COE 545 - Wireless Sensor Networks

Introduction and Applications

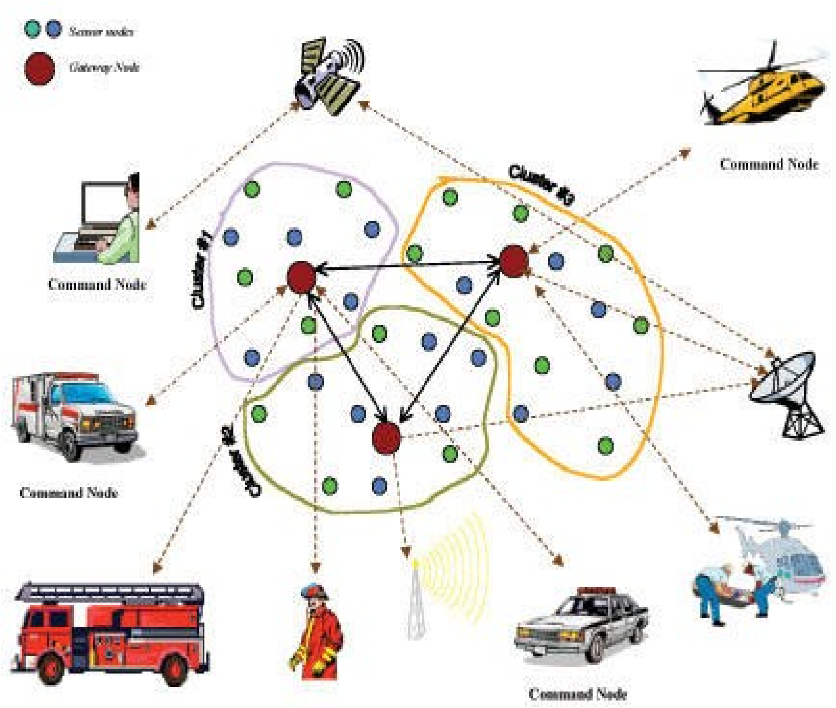
Dr. Abdulaziz Barnawi

COE Dept.

KFUPM

Introduction

- WSN an emerging kind of wireless networks, where a large number of small sensor nodes are distributed over a field to obtain fine-grain, high-precision sensing data.
  - Mission-oriented deployment in unattended areas
  - Battery operated nodes
  - Individual nodes interact with their environment (sensing, applying control functions-*actuation*)
  - Nodes collaborate to fulfill a specific sensing task



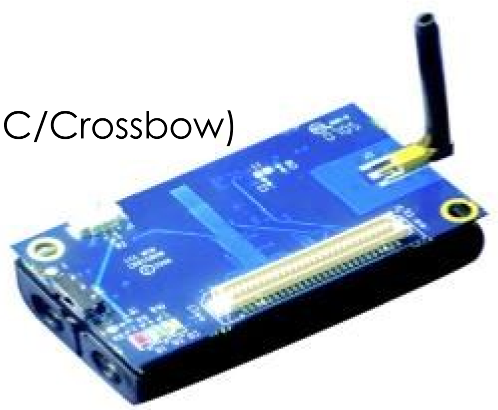
WSN Hardware

TMote Sky
(Sentilla)

TelosB
(MEMSIC/Crossbow)

