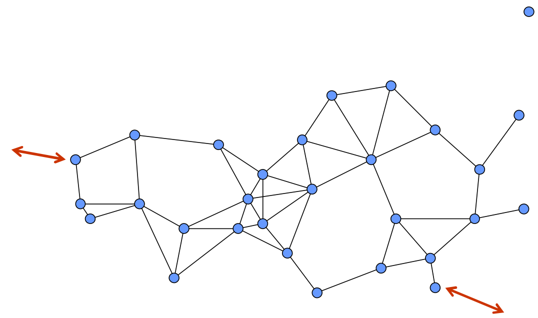
Wireless Sensor Networks

- Important trend in embedded computing
- Connecting the physical world to the world of information
  - Sensing (e.g., sensors)
  - Actuation (e.g., robotics)
- Wireless sensor networks are enabled by three trends:
  - Cheaper computation (Moore's Law)
  - Compact sensing (MEMS sensors)
  - Wireless networking (low-power radios)

The Basic Idea

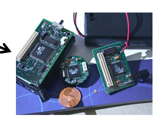


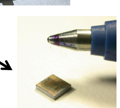
Applications

- Untethered micro sensors will go anywhere and measure anything – traffic flow, water level, number of people walking by, temperature. This is developing into something like a nervous system for the earth.
  - Horst Stormer in Business Week, 8/23-30, 1999.
- Applications
  - Environmental sensing
  - Habitat monitoring
  - Precision agriculture
  - Military operations
  - Condition-based maintenance
  - Health care

Range of Sensor Nodes

- Large
- Medium
- Small
- Tiny





- Resources
  - Computation/memory
  - Communication/range
  - Power
  - Sensors

Computation/memory

- Microprocessor
  - 8-bit microcontrollers
  - Xscale processors
  - Digital signal processors
- Memory
  - Flash for non-volatile logging of sensor data
  - Store and forward data from other nodes

Communication

- Radio communication (some infrared)
  - Power tradeoff with bandwidth
    - More power, more range, more interference
    - Less power, less range, may disconnect
- Protocol stack
  - Reliability
  - Routing
  - Naming
  - Broadcast, multicast, unicast

Power

- Battery
  - Rechargeable Li-ion, fuel cell, etc.
- Harvest from environment
  - Solar, piezo (vibration), RF energy, etc.

- Sleep
  - Minimize communication – use radio sparingly
    - What might it miss (sensing, from neighbors)?
    - How often should it communicate (stay connected to network)?
  - Minimize computation – distill data and store/send summaries
    - What info might it lose?
    - When is processing warranted (don't waste it)?

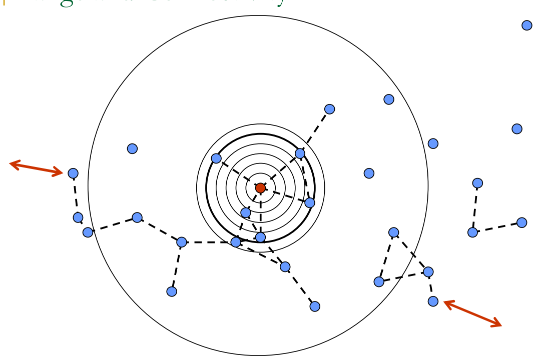
Sensing

- Microphones
- Accelerometers
- Magnetometers
- Light sensors
- Barometric pressure
- Thermopyle
- Humidity
- Temperature

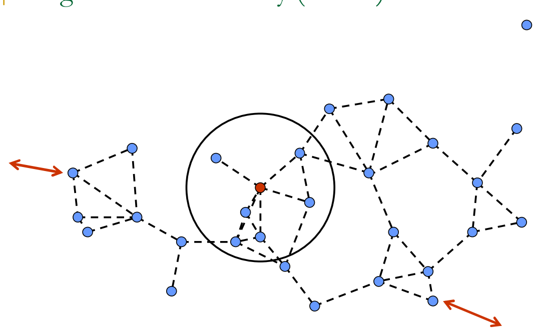
Issues

- Range and connectivity
- Localization and synchronization
- Routing protocols
- Power management
- Computation

Range and Connectivity



Range and Connectivity (cont'd)



Range and Connectivity

- How do sensor nodes discover their neighbors?
  - Transitively, who can their neighbors talk to?
- What radio range to use?
  - Smaller, less power, more bandwidth (less interference)
  - Larger, more power, more interference
- What to do when nodes are really close together?
  - Let one handle region and others sleep?
- What happens when there are isolated islands?
  - Use mobile nodes?
  - Add more nodes?
- Vary transmit power?
  - Adjust to situation?

