IPP HURRAY!

www.hurray.isep.ipp.pt

enabling ubiquitous computing and cyber-physical systems with wireless sensor/actuator networks

what is at stake?

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FCT Research Unit 608

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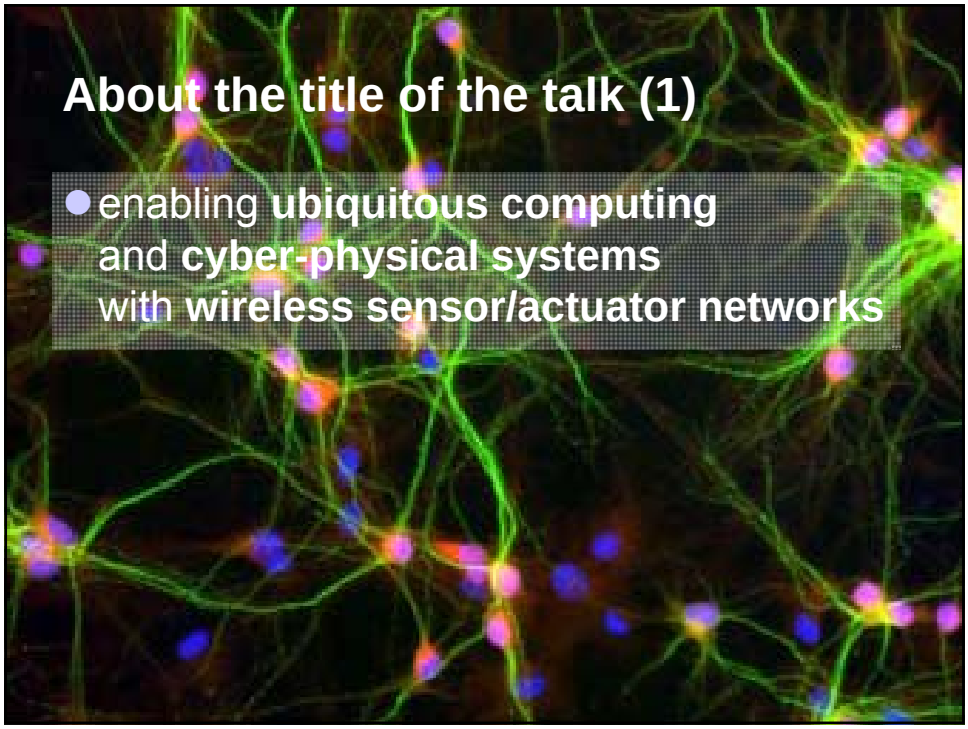
Who should you blame…

- I am here due to:
  - Peppe (decided to invite Eduardo)
  - Eduardo (decided to delegate to me)
  - My wife and kids (authorized me to come)
  - My parents (decided to have a third child)
- And now you have to stand me ☺
- Credits (i.e. complaint to):
  - Anis Koubaa, Nuno Pereira, Ricardo Severino, Shashi Prabh, Petr Jurcik, Bjorn Andersson



About the title of the talk (2)

- what is "**ubiquitous computing**"?
  - **"ubiquitous"**
    - from Latin ***ubique***, everywhere
    - being everywhere at once: omnipresent.
    - seeming to appear everywhere at the same time.
  - **"ubiquitous computing"**
    - is a post-desktop model of human-computer interaction in which **information processing has been thoroughly integrated into everyday objects and activities**;
    - **opposed to the desktop paradigm**, in which a single user consciously engages a single device for a specialized purpose;
    - someone "using" ubiquitous computing engages **many computational devices and systems simultaneously**, in the course of ordinary activities, and **may not necessarily even be aware to be doing so**.

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About the title of the talk (2)

- what are "**cyber-physical systems**"?
  - cyber-physical systems (CPS) are computing systems that **do not only compute abstract quantities**; they are also **tightly integrated and interacting with their physical environment**, by taking sensor readings and acting on it.
  - integration of physical processes and computing is not new; **embedded systems** have been since a long time in place to denote systems that combine physical processes with computing.
  - **The revolution will come from massively networking embedded computing devices**

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About the title of the talk (3)

- what are "**wireless sensor/actuator networks**"?
  - **"wireless (communication)"**
    - "wireless communication" is the transfer of information over a distance without the use of electrical conductors or "wires" using some form of energy, e.g. radio frequency (RF), infrared light (IR), laser light, visible light, acoustic energy
  - **"sensor"**
    - a sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument, e.g. thermocouple, strain gauge;
    - sensors tend to be manufactured on a microscopic scale (MEMS technology)
  - **"actuator"**
    - devices which transform an input signal (mainly an electrical signal) into motion
    - e.g. electrical motors, pneumatic actuators, hydraulic pistons, relays, electrovalves, piezoelectric actuators, buzzers, lamps
  - **"network"**
    - a "computer network" is a group of interconnected computers

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About the title of the talk (5)

- **"wireless sensor network"**
  - **A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions**, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations.
  - originally motivated by military applications such as battlefield surveillance; now used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, and traffic control
- "**sensor node**"
  - a sensor node (a.k.a. "mote"), is a node in a wireless sensor network that is capable of performing some **processing, gathering sensory information and communicating** with other connected nodes in the network
  - in addition to **one or more sensors**, each node in a sensor network is typically equipped with a **radio transceiver** or other wireless communications device, a small **microcontroller**, and an **energy source**, usually a battery.

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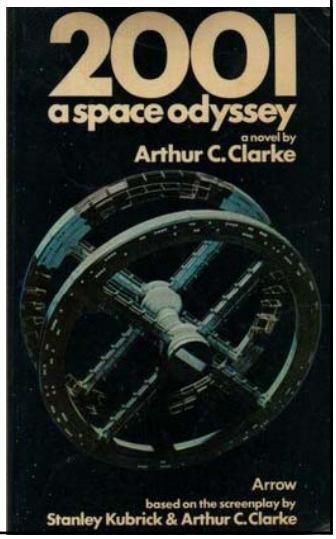
About the title of the talk (4)

- So,
  "**wireless sensor/actuator networks**"
  are
  networking infrastructures
  for
  "**ubiquitous computing** and **cyber-physical systems**"

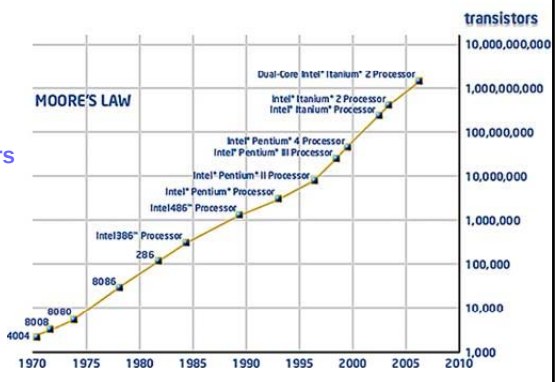
Envisioning ICTs future (1)

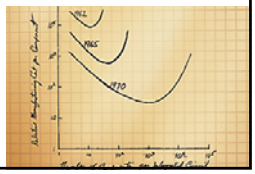
- Imagination is the limit…
  - **Arthur C. Clarke's Laws** (1917-2008):
    - "When a distinguished but elderly scientist states that **something is possible** he is almost certainly **right**. When he states that **something is impossible**, he is very probably **wrong**"
    - "The only way of **discovering the limits of the possible** is to venture a little way past them into the impossible"
    - "Any sufficiently **advanced technology** is indistinguishable from **magic**"



Envisioning ICTs future (2)

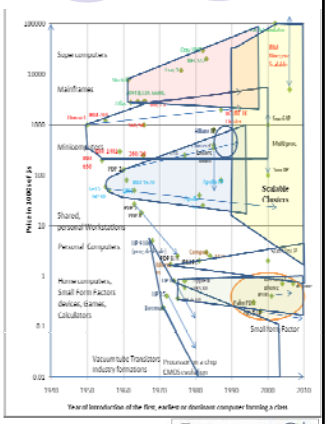
- and ICTs trend may help…
  - Gordon **Moore's Law** (born 1929):
    - "The **number of transistors** that can be inexpensively placed on an integrated circuit is **increasing exponentially**, doubling approximately every two years" (paper from **1965**)
    - In **2005**, he stated that **the law cannot be sustained indefinitely** and noted that transistors would eventually reach the **limits of miniaturization** at atomic levels