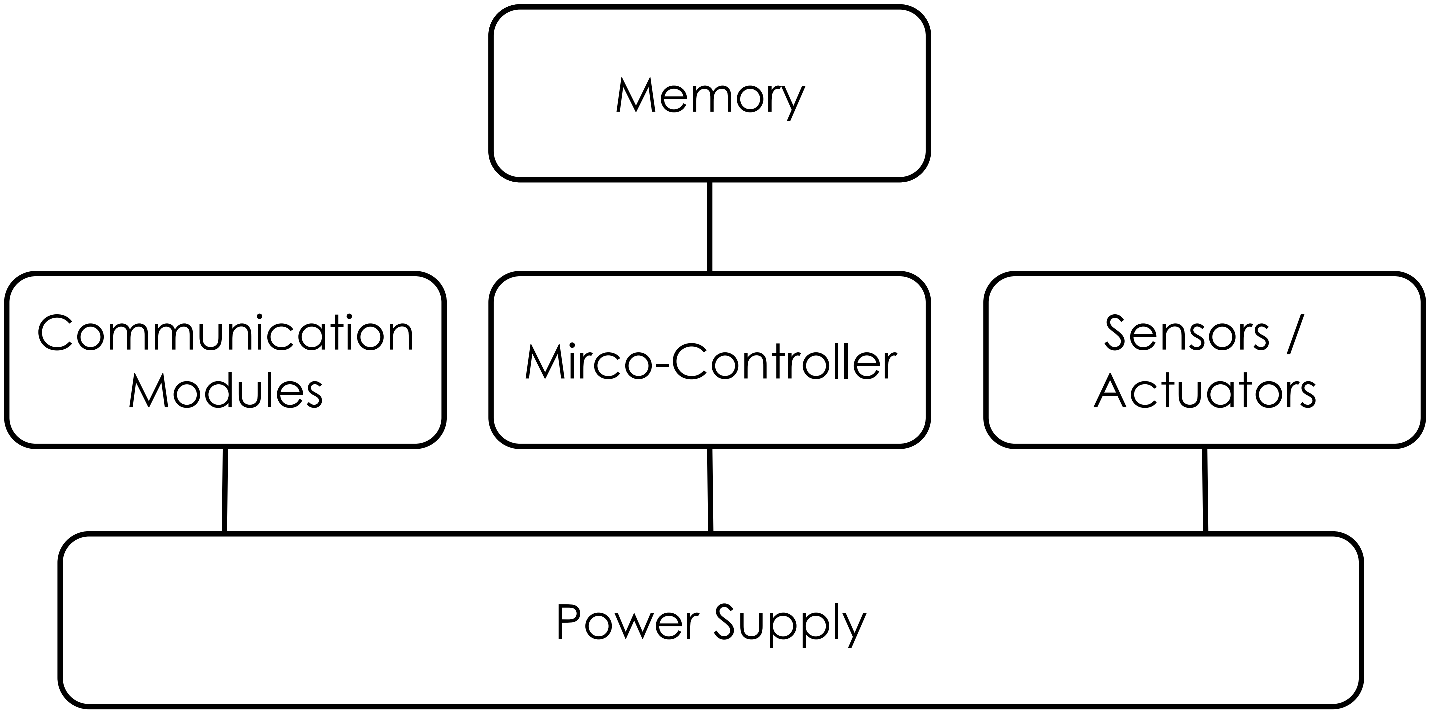
MicaZ
(MEMSIC/Crossbow)

IRIS
(MEMSIC/Crossbow)



iMote2
(Intel)