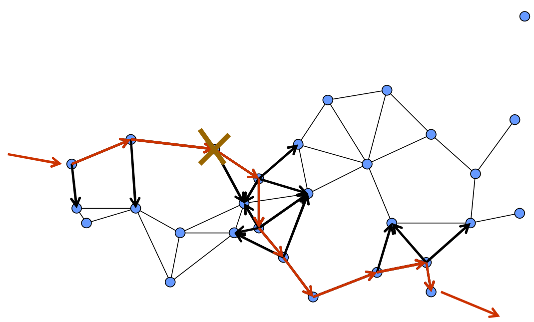
Localization and Synchronization

- Node location is important knowledge
  - Make decisions about which are active and which sleep
- Need synchronized clocks
  - Know the time an event is observed at each of multiple nodes
- Spatial signal processing
  - Determine location of sensed phenomena
  - Need to know relative locations for triangulation
  - Need to know time for time-of-arrival calculations

Routing Protocols

- Getting data from one point to another
  - Reliability of communication
  - Best effort or acknowledgements with retransmit
- Which nodes forward data
  - If all, then may saturate available bandwidth
  - If not enough, may not get to where it needs to go
- Adjust as nodes are added/removed
- Number of hops per packet
  - Loss at each hop
  - Power for each hop

Routing Protocols



Power Management

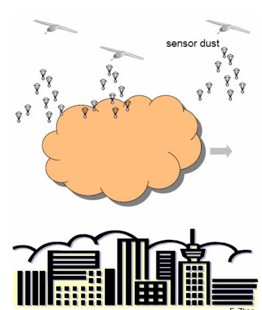
- Maximize lifetime of node
  - Independent power management
  - Rendezvous for communication
    - make sure both awake at same time
- Maximize lifetime of network
  - Judiciously choose which nodes sleep
  - Wakeup to fill in for others that run out of power

Computation

- How is data processed?
  - In network – more computation
  - At edges, after it is gathered – more communication
- How much aggregation is done?
  - Summary data vs. raw data
- Pushing new computation into network
  - Security concerns
- Collaborative signal processing
  - Multiple nodes working together
- Where is data stored?
  - Can I "google" the real world?
- What is the programming model?

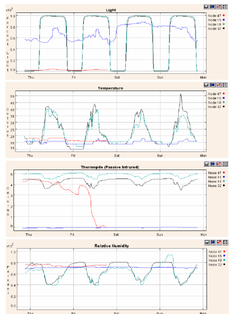
Application: Environmental Sensing

- Tracking a chemical cloud
- Emergency response
- Sprinkle sensors over affected area and vicinity
- Track movement of cloud and warn affected communities



Application: Habitat Monitoring

- Great Duck Island, ME
- Monitoring burrow nest and environment of petrels
- Data previously unavailable
  - Much too expensive to gather



Application: Precision Agriculture

- Monitor micro-climates throughout vineyard
- Add water, heat, and fertilizer where needed
- Cost-savings, maximum yield, customize grape

Application: Military Operations

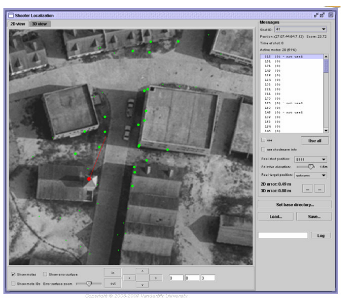
- Sniper detection
- Vehicle tracking

Red circle:
→ Shooter position

Red line:
→ Shot direction

Large green circle:
→ Sensor node (good measurement)

Small green dot:
→ Sensor Node (no or unused measurement)

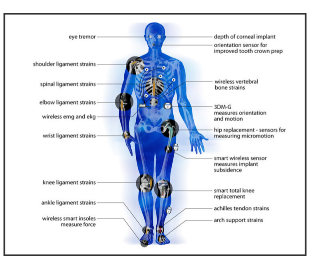


Application: Condition-based Maintenance

- Monitor structural stresses
- Data collection from vehicle driving by
- Early warning of problems

Application: Health Care

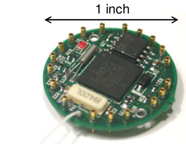
- Monitor all aspects of human activity
  - Mechanics/chemistry of body
  - Trends over time
  - Detect problems early
  - Monitor effects of medication
  - Elder care



Our Sensor Network Platform

- UC Berkeley sensor "mote"
  - ATmega 8-bit microcontroller
  - 40Kb/sec radio (433MHz)
  - 128K code, 4KB data
- Common platform for sensor network research community
- Two form factors
  - Mica2
  - Dot
- Produced by Crossbow (xbow.com)

