Institute for the Wireless Internet of Things at Northeastern University

EECE 5155 Wireless Sensor Networks (and the Internet of Things)

Prof. Francesco Restuccia

Email: f.restuccia@northeastern.edu

Course Content

Course Content

- We will cover design and modeling of architectures, communication protocols and algorithms for WSNs and the IoT

- The **first part of the class** will cover general aspects of wireless sensor networking, including protocol design, modeling, and simulation at all layers of the communication stack

Course Content (2)

- The **second part** will cover **standards** such as Bluetooth, IEEE 802.15.4/Zigbee, and Sigfox/LoRa

- The **third part** will illustrate applications of sensor networks technology to many challenging problems of our times, including mobile crowdsensing, smart cities, and cyber-physical systems, AI+Wireless, O-RAN, and so on

Course Management

Canvas

- Everything will be handled through Canvas
  - Announcements
  - Group formation for research projects
  - Assignments (Midterms, Homework)
- Make sure you are receiving notifications for EECE 5155

- If you can, update your Canvas profile
- If comfortable, use the "**Introduce Yourself**" discussion in Canvas to tell a bit more about yourself!
- Use Canvas for asking questions about the course content, so others can also benefit

Course Target

Course Target

- This course will provide you with:
  - Strong background on **established WSNs topics**
  - Knowledge of ongoing, cutting-edge **IoT research efforts**
  - **Hands-on experience** with WSNs (simulations)

- Emphasis is on developing **practical skills** that you can reuse in your research/professional life

Required Background

Required Background

- <u>Fundamentals of Networks (or equivalent class)</u>
  - What is a network of computers?
  - What is a packet?
  - How do we make sure that information is transmitted from one host to another reliably?
- <u>Basic/Intermediate C/C++ Programming</u>
  - Variables, classes, structs,
  - Functions/methods, pointers
  - We will have a review of these concepts during class
  - **No** advanced knowledge of modern C++ required!
- You will write some C/C++ code during the assignments (more later…)

Textbook

Textbook

- ➢ The class will be based on lecture slides from the instructor and on research papers. Suggested (but **<u>not required</u>**) textbooks are:

  - H. Karl, A. Willig, *"Protocols and Architectures for Wireless Sensor Networks,"* Wiley, 2005
  - B. Krishnamachari, *"Networking Wireless Sensors,"* Cambridge University Press
  - I. Akyildiz, M. Vuran, *"Wireless Sensor Networks,"* Wiley, 2010.

Grading

Grading

- Grades will be assigned according to the following policy:

– Attendance	**5%**
– Homework Assignments (2)	**35%**
– Midterms (2)	**30%**
– Final Project	**30%**

- More weight on **hands-on activities** (65% of total grade)
- TA for EECE 5155:
  - Ms. Li Wang (wang.li4@northeastern.edu)
- Office Hours: by appointment (Zoom)

Attendance

- Attendance is measured at the **beginning** of each lesson
  - The Teaching Assistant (TA) is tasked to measure attendance
  - ***Attendance*** for a class session is defined as remaining in the classroom for the duration of the class.
  - Each student will receive a grade of "**A**" in the ``Class Attendance'' category if the percentage of attended classes will be **90%** or more at the end of the course, and ``**B**'' otherwise. Students may miss more than **10%** of the class meetings with valid excuse(s).
  - **Exceptions** to class attendance in East Village 002:
    - COE-approved remote students
    - Students attending remotely from other campuses

Homework Assignments

Assignments

- **Two** homework assignments based on OMNeT++
  - Performance evaluation of algorithms for WSNs based on existing research
  - Implement (a simplified version of) the proposed algorithm/protocol
  - Extract performance metrics (e.g., delay, energy consumption)
  - Analysis of results (i.e., why did I get those results?)
  - If you want, you can go ahead and familiarize yourself with OMNeT++ (we will do it in class anyway)

- **You will be guided throughout the assignments**
  - Dedicated lessons to understand algorithms and what to do
  - Walkthroughs during class
  - …

Midterms

- Set of questions regarding concepts explained in class

- First ~ **mid October** (tentative)
- Second ~**late November** (tentative)

Interactive Lessons

Interactive Lessons

- ➢ We live in very difficult times
- ➢ Still, we need to make the most out of it!
- ➢ Very interactive class
  - Ask a lot of questions during the class
  - **Don’t feel intimidated** ☺
  - Your answers are **not graded**
  - Remote students can use the Zoom chat
  - We need to understand not only the topic…
    - but also **why** protocols/algorithms were designed in a certain way

Research Project

What is the Internet of Things?

What are the “Things”?

- **Things:** Objects, not a computer
- Phone, watches, thermostats, cars, Electric Meters, sensors, clothing, band-aids, TV, medical devices
- Anything, Anywhere, Anytime, Anyway, Anyhow (5 A’s)

Source: Raj Jain, Internet of Things: Challenges and Issues

The Internet of Things

- Today, less than 1% of things around us is connected. Refrigerator, car, washing machine, heater, a/c, garage door, should all be connected but are not
- From 10 Billion today to 22 Billion in 2025
- Should include processes, data, things, and people
- IoT value: $14 Trillion over 10 years
  - Third in the list of top 10 strategic technologies by Gartner (After Mobile devices, Mobile Apps, but before Clouds, …)
- a.k.a. **Internet of Everything** by Cisco, **Smarter Planet** by IBM

What is IoT?

The Internet of Things
is a shorthand way
of describing a
globally
interconnected continuum
of devices and objects
interacting with the
physical environment,
people and
each other

What is IoT?

- Combination of Technologies + Funding + Business Hype!
- IoT = Sensing + Communication + Computation

1. Micro-Sensors: Temperature, Moisture, Pressure, air quality, …
2. Tags: Radio Frequency Id (RFID), Quick Response (QR) Codes, …
3. Energy Efficient Communication: Small or no batteries, Personal area communication (PAN), Bluetooth, ZigBee, …
4. Micro-Computing: Micro multi-core chips, Raspberry Pi, Intel Galileo, Arduino, …
5. Cloud Computing: Little or no local computing
6. Open/Small operating systems: Linux

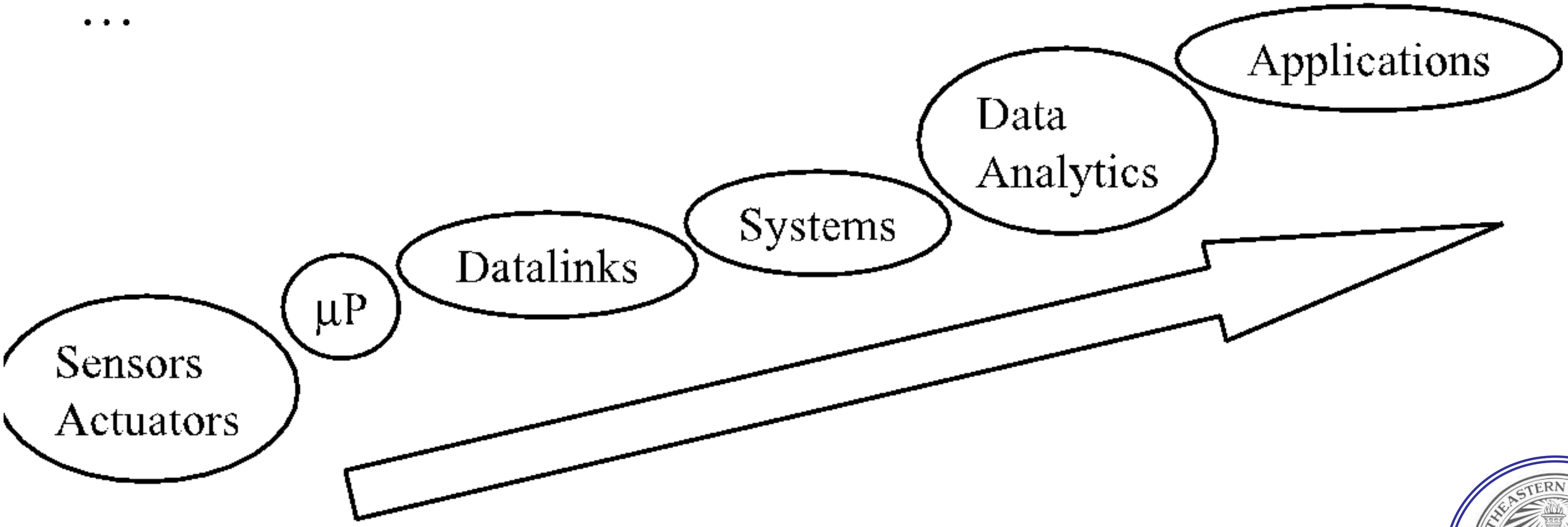
Ref: CTIA, "Mobile Cyber security and the Internet of Things,"

Research Funding for IoT

- 70 M € in European Research program FP7 Internet of European Things
- Networking and Information Technology Research and Development (NITRD)
  - Group of 15 Federal agencies: NSF, NIH, NASA, DOE, DARPA, ONR, ...
  - Recommends supplement to the president's annual budget
- CPS is one of the areas recommended by NITRD
  - **Smart infrastructure:** Smart Grid, Smart Bridges, Smart Cars, tele-operational surgical robots, Smart Buildings
  - **March 2014:** £45M for IoT research in UK by David Cameron

Business Opportunities

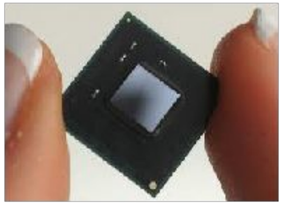
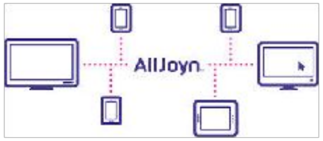
- Components: Sensors, wireless radios, protocols,
- Smart Objects: Smart TV, Camera, Watch, …
- Systems: Buildings, Cars, Health, …
- Network service providers: ISP
- Application Service Providers: Monitoring, Analytics, Apps, …



Venture Activities

- $1.1B invested in IoT startups by VCs in 153 deals in 2013
  - Quantified Self: Know your body and mind
  - Healthcare sensors: Wearable clock, sleep monitors
  - Energy management
  - Home Automation: Kitchenware, locks
  - Environmental monitoring: Air Quality sensors, personal weather stations
- January 2014: Google buys NEST for 3.3B
- May 2014: $150M in VC investments in IoT by Cisco

Recent IoT Products

 NEST Thermostat	 Corventis: Wireless Cardiac Monitor	 WEMO Remote	 Tractive Pet Tracker
 Ninja Blocks	 Revolve Home Automation	 ThingWorx Application Platform	 Lings Cloud Platform
 Mbed Development Platform	 Xively Remote Access API	 Intel Quark Processor	 AllJoyn S/W Framework

Research Challenges?

Research Challenges

- Naming and Addressing: Advertising, Searching and Discovery
- Power/Energy/Efficient resource management. Energy harvesting
- Things to Cloud: Computation and Communication Gateways
- Miniaturization: Sensors, CPU, network
- Big Data Analytics: By 2025, total data volume of connected IoT devices worldwide is forecast to reach XXX zettabytes (ZBs, 1000 TBs)
- Semantic technologies: Information and data models for interoperability
- Virtualization: Multiple sensors aggregated, or a sensor shared by multiple users
- Privacy/Security/Trust/Identity/Anonymity Target Pregnancy Prediction
- Heterogeneity/Dynamics/Scale

Wireless Sensor Networks

PART 1 - Introduction

- Infrastructureless wireless networks
- (Mobile) Ad Hoc Networks (MANET)
- Wireless Sensor Networks (WSN)
- Comparison

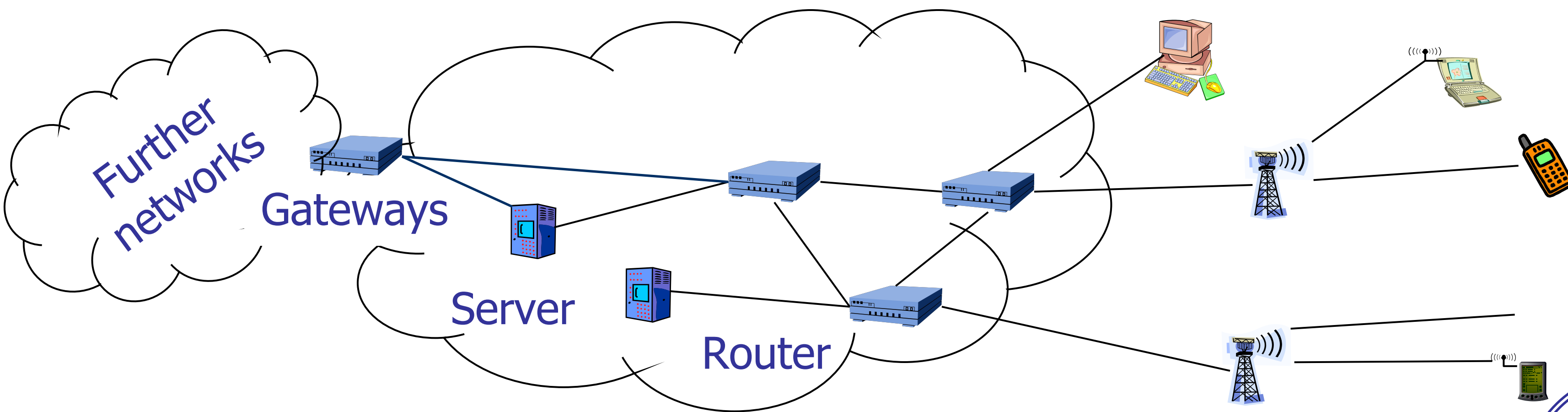
PART 2 - Applications

- Applications of Wireless Sensor Networks
- Underground Sensor Networks
- Underwater Sensor Networks
- Wireless Sensor and Actor Networks
- Generalization: Wireless Multimedia Sensor Networks

Infrastructure-less Networks

Infrastructure-based Wireless Networks

- Traditional wireless network: based on infrastructure
  - E.g., 4/5G Networks
  - Base stations connected to a wired backbone network
  - Mobile devices communicate wirelessly to these base stations
  - Traffic between different mobile entities is relayed by base stations and wired backbone
  - Mobility is supported by switching from one base station to another
  - Backbone infrastructure required for administrative tasks

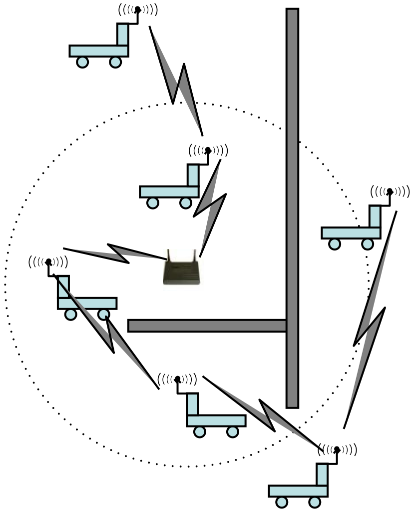


Limits

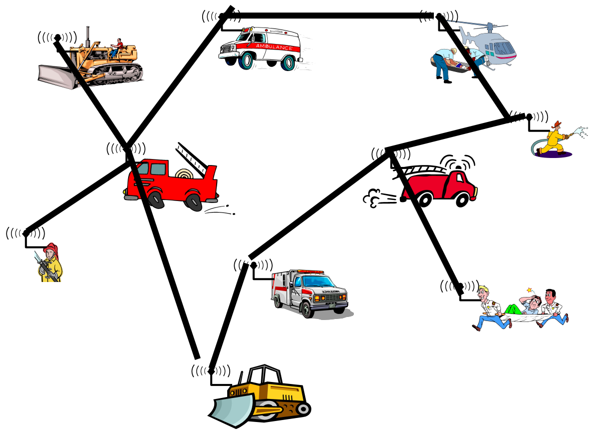
- What if…
  - No infrastructure is available?
    - Disaster areas
  - It is too expensive/inconvenient to set up?
    - Remote, large construction sites
    - Houses
  - There is no time to set it up?
    - Military operations

Applications of Infrastructure-less Networks

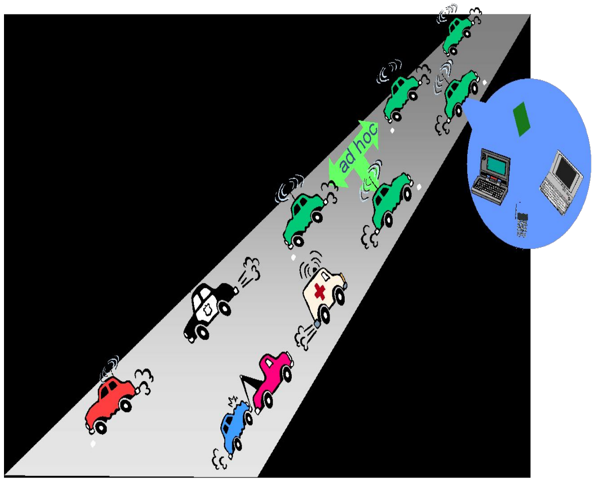
- Factory floor automation



- Disaster recovery



- Vehicular communication

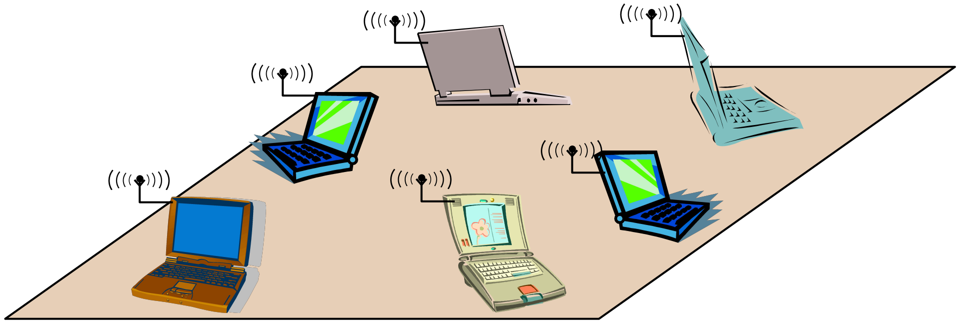


- **Military networking:** Tanks, soldiers, …
- Finding out **empty parking lots** in a city, without asking a server
- **Search-and-rescue** in an avalanche
- **Personal area networking** (watch, glasses, medical appliance, …)