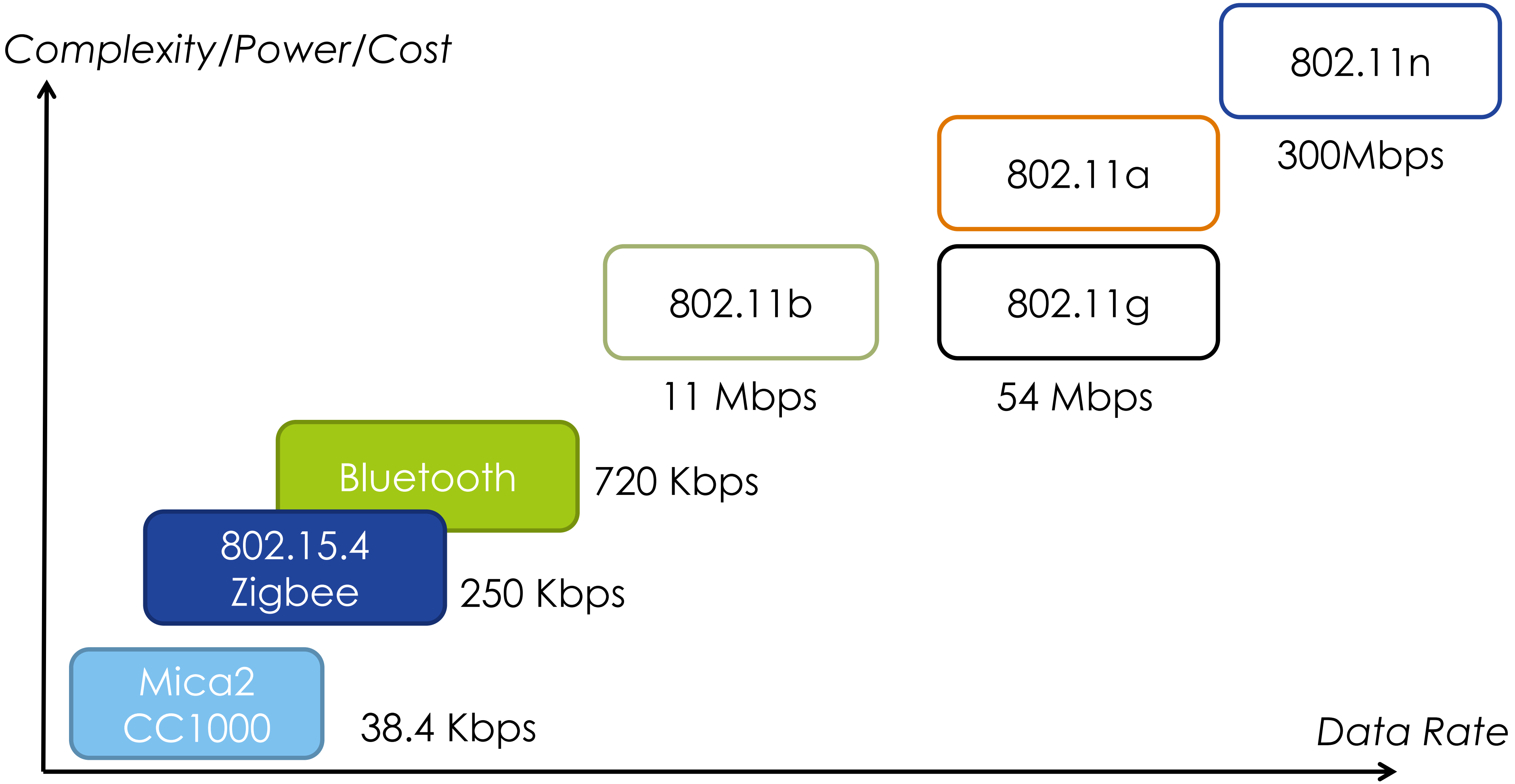
Sensor Node Architecture



WSN Hardware Characteristics

- Limited processing power
  - Slow (8 MHz) -- No floating point computation
  - 512-point FFT takes 450 ms, IFFT takes 144 ms
- Limited memory
  - 10 KB of RAM and 60 KB of program ROM
  - Much of this taken up by system software
- Potentially lots of storage
  - Some designs support up to 2 GB of MicroSD flash
  - But, expensive to access: 13 ms to read/write a 512-byte block; ~ 25 mA
- Low-power radio
  - Date rate: 802.15.4 best case performance: 100-250 Kbps or so (single node transmitting, no interference, short range)
  - Range: Approx. 10s to few 100s m, and very unreliable!!

Wireless Technology Comparison



Wireless Technology Comparison

	Bluetooth	Zigbee	802.11a/b/g	802.11n
Range	< 10m	75~100m	100m~200m	250m~500m
Modulation	Adaptive FHSS	DSSS	DSSS	DSSS
Frequency Range	2.4GHz	868/915MHz 2.4GHz	2.4GHz - b/g 5.8GHz - a	2.4GHz/5GHz
Transmit Power	1 mW / 30 mW	1 mW	100 mW	200 mW
Power Consumption	35 – 300mA(*Tx*) 35 – 300mA(*Rx*)	17.4 mA (*Tx*) 19.7 mA(*Rx*)	285-490 mA (*Tx*) 170-350 mA (*Rx*)	Very High
Application	Cable replacement	Sensor networks	WLAN, Internet	WLAN, Internet