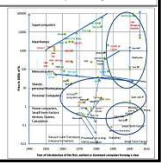




Envisioning ICTs future (3)

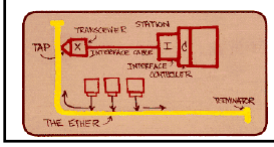
- and ICTs trend may help…
  - Gordon **Bell's Law** (born 1934)
    - "Roughly every decade a new, lower priced computer class forms based on a new programming platform, network, and interface resulting in new usage and the establishment of a new industry" (paper from 1972)
    - "**As of 2005**, the computer classes include:
      - mainframes (**1960s**)
      - minicomputers (**1970s**)
      - PCs and workstations evolving into a network enabled by Local Area Networking (**1980s**)
      - web browser client-server structures enabled by the Internet (**1990s**)
      - small form-factor devices such as cell phones and other cell phone sized devices (c. 2000)
      - wireless sensor networks, aka motes (c. **>2005**)
      - home and body area networks **(> 2010**)"



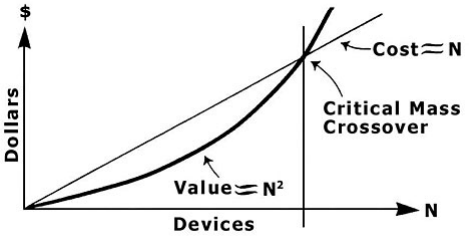


Envisioning ICTs future (4)

- and ICTs trend may help…
  - **Robert Metcalfe's Law** (born 1946):
    - "the value of a network grows as the square of the number of its users"

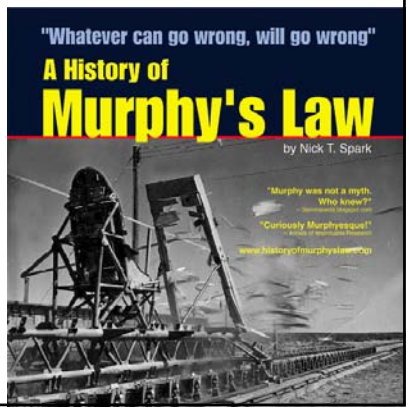


The Systemic Value of Compatibly Communicating Devices Grows as the Square of Their Number:



Envisioning ICTs future (5)

- but be very careful with the consequences…
  - **Edward Murphy's Law** (1918-1990):
    - "If there are two or more ways to do something, and one of those ways can result in a catastrophe, then someone will do it" (original version, c. 1952)

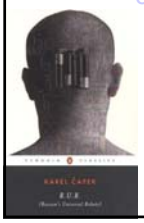


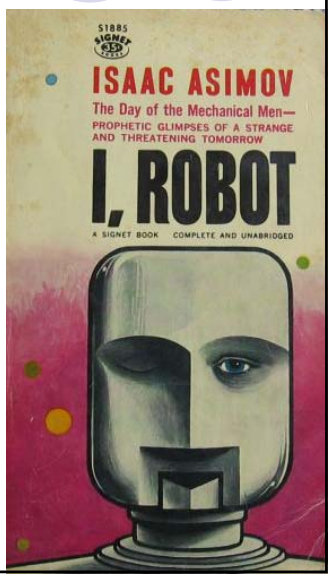
Envisioning ICTs future (6)

- but be very careful with the consequences…
  - **George Orwell's "vision"** (1903-1950):
    - **"BIG BROTHER IS WATCHING YOU"** ('1984' book, pub. 1949)
    - vision of all-knowing governments which uses **pervasive and constant surveillance** of the populace

Envisioning ICTs future (7)

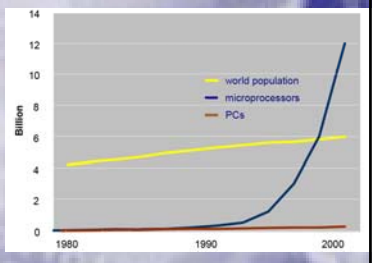
- but be very careful with the consequences…
  - **Isaac Asimov's Laws** (1920-1992):
    1. "a **robot may not injure a human** being or, through inaction, allow a human being to come to harm"
    2. "a **robot must obey orders** given to it by a human being except where such orders would conflict with the first law"
    3. "a **robot must protect its own existence** as long as such protection does not conflict with the first or second law"

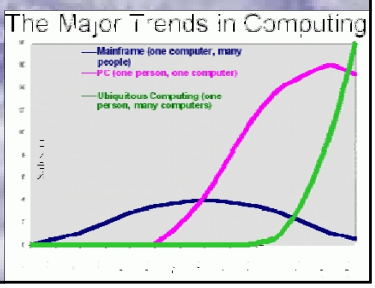




Envisioning ICTs future (8)

- **so do not forget…**
  - **Mark Weiser** (1952-1999):
    - **principles of ubiquitous computing**:
      - "the purpose of a computer is to **help you** do something else; the best computer is a quiet, **invisible servant**"
      - "the more you can do by intuition the smarter you are; **the computer should extend your unconscious**"
      - "technology should create **calm**"
    - major trends in computing
      - "ubiquitous computing names the third wave in computing, just now beginning. First were mainframes,…. Now we are in the personal computing era, …. **Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives**"





[Mark Weiser, "The Computer for the 21st Century" - Scientific American Special Issue on Communications, Computers, and Networks, September, 1991]

Prospective applications (1)

- "typical":
  - environmental monitoring
  - ambient intelligence (homes, public spaces)
  - critical physical infrastructures (e.g. bridges, tunnels) monitoring
  - homeland security
  - utilities transportation systems (e.g. electrical, gas, water, oil)
  - factory automation and process control in large plants
  - domotics (home/building automation)
  - park/forest hazard monitoring
  - sports/religious/cultural events monitoring
  - disaster management (e.g. search&rescue in buildings/mines)
  - health care monitoring/management (e.g. hospitals)
  - intelligent transportation systems (e.g. highways, trains, metro)
  - the "Internet of Things"
  - games
  - participatory sensing

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Prospective applications (2)

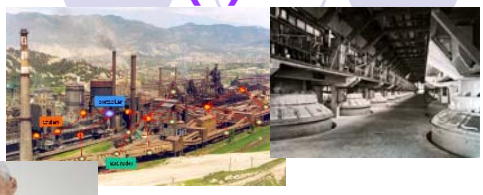
- Habitat Monitoring

- Infrastructure Monitoring

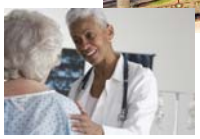
- Smart Farming and Irrigation

Prospective applications (3)

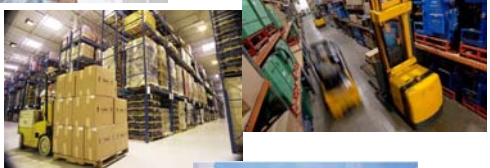
- Industrial Plant Monitoring



- Health Monitoring



- Asset Management



- Target Tracking

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Prospective applications (4)

- Ex. 1: smart dust into my body?
  - to monitor (eventually to correct):
    - operation of main organs, blood, urine, muscles
    - evolution of specific diseases (cancer, infections)
    - prosthesis (namely correct absorption)
  - either in
    - punctual fashion
      - check-up, diagnosis of specific disease
      - monitoring top athletes
    - continuous fashion
      - pregnancy, pre/post-natal babies, premature babies
      - people with transient or permanent diseases
      - elderly people (trend in upcoming society)

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Prospective applications (5)

- Ex. 1: smart dust into my body? why?
  - continuous health monitoring leads to **improved quality of life**
    - "real-time" diagnosis of unknown problems
    - *pervasive* means more probability of detecting (otherwise unknown) problems
  - for people with **special needs**
    - pre and post-natal baby monitoring
    - elderly people: **the ageing society paradigm**
    - handicapped (physical/mental) people
    - sport professionals/amateurs

