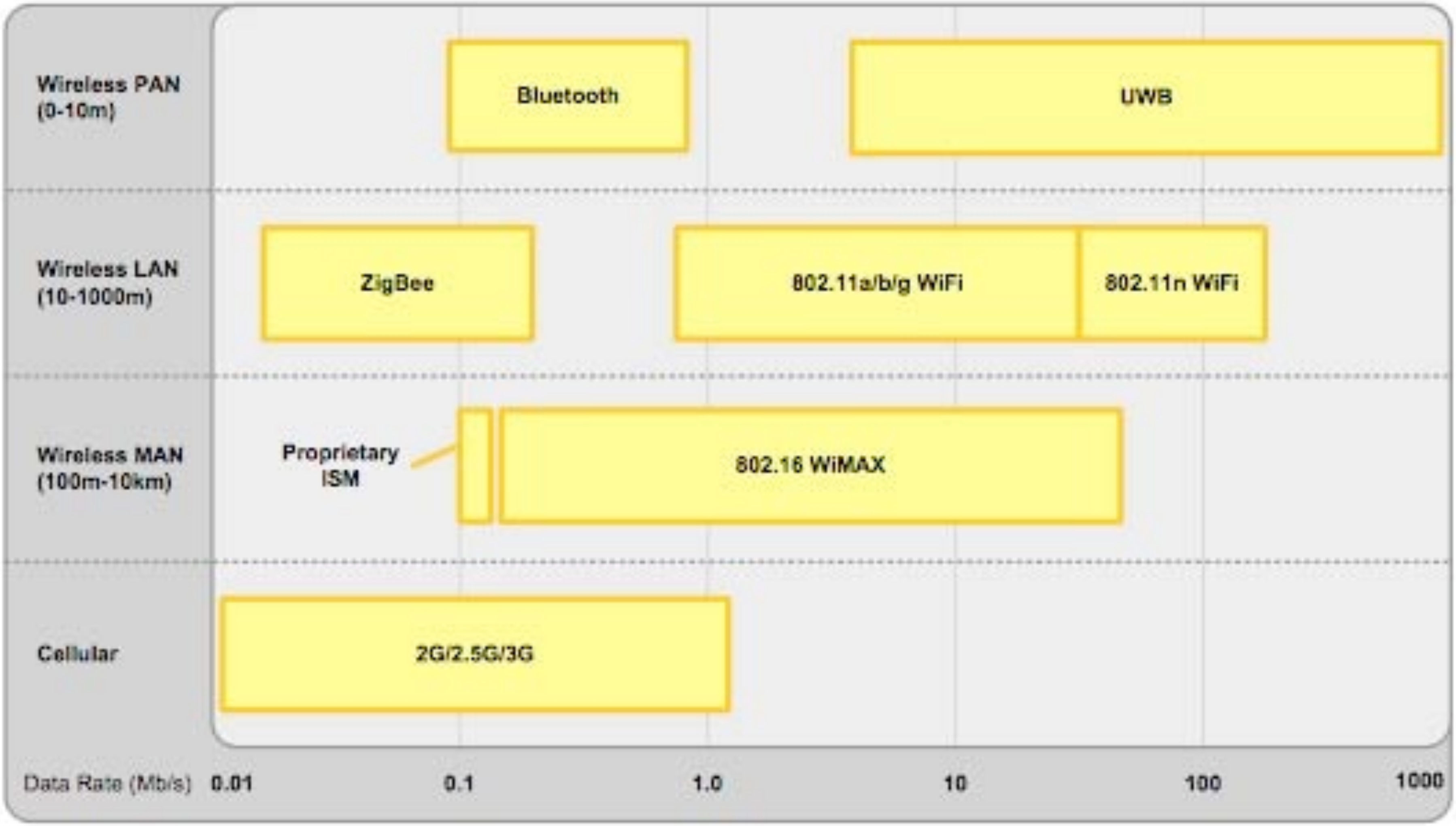
Wireless Networks

- 802.11b/a/g (Wireless Local Area Network - WLAN)
- Intended for use in a limited geographical region (home, office, building, campus) and its primary challenge is to mediate access to a shared communications medium
- Similar to Ethernet, in 802.11 protocol a transmitter waits until link is idle before transmitting and then backs off if a collision occurs
- Wireless networks are more complicated due to not all nodes always within reach of each other (hidden node problem) - critical issue is the noise level at the receiver not at the transmitter
- Hidden node problem addressed using Multiple Access with Collision Avoidance (MACA) algorithm
- Sender and receiver exchange control frames before sender actually transmits data - exchange informs all nearby nodes that a transmission is about to begin and duration of the transmission