Wireless Technology Comparison

	Bluetooth	Zigbee	802.11a/b/g	802.11n
Range	< 10m	75~100m	100m~200m	250m~500m
Modulation	Adaptive FHSS	DSSS	DSSS	DSSS
Frequency Range	2.4GHz	868/915MHz 2.4GHz	2.4GHz - b/g 5.8GHz - a	2.4GHz/5GHz
Transmit Power	1 mW / 30 mW	1 mW	100 mW	200 mW
Power Consumption	35 – 300mA(*Tx*) 35 – 300mA(*Rx*)	17.4 mA (*Tx*) 19.7 mA(*Rx*)	285-490 mA (*Tx*) 170-350 mA (*Rx*)	Very High
Application	Cable replacement	Sensor networks	WLAN, Internet	WLAN, Internet

Types of Applications

- Event detection
  - Nodes locally detect specific events (may collaborate with nearby neighbors), report these events to interested sink(s)
- Periodic measurements
  - Use sensor network to approximate a function of space and/or time
- Tracking
  - Determine and/or report position of an observed object sensors. Nodes may collaborate with nearby neighbors before reporting decision.
- Query Based
  - Sensors responds only to query for data with some specific attributes (e.g. determine which has sensed a raise in temperature beyond specific level)

Types of Applications

- Military Applications
  - *Examples*: monitoring friendly forces, equipment, and ammunition; battlefield surveillance; reconnaissance of opposing forces and terrain; battle damage assessment; and nuclear, biological, and chemical (NBC) attack detection
- Environmental Applications
  - *Examples*: tracking the movements of birds, small animals, and insects; monitoring environmental conditions that affect crops and livestock; irrigation; chemical/biological detection; precision agriculture; environmental monitoring in marine, soil, and atmospheric contexts; forest fire detection

Types of Applications

- Health Applications
  - *Examples*: integrated patient monitoring; diagnostics; drug administration in hospitals; and tracking and monitoring doctors and patients inside a hospital
- Industrial Applications
  - *Examples*: managing inventory; monitoring product quality; robot control and guidance in automatic manufacturing environments; interactive museums; factory process control and automation; machine diagnosis; transportation; factory instrumentation
- Home Applications
  - *Examples*: home automation