Solution: Wireless Ad Hoc Networks

- Build a network without infrastructure, using networking abilities of the participants
  - *Ad hoc network* – a network constructed "for a special purpose"

- Example: Laptops in a conference room – a ***single-hop ad hoc network***



Challenges in Ad Hoc Networks

- Without a central infrastructure, things become much more difficult

- **Think-Share!**

- Problems are due to
  - Lack of central entity for organization available
  - Limited range of wireless communication
  - Mobility of participants
  - Battery-operated devices

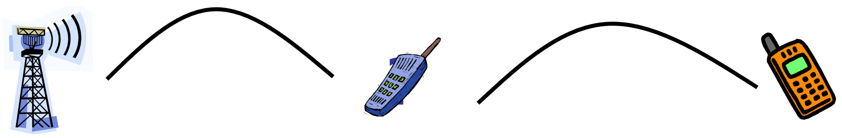
Self-organization

- Without a central entity, participants must organize themselves into a network (***self-organization***)

- **Challenges (among others):**
  - Discovering the presence of neighboring devices
  - Medium access control – no base station can assign transmission resources, must be decided in a distributed fashion
  - Finding a route from one participant to another

Multi-hop Wireless Networks

- For many scenarios, communication with peers outside immediate communication range is required
  - Direct communication limited because of distance, obstacles
  - Solution: ***multi-hop network***

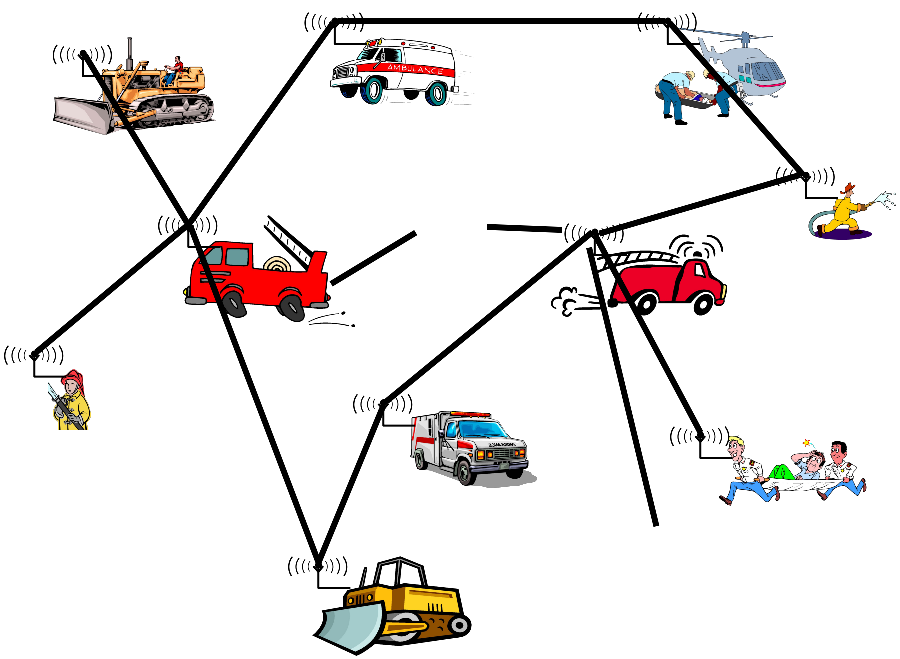


  - ***Under some circumstances, multi-hopping may help save energy***

Adaptive Protocols

➢ In several ad hoc network applications, participants move around
  – In cellular network: simply hand over to another base station

- In ***mobile ad hoc networks (MANET)***:
  - Mobility changes neighborhood relationship
  - Routes must be reconfigured adaptively



- **Complicated by scale**
  - When the network size increases, reconfiguration becomes more difficult

Energy-efficient Operation

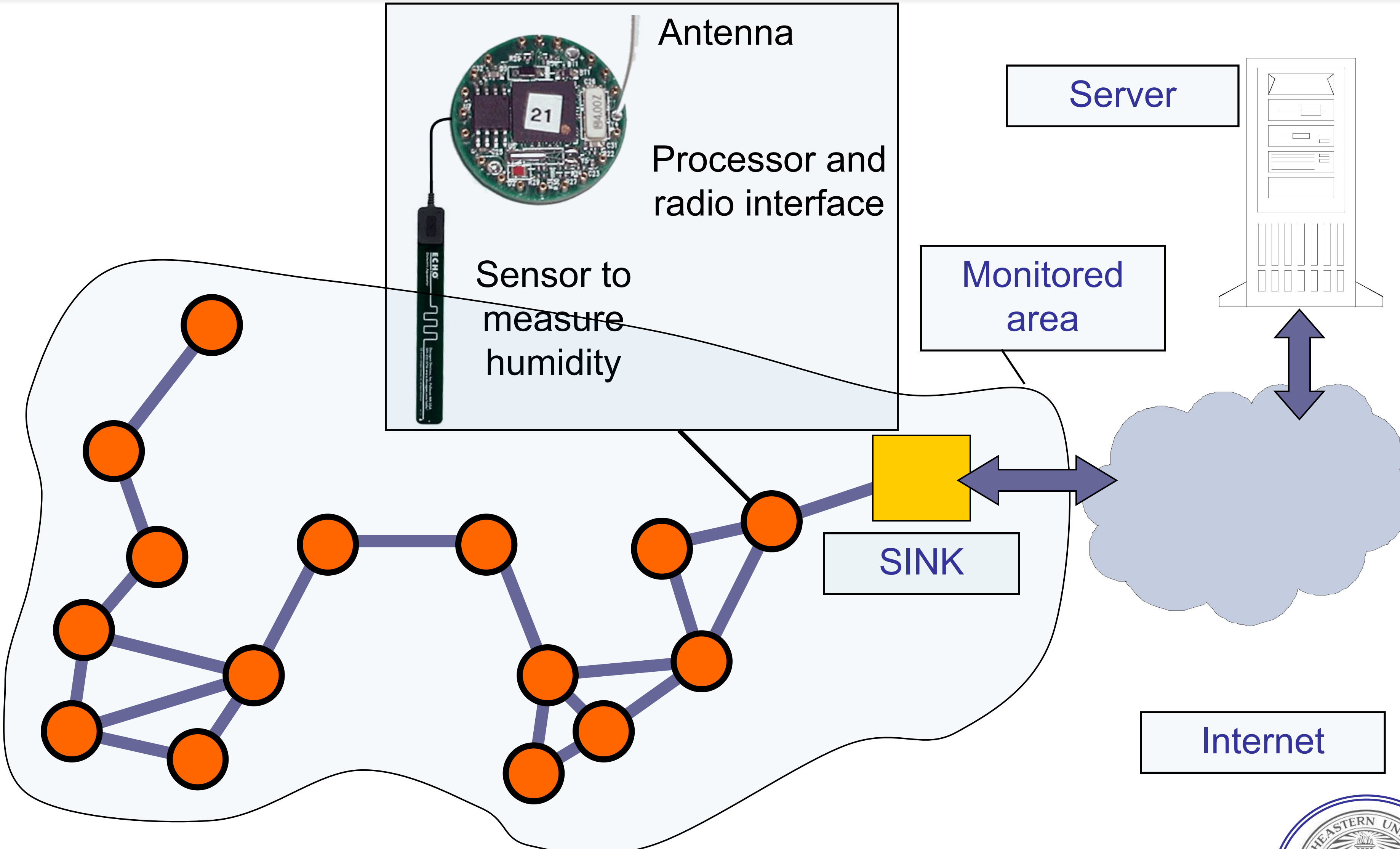
- Participants in an ad hoc network often draw energy from batteries

- We want long lifetime for
  - Individual devices
  - Network as a whole

- Energy-efficient networking protocols
  - E.g., use multi-hop routes with low energy consumption (energy/bit)
  - E.g., take available battery capacity of devices into account
  - How to resolve conflicts between different optimizations?

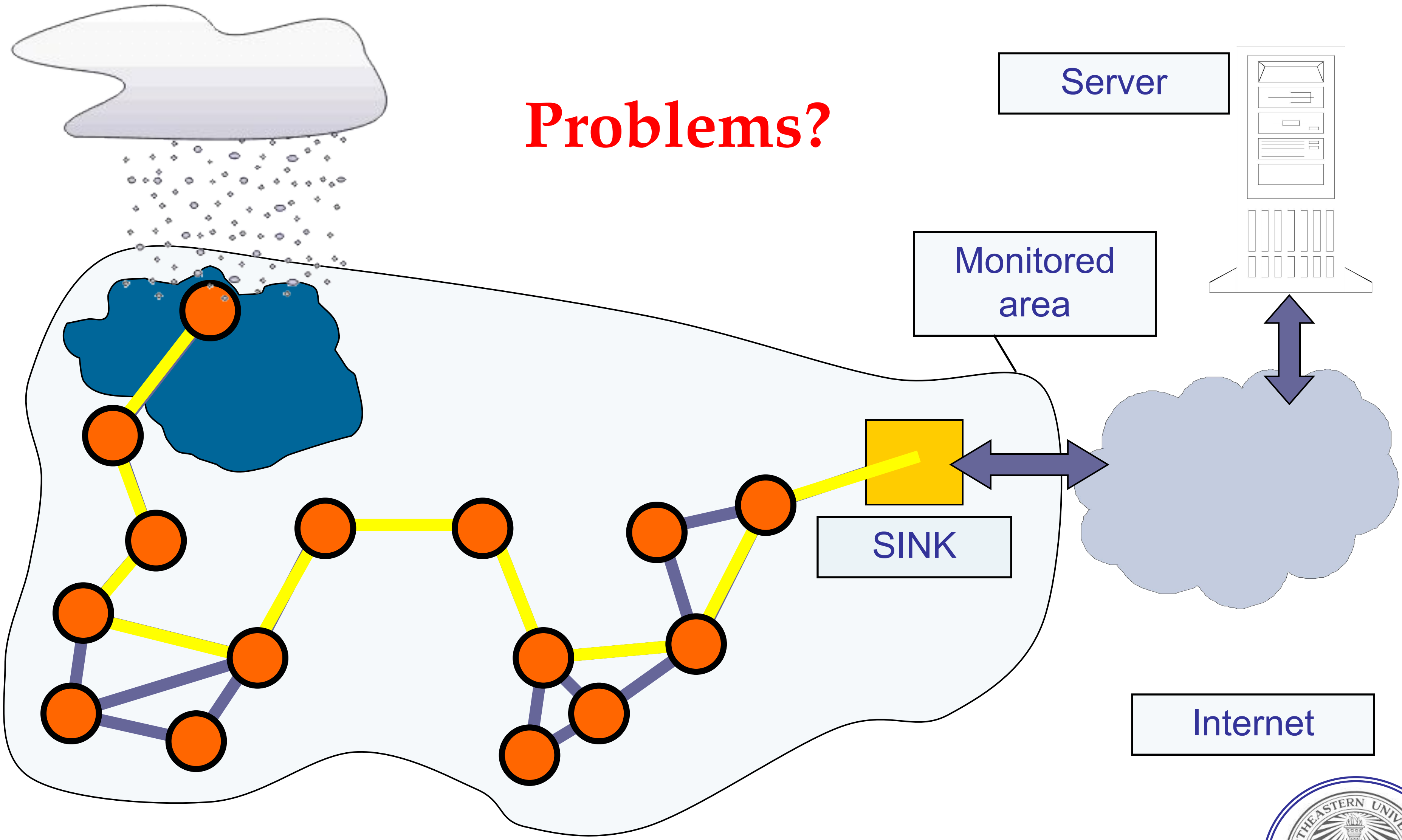
Wireless Sensor Networks

Wireless Sensor Network



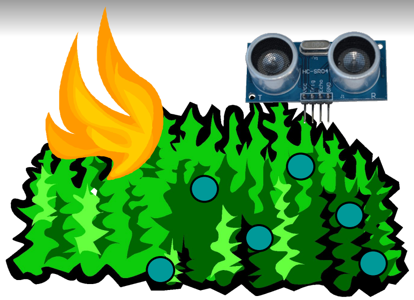
Wireless Sensor Networks

Problems?

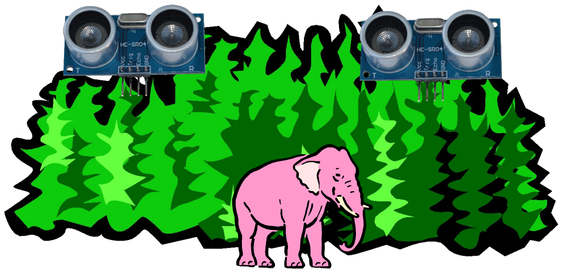


WSN Application Examples

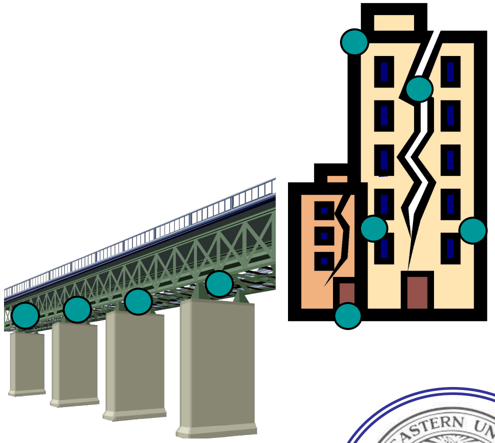
- ➢ Disaster relief operations
  - – Drop sensor nodes from an aircraft over a wildfire
  - – Each node measures temperature
  - – Derive a "temperature map"



- ➢ Biodiversity mapping
  - – Use sensor nodes to observe wildlife

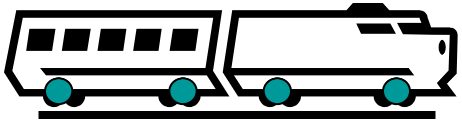


- ➢ Intelligent buildings (or bridges)
  - – Reduce energy wastage by proper humidity, ventilation, air conditioning (HVAC) control
  - – Needs measurements about room occupancy, temperature, air flow, …
  - – Monitor mechanical stress after earthquakes



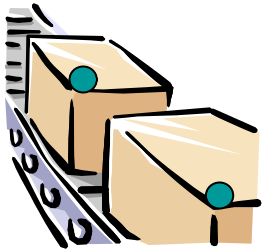
WSN Application Scenarios

- 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



- Precision agriculture
  - Bring out fertilizer/pesticides/irrigation only where needed
- Medicine and health care
  - Post-operative or intensive care
  - Long-term surveillance of chronically ill patients or the elderly

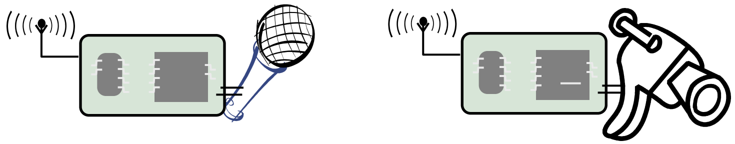
WSN Application Scenarios



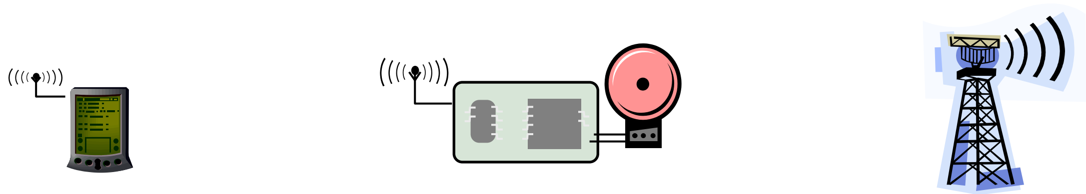
- Logistics
  - Equip goods (parcels, containers) with a sensor node
  - Track their whereabouts – ***total asset management***
  - Note: passive readout might suffice – compare RFIDs
- Telematics
  - Provide better traffic control by obtaining finer-grained information about traffic conditions
  - ***Intelligent roadside***
  - Cars as the sensor nodes

Roles of Participants in WSN

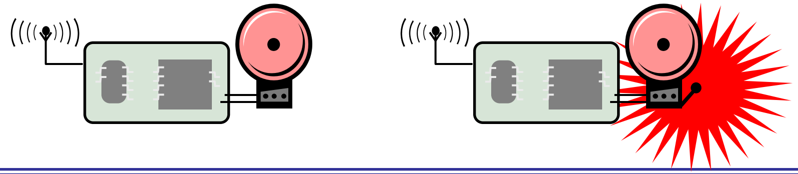
- *Sources* of data: Measure data, report them "somewhere"
  - Typically equip with different kinds of multimedia sensors



- *Sinks* of data: Interested in receiving data from WSN
  - May be part of the WSN or external entity, PDA, gateway, …



- *Actors/actuators*: Control some device based on data, usually also a sink



WSN application types

- ***Event detection***
  - Nodes locally detect events (maybe jointly with nearby neighbors), report these events to interested sinks
- ***Event classification***
- ***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 position of an observed object

Deployment Options

- ***Random deployment***
  - Dropped from aircraft
  - Usually uniform random distribution for nodes over finite area is assumed
- ***Regular deployment***
  - Well planned, fixed
  - 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
  - Lesson and HW-2 dedicated to WSNs with Mobile Sinks

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Prof. Francesco Restuccia
Email: f.restuccia@northeastern.edu

September 14, 2021

Characteristics of WSN

- **Scalability**
  - Support large number of nodes
  - Performance should not degrade with increasing number of nodes
- **Wide range of densities**
  - Vast or small number of nodes per unit area, very application-dependent
- **Limited resources for each device**
  - Low amount of energy
  - Low cost, size, and weight per node
  - Nodes may not have a global ID such as an IP address
- **Mostly static topology**