Wireless Networks

- 802.15 (Personal Area Network)
- Bluetooth (802.15.1)
    - Conceived as a low power and short range (3-10 m) wireless cable replacement to enable devices to communicate in very small ad hoc networks (piconets)
    - A Bluetooth piconet can have a total of 8 devices with one being the master (a set of nearby piconets can merge into a larger scatter-net since a Bluetooth node can be a slave in one network while at the same time being a master in another)
- ZigBee (802.15.4)
    - Supports several architectures including star, tree, and mesh topologies with distances between nodes of ~100 m
    - Mesh networks enable low power networking of sensor data over large areas without the need for every node to communicate directly with the gateway

Wired and Wireless Networks



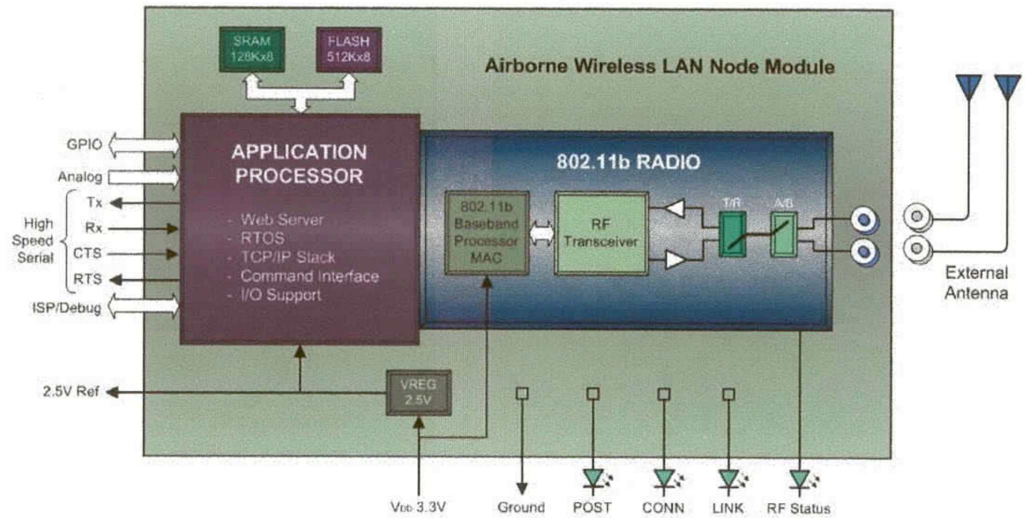
http://www.dpactech.com

Wired and Wireless Networks

	Bluetooth	UWB	ZigBee	802.11a/b/g	802.11n	Proprietary	802.16a	2G/2.5G/3G
Typical Range	< 10m	10-30m	70-300m	100m	100m	10km	50km	Cellular Network
Modulation	Adaptive FHSS	OFDM or DS-UWB	DSSS	DSSS	DSSS	FHSS	QAM	CDMA/GSM/ AMPS
Freq. Range	2.4GHz	3.1-10.6GHz	868/915MHz 2.4GHz	2.4GHz -b/g 5.8GHz - a	2.4GHz	915MHz & 2.4GHz	2-11GHz	869-894MHz
Network	P2P	P2P	Mesh	IP & P2P	IP & P2P	P2P	IP	IP
IT Network Connectivity	No	No	No	Yes	Yes	No	Yes	Yes
Cost of Data	Free	Free	Free	Free	Free	Free	Free	Monthly Charge
Application	Cable replacement	Sync and Transmission of video/ audio data	Sensor networks	LAN, Internet	LAN, Internet	Point to point connectivity	Metro area broadband Internet connectivity	Celular telephones and telemetry