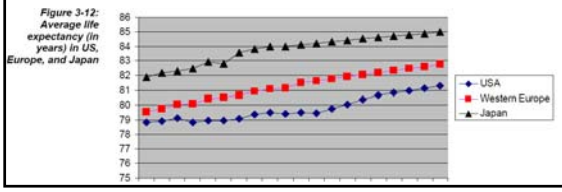
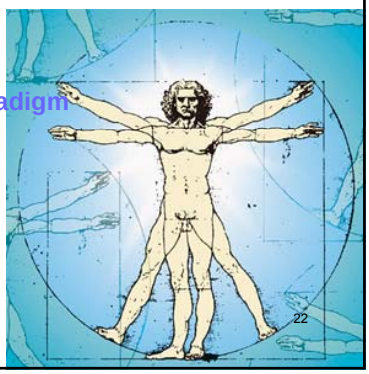


Figure 3-12: Average life expectancy (in years) in US, Europe, and Japan



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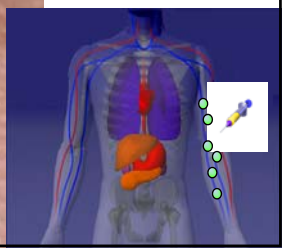
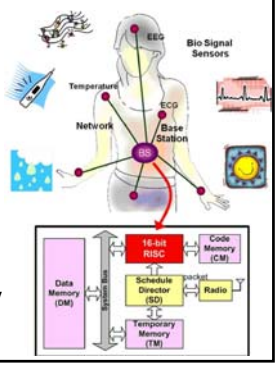
Prospective applications (6)

- Ex. 1: smart dust into my body? how?
  - sensors are (?) migrating from macro to microscopic scale
  - organic materials (as pace makers and other prosthesis)
  - introduced orally (pills), blood (injection), skin absorption
  - minimized functionality
    - minimum dedicated sensing
    - close to 0 (?) processing/memory (just info grab. and tx)
    - radically simplified communications
  - energy must be drained from human body (chemical, vibration, heat)
  - some limited corrective actions may be possible (by influencing body agents – e.g. cells)



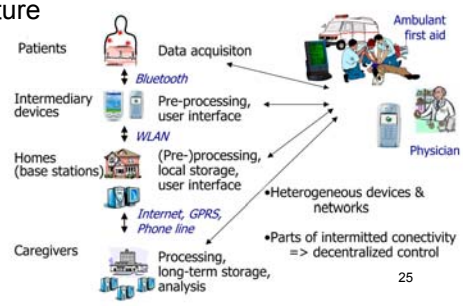
Prospective applications (7)

- Ex. 1: smart dust into my body? potential features
  - sensors can be
    - statically monitoring a specific parameter
    - sensor mobility can be useful
      - e.g. follow blood flow (for detecting arteriosclerosis drawing 3D map of channel obstruction)
  - **macroscopic nodes** may be needed due to
    - large-scale number of sensors (100s – 1000s)
    - sensor nodes huge limitations (processing, communication, energy)
  - located in strategic locations (skin, glasses, watch), forming one or more data sinks/clusters
  - more powerful processing/communication/energy capabilities



Prospective applications (8)

- Ex. 1: smart dust into my body? QoS requirements:
  - some organs/areas may be more critical than other
  - critical situations must be tackled (in real-time) according to their priority
- multi-tiered communication architecture
  - sensor/organ – cluster manager (macroscopic node) –
    - building/area – hospital/health care centre - …



Prospective applications (9)

- Ex. 2: big events management
  - WSN nodes embedded in participants
    - guidance/orientation/positioning/ tracking of participators
    - access control (depending on ticket price; special permissions – staff, handicapped, happy hours)
    - vital signals monitoring (due to queue waiting, riots, crowd smashing)
  - visitors to
    - exhibitions, concerts, religious events, sports events,…
  - QoS requirements
    - people in risk could be rescued
    - access violations could be punished

Some projects/deployments (1)

Great Duch Island

Observe the breeding behavior of the Leach's Storm Petrel.

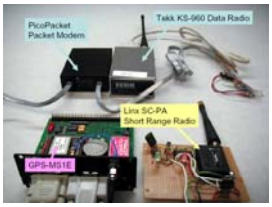
Goal: Develop a reliable and predictable sensor kit for this class of applications.

Wireless sensor networks for habitat monitoring (2002)
by Alan Mainwaring, Joseph Polastre, Robert Szewczyk, David Culler
http://www.intel-research.net/Publications/Berkeley/120520021024_43.pdf

Some projects/deployments (2)

ZebraNet

Observe the behavior of zebras, wild horses, lions, etc



Goal: Study the design tradeoffs in a mobile sensor network for this application class.

Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet. (2002)
by P. Juang, H. Oki, Y. Wang, M. Martonosi, L. S. Peh, and D. Rubenstein.

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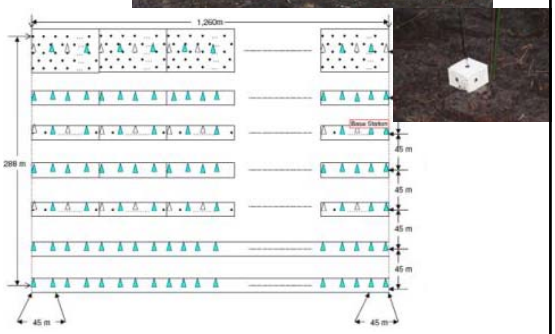
Some projects/deployments (3)

ExScal

Deployment of more than 1000 nodes.



Goal: Address the challenges in scaling to very large networks.

ExScal: Elements of an Extreme Scale Wireless Sensor Network (2005)
by Anish Arora, Rajiv Ramnath, Emre Ertin, Prasun Sinha, Sandip Bapat, Vinayak Naik, Vinod Kulathumani, Hongwei Zhang, Hui Cao, Mukundan Sridharan, Nick Seddon, Chris Anderson, Ted Herman, Nishank Trivedi, Chen Zhang, Romil Shah, Sandeep Kulkarni, Mahesh Aramugam, Limin Wang
http://cast.cse.ohio-state.edu/exscal/

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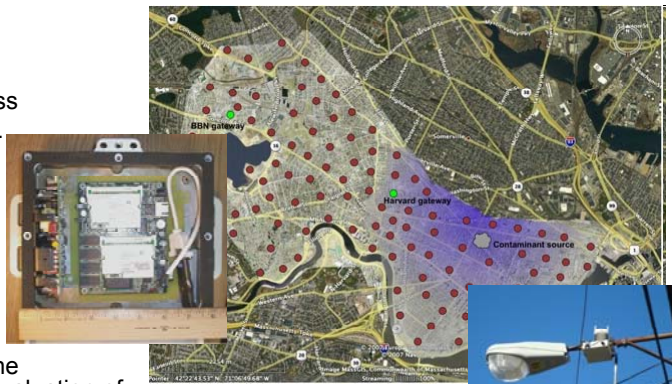
Some projects/deployments (4)

CitySense

Urban-scale wireless networking testbed.



Goal: Supporting the development and evaluation of novel wireless systems that span an entire city.

CitySense: An Urban-Scale Wireless Sensor Network and Testbed
by Rohan Murty; Geoffrey Mainland; Ian Rose; Atanu Roy Chowdhury; Abhimanyu Gosain; Josh Bers; Matt Welsh
http://www.citysense.net/

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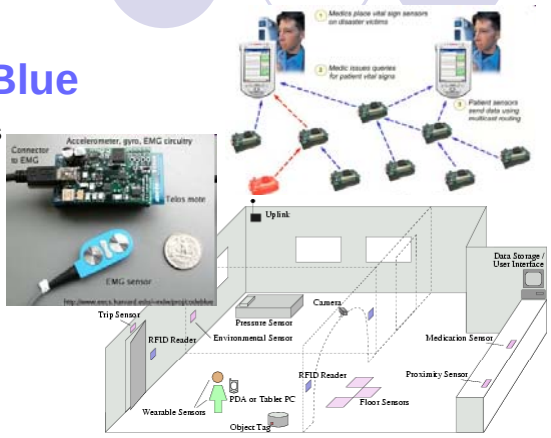
Some projects/deployments (5)

Alarm-Net, CodeBlue

Hardware/Software architectures for smart healthcare.



Goal: Explore the future of wireless sensor networks in medical applications.