Characteristics of WSNs

- **Service in WSN**
  - Not simply moving bits like traditional networks
  - In-network processing
    - Provide ***answers*** (not just numbers)
  - Communication is triggered by queries or events
  - Asymmetric flow of information
- **Quality of service**
  - Traditional QoS metrics do not apply
- **Fault tolerance**
  - Be robust against node failure
    - Running out of energy, physical destruction

Characteristics of WSNs

- **Lifetime**
  - The ***network*** should fulfill its task as long as possible – definition depends on application
  - Lifetime of individual nodes relatively unimportant
  - But often treated equivalently

- **Programmability**
  - Re-programming of nodes in the field might be necessary, improve flexibility

- **Maintainability**
  - WSN has to adapt to changes, self-monitoring, adapt operation
  - Incorporate possible additional resources, e.g., newly deployed nodes

Typical Adopted Mechanisms

- Multi-hop wireless communication
- Energy-efficient operation
  - Both for communication and computation, sensing, actuating
- Self-configuration
- Collaboration & in-network processing
  - Nodes in the network collaborate towards a joint goal
  - Preprocessing data in network (as opposed to at the edge) can greatly improve efficiency

Mechanisms to Meet Requirements

- **Data centric networking**
  - Focusing network design on ***data***, not on ***node identifiers*** (id-centric networking)
- **Locality**
  - Do things locally (on node or among nearby neighbors) as far as possible
- **Exploit tradeoffs**
  - For example between invested energy and accuracy

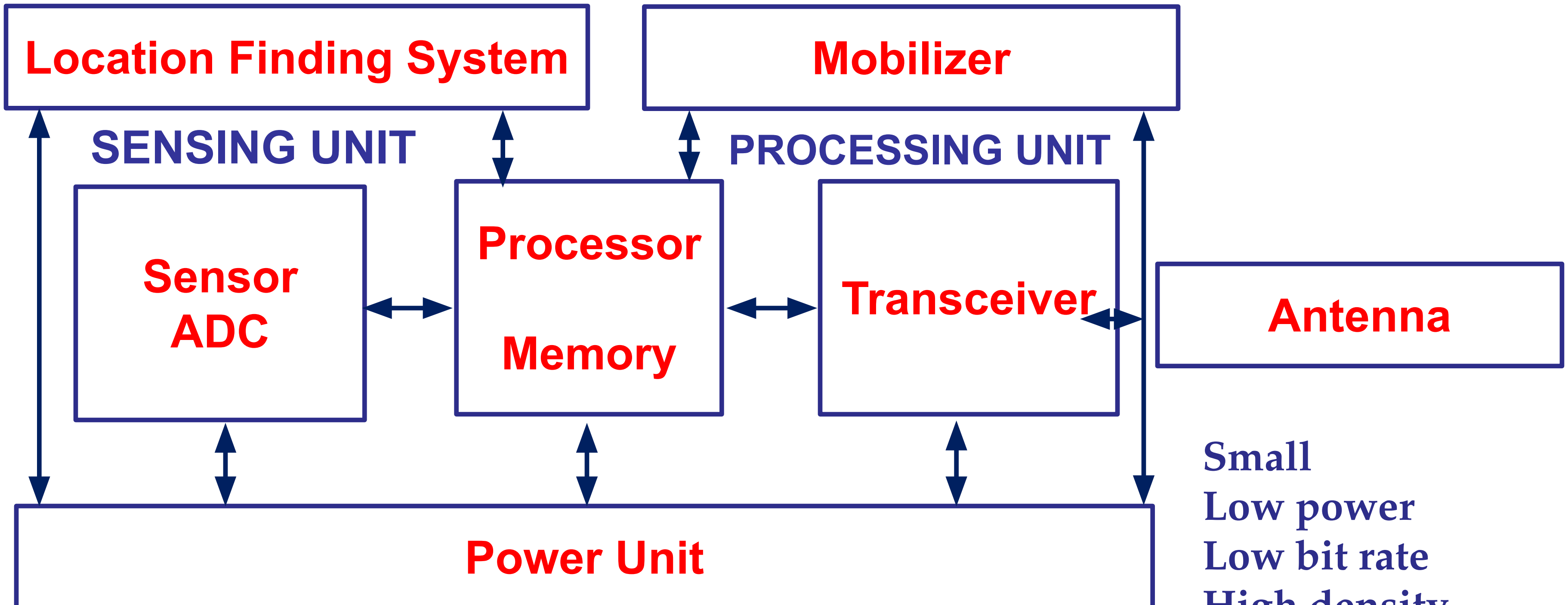
MANET vs. WSN

- ***Applications, equipment***:
  - MANETs more powerful equipment assumed, often "human in the loop"-type applications, higher data rates, more resources
- ***Application-specific***:
  - WSNs depend much stronger on application specifics
- ***Scale***:
  - WSN likely to be much larger
- ***Energy***:
  - WSN tighter requirements, maintenance issues
- ***Dependability/QoS***:
  - in WSN, individual node may be dispensable (network matters), QoS different because of different applications
- ***Data centric* vs. id-centric networking**
- ***Mobility***

Enabling technologies for WSN

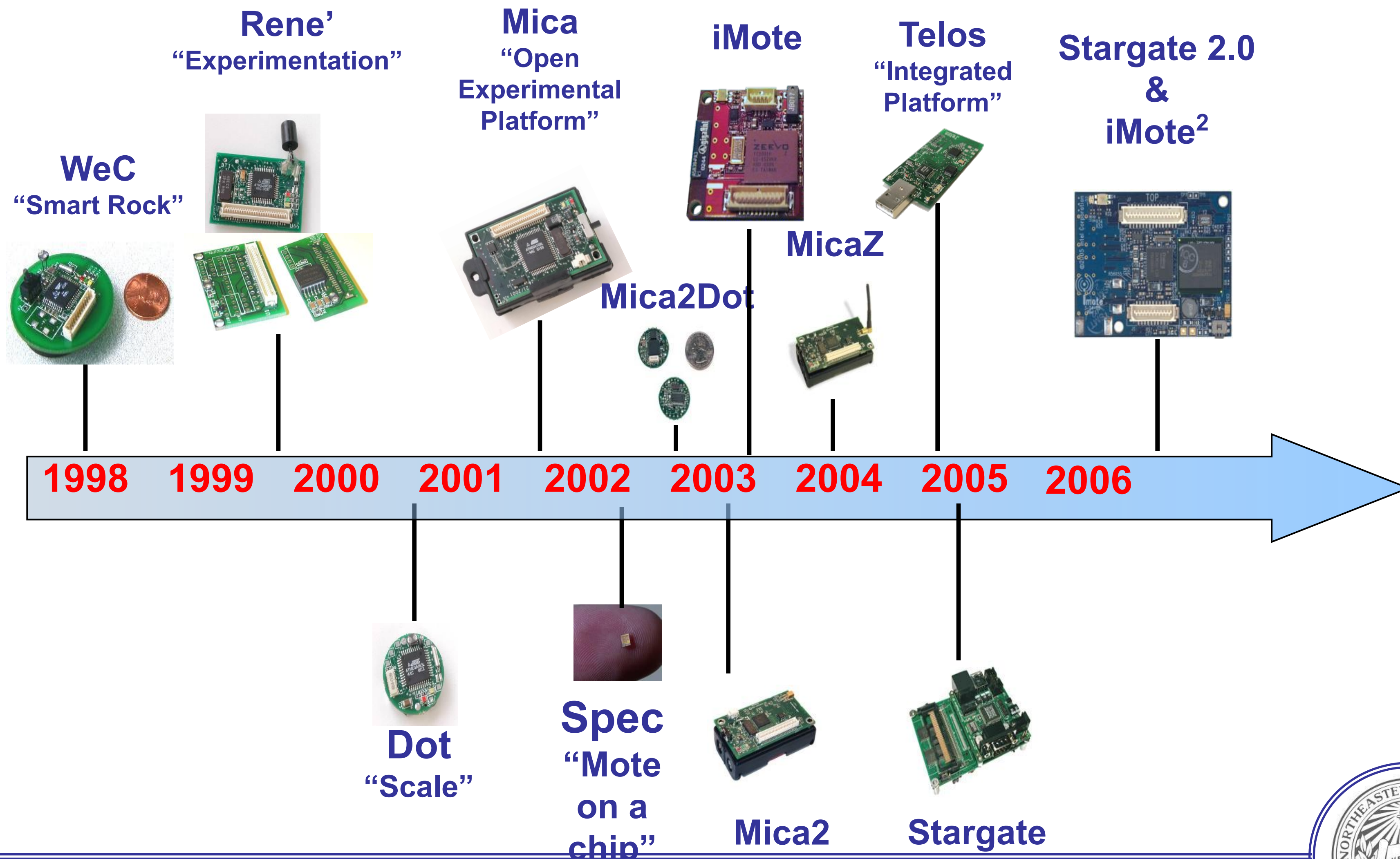
- **Cost reduction**
  - For wireless communication, simple microcontroller, sensing, batteries
- **Miniaturization**
  - Some applications demand small size
  - "Smart dust" as the most extreme vision
- **Energy scavenging**
  - Recharge batteries from ambient energy (light, vibration, …)

Sensor Node Hardware

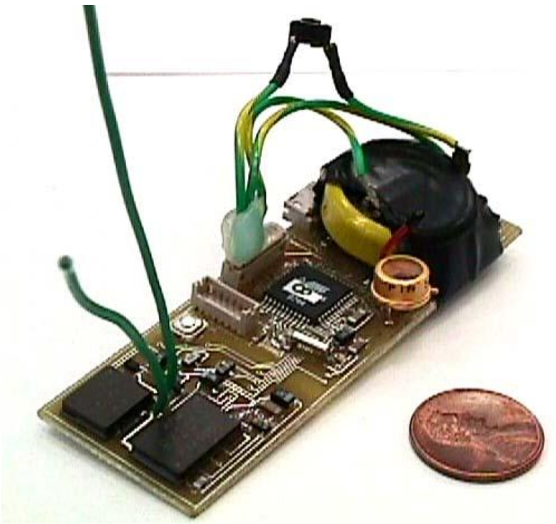


Small
Low power
Low bit rate
High density
Low cost (dispensable)
Autonomous
Adaptive

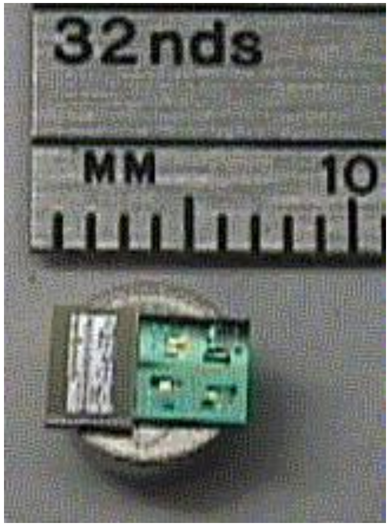
Sensor Motes Timeline



Examples of Sensor Devices



Dust



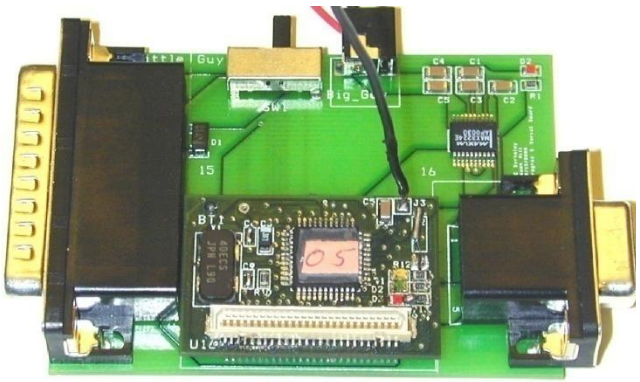
Smart Dust

Rockwell

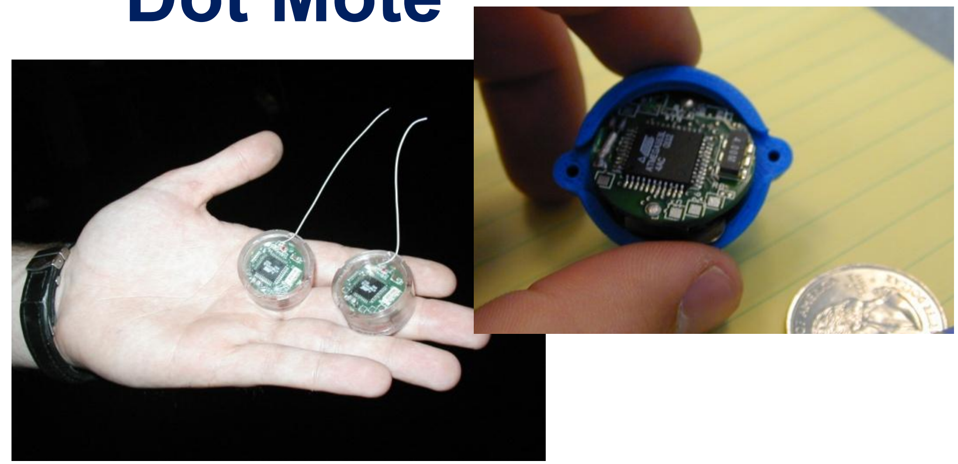
JPL Sensor

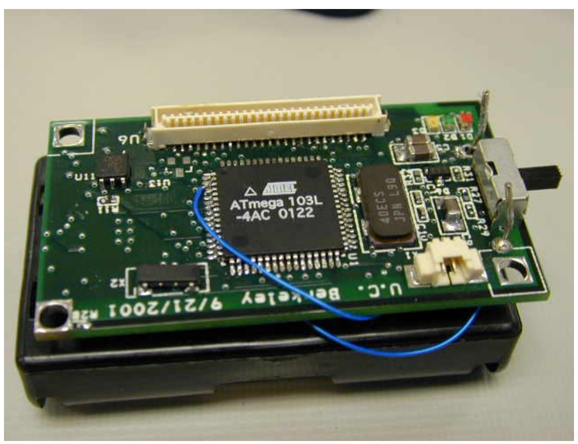
Examples of Sensor Devices

Rene Mote

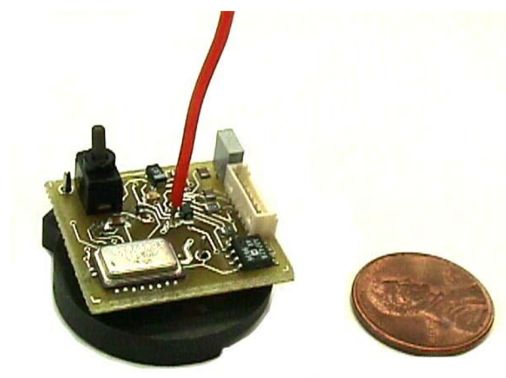


Dot Mote





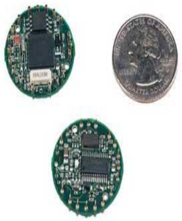
MICA Mote

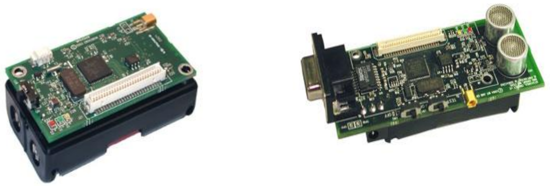


weC Mote

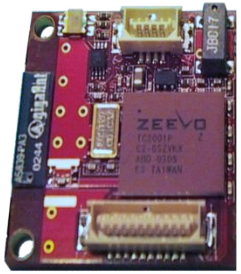
Low-End

- ➢ Mica2DOT (2003)
  - 16Kb program memory
  - RFM TR1000 (CSMA/ASK)
  - Lightweight and small
- ➢ Mica2 & Cricket platform (2003)
  - 128Kb program memory
  - ChipconCC1000 (CSMA/FSK)
  - 40Khz Ultrasounders (Cricket only)
- ➢ MicaZ (2004) & Telos (2005)
  - 128Kb (MicaZ), 48Kb (Telos) program memory
  - 802.15.4/Zigbee stack
  - Spread Spectrum radio handles multipath better
  - Integrated antenna (Telos only)





High-End



- Imote (2003) & Imote^2
  - Higher processing power
  - Bluetooth (Imote, Imote^2), 802.11 (Imote^2 only) capable

- Stargate (2005) & Stargate 2.0
  - Pentium class processor
  - Linux OS => easy development (C/C++)
  - More processing capabilities => energy intensive
  - 802.11 capable

Sensor Node Features

Feature	Imote (2003)	Mica2 (2003)	MicaZ (2004)	Telos (2005)	Stargate (2005)	Imote2
Speed [MHz]	12	8	8	8	400	13-416*
Flash [kB] (Program)	512	128	128	48	32,000	32,000
Serial Flash [kB] (Measurement data)	N/A#	512	512	1024	N/A#	N/A#
SRAM / EEPROM / SDRAM ‡ [kB] (Configuration)	64	4	4	10	64,000	256-32,000 ◊

*Multiple processor speed levels

#Imote, Stargate, and Imote2 use a single Flash for program and measurement data

‡Imote, Imote2, and Telos use SRAM; Mica2 and MicaZ use EEPROM; Stargate uses SDRAM

◊Imote2 will have different versions, SRAM changes accordingly

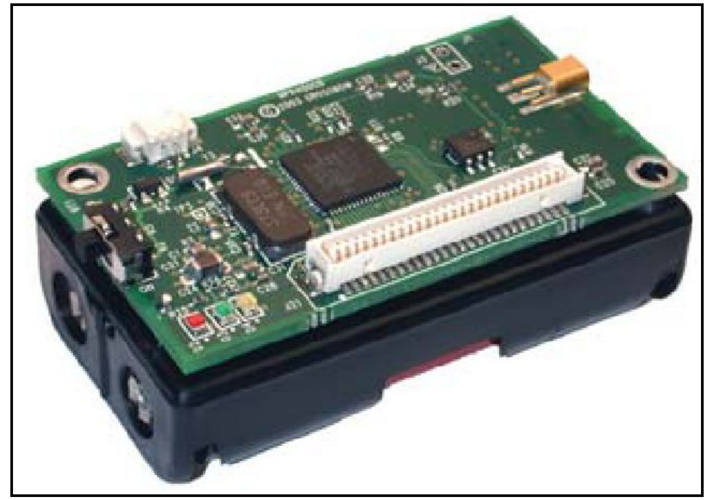
Sensor Node Features

Feature	Imote (2003)	Mica2 (2003)	MicaZ (2004)	Telos (2005)	Imote^2
Radio Frequency	2.4 GHz	300-900MHz	2.4 GHz	2.4 GHz	2.4 GHz
DataRate [kb/s]	720	15	250	250	250 (720 $^{\Delta}$ /11,000 $^{\bullet}$)
Power CarrierSense/Rx./Tx. [mA]	15 / 24 / 24	8 / 10 / 27	8 / 20 / 18	1 / 20 / 18	40/20/18
PowerSleep [mA]	1-250 $^{@}$	19	27	6	1-100 $^{@}$
Radio Range	32 ft (10 m)	500 ft (150m)	300 ft (100m)	400 ft (125m)	Under dev.
Power source	AA Battery	2xAA	2xAA	2xAA	Under dev.