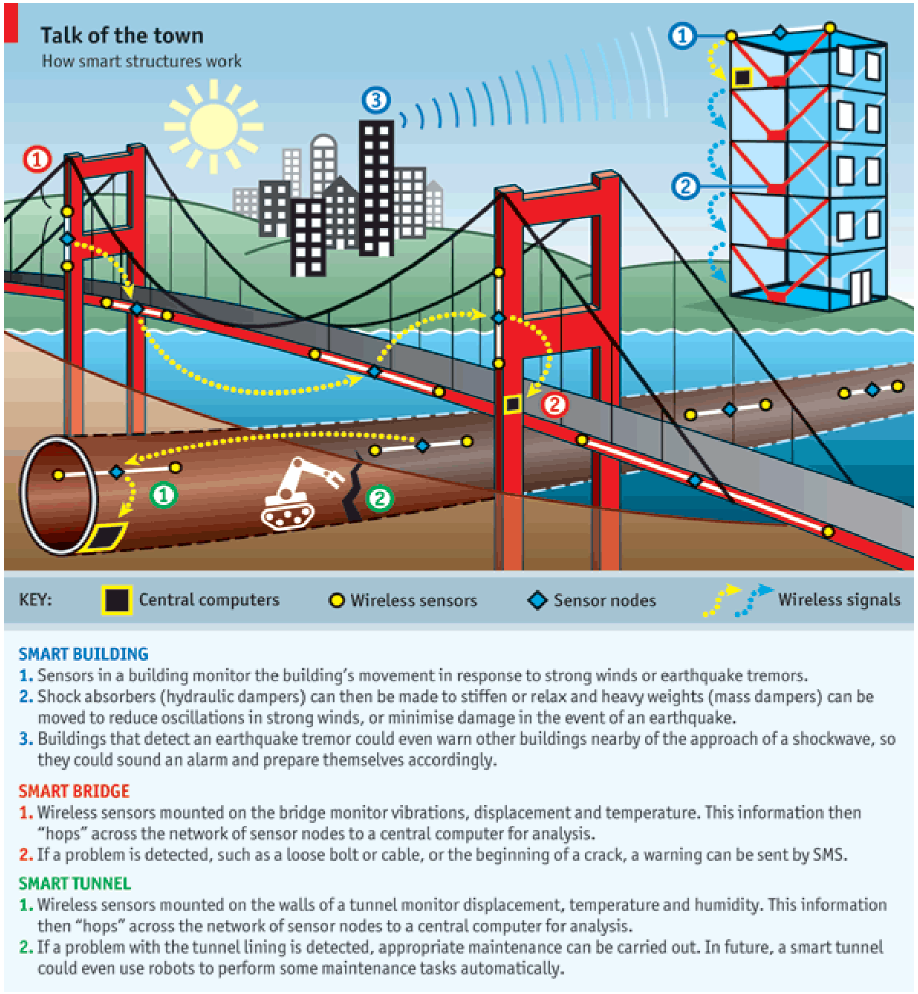
Smart Structures

- Problem
  - "structurally deficient" infrastructure
  - Catastrophic accidents in case of failure
  - Cost
- Suggested solution
  - Smart Infrastructures

April 29th, 2007 → I-580 bridge between Oakland and SFO collapses

Smart Structures (UC Berkeley)

- Problem
  - "structurally deficient" infrastructure
  - Catastrophic accidents in case of failure
  - Cost
- Design
  - Chained sensors, 45 "hops" to processing center
  - Monitor physical conditions around the structure such as temperature, vibration and strain



Steam Pipes Monitoring

OAK RIDGE National Laboratory (Computational Sciences and Engineering Division)

- Problem
  - undetected and unrepaired failed trap, 1,600 steam traps
  - 20% wasted steam → energy waste
  - Manual inspections of each trap is a difficult and dangerous task
- Design
  - 30 sensors at five steam trap locations
  - Collected data provides an early warning of component failures or impending failures

Real-Time Electronic Monitoring For Coastal Waters (North Carolina State University)

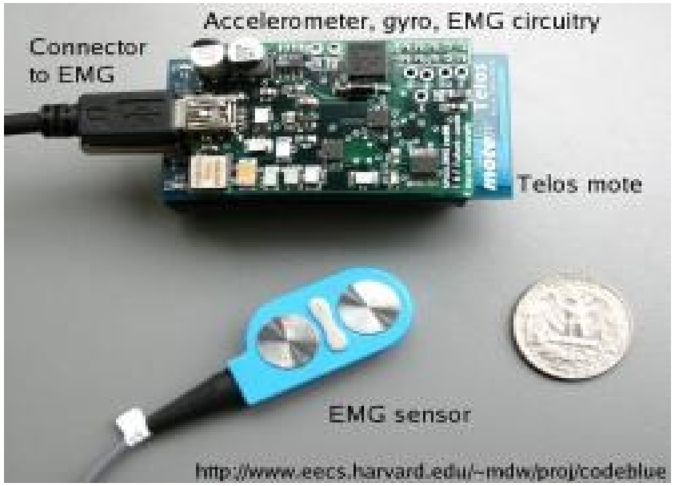
- Objectives
  - Advance researchers' understanding of critical coastal ecosystems
  - Cost-effective monitoring system
  - Track water-quality data from these coastal ecosystems in real time
  - "Existing technology is costly to implement on a large scale, and is not easy to use"
  - Energy efficient design, longer lifetime
- Design
  - Wireless sensors anchored to the sea bed or behind vessels
  - Collected data includes water temperature, salt levels in the water and water clarity

Mebius Sensor Project (keio University)

- Sense the natural environment of Shonan Fujisawa Campus
- Temperature, humidity and an illuminance sensor
- Solar battery panel equipped nodes
- ubiquitous computing applications, e.g. enhancing people's awareness of the natural environment

CodeBlue: Emergency Medical Care and Disaster Response (Harvard)