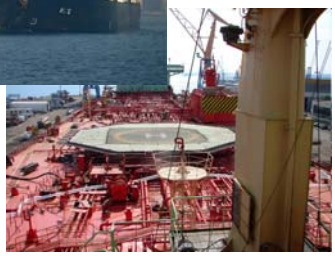
ALARM-NET: Wireless Sensor Networks for Assisted-Living and Residential Monitoring (2006)
by A. Wood, G. Virone, T. Doan, Q. Cao, L. Selavo, Y. Wu, L. Fang, Z. He, S. Lin, J. Stankovic
http://www.cs.virginia.edu/wsn/medical/

CodeBlue: An Ad Hoc Sensor Network Infrastructure for Emergency Medical Care (2004)
by David Malan, Thaddeus Fulford-Jones, Matt Welsh, Steve Moulton
http://fiji.eecs.harvard.edu/CodeBlue

Some projects/deployments (6)

The BP Experiment

Preventive Maintenance on an Oil Tanker in the North Sea.



Goal: test the use of sensor networks to support preventive maintenance

BP Preventive Maintenance Tanker Project
By Intel Research
http://www.intel.com/research/vert_manuf_prevmaint.htm

Problems and Challenges (1)

- Embedded computing systems are **scaling**
  - ▲ **up**
    - in **number of nodes** (10^3…10^6…), and **area** (10^3…10^6… m^2)
  - ▼ **down**
    - in node **size** (“smart dust”) and **cost** (<1 €/$)
- which implies
  - very low **cost** per node (for cost-effective deployment)
  - no **maintenance** (at least for most of the nodes)
  - long network/node **lifetime** (years)
- and stringent node **resource limitations**
  - **processing/memory** – speed, size
  - **communications** – radio coverage, bit rate
  - **energy** – battery size vs. capacity

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Problems and Challenges (2)

- resource limitations are **big impairments** to
  - network/system **lifetime**
    - energy-efficiency
  - processing/transmitting **huge** amounts of information
    - data fusion/aggregation, information processing, network topologies, MAC and routing protocols
  - get tasks finished **correctly** and **on time**
    - **reliable** and **real-time** computing
  - get messages transmitted **correctly** and **on time**
    - **reliable** and **real-time** communications
- paradigm is very different from traditional WLANs (even Bluetooth)…
  - low cost/node (for large scale apps.), low comm. rate (energy), low comm. range (energy), low duty cycle (energy)

Problems and Challenges (3)

- some important challenges in WSNs: (1)
  - **energy-efficiency**
    - adequate design at all levels: energy harvesting, architecture (e.g. clustering, multiple-tiered), MAC/routing, cross-layer integration, applications, hardware optimization
  - **dependability (reliability, availability, security, safety)**
    - ability to withstand harsh environmental conditions/error prone environments, to cope with node and communication failures; privacy, authentication, encryption; unattended operation/limited or no maintenance
  - **real-time operation**
    - tasks/traffic differentiation (lower/higher priority); time-bounded computing/communications, scheduling, MAC, routing
    - node/network time synchronization
  - **network dynamics**
    - mobility of sensor nodes, cluster-heads, clusters, cluster groups,…
    - scalability/dynamic network topology (due to environmental changes, events, upgrading)
    - dynamic QoS needs (tackling events, different locations)

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Problems and Challenges (4)

- some important challenges in WSNs: (2)
  - **heterogeneity**
    - different mote and gateway hardware,
    - different operating systems and communication protocols
    - different agents involved (ICT designers, area experts, hardware/software suppliers, end users, normalization/regulatory/fiscal entities
  - **operating systems**
    - for extremely resource-constrained embedded devices
    - energy-efficiency and real-time concerns
  - **programming**
    - simple/adequate languages/compilers/debuggers
    - over-the-air programming
  - **designing, debugging and managing large-scale systems**
    - simulators - simple/non-realistic vs. test-beds complex/realistic; somewhere in between?
    - node (OS) and network (protocol) level analysers; merging both capabilities?
    - network management

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Problems and Challenges (5)

- some important challenges in WSNs: (3)
  - **localization**
    - GPS (proprietary solution; does not work for in-door/underground; is not scalable (uncertainty of meters)), RSS-based, …
  - **MEMS (micro-electromechanical systems)**
    - microsensors, microprocessors, RFIDs, nanonetworks,…
  - **sensor calibration**
    - large-scale brings extreme complexity
  - **node/system cost**
    - how far can industry go?
  - **radio communications**
    - improving modulation/codification techniques, antennas
    - utilization of the electromagnetic spectrum (ISM is limited)
    - hidden-node problem
  - **social/political/ethical aspects**
    - how will people face and deal with these tech.; “big brother” again…
    - computer pollution (discarding is cheaper than upgrading/maintaining)

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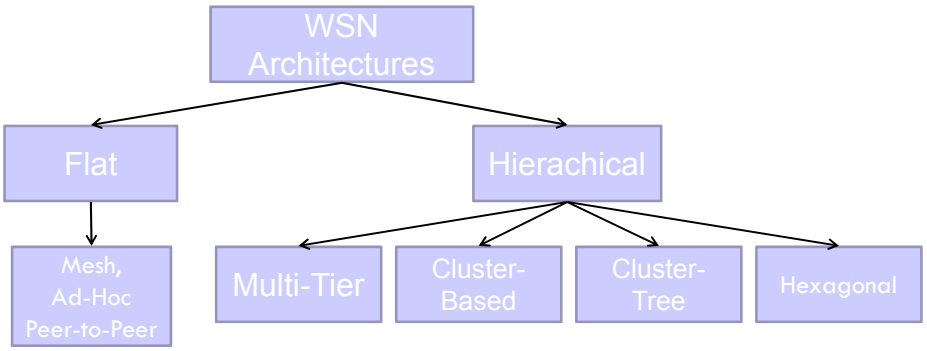
Problems and Challenges (6)

Body Sensor Networks might be even more challenging
[Yang, Guang-Zhong (Ed.), 2006]

Challenges	WSN	BSN
Scale	As large as the environment being monitored (metres/kilometres)	As large as human body parts (millimetres/centimetres)
Node Number	Greater number of nodes required for accurate, wide area coverage	Fewer, more accurate sensors nodes required (limited by space)
Node Function	Multiple sensors, each perform dedicated tasks	Single sensors, each perform multiple tasks
Node Accuracy	Large node number compensates for accuracy and allows result validation	Limited node number with each required to be robust and accurate
Node Size	Small size preferable but not a major limitation in many cases	Pervasive monitoring and need for miniaturisation
Dynamics	Exposed to extremes in weather, noise, and asynchrony	Exposed to more predictable environment but motion artefacts is a challenge
Event Detection	Early adverse event detection desirable; failure often reversible	Early adverse events detection vital; human tissue failure irreversible
Variability	Much more likely to have a fixed or static structure	Biological variation and complexity means a more variable structure
Data Protection	Lower level wireless data transfer security required	High level wireless data transfer security required to protect patient information
Power Supply	Accessible and likely to be changed more easily and frequently	Inaccessible and difficult to replace in implantable setting
Power Demand	Likely to be greater as power is more easily supplied	Likely to be lower as energy is more difficult to supply
Energy Scavenging	Solar, and wind power are most likely candidates	Motion (vibration) and thermal (body heat) most likely candidates
Access	Sensors more easily replaceable or even disposable	Implantable sensor replacement difficult and requires biodegradability
Biocompatibility	Not a consideration in most applications	A must for implantable and some external sensors. Likely to increase cost
Context Awareness	Not so important with static sensors where environments are well defined	Very important because body physiology is very sensitive to context change
Wireless Technology	Bluetooth, Zigbee, GPRS, and wireless LAN, and RF already offer solutions	Low power wireless required, with signal detection more challenging
Data Transfer	Loss of data during wireless transfer is likely to be compensated by number of sensors used	Loss of data more significant, and may require additional measures to ensure QoS and real-time data interrogation capabilities

WSN architectures overview (1)



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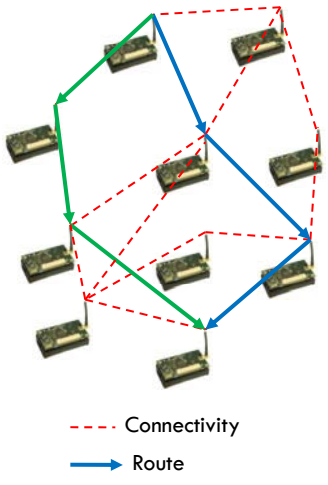
WSN architectures overview (2)