Δ With external Bluetooth adapter
• With external WLAN adapter
@ Different sleep levels

Stargate communication and power properties depend on the connected module (Mica2,MicaZsensors or WLAN)
Stargate powered by 5-6V DC or A/C adaptor

MicaZ Motes

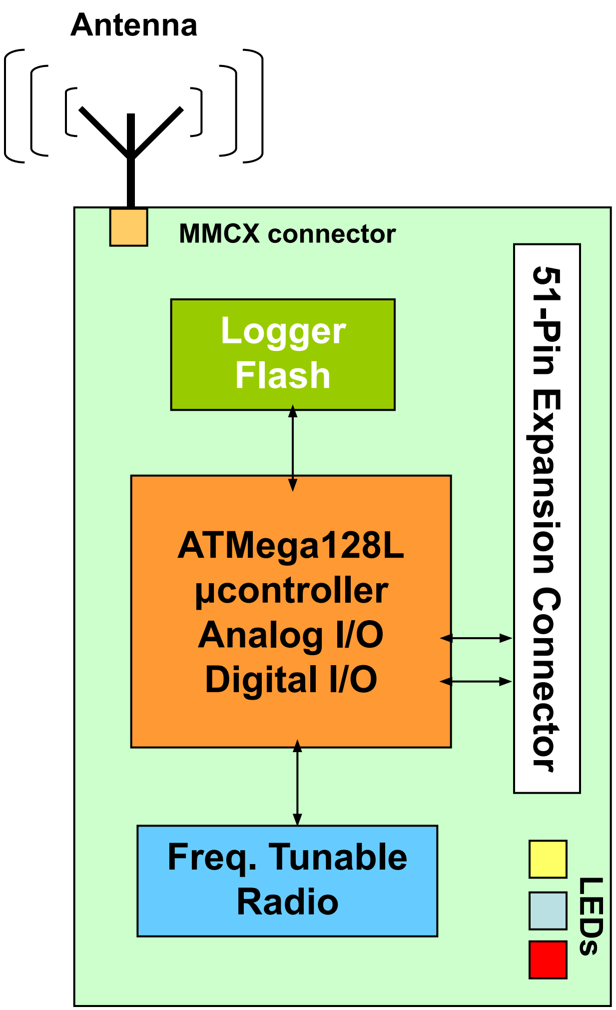


Original IBM PC (1981)	*MICAZ Mote (2005)*
4.77 MHz	8 MHz
16-256 KB RAM	128 KB RAM
160 KB Floppies	512 KB Flash
~ $6K (today)	~ $35
~ 64 W	~14 mW
25 lb, 19.5 x 5.5 x 16 inch	0.5 oz, 2.25 x 1.25 x 0.25 inch

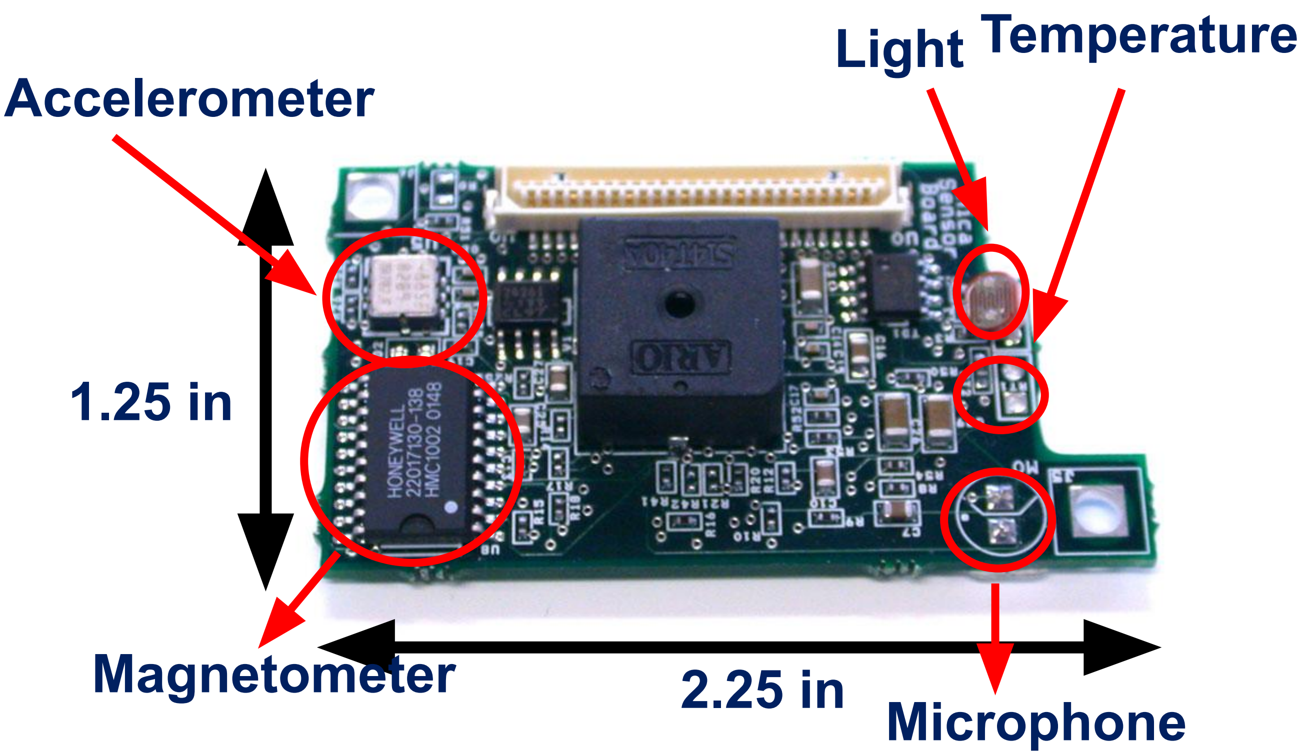
MICAz Platform

Now FCC/ARIB certified

- **Microprocessor:** Atmel ATmega128L
  - 7.3728 MHz clock
  - 128 kB of Flash for program memory
  - 4 kB of SRAM for data and variables
  - 2 UARTs (Universal Asynchronous Receive and Transmit)
  - Serial Port Interface (SPI) bus
  - Dedicated hardware I2C bus
- **Radio:** Chipcon's CC2420 (IEEE 802.15.4)
  - 250 kbit/s
- **External serial flash memory:** 512 Kb
  - xbow estimates > 100000 samples
- **51-pin expansion connector**
  - Eight 10-bit analog I/O
  - 21 general purpose digital I/O
- **User interface:** 3 programmable LEDs
- **JTAG port**
- **Powered by two AA batteries**
  - 1850 mAh capacity



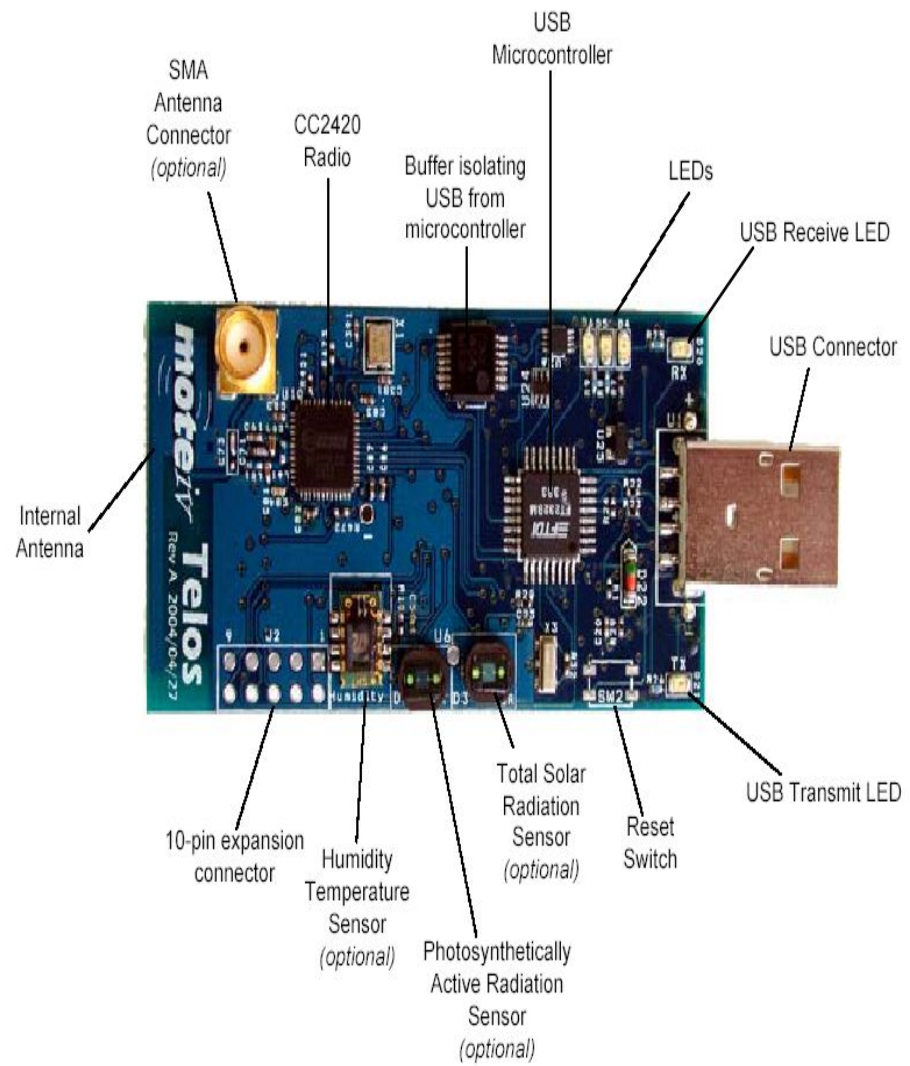
Mica Sensor Board



- ➢ Light (Photo)
- ➢ Temperature
- ➢ Acceleration
  - – 2 axis
  - – Resolution: ±2m*g*
- ➢ Magnetometer
  - – Resolution: 134μG
- ➢ Microphone
- ➢ Tone Detector
- ➢ Sounder
  - – 4.5kHz

Telos Platform

- Robust
  - USB interface
  - Integrated antenna (30m-125m)
  - External antenna capability (~500m)
- High Performance
  - 10kB RAM, 48 KB ROM
  - 12-bit ADC and DAC (200ksamples/sec)
  - Hardware link-layer encryption

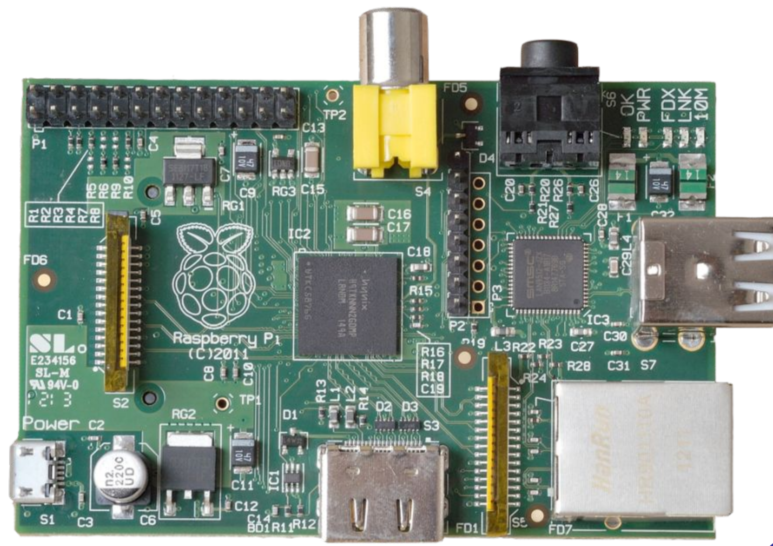


Telos by MOTEIV.com

- **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
- **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

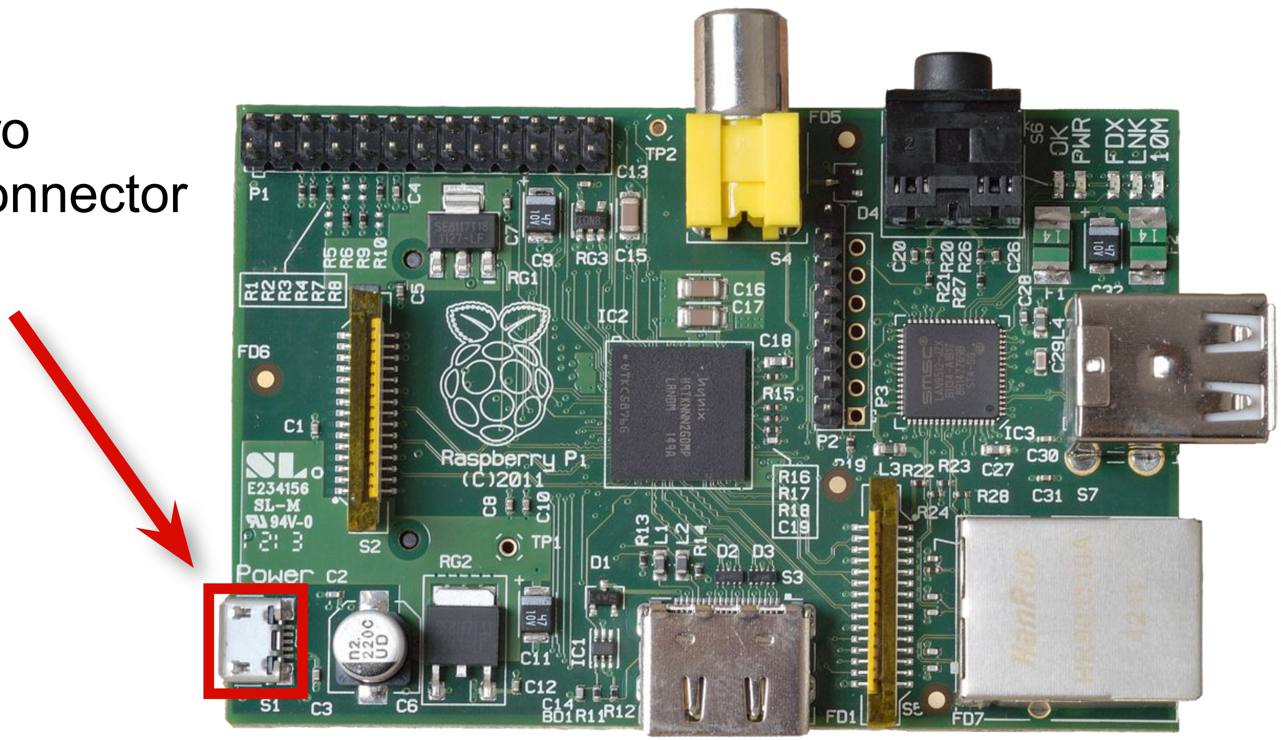
Raspberry PI

- A credit card sized PC
- Plugs into a TV or monitor
- Inexpensive(ish) ~$35
- Capability:
  - Programming
  - Electronic Projects
  - Office
  - Play HD Videos



Power

5v micro
USB connector

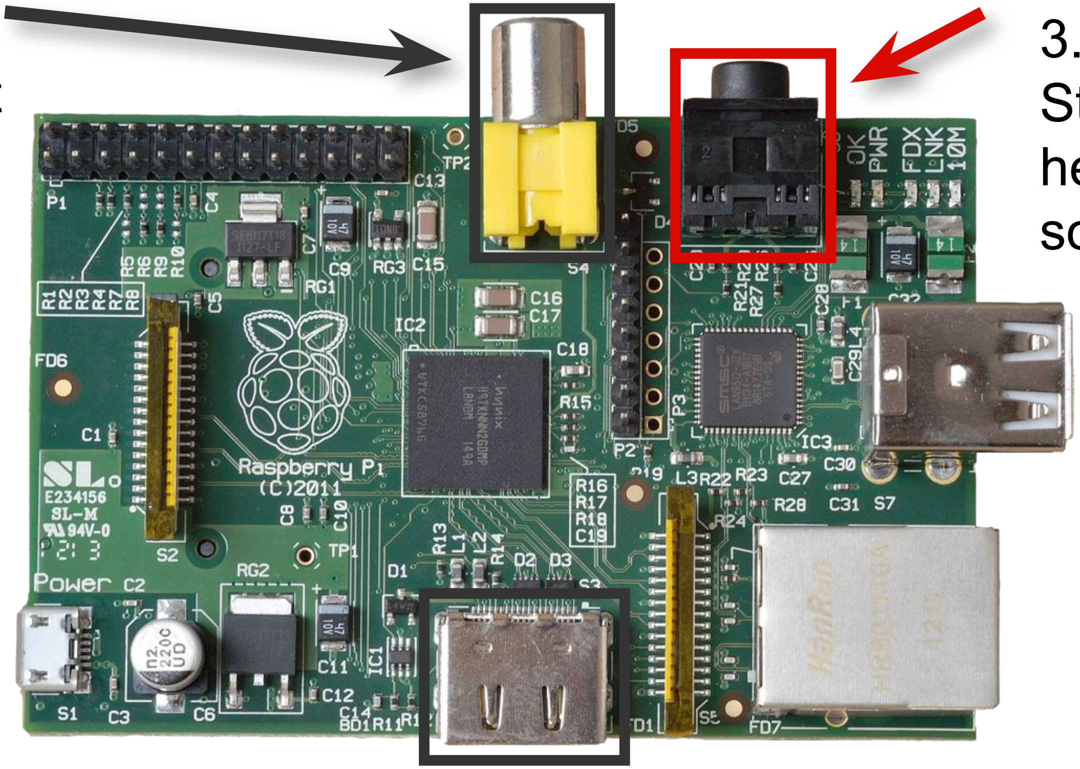


(Similar to the one on a lot of mobile phones!)