http://www.dpactech.com

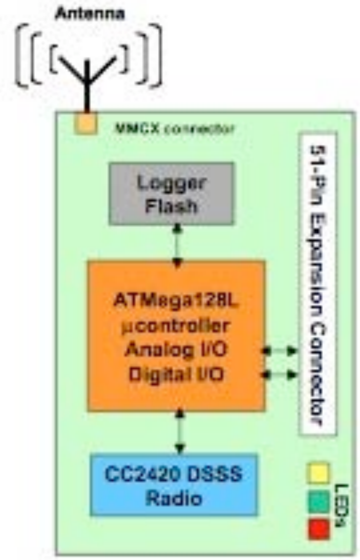
DPAC Technologies Airborne 802.11b Wireless LAN Node Module



- Integrated 802.11b radio and application processor
- TCP/IP stack, web server
- Serial I/O - UART, SPI, and I^2C
- Analog - 8 channels with 10 bit A/D

http://www.dpactech.com

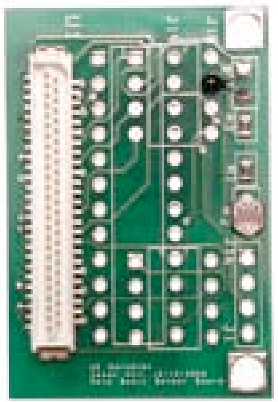
Crossbow MICAz Mote



- IEEE 802.15.4 compliant radio (2.4 GHz ISM band)
- Mesh networking, multi-hop data transfers
- Berkeley TinyOS
- ATmega128L microcontroller supports 8 analog inputs (10 bit A/D), digital I/O, SPI, I^2C, and UART
- 51-pin expansion connector for sensor boards and gateway

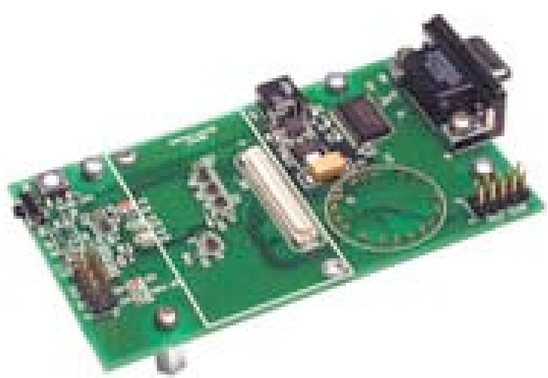
http://www.xbow.com

Crossbow Sensor Boards and Gateways



MTS101CA Sensor Basic Sensor Module (light and temperature)

MTS310CA Multi-Sensor Module (light, temperature, microphone, sounder, 2-axis accelerometer, 2-axis magnetometer)



MIB510 Serial Gateway

MIB600 Ethernet Gateway

http://www.xbow.com

Mesh Network References - Software, Hardware, and Applications

- http://www.tinyos.net
- http://www.xbow.com
- http://www.ember.com
- http://www.millennial.net
- http://www.dustnetworks.com