1 inch

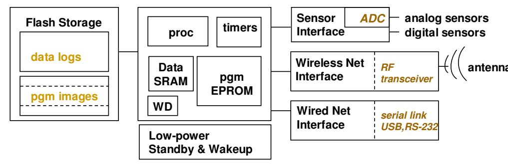


Platform details

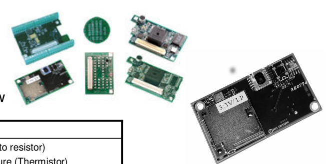
- ATmega microcontroller (103L, 128)
  - 32Khz crystal and 4Mhz crystal
    - 10 bit ADC
    - 2 UARTs
    - SPI bus
    - I2C bus
    - Radio (RFM or Chipcon 1000)
- External serial flash memory (512K byte)
- Connectors for interfacing to sensor and programming boards
- 3 programmable leds (1 for dot)
- JTAG programming port

Key Design Elements

- Efficient wireless protocol primitives
- Flexible sensor interface
- Ultra-low power standby
- Very fast wakeup
- Watchdog and monitoring
- Data SRAM is critical limiting resource

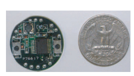


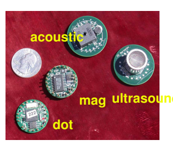
Sensors



- Add-on boards from Crossbow

Part #	Mote Support	Sensors
MTS101CA	Mica2	Light (photo resistor) Temperature (Thermistor) Prototyping area
MDA300CA	Mica2Dot	Protoyping
MTS300CA	Mica2	Light, Temperature, Acoustic, Sounder, 2-Axis Accelerometer (ADXL202), and 2-Axis Magnetometer
MTS500CA	Mica2Dot	Protoyping
MDA300CA	Mica2	On board humidity/temp. External sensors.
MTS400/420	Mica2	GPS weatherboard
Not released:	Mica2Dot	Weatherboards



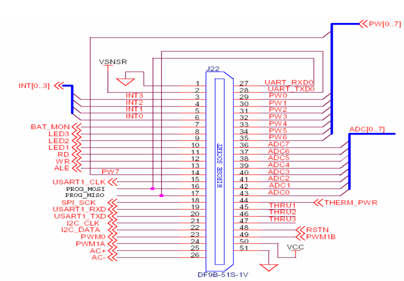


- Add-on boards by researchers
  - Ultrasound (MIT), RFID reader (UW), etc.

The CC1000 Radio Interface

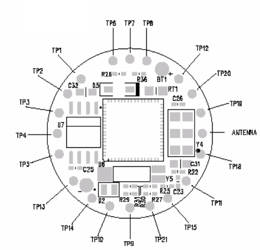
- Dedicated cpu bus (lines) to configure radio registers for radio frequency, power,…
- Dedicated SPI bus for data transfer
  - CC1000 is bus master.
- Radio generates one interrupt every 8 bits when in receive mode.
- Runs usually at 38K or 19K bit rate (default) Manchester (2x bit)

Mica2 Sensor Interface



Mica2Dot Sensor Interface

PIN	DESCRIPTION
TP1	GND
TP2	ADC7
TP3	ADC6
TP4	ADC5
TP5	ADC4
TP6	VCC
TP7	PW1
TP8	PW0
TP9	UART_TXD
TP10	UART_RXD
TP11	RESETN
TP12	SPI_CK
TP13	ADC3
TP14	ADC2
TP15	PWM1B
TP18	GND
TP19	INT1
TP20	INT0
TP21	THERM_PWR



Power Budgets

- Average, full operation, current: ~15 ma
- AA Batteries are ~1800ma which mean ~ 120hrs (5 days)

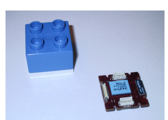
SYSTEM SPECIFICATIONS		
Currents		
	value	units
Micro Processor (Atmega128L)		
current (full operation)	6	ma
current sleep	8	ua
Radio (Chipconn 1000)		
current in receive	8	ma
current xmit	12	ma
current sleep	2	ua
Flash Serial Memory (AT45DB041)		
write	15	ma
read	4	ma
sleep	2	ua
Sensor Board		
current (full operation)	5	ma