A/V (Audio/ViDeo)

RCA Video
(works with most
older TVs)

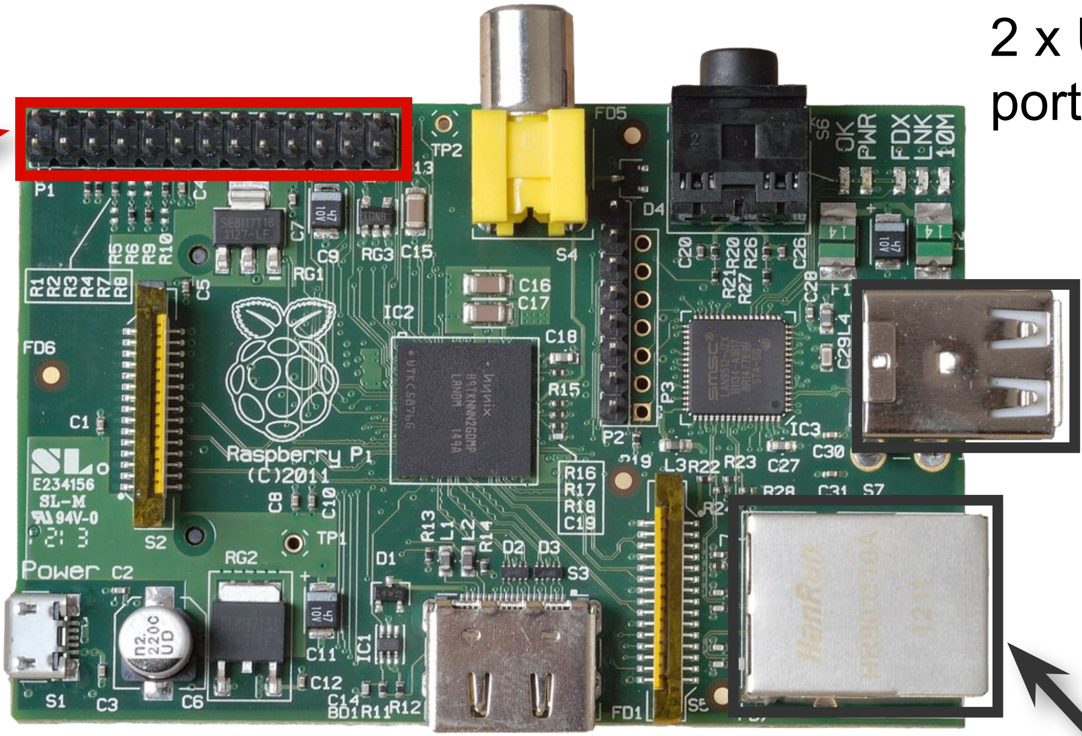
3.5mm Audio
Standard
headphone
socket



HDMI Audio & Video
(works with modern TVs and DVI monitors)

Connectivity

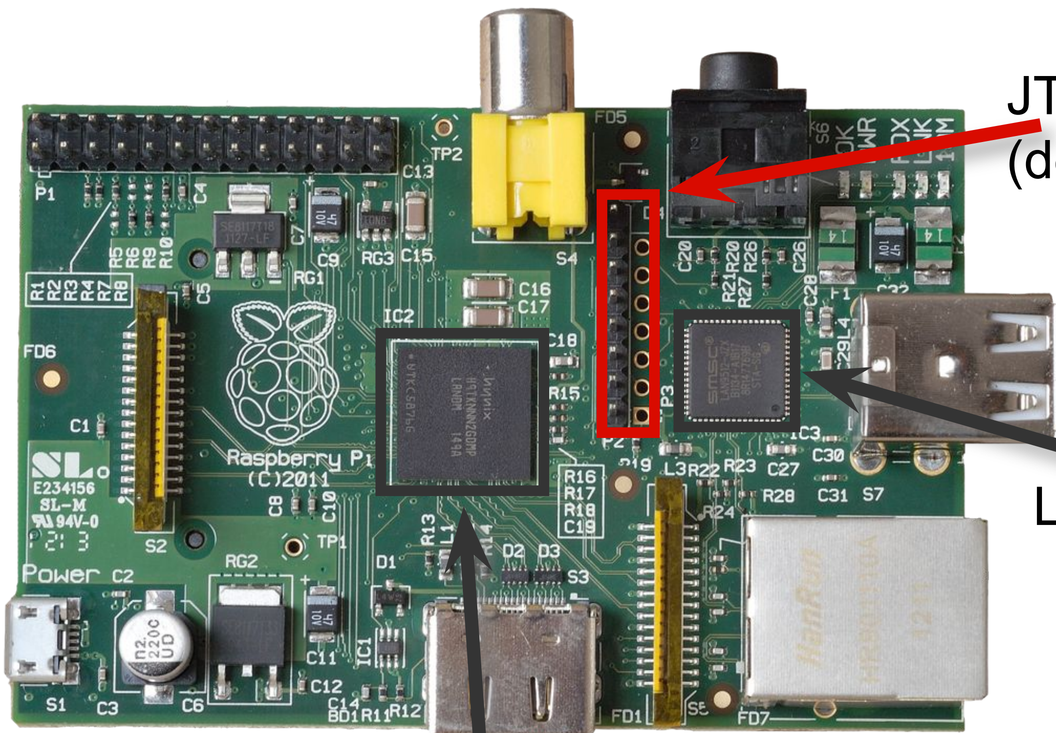
GPIO (General Purpose Input & Output)



2 x USB 2.0 ports

10/100Mb Ethernet

Internals



JTAG
(debug ports)

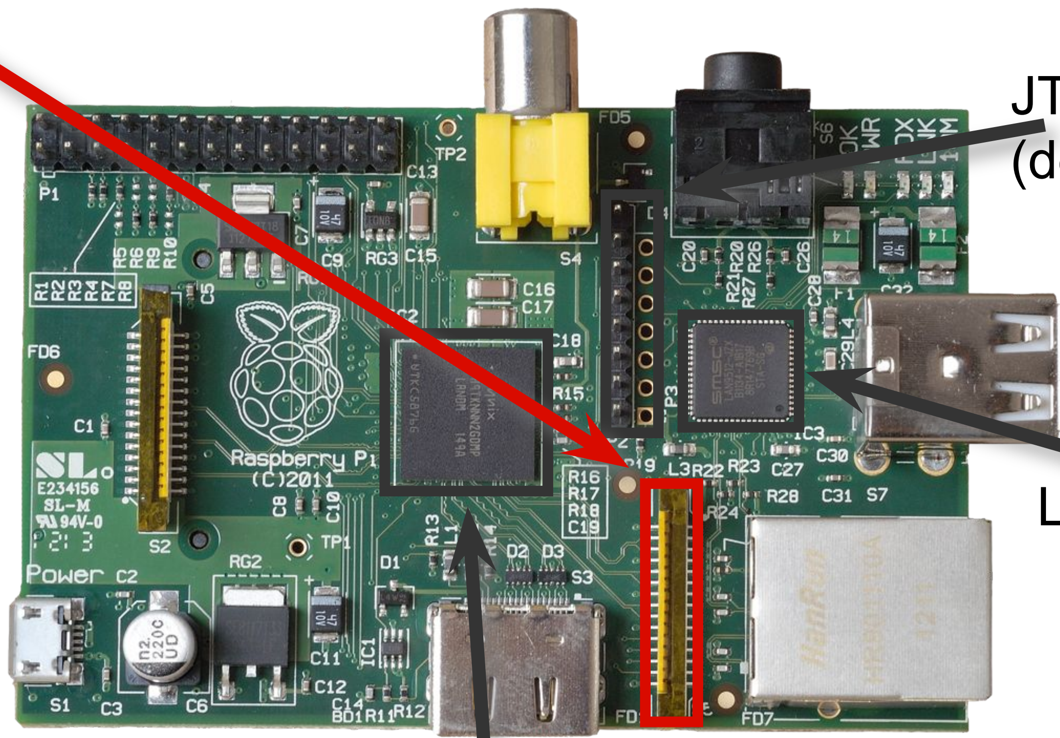
LAN Controller

SOC (System On a Chip)
Broadcom BCM2835 700Mhz & 256Mb / 512Mb RAM

Internals

CSI
(camera interface)

JTAG
(debug ports)



LAN Controller

SOC (System On a Chip)
Broadcom BCM2835 700Mhz & 256Mb / 512Mb RAM

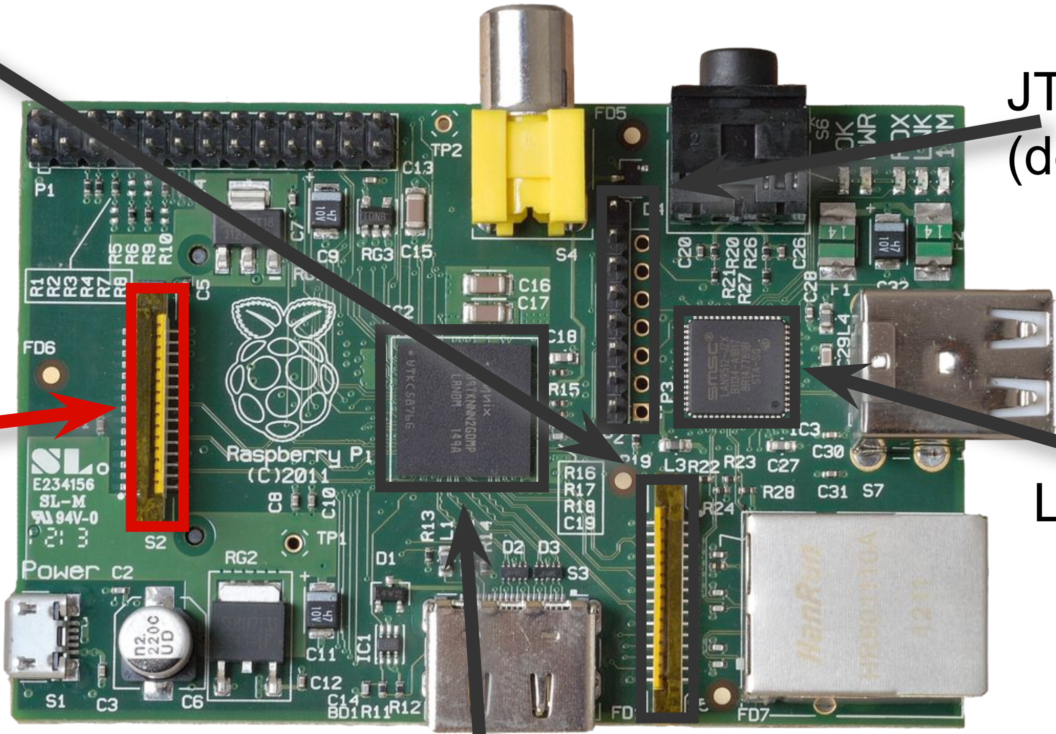
Internals

CSI
(camera interface)

JTAG
(debug ports)

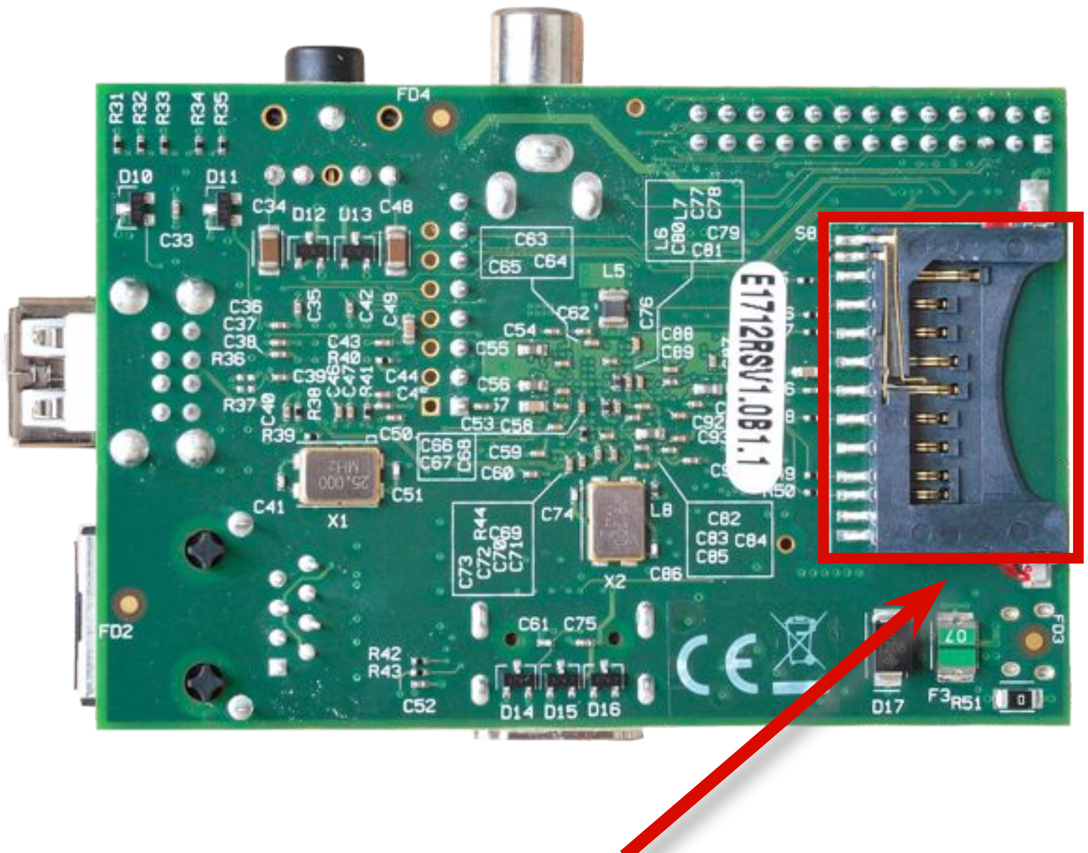
DSI
(display interface)

LAN Controller



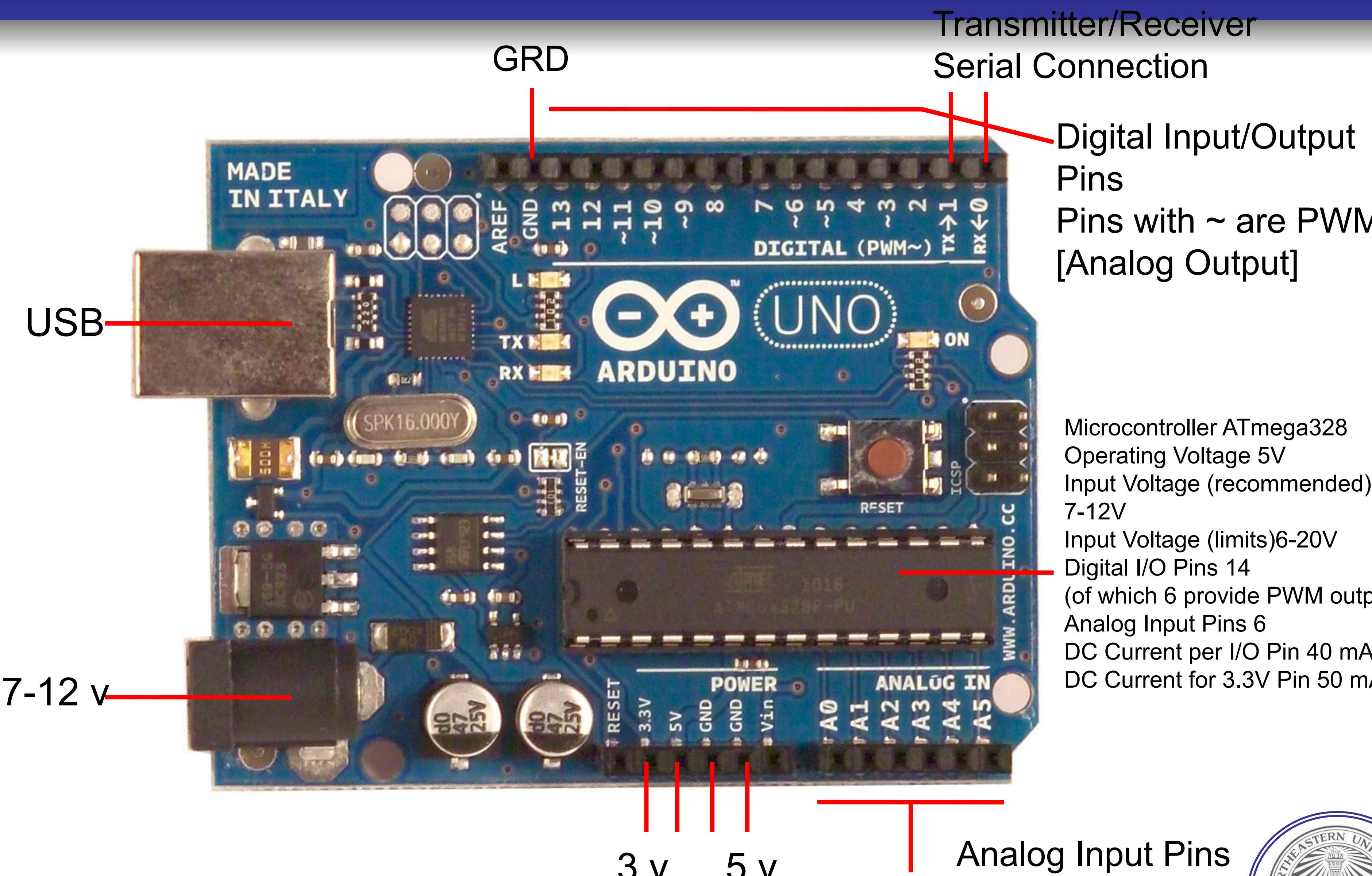
SOC (System On a Chip)
Broadcom BCM2835 700Mhz & 256Mb / 512Mb RAM