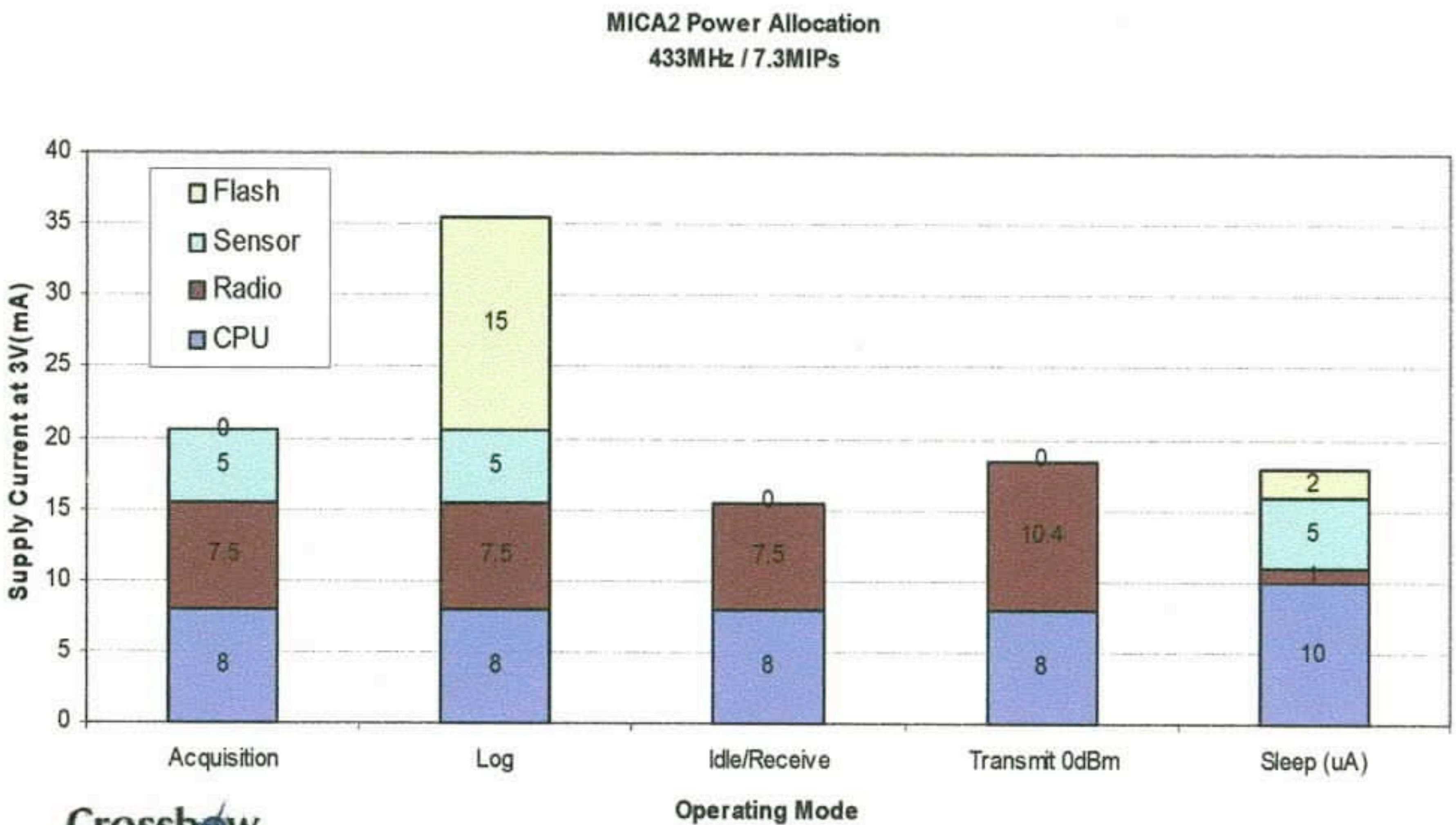
Power Consumption and Energy Sources

Power Consumption

- All system components have different voltage and current requirements
- These may vary with time due to natural cycles of sensor data sampling, writing data to memory, and radio reception/transmission
- Battery operation for extended periods usually dictates that the system must sleep most of the time

Power Consumption and Energy Sources

What Uses How Much?