- **Flat**
  - No infrastructure
  - Peer-to-peer (flat) routing
  - Very flexible
  - Low Management Complexity
  - Limited QoS guarantees
  - All nodes have the same role
  - Basically, contention-based MAC protocols (CSMA/CA, Aloha)
  - Unsynchronized or synchronized (e.g. S-MAC)



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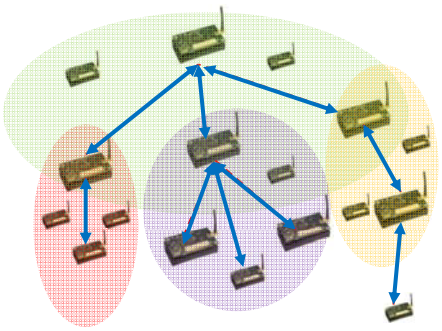
WSN architectures overview (3)

- **Cluster-Tree**
  - Network infrastructure: Backbone
  - Hierarchical routing
  - Low flexibility
  - Good QoS support
  - Complex network management
  - Basically, contention-FREE MAC protocols (TDMA)
  - Synchronized (e.g. LEACH)
  - Nodes have different roles
    - e.g. coordinator, sink, router, leaf



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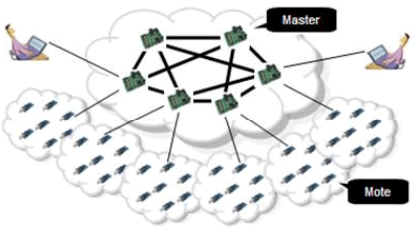
WSN architectures overview (4)

- **Multiple-Tiered**
  - Tier-1: sensor network
  - Tier-2: backbone network
  - Tier…: Internet?

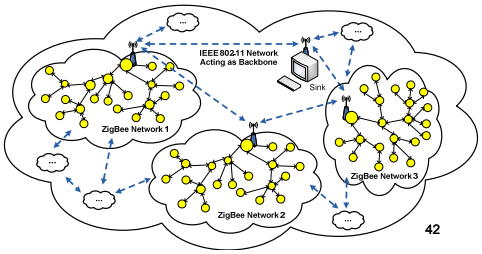


Tenet

http://research.cens.ucla.edu/projects/2007/Systems/Tenet

ART-WiSe

http://www.hurray.isep.ipp.pt/ART-WiSe



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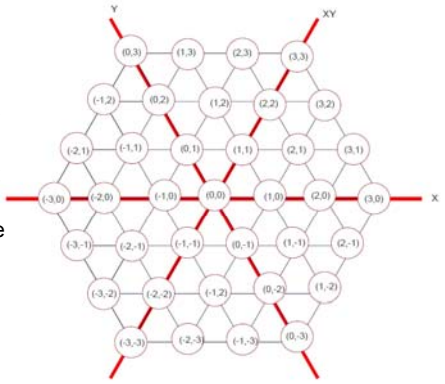
WSN architectures overview (5)

- **Hexagonal**
  - each node has six neighbors except for nodes at the edges
  - in the event of arbitrary deployments, consider a two-tier hierarchy
    - upper layer consists of nodes in hexagonal topology which are cluster heads
    - lower layer consists of the nodes that belong to one of the clusters
    - cluster heads route data over multiple hops
  - benefits of hexagonal WSN:
    - simple/low overhead MAC/network protocols
    - easy to guarantee real-time communications



S. Prabh, T. Abdelzaher

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WSN routing overview (1)

- **Routing classification (destination)**
  - unicast
    - delivers a message to a single specified node;
  - broadcast
    - delivers a message to all nodes in the network;
  - multicast
    - delivers a message to a group of nodes that have expressed interest in receiving the message;
  - convergecast
    - disseminates and aggregates data towards a sink
- **Routing classification (determinism)**
  - probabilistic
    - routing path may vary with time (node/network status)
  - deterministic (tree routing)
    - unique routing path from any source to any destination (though nodes connectivity may be much larger)

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WSN routing overview (2)

- **Routing classification (dynamics)**
  - proactive
    - First Compute all Routes; Then Route
  - reactive
    - Compute Routes On-Demand
  - hybrid
    - First Compute all Routes; then Improve While Routing
- **Routing classification (architecture)**
  - direct
    - Node and Sink Communicate Directly (Fast Drainage; Small Scale)
  - flat (equal)
    - Random Indirect Route (Fast Drainage Around Sink; Medium Scale)
  - clustering (hierarchical)
    - Route Thru Distinguished Nodes

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WSN routing overview (3)

- **Routing classification (location-awareness)**
  - Location-aware
    - nodes knows where they are
  - location-less
    - nodes location is unimportant
  - mobility-aware
    - nodes may move (sources; sinks; all)
- **Routing classification (addressing)**
  - data-centric
    - the sink sends queries to certain regions and waits for data from the sensors located in the selected regions
    - data aggregation during the relaying of data
  - address-centric
    - routes are created between addressable nodes managed in the network layer of the communication stack.

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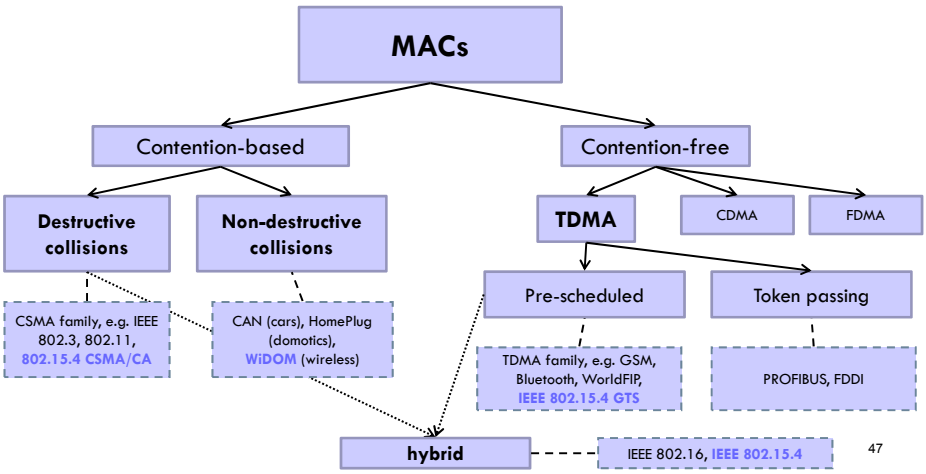
WSN MAC aspects (1)

- Types of MACs



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WSN MAC aspects (2)

1. contention-based
   - destructive collisions
     - nodes listen to the medium; if idle, transmit; if collision, backoff
     - CSMA family, e.g. IEEE 802.3, 802.11, 802.15.4 CSMA/CA
     - pros: simple, very flexible
     - cons: not energy efficient (collisions lead to retransmissions); no timing guarantees (non-deterministic); prone to hidden node problem; limited network throughput
   - non-destructive collisions
     - resolve bus conflicts by using a bitwise arbitration; each node has a unique identifier (= priority); Wire acts like a logic AND (0 is dominant, 1 is recessive); transmit identifier bit by bit and hear the medium; if a node sends a '1' but hears a '0', he loses;
     - CAN (cars), HomePlug (domotics), WiDOM (wireless)
     - pros: deterministic, time and energy-efficient
     - cons: synchronization, short tx/rx turnaround time (or 2 transceivers); multiple broadcast domains

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WSN MAC aspects (3)

2. **contention-free**
   - transmissions are differentiated in time (**TDMA**), frequency (FDMA) or coding (CDMA)
   - **pre-scheduled access**
     - each node's transmission (which node, starting time, duration) is scheduled a priori
     - TDMA family, e.g. GSM, Bluetooth, WorldFIP, **IEEE 802.15.4 GTS**
     - **pros**: energy efficient; timing guarantes; ~100% network throughput
     - **cons**: not flexible (not adaptable to network dynamics – if scheduling is static)
   - **token passing**
     - each node transmits during its token holding time; when it expires, token is passed to the next node in a predefined sequence (e.g. logical ring)
     - e.g PROFIBUS, FDDI
     - **pros**: energy efficient; timing guarantes; ~100% network throughput
     - **cons**: not very flexible; very error-prone (token losses) in harsh environments
3. **hybrid**
   - merge both previous for more flexibility (best effort/real-time)
   - usually **CSMA+TDMA**, e.g. IEEE 802.16, **IEEE 802.15.4**
   - **pros**: best of both worlds
   - **cons**: management complexity