Storage



SD Card Slot
(supports SD cards up to 32GB)

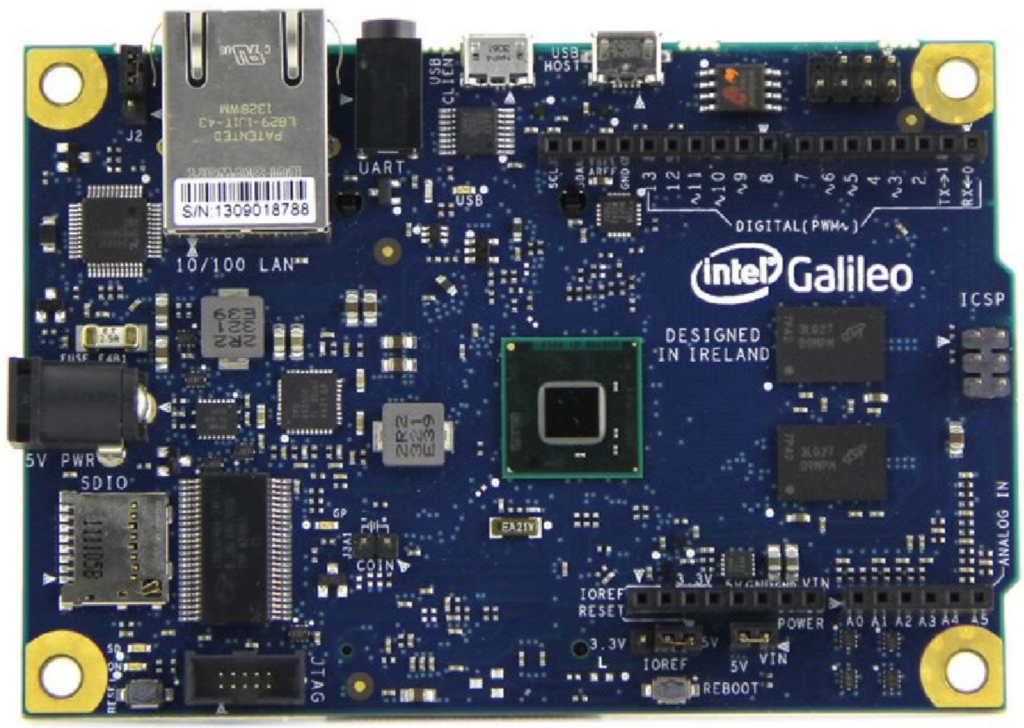
Arduino UNO



Microcontroller ATmega328
Operating Voltage 5V
Input Voltage (recommended) 7-12V
Input Voltage (limits)6-20V
Digital I/O Pins 14
(of which 6 provide PWM output)
Analog Input Pins 6
DC Current per I/O Pin 40 mA
DC Current for 3.3V Pin 50 mA

Intel Galileo

- ➢ An Arduino Board with an Intel Processor Inside
- ➢ Intel Quark Processor (SoC)
- ➢ 32 bit Core clocked at 400MHz



Intel Edison

➢ SD-Card Size Platform with Quark Processor

Applications of WSNs

WSNs for 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

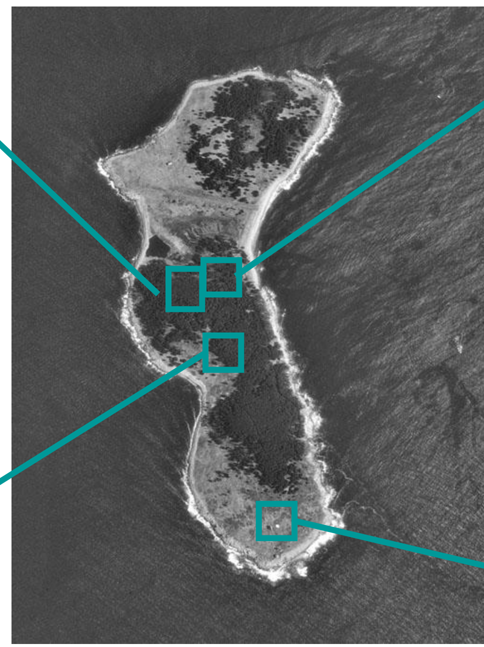
- Intrusion detection (mine fields)
- Detection of firing gun (small arms) location
- Chemical (biological) attack detection
- Targeting and target tracking systems
- Enhanced navigation systems
- Battle damage assessment system
- Enhanced logistics systems

WSNs for 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

Great Duck Island

http://www.greatduckisland.net Great Duck Island in Maine
Beaming back raw data about conditions of burrows and island's microclimate



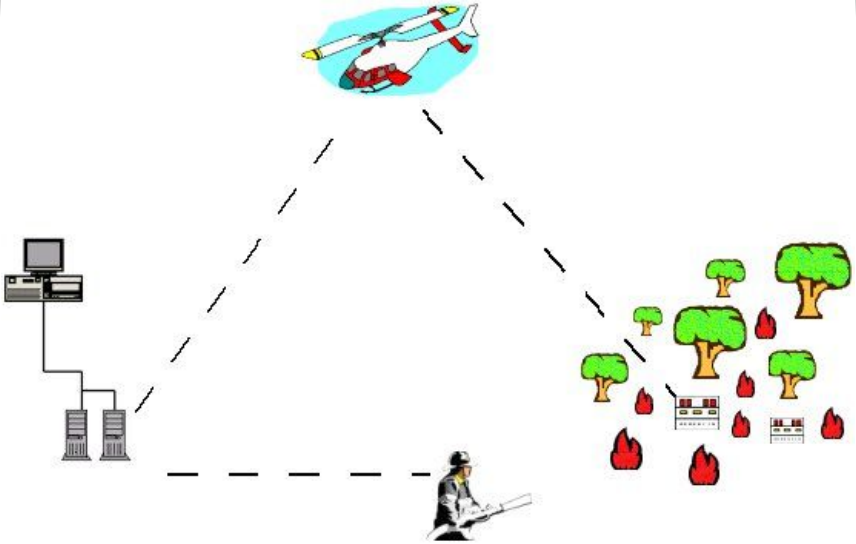
Forest Fire Detection: Firebug

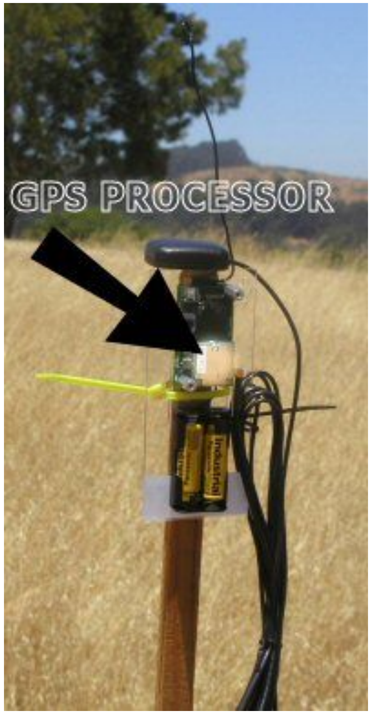
http://firebug.sourceforge.net/

- 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: Columbia River

WSNs for 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

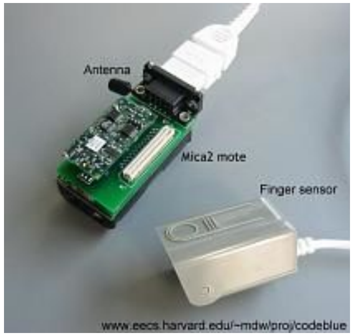
CodeBlue: WSNs for Medical Care

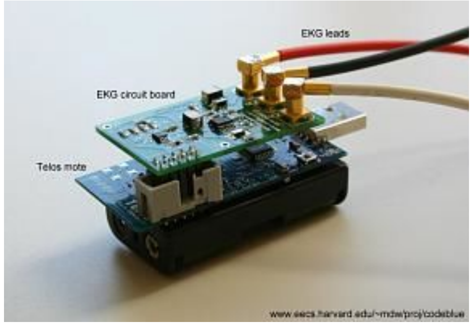
http://www.eecs.harvard.edu/~mdw/proj/codeblue

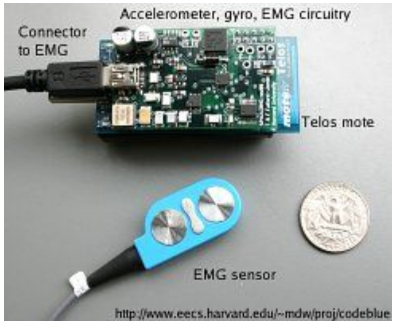
- NSF, NIH, U.S. Army, Sun Microsystems and Microsoft Corporation
- Motivation - Vital sign data poorly integrated with pre-hospital and hospital-based patient care records

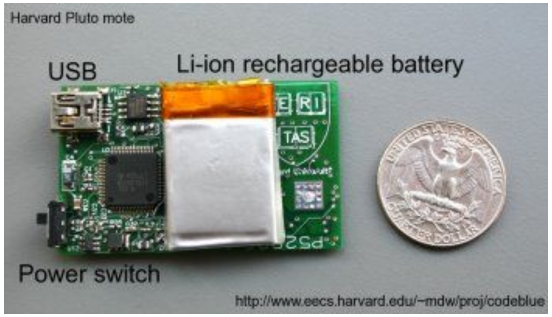
CodeBlue: WSNs for Medical Care

- 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)

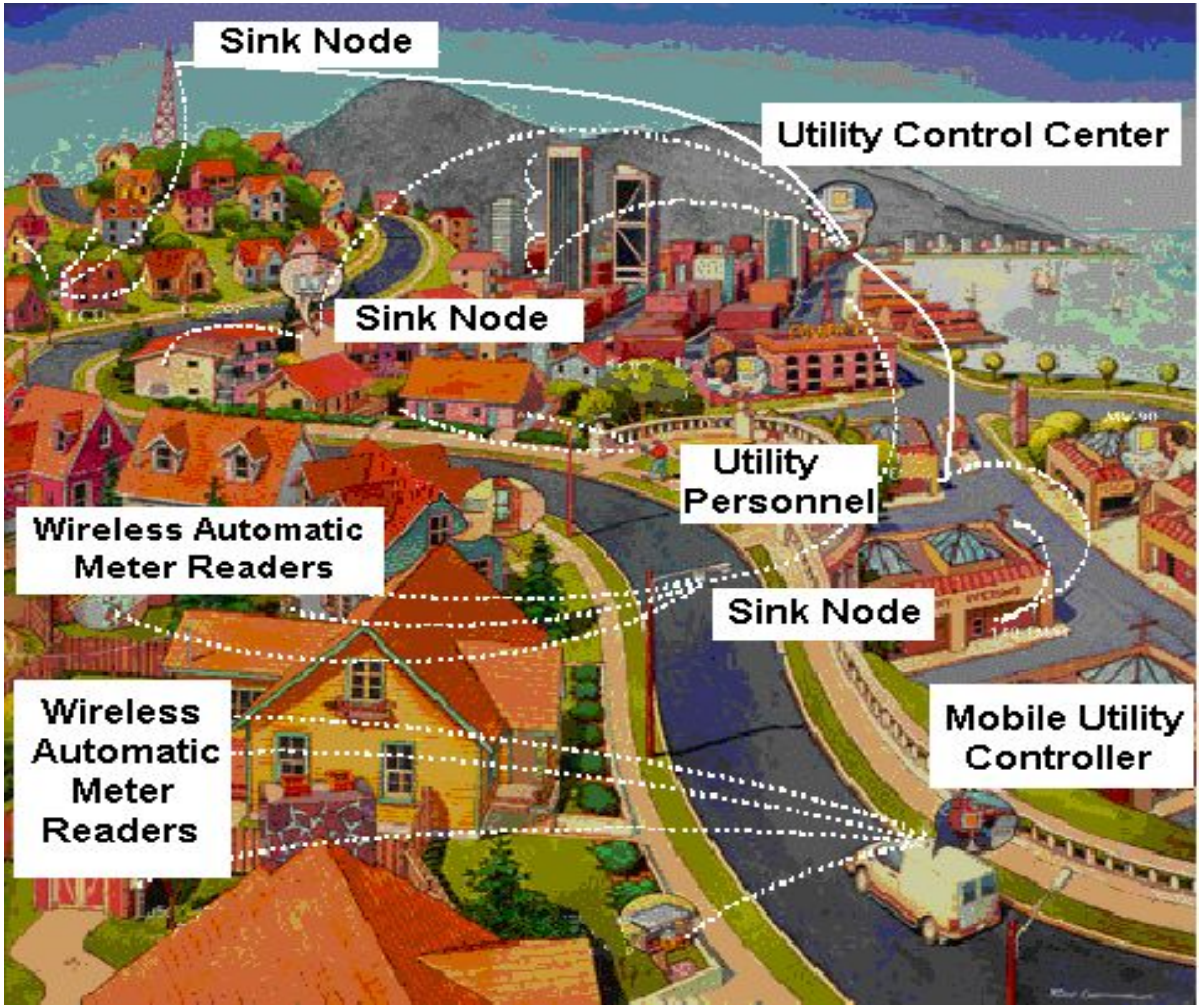
Further Applications

- 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

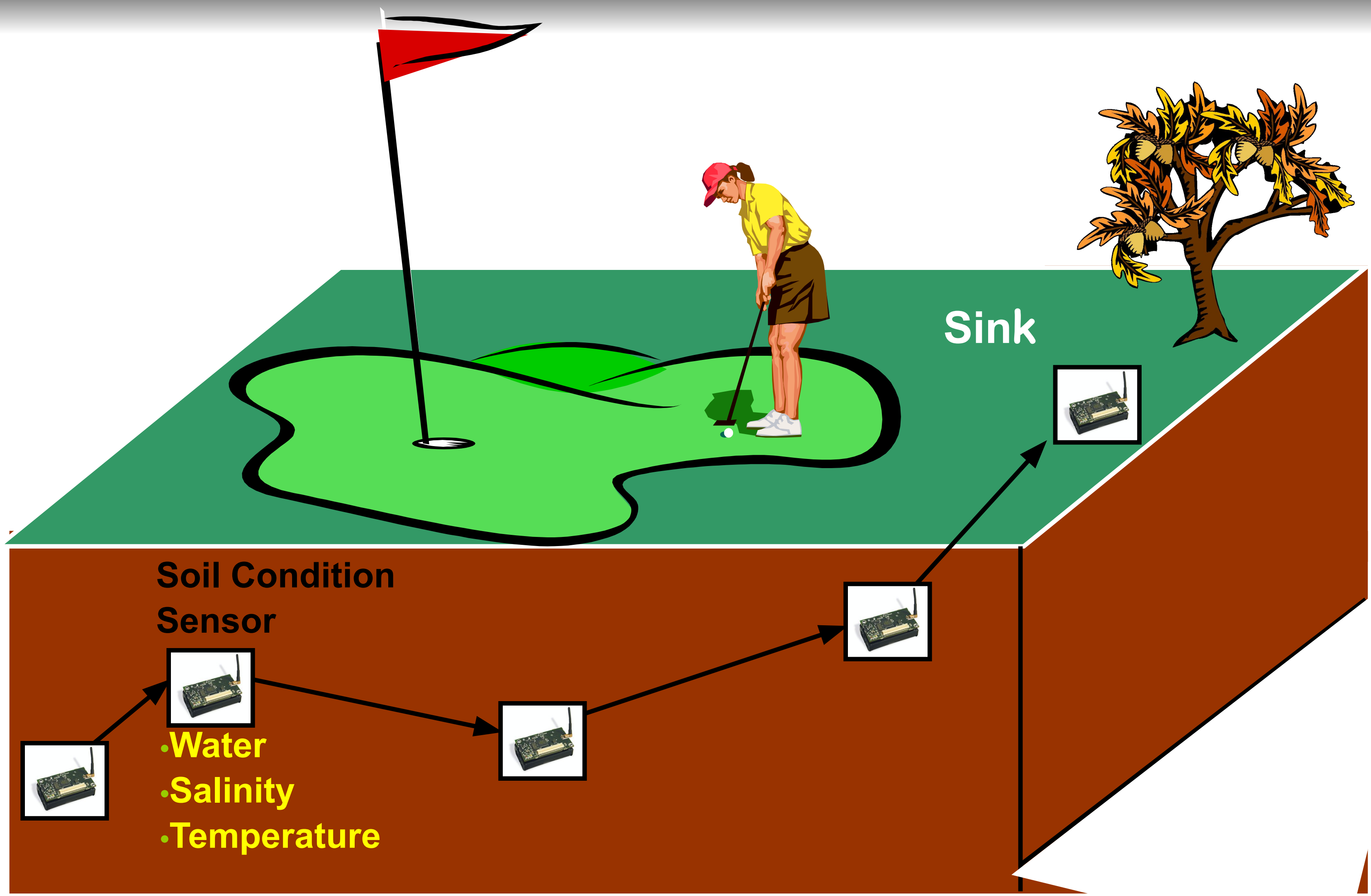
Wireless Automatic Meter Reading (WAMR)