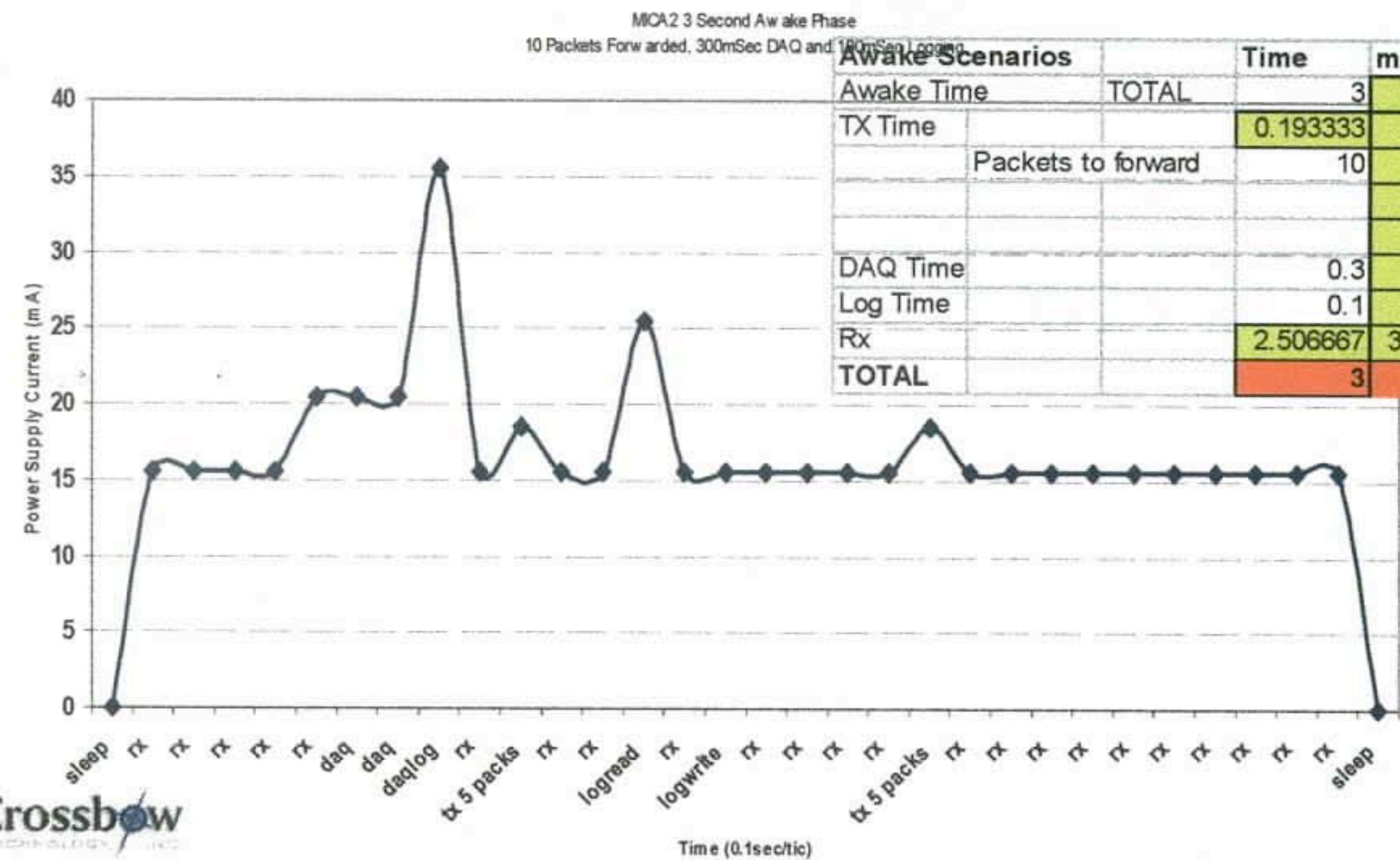


Crossbow

http://www.xbow.com

Power Consumption and Energy Sources

MICA2 Awake Phase - Power Requirements



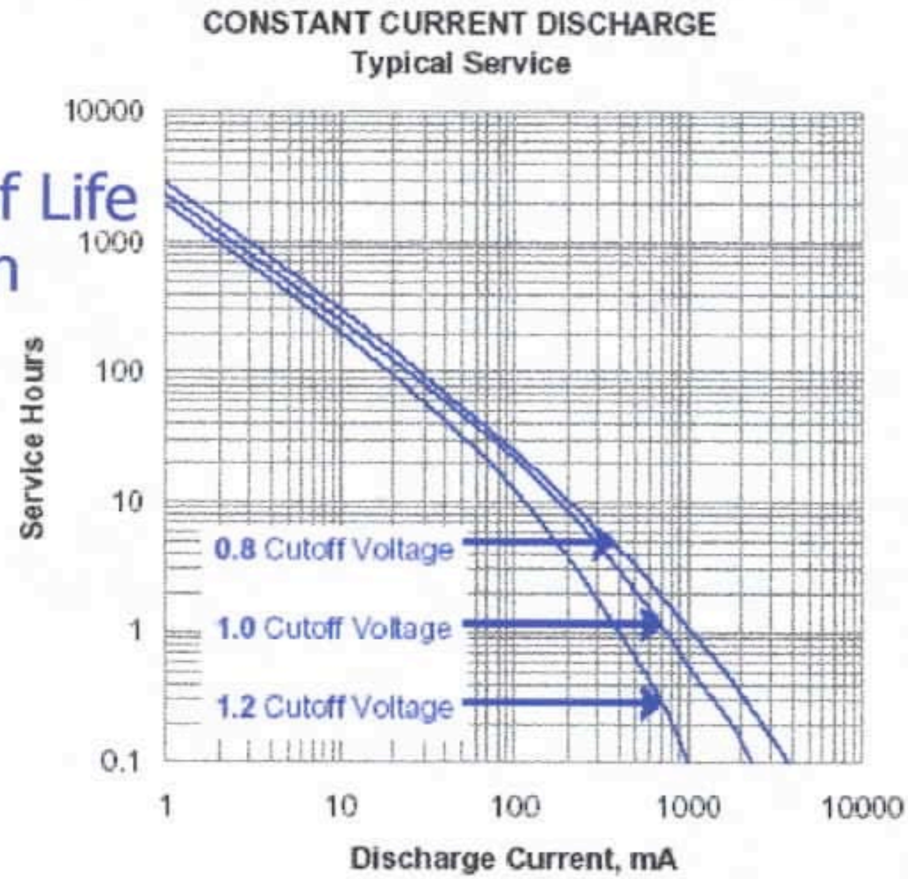
Awake Scenarios			Time	mA-sec
Awake Time		TOTAL	3	50.0995
TX Time			0.193333	3.57802
	Packets to forward		10	
DAQ Time			0.3	6.1506
Log Time			0.1	1.5
Rx			2.506667	38.87088
TOTAL			3	50.0995

Crossbow

http://www.xbow.com

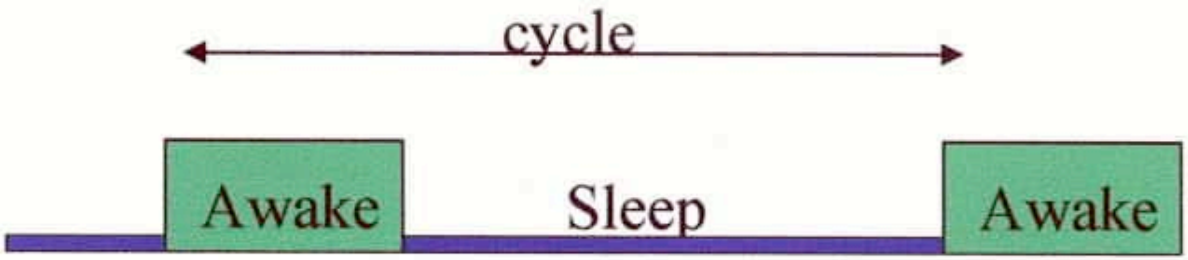
Battery Characteristics

- Voltage
  - Open Terminal / Start of Life
  - Voltage vs Current Drain
  - End of Life Voltage
- Current
  - Current Drain
  - Peak Current Drain
- Capacity
  - mA-hrs



http://www.xbow.com

Power Sequencing



- Cycle = Sleep Time + Awake Time
- Sleep (10uA)
  - For most Power Sources this can be supplied for years.
- Awake 3 seconds - Forward 10 Packets & DAQ
  - Consume 50mA-Sec = 0.14mA-Hr
  - 1000 Cycles requires 140 mA-Hrs