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WSN MAC aspects (4)

- **Characteristics of a good MAC/DLL protocol for WSNs**
  - **energy efficiency (to prolong the network lifetime)**
    - flexible enough to adapt duty-cycles (100% → 0%)
      - dynamically
      - in a per cluster basis
    - must address some causes of energy loss:
      - collisions – due to retransmissions
      - hidden-nodes and exposed-nodes problems – lead to unnecessary extra collisions
      - overhearing – waste effort in receiving a packet destined for another node
      - idle listening – sitting idly and trying to receive when nobody is sending
  - **scalability and adaptability to changes**
    - changes in network size, node density and topology should be handled rapidly and effectively
  - **reliability**
    - error detection/correction mechanisms
  - **traffic differentiation**
    - support higher/lower priority traffic classes
    - support best effort and real-time traffic
  - **minimized frame overhead (for optimal bandwidth utilization)**
    - but still support network management, security, error detection/correction

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Physical layer aspects (1)

- **Radio link characteristics**
  - **asymmetric links**
    - node A is connected to Node B does not mean that Node B is connected to node A
  - **non-isotropical connectivity**
    - connectivity depends on the direction of the signal (at same distance from source)
  - **non-monotonic distance decay**
    - nodes geographically far away from source may get better connectivity than nodes that are geographically closer

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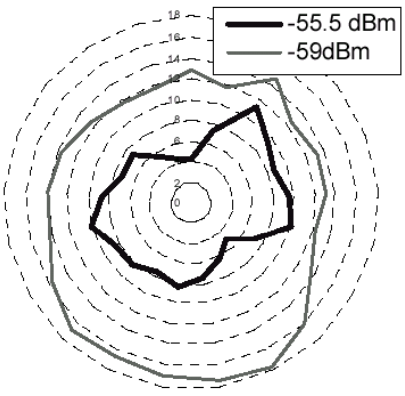
*Ganesan et. al. 02; Woo et. al. 03; Zhao et. al. 03; Cerpa et. al. 03; Zhou et. al. 04

Physical layer aspects (2)

- **non-isotropy of radio links**
  - the assumption of a circular disk model does not hold for radio propagation, in practice.



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*Zhou et. al. 04

Physical layer aspects (3)

- **propagation phenomena**
  - reflection
    - is the change in direction of a wave front at an interface between two different media sc that the wave front returns into the medium from which it originated
  - diffraction
    - refer to various phenomena which occur when a wave encounters an obstacle
  - scattering
    - from objects that are small (when compared to the wavelength), e.g.: Rough surfaces

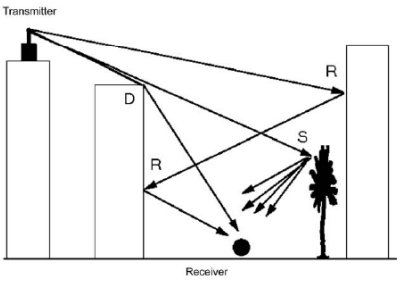

Figure 2.5 Reflection (R), diffraction (D) and scattering (S)

Source: **Wireless Networks,**
P. Nicopolitidis, A. S. Pomportsis,
G. I. Papadimitriou, M. S. Obaidat
Publisher John Wiley & Sons, Inc. New York, NY, USA (2003)

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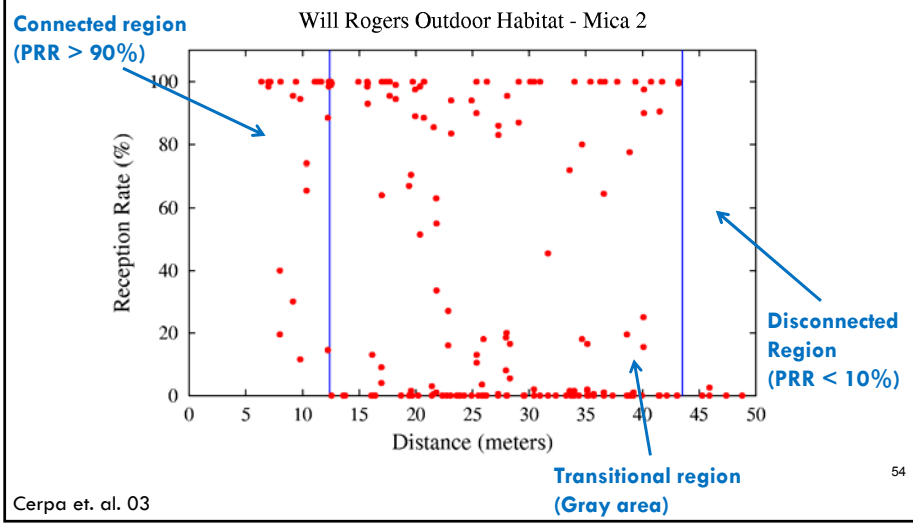
Physical layer aspects (4)

- **Spatial characteristics**



Cerpa et. al. 03

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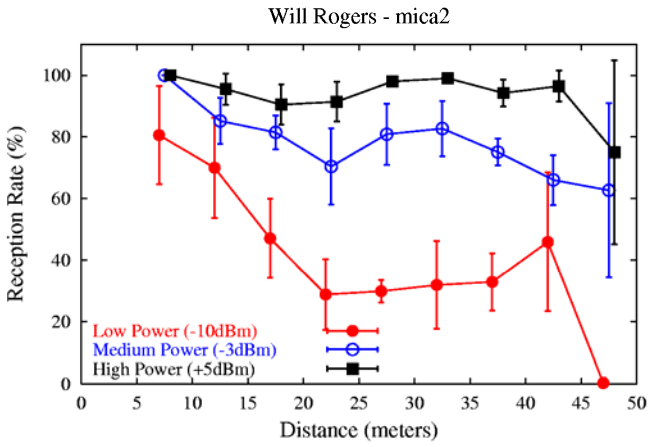
Physical layer aspects (5)

- **Packet Reception Rate versus Distance**



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Cerpa et. al. 03

Technology (1) – mote examples

Node Type	Name	Typical Application
Specialized Sensing Platform	Spec	Specialized low-bandwidth sensor, or RFID tag
Generic Sensor Platform	Mica, Mica2, MicaZ, Telos, ESB, Firefly, Particle, SquidBee, SHIMMER	General purpose sensing or communication relay
High-bandwidth sensing/Gateway	iMote1, iMote2, SunSPOT, Stargate1, Stargate2, gumstix	High bandwidth sensing (video, acoustic, vibration), communication aggregation, compute node or gateway

Technology (2) – mote 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			60
RAM (KB)	0.5		1		4			2
Active Power (mW)	15		15		8		33	3
Sleep Power (μW)	45		45		75		75	6
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	41
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

…

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Technology (3) – mote common radios

	CC1000	CC1021	CC2420	TR1000	XE1205
Manufacturer	Chipcon	Chipcon	Chipcon	RFM	Semtech
Operating Frequency [MHz]	300 - 1000	402 - 470 / 804 - 940	2400	916	433 / 868 / 915
Bit Rate [kbps]	76.8	153.6	250	115.2	1.2 - 152.3
Sleep Mode [uA]	0.2 – 1	1.8	1	0.7	0.2
RX [mA]	11.8 (868 MHz)	19.9	19.7	3.8 (115.2kbps)	14
TX Min [mA]	8.6 (-20dBm)	14.5 (-20dBm)	8.5 (-25dBm)		33 (+5dBm)
TX Max [mA]	25.4 (+5dBm)	25.1 (+5dBm)	17.4 (0dBm)	12 (+1.5dBm)	62 (+15dBm

Technology (4) – RFID

- **RFID tag (or transponder)**
  - is an object that can be applied to or incorporated into a product, animal, or person for the purpose of identification using radio waves
  - from centimeters to meters distance (tag-reader) with or without line-of-sight
  - composed of
    - antenna - for receiving and transmitting the signal
    - integrated circuit (optional) for storing and processing information, modulating and demodulating a (RF) signal, and other specialized functions
- **Types**