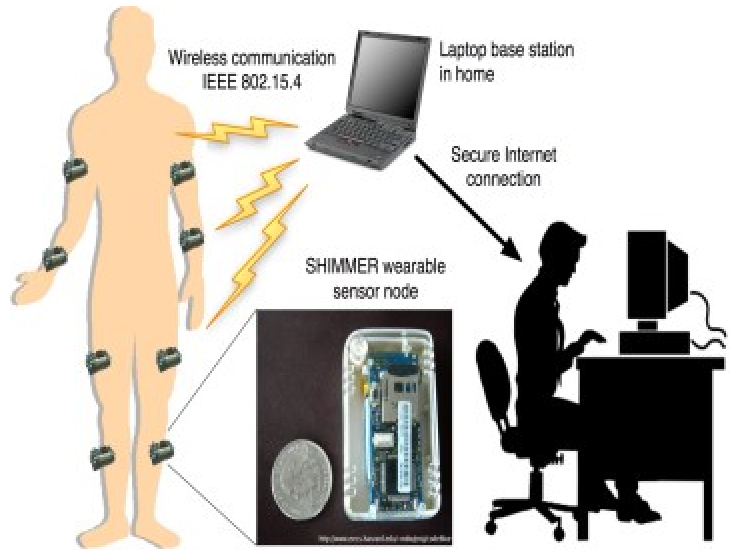
- Sensors monitor heart rate (HR), oxygen saturation (SpO2), and EKG data
- Short-range (100m) wireless network
- Data is collected at PDAs, laptops, or ambulance-based terminals
- Used in the AID-N project at Johns Hopkins Applied Physics Laboratory



CodeBlue architecture for emergency response.

Mercury: A Wearable Sensor Network Platform (Harvard)

- Objectives
  - Supporting health care applications that are data-intensive
  - Adaptive solution to fluctuations in resource availability and load
  - Energy efficient design, longer lifetime
  - Autonomous operation
- Design
  - wearable sensors and a base station installed in the patient's home
  - Collect accelerometer, gyroscope, and/or physiological data
  - Each node dynamically tunes the number of data transfers and degree of computation applied to the sampled signal to meet a target lifetime



PIPENET: A Wireless Sensor Network for Pipeline Monitoring (Cambridge-MIT Institute (CMI))

PipeNET

Detecting Bursts & Valve Failures	Detecting Small Leaks	Generic
Pressure & Flow velocity	*Acoustic/Vibration Data*	*Hydraulic/Water quality*

Detecting Bursts & Valve Failures — Pressure & Flow velocity

Powered sensor nodes:
- Continuous (600 S/s)
- Time Reference: 1ms
- Data processed locally
- Communication established when an event is detected
- Hydraulic transient model is used for the analysis of the transmitted data buffer

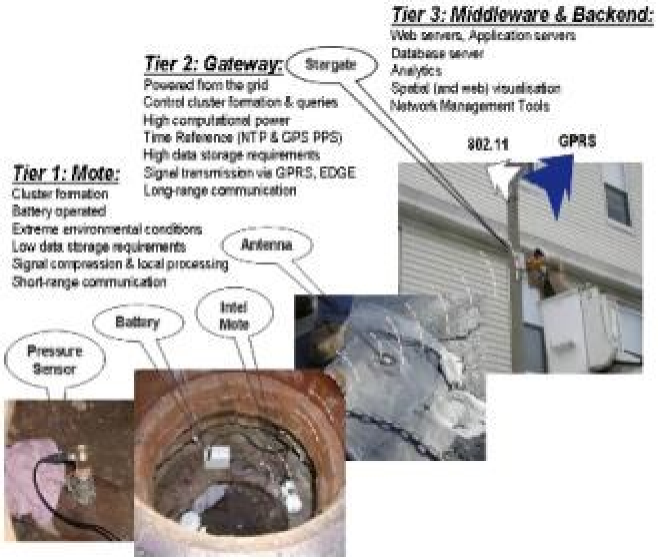
Battery operated nodes:
- Periodic monitoring (600 S/s)
- Time reference: 1ms
- Data compressed locally
- Communicate data to server
- Dynamic state-estimator is used for the analysis of the transmitted data buffer

Detecting Small Leaks — Acoustic/Vibration Data

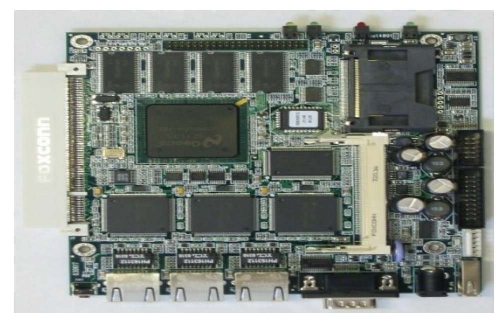
Battery operated nodes:
- Periodic monitoring (5 KHz)
- Time reference: 1ms
- Data processed locally: Status Information
- Communication established when an event is detected
- Remote pair-wise cross correlation carried out at server/gateway level