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

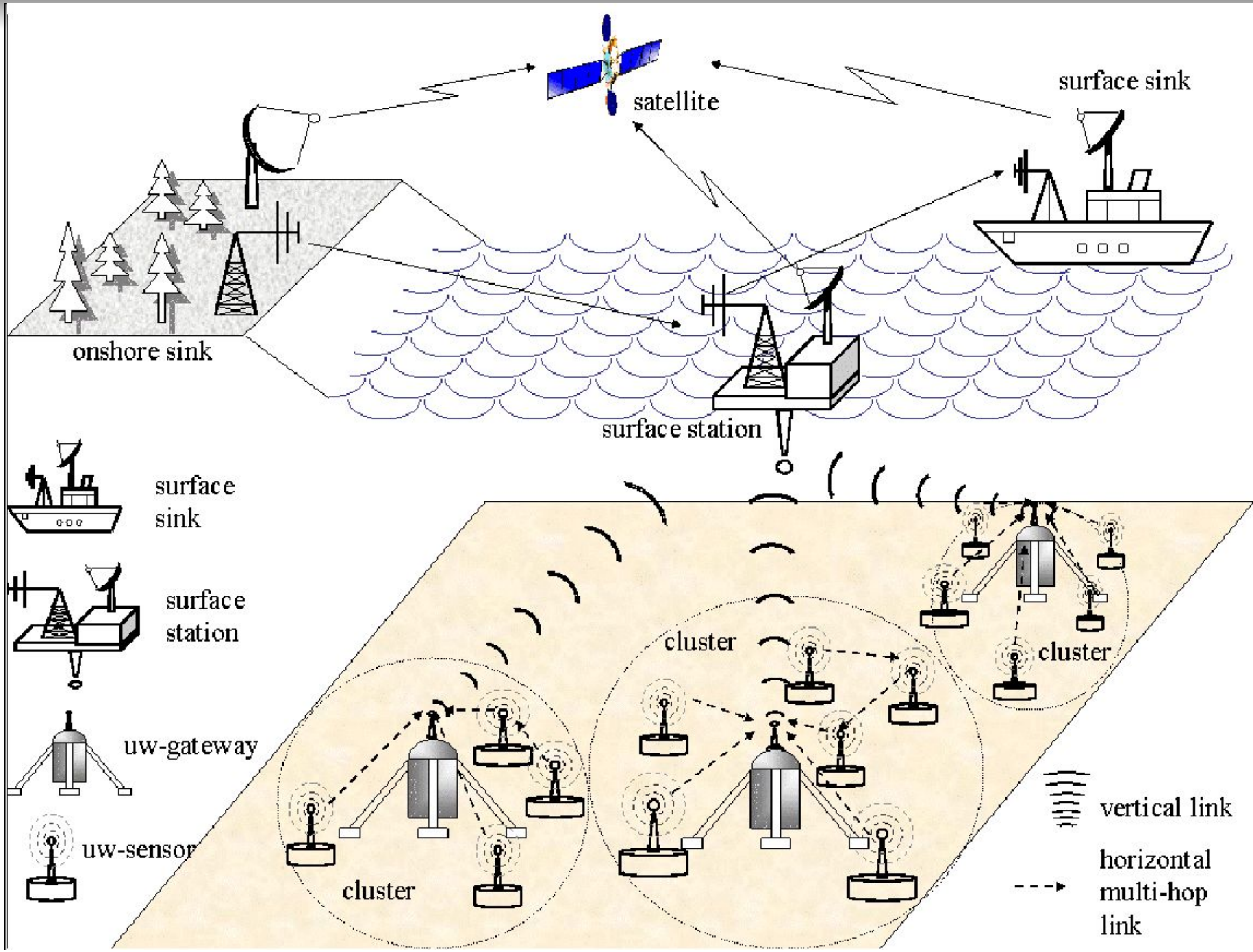


I.F. Akyildiz and Erich Stuntebeck, “Wireless Underground Wireless Sensor Networks: Research Challenges”, Ad Hoc Networks (Elsevier) Journal, Nov 2006

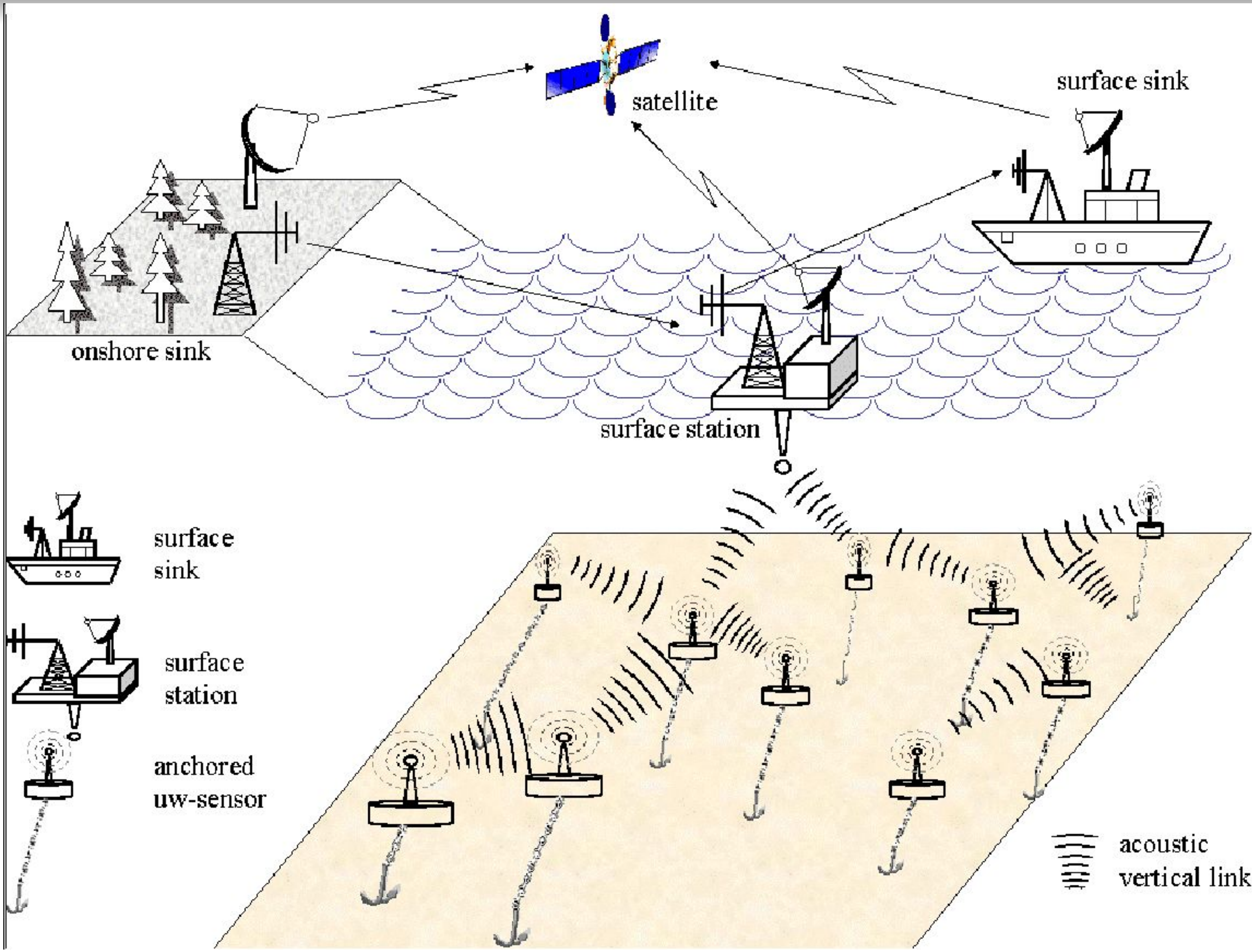
UGSN Applications

- Soil condition monitoring for agriculture, landscaping, and sports field maintenance
- Toxic substance monitoring near wells and aquifers
- Earthquake and landslide prediction and monitoring
- Security – underground pressure sensors can be used to detect intruders
- Coal Mines, Diamond Mining
- Golf Courts
- Locating people in a collapsed building
- Monitoring structural health (sensors within beams)

Underwater Sensor Networks



Three-dimensional Architecture



Buoys (Surface Stations / Sinks)

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/

DART (Deep-ocean Assesment and reporting of Tsunamis)

http://nctr.pmel.noaa.gov/

Spread Spectrum Modem

http://www.dspcomm.com/

Precision Marine Geodetic Systems

http://www.link-quest.com/

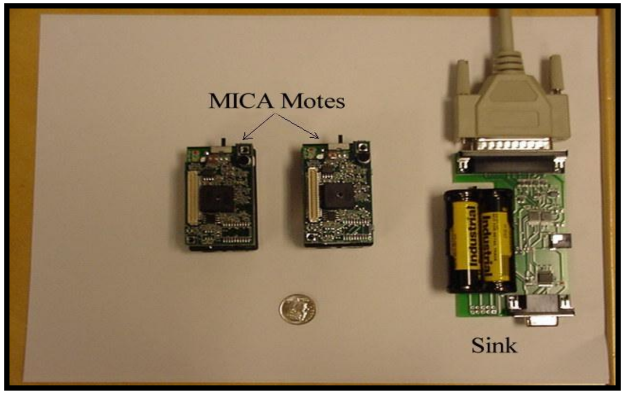
Acoustic Transponders

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 kbps (max)
Transmit Power	0.75 mW
Radio Range	100 feet
Power	2 x AA batteries

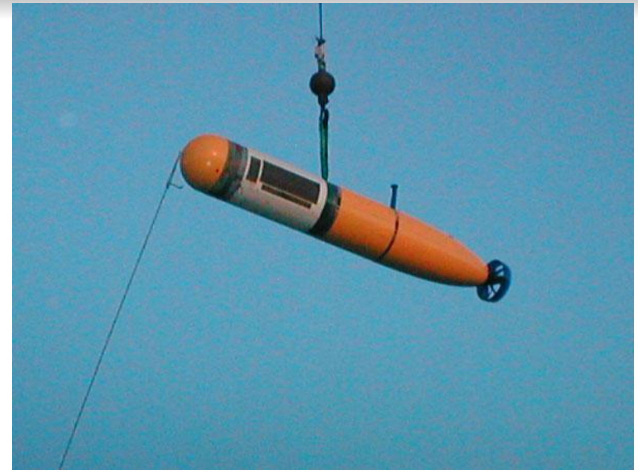
Underwater Acoustic Modem	Short-range	Medium-range
Acoustic Frequency	27- 45 kHz	54-89 kHz
Data Rate	7 kbps	14 kbps
Transmit Power	1 W	6 W
Receive Power	0.75 W	1 W
Sleep Power	8 mW	12 mW
Radio Range	1000 feet	3000 feet



Autonomous Underwater Vehicles (AUVs)

Caribou, by Bluefin Robotics Corporation, is 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
- development of concurrent mapping and localization techniques



Different sensors are integrated in the Bluefin AUV:

- Doppler Velocity Logs
- Acoustic Doppler Current Profilers
- Conductivity and Temperature
- Fluorometer
- Li-Cor PAR sensor
- Inertial Navigation Systems
- Attitude Heading Reference
- Marine Global Positioning Systems
- Depth Gauges

UWSN Applications

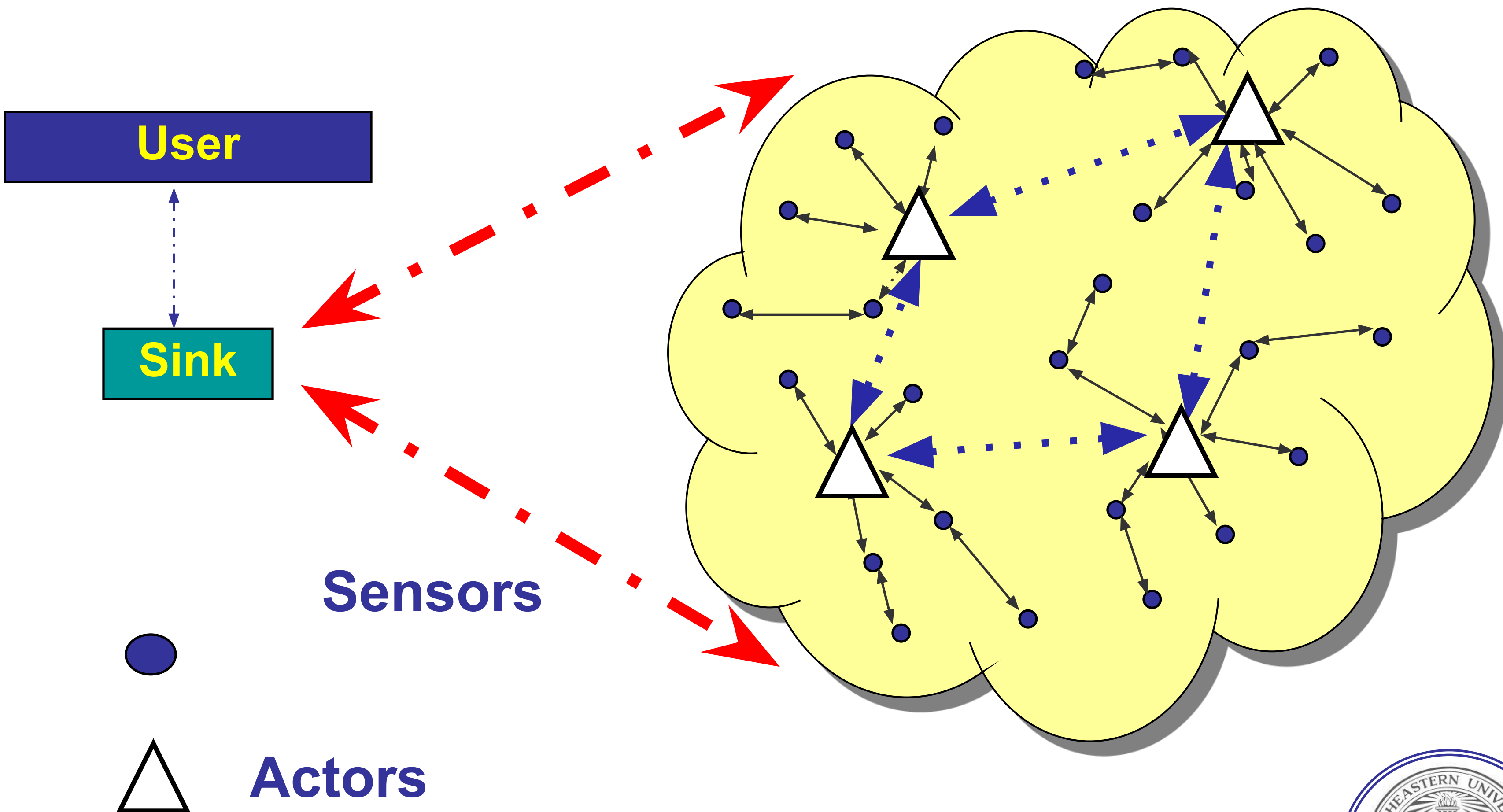
- Ocean Sampling Networks
  - Networks of sensors and Acoustic Underwater Vehicles (AUV) for cooperative adaptive sampling of the ocean environment
- Pollution Monitoring and other environmental monitoring (chemical, biological)
  - Monitoring of ocean currents and winds, detecting climate change, understanding human activities on marine ecosystems
- Disaster Prevention
  - Sensor networks that measure seismic activity from remote locations and provide tsunami warnings to coastal areas
- Assisted Navigation
  - Sensors can be used to locate dangerous rocks or shoals in shallow waters, mooring positions, submerged wrecks
- Distributed Tactical Surveillance
  - AUVs and fixed underwater sensors can monitor areas for surveillance, reconnaissance, targeting and intrusion detection
- Mine Reconnaissance
  - Multiple AUVs with acoustic and optical sensors can perform rapid environmental assessment and detect mine like objects

What are the challenges in **Underwater WSNs** and **Underground WSNs?**

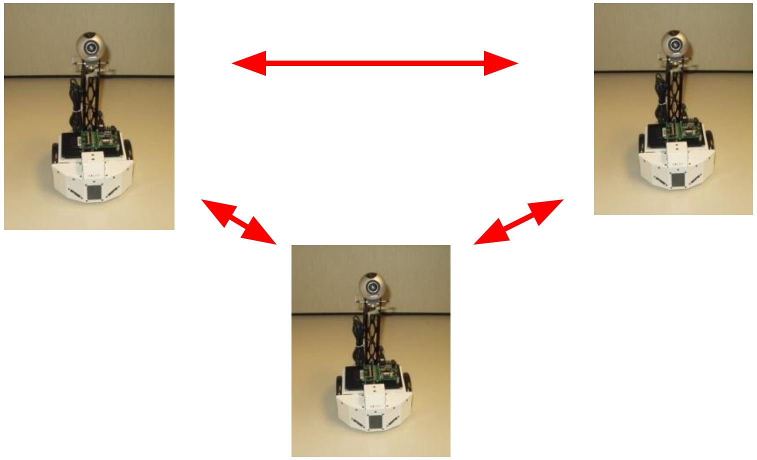
Wireless Sensor and Actor Networks

Wireless Sensor and Actor Networks

[1] I.F. Akyildiz and I. H. Kasimoglu, *"Wireless Sensor and Actor Networks: Research Challenges,"* Ad Hoc Networks Journal (Elsevier), pp.351-367, Oct. 2004.