	Active Tag	Semi-passive Tag	Passive Tag
Power Source	Battery on tag.	Battery for chip operation. Radio wave energy from Reader for communication	Radio wave energy from Reader for operation and communication.
Tag Signal Availability	Always on, 100 feet	Only within field of reader	Only within field of reader, less than 10 feet
Signal Strength Tag	High	Low	Very low
Required Signal Strength from Reader	Very low	Low	Very high
Typical Applications	Useful for tracking high-value goods that need to be scanned over long ranges. Example: railway cars on a track.		Useful for high-volume goods, where items can be read from short ranges. Example: retail check out.

any similarities with WSN nodes?

http://java.sun.com/developer/technicalArticles/Ecommerce/rfid/

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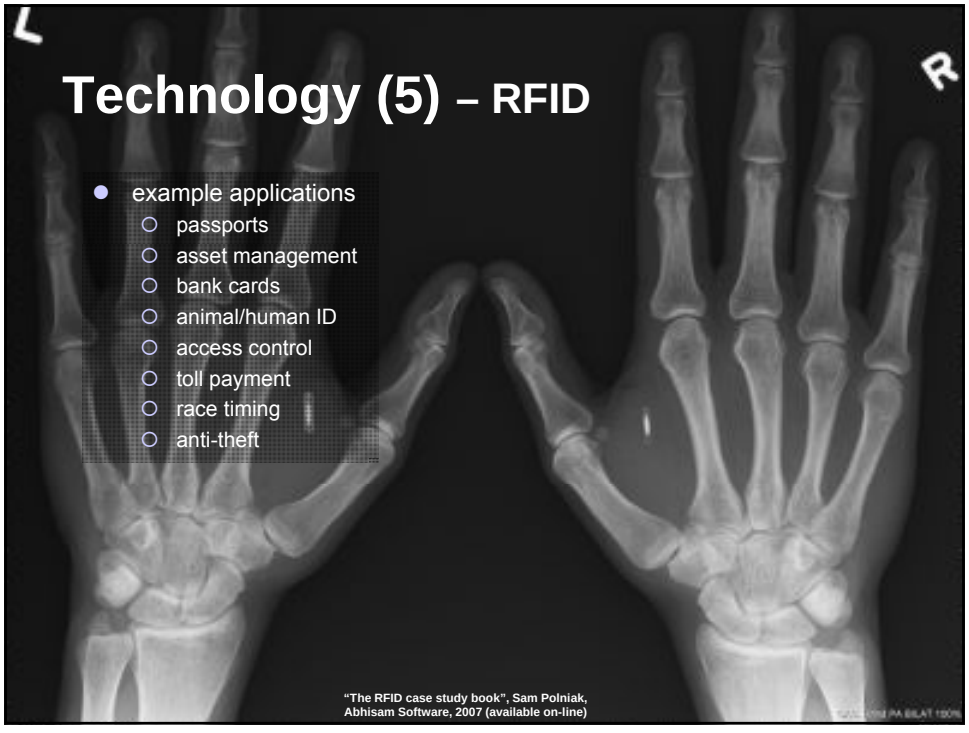


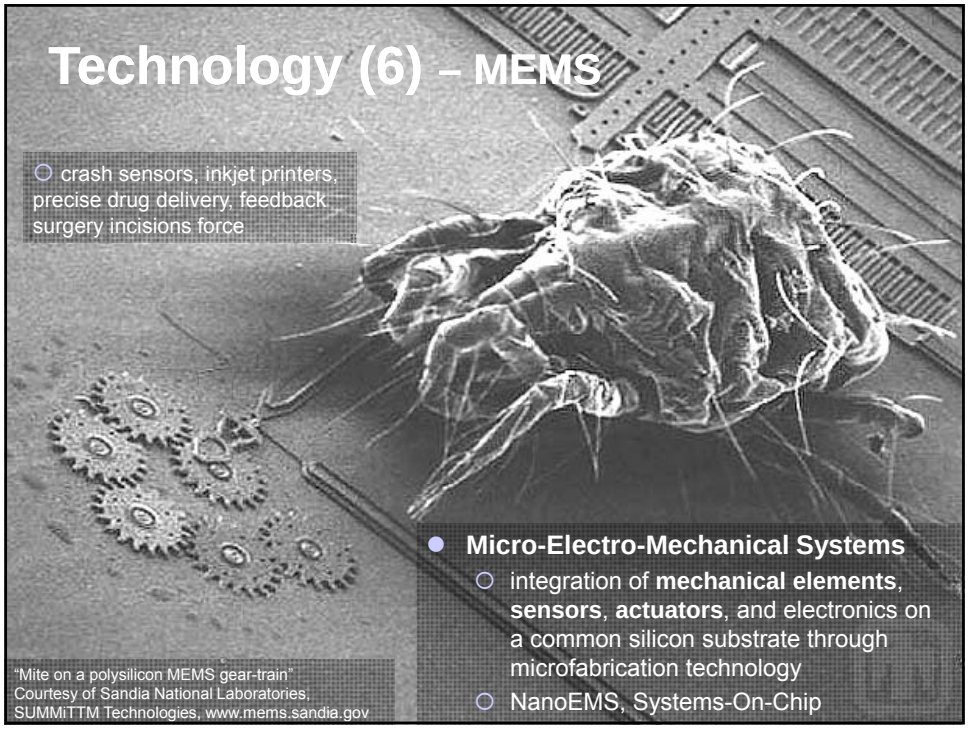
Technology (5) – RFID

- example applications
  - passports
  - asset management
  - bank cards
  - animal/human ID
  - access control
  - toll payment
  - race timing
  - anti-theft

"The RFID case study book", Sam Polniak, Abhisam Software, 2007 (available on-line)

Technology (6) – MEMS

- crash sensors, inkjet printers, precise drug delivery, feedback surgery incisions force



"Mite on a polysilicon MEMS gear-train"
Courtesy of Sandia National Laboratories, SUMMiTTM Technologies, www.mems.sandia.gov

- **Micro-Electro-Mechanical Systems**
  - integration of **mechanical elements**, **sensors**, **actuators**, and electronics on a common silicon substrate through microfabrication technology
  - NanoEMS, Systems-On-Chip

Technology (7) – communication protocols

WSAN can span over all of these…

Distance between nodes	Nodes located in the same	Network Class (dimension)	Example protocols
x µm – x mm	Chip	**NanoNetworks,NoC** (Networks on Chip)	?
x mm – x m	Body	**BAN** (Body Area Networks)	(IEEE 802.15.6)
x m – x0 m	Room	**PAN** (Personal Area Networks)	USB, FireWire, 6lowpan IEEE 802.15.1/Bluetooth, IEEE 802.15.4/ZigBee, IEEE 802.15.3/UWB
x0 m – x00 m	Building, Campus	**LAN** (Local Area Networks)	IEEE 802.11/WiFi, IEEE 802.3/Ethernet, WirelessHART, fieldbus networks
x00 m – x0 km	City	**MAN** (Metropolitan Area Networks)	IEEE 802.16/WiMAX, IEEE 802.20/MBWA, ATM, FDDI
x0 km – x… km	Country – …	**WAN** (Wide Area Networks)	IEEE 802.22/WRAN, ATM, X.25, Frame Relay, Satellite…

Alves ☺

Tanembaum

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	Local area network
100 m	Building	
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	
10,000 km	Planet	The Internet

Technology (8) – operating systems

- some OS for resource-constrained WSN devices
  - tens of others…

Operating System	Origin	Open source	Real-time	Link
TinyOS	UCB, Intel (USA)	Yes	No	http://www.tinyos.net
Contiki	SICS (Sweden)	Yes	No	http://www.sics.se/contiki
Nano-RK	CMU (USA)	Yes	Yes	http://www.nanork.org
ERIKA	SSSUP (Italy)	Yes	Yes	http://erika.sssup.it
MANTIS	UC Boulder (USA)	Yes	No	http://mantis.cs.colorado.edu
SOS	UCLA (USA)	Yes	No	https://projects.nesl.ucla.edu/public/sos-2x/doc

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Technology (7) – simulation tools