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Duty Cycle

- AA Alkaline Battery Pack Model
  - Capacity ~ 1700mA-Hrs at 15mA drain
  - 12000 Cycles at 140 mA-Hr per 1000 Cycles
- 100% Awake – 3 Second Cycles
  - 100 Hrs Service Life = 12000 Cycles * 3 sec/cy
- 1% Awake – 300 Second (5 minute) Cycles
  - 10,000 Hrs = 1.1 years
- 0.3% Awake – 15 minute Cycles
  - 3 years

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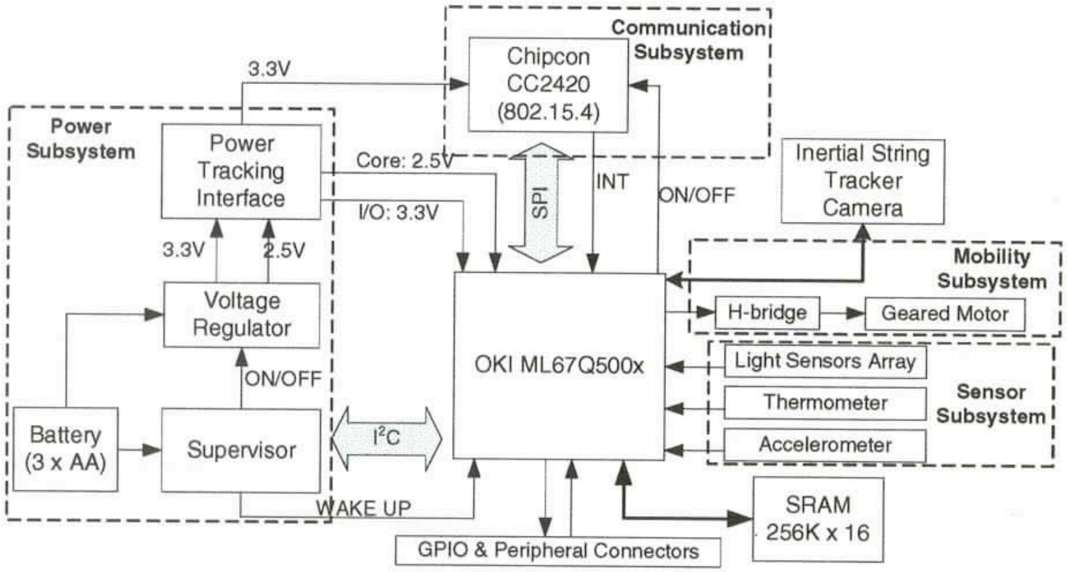
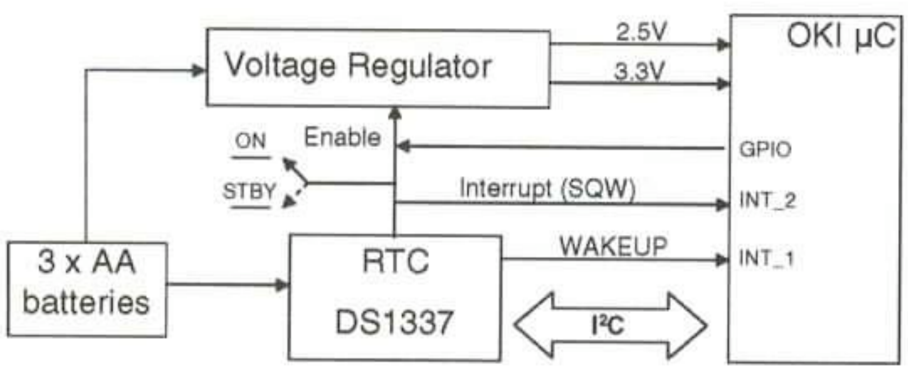
Power Consumption and Energy Sources

Power Aware Sensor Node Platform



XYZ node architecture enables support of long-term sleep modes through an external supervisor circuit.



Supervisor circuit for deep sleep modes.

D. Lymberopoulos and A. Savvides, " XYZ: A Motion-Enabled, Power Aware Sensor Node Platform for Distributed Sensor Network Applications," IPSN'05 (2005).