Actors



Networked robots

pan/tilt cameras, water sprinklers, moving arms

Autonomous Underwater Vehicles (AUVs)

Unmanned aerial vehicles (UAVs)

Wireless Sensor and Actor Networks (WSAN)

- Increased need for automation
  - Smart houses
  - Industrial environments
  - Surveillance

- Sensor-driven automated interaction with the environment

A wireless Internet of sensors and actors will surround our daily lives

WSAN Applications

- **Transport and parking solutions**
  - Optimizing vehicular flow in congested areas
  - Improve mobility in the urban area by finding free parking spots for drivers willing to park
- **Environmental Applications**
  - Detecting and extinguishing forest fire
- **Microclimate control in buildings**
  - Distributed heating, ventilating, and air conditioning (HVAC)

WSAN Applications

- **Agricultural Applications**
  - Monitor the humidity of a terrain and control irrigation or chemical dispensers
- **Distributed Robotics & Sensor Network**
  - (Mobile) robots dispersed throughout a sensor network
  - Surveillance, monitoring, plume detection
  - Pursuit-evasion game
  - Rescue missions in disaster areas

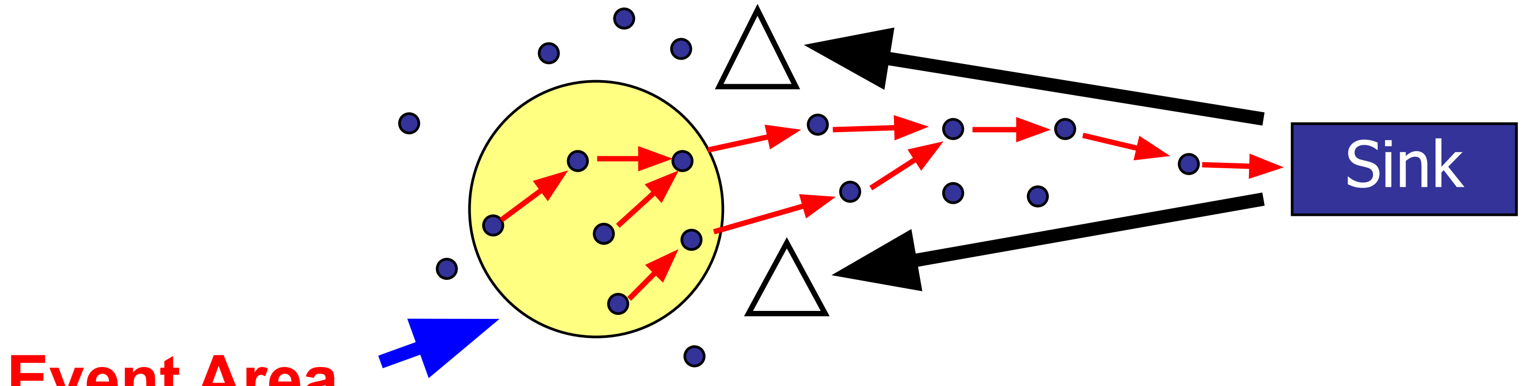
WSANs vs. Wireless Sensor Networks

- **Real-Time Requirements for Timely Actions**
  - Rapidly respond to sensor input (e.g., fire application)
  - To perform right actions, sensor data must be valid at the time of acting

- **Heterogeneous Node Deployment**
  - Sensors → ***Densely deployed***
  - Actors → ***Loosely deployed***

- **Coordination Requirements**
  - **Sensor-Actor Coordination**
  - **Actor-Actor Coordination**

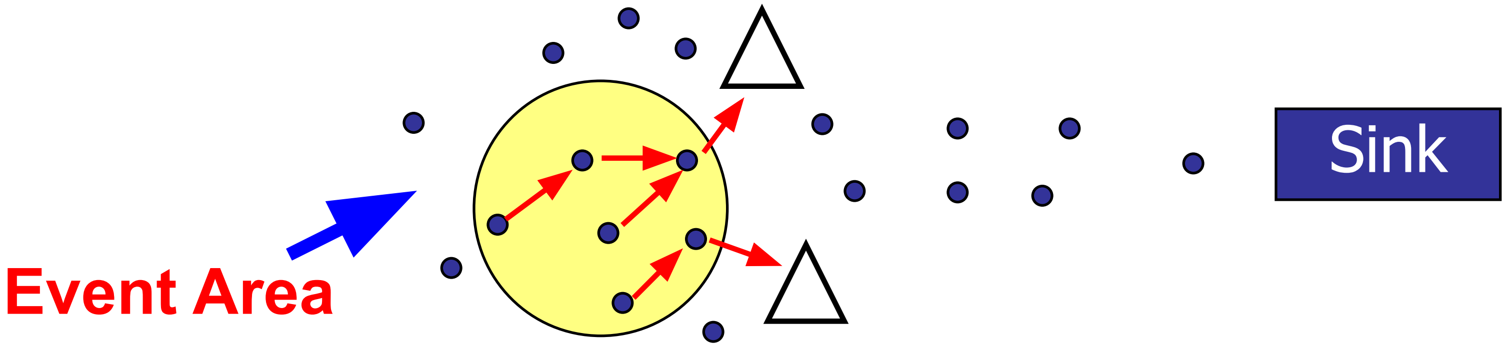
Semi-Automated Architecture



Sensors → Sink → Actors

- No sensor-actor and actor-actor coordination needed
- Similar to the conventional WSN architecture

Automated Architecture



- *Sensors → Actors*
- Localized information exchange
- Low latency, energy consumption
- *Distributed sensor-actor and actor-actor coordination required*

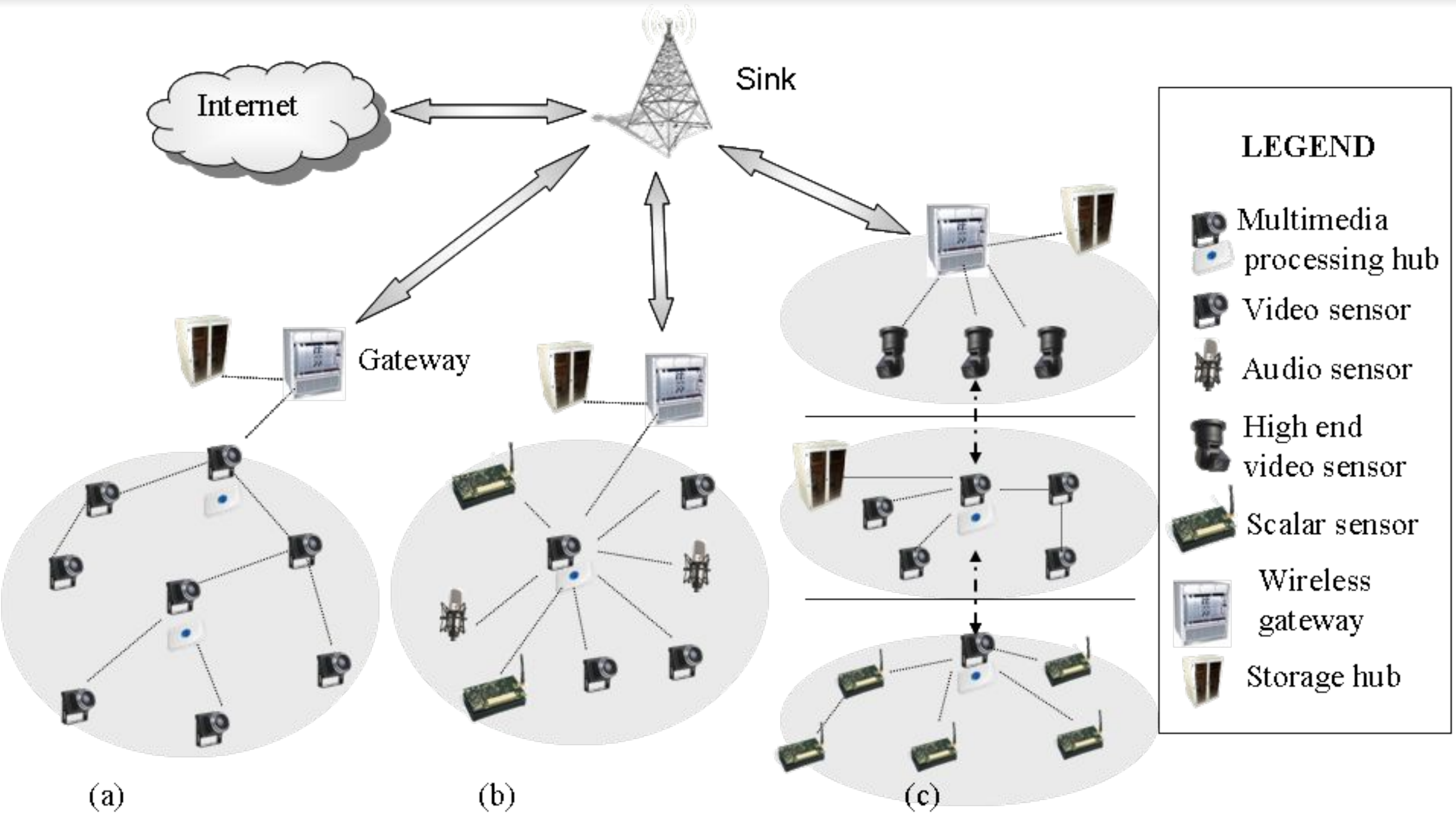
Wireless Multimedia Sensor Networks

Wireless Multimedia Sensor Networks

- Networks of wirelessly interconnected devices that allow retrieving video and audio streams, still images, and scalar sensor data

- Able to store, process in real-time, correlate and fuse multimedia data originated from heterogeneous sources

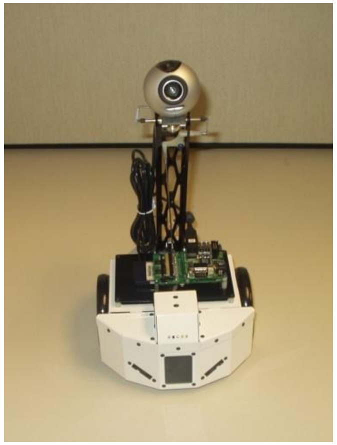
Wireless Multimedia Sensor Networks



(a)
Single-tier flat,
homogeneous sensors,
distributed processing,
centralized storage

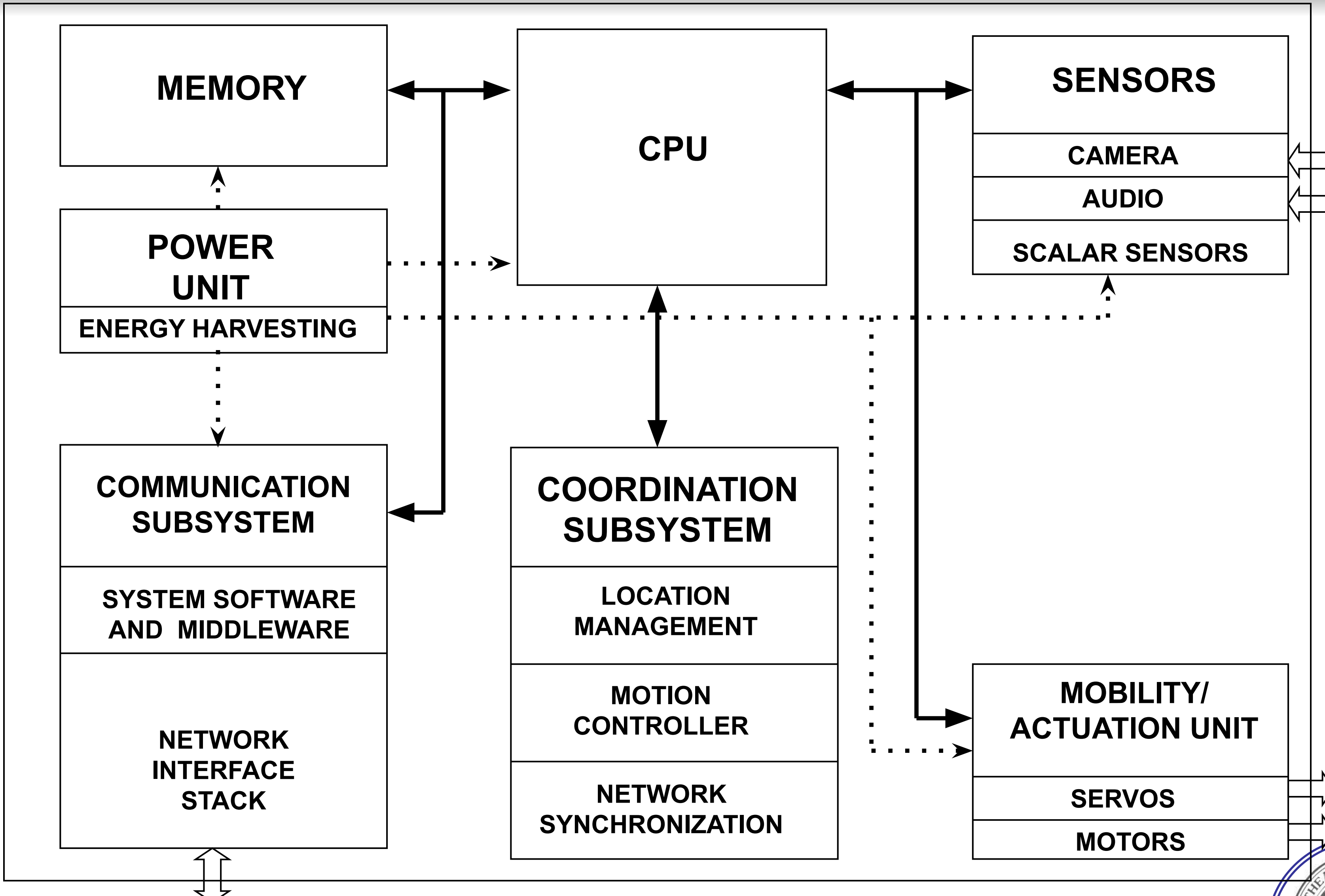
(b)
Single-tier clustered,
heterogeneous sensors,
centralized processing,
centralized storage

(c)
Multi-tier,
heterogeneous sensors,
distributed processing,
distributed storage



[7] I.F. Akyildiz, T. Melodia, K. Chowdhury, "A Survey on Wireless Multimedia Sensor Networks", Computer Networks (Elsevier), March 2007.

Organization of a Multimedia Sensor

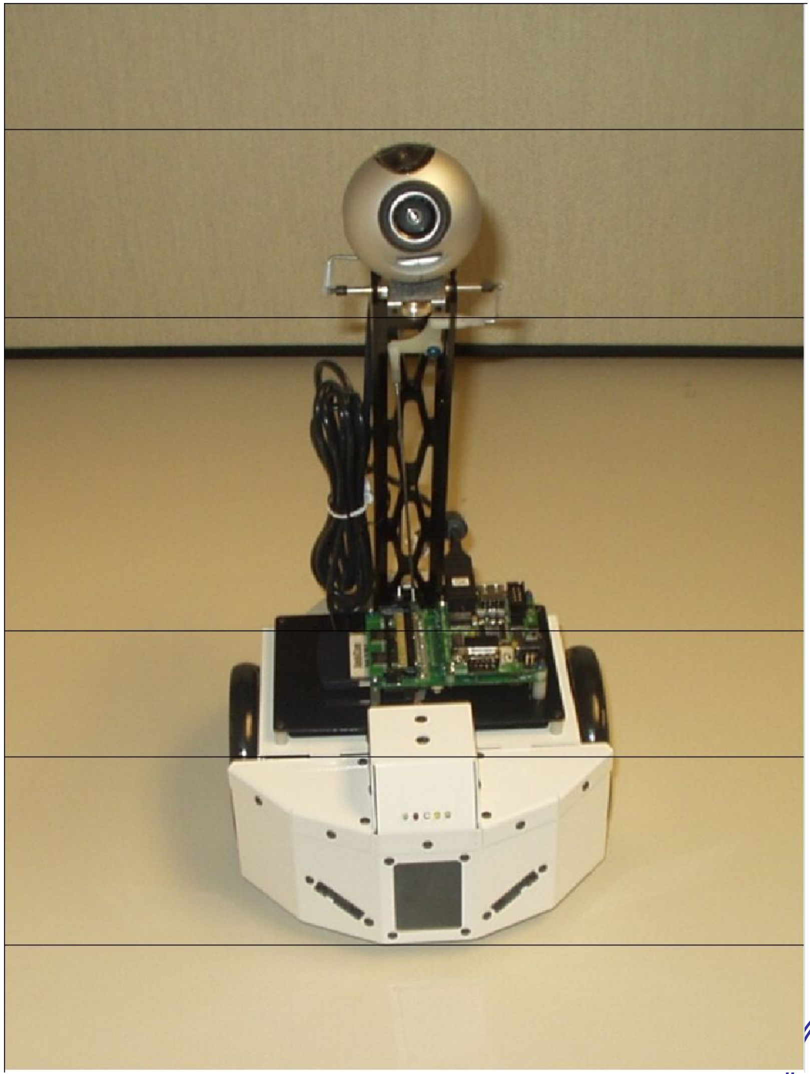


Video Sensors

- Stargate board interfaced with a medium resolution camera
- Stargate hosts an 802.11 card and a MICAz mote that functions as gateway to the sensor network

Stargate + Garcia = Multimedia Actor

- Acroname GARCIA
- Mobile
- Controlled by a Stargate board
- Stargate also provides 802.11 as well as ZigBee interfaces
- Onboard IR Sensors
- Pan-tilt Camera
- Connects to a MICAz network
- Onboard Linux Operating System



Multimedia Actor + Sensors

- GARCIA deployed on the sensor test-bed
- It acts as a mobile sink, and can move to the area of interest for closer visual inspection
- It can also coordinate with other actors and has built-in collision avoidance capability

Slide Credits

- Most slides in this course are readapted from lecture slides from Prof. Melodia (NEU), Prof. Ian Akyildiz (Georgia Insitute of Technology) and Prof. Holger Karl (University of Paderborn)

Questions?