Mote Platform Evolution

Mote Type / Year	*WeC* 1998	*René* 1999	*René 2* 2000	*Dot* 2000	*Mica* 2001	*Mica2Dot* 2002	*Mica 2* 2002	*Telos* 2004
Microcontroller								
Type	AT90LS8535		ATmega163		ATmega128			TI MSP430
Program memory (KB)	8		16		128			48
RAM (KB)	0.5		1		4			10
Active Power (mW)	15		15		15		60	0.5
Sleep Power (μW)	45		45		75		75	2
Wakeup Time (μs)	1000		36		180		180	6
Nonvolatile storage								
Chip	24LC256				AT45DB041B			ST M24M01S
Connection type	I^2C				SPI			I^2C
Size (KB)	32				512			128
Communication								
Radio	TR1000				TR1000	CC1000		CC2420
Data rate (kbps)	10				40	38.4		250
Modulation type	OOK				ASK	FSK		O-QPSK
Receive Power (mW)	9				12	29		38
Transmit Power at 0dBm (mW)	36				36	42		35
Power Consumption								
Minimum Operation (V)	2.7		2.7		2.7			1.8
Total Active Power (mW)	24				27	44	89	38.5
Programming and Sensor Interface								
Expansion	none	51-pin	51-pin	none	51-pin	19-pin	51-pin	10-pin
Communication	IEEE 1284 (programming) and RS232 (requires additional hardware)							USB
Integrated Sensors	no	no	no	yes	no	no	no	yes

Future Motes

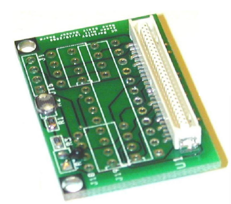
- MicaZ
  - Zigbee (802.15.4) radio, 250Kb/sec
  - Lower-power (2.4 uW)
  - Hardware security



- Intel mote (iMote)
  - Bluetooth radio, 700Kb/sec
  - ARM7 processor
  - More memory
- Intel Zigbee mote
  - Zigbee radio
  - Bulverde processor (incl. audio codec + DSP)
  - Lots more memory

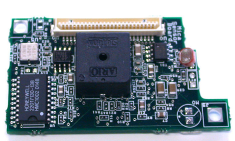
MTS101CA

- Light photo resistor-Clairex CL94L
- Thermistor - YSI 44006
- Both sensor are highly non-linear
- Good prototyping area



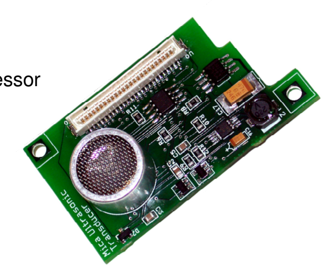
MTS300CA/MTS310CA

- Light (Photo)-Clairex CL94L
- Temperature-Panasonic ERT-J1VR103J
- Acceleration-ADI ADXL202
  - 2 axis
  - Resolution: ±2*mg*
- Magnetometer-Honeywell HMC1002
  - Resolution: 134mG
- Microphone
- Tone Detector
- Sounder
  - 4.5kHz



Ultrasonic Transceiver

- Used for ranging
- Up to 2.5m range
- 6cm accuracy
- Dedicated microprocessor
- 25kHz element
- Mica2 and Mica2Dot versions

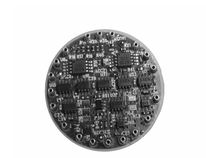


Mica2Dot WB

- UCB environmentally packaged weatherboards for GDI
- Temperature & humidity (Sensirion SHT11)
  - All digital (14 bits)
  - 3.5% RH accuracy, 0.5degC Temperature accuracy
- Barometric Pressure and Temperature (Intersema MS5534A)
  - All digital
  - 300 to1100 mbar, 3% accuracy
  - -10 to +60 degC, 3% accuracy
- Ambient Light (TAOS TSL2250)
  - All digital
  - 400-1000nm response
- Photosensitive light sensor

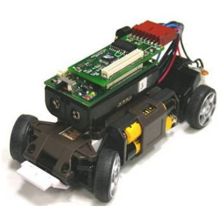
Mote In Tires

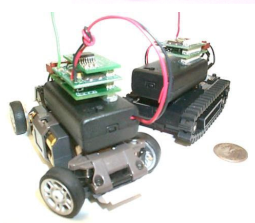
- Real time control of vehicle dynamics
- 3 bridge accelerometers (500g-1000g) mounted in tire
- Sensor board has 3 channels of amplifiers, filters, programmable D/As for bridge balancing
- Monitor and analyzed acceleration forces when tire is in contact with ground
- Transmit results every revolution
- 3 motes, 1 master, 2 slaves



COTS-BOTS (UCB)

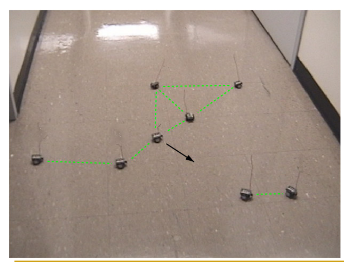
- 5” x 2.5” x 3” size
- <$250 total
- 2-axis accelerometer





Robomote (USC)

- Less than 0.000047m^3
- $150 each
- Platform to test algorithms for adaptive wireless networks with autonomous robots



Enclosures for Environmental Monitoring