Generic — Hydraulic/Water quality

Battery operated nodes:
- Periodic monitoring
- Time reference
- Data processed locally
- Communication established when an event is detected
- Applications: hydraulic and water quality monitoring (low duty cycle) & monitoring combined sewer outflows



FireWxNet: Forest Fire Detection
(U. Colorado)



Mobile ad hoc networks vs. wireless sensor network

- Applications and equipment
  - A specific MANET supports different applications as well as different user equipment than WSNs.
- Application specific
  - No single WSN "fits-all"
  - Density, Hardware type, protocols
- Environment interaction
  - WSNs have different traffic characteristics (very low date rate, suddenly bursty traffic)
- Density/Scalability
  - WSN should support any number of nodes
  - Vast or small number of nodes per unit area, application-dependent

Mobile ad hoc networks vs. wireless sensor network

- Fault Tolerance
  - Nodes in WSN experience more faults due to lack of power, physical damage, environmental interference, or software problems
- Energy/Lifetime
  - WSN should fulfill its task as long as possible – definition depends on application
  - Lifetime of individual nodes relatively unimportant
- Self configurability
  - Adapt to current network conditions
  - Solutions for WSN are different from those for MANETs
- Simplicity and resource scarceness
  - WSN – scarce resources simple operating and networking software

Mobile ad hoc networks vs. wireless sensor network

- Mobility
  - WSN - application dependent, mostly static nodes
- Programmability
  - WSN - re-programming of nodes in the field might be necessary, improve flexibility
- Maintainability
  - WSN - incorporate possible additional resources, e.g., newly deployed nodes

Research Questions

- Low-power wireless networking
  - Dealing with complexities of RF propagation – not a "disc model"
  - Limited bandwidth and power, very expensive to transmit, receive, and even listen!
  - Every node is a router – addressing, route selection, reliable transfers
  - Application specific – what is the best architecture, MAC, routing, deployment for that specific application
- Distributed network services
  - Nodes in a WSN don't exist in isolation. They must coordinate their behavior.
  - Localization – how do you know where nodes are? Use RF signals? Ultrasound
  - Time synchronization – how do nodes agree on a global clock?

Research Questions

- In-network sensor data processing
  - Communication is expensive: transmitting one packet costs same energy as thousands of CPU cycles.
  - Better to process the data closer to its source
  - Example: aggregation – nodes can collect data locally, compute aggregates (mean, max-min, etc.) rather than sending raw data
  - Tracking: sensors can collaborate to detect, localize, and track a target object

References

- Holger Karl and Andreas Willig, **Protocols and Architectures for Wireless Sensor Networks,** *Wiley, ISBN:* 0-470-09510-5, June 2005
- **ORNL uses new technologies to take steam out of wasted energy**, http://www.ornl.gov/info/press_releases/get_press_release.cfm?ReleaseNumber=mr20101005-00
- **Superstructures**, http://www.economist.com/node/17647603?story_id=17647603&fsrc=rss
- **Mebius Sensor**, http://www.ht.sfc.keio.ac.jp/~niya/mebiussensor.html
- **Real-Time Electronic Monitoring For Coastal Waters**, http://www.ece.ncsu.edu/news/17625/realtime-electronic-monitoring-for-coastal-waters
- **CodeBlue**: Wireless Sensors for Medical Care, http://fiji.eecs.harvard.edu/CodeBlue
- Stoianov, I. Nachman, L. Madden, S. Tokmouline, T. Csail, M. "**PIPENET: A Wireless Sensor Network for Pipeline Monitoring**", 6th International Symposium on Information Processing in Sensor Networks, 2007.
- Carl Hartung, Richard Han, Carl Seielasted and Saxon Holbrook, "**FireWxNet: a multi-tiered portable wireless system for monitoring weather conditions in wildland fire environments**", Proceedings of the 4th international conference on Mobile systems, applications and services , 2006.