- some network simulation tools
  - tens of others…

Simulator	Origin	Open-source	WSN oriented?	Link
OPNET	OPNET Tech. Inc.	No (free for U.)	Yes	http://www.opnet.com
OMNeT++	TU Budapest (Hung)	Yes	No	http://www.omnetpp.org
Castalia (OMNet++ based)	NICTA (Australia)	Yes	Yes	http://castalia.npc.nicta.com.au
ns-2	USC (USA)	Yes	No	http://nsnam.isi.edu/nsnam
SENSORSIM (ns-2 based)	UCLA (USA)	Yes	Yes	http://nesl.ee.ucla.edu/projects/sensorsim/
GloMoSim	UCLA (USA)	Yes	No	http://pcl.cs.ucla.edu/projects/glomosim
TOSSIM	UCB (USA)	Yes	Yes	http://www.cs.berkeley.edu/~pal/research/tossim.html
SENSE 3.0	Rensselaer PI (USA)	Yes	Yes	http://www.ita.cs.rpi.edu/sense

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Scientific targets – conf.&workshop

- **Wireless Sensor Networks-oriented**
  - SenSys, IPSN, MASS, SECON, EWSN, INSS, EmNets, HotEmNets, Internet of Things, Nano-Net, BSN
- **Distributed Systems-oriented**
  - ICDCS, IPDPS, DCOSS
- **Real-Time and Embedded Systems-oriented**
  - RTSS, RTCSA, ECRTS, RTAS, WPDRTS, RTNS
- **Industrial Networks-oriented**
  - FET, ETFA, WFCS
- **Networking-oriented**
  - Networking, Infocom, SIGCOMM, MobiHoc, WoWMoM, AdHoc-Now
- **Ubiquitous computing-oriented**
  - PerCom, SUTC
- **Simulation-oriented**
  - MASCOTS, MSWiM

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Scientific targets – journals

- **Transactions on Sensor Networks**
  - ACM
- **Ad Hoc & Sensor Wireless Networks**
  - Old City Publishing
- **Ad Hoc Networks**
  - Elsevier
- **Computer Communications**
  - Elsevier
- **Computer Networks**
  - Elsevier
- **Performance Evaluation**
  - Elsevier
- **Pervasive and Mobile Computing**
  - Elsevier
- **Real-Time Systems**
  - Springer
- **Transactions on Wireless Communications**
  - IEEE
- **Wireless Communications and Mobile Computing**
  - Wiley

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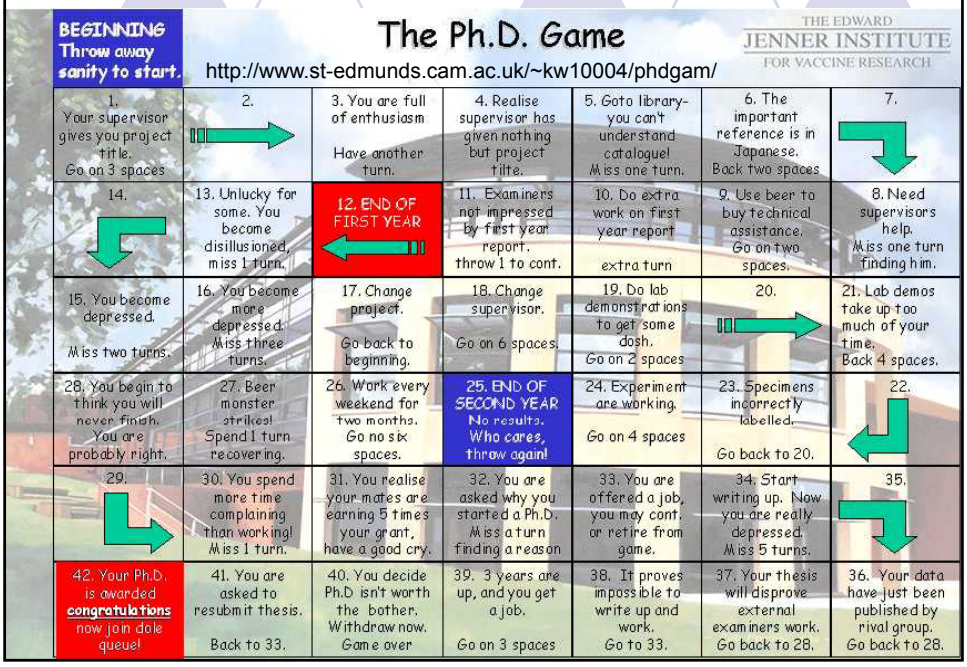
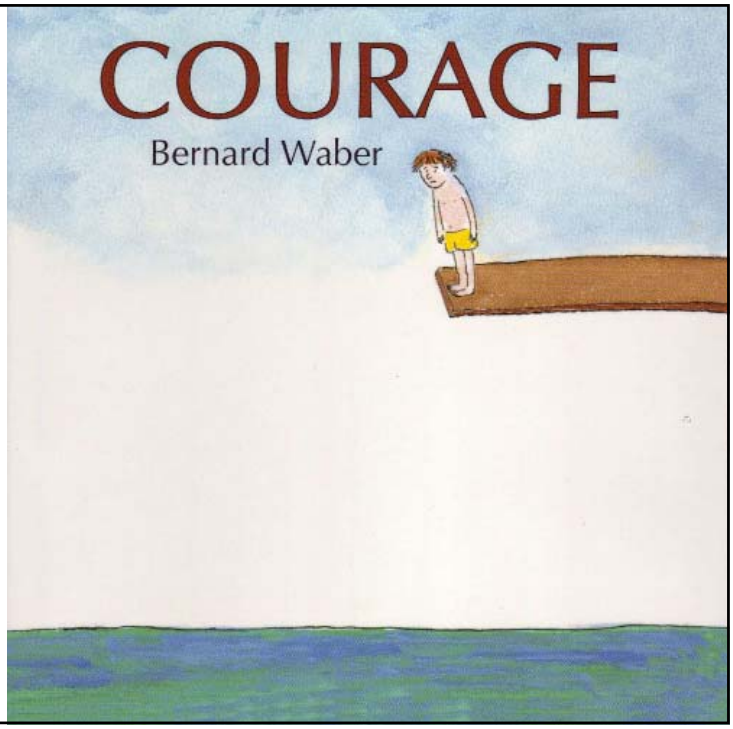
http://www.wsnblog.com

Now, think about what you have been doing ☺



But…



You can learn from experienced people!

- Best research practices
  - at CMU
    - http://www.cs.cmu.edu/afs/cs.cmu.edu/user/mleone/web/how-to.html
      - …
  - at UIUC
    - https://agora.cs.uiuc.edu/display/realTimeSystems/Improving+Your+Research+Skills
      - "Building a Research Career", Indranil Grupta
      - "On Conducting Research", P. R. Kumar
      - "Having Fun In Research", YuanYuan Zhao
      - "Towards Productive Research in CS", Jiawei Han
      - "Improve Research Productivity", Tarek Abdelzaher
      - "Problems Follow System", Kevin Chang
      - "Elements of Research", Lui Sha
      - "Excellence in Oral Presentation for Technical Speakers", Klara Nahrstedt
      - "Writing Good Research Papers", Mary Shaw
      - "CORE Method for Planning Research Paper Writing", Jim Frost
      - "Learning to Write", Ralph Johnson

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Where do I come from?

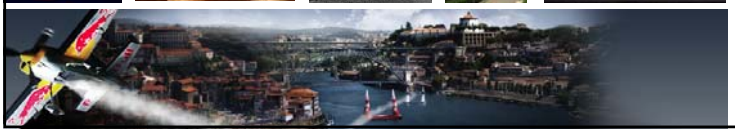
Somewhere around here
(Porto, Portugal)

knew about these?









CISTER/IPP-HURRAY snapshot

- FCT Research Unit 608
  - rated **Excellent** (2004-2006) (only one among 28 units in the ECE area)
  - around 25 researchers (currently 10 PhD)
  - based at the Polytechnic Institute of Porto (ISEP/IPP)
- Leading international research in:
  - **Wireless Sensor Networks for time-critical applications**
    - COTS-based sensor networks communication architecture (ART-WiSe)
    - innovative dominance-based MAC Protocols (WiDom, WiseCan)
    - innovative data aggregation, interpolation and in-network computing mechanisms
  - **Real-Time Software Infrastructure**
    - QoS-aware Middleware
    - collaborative Computing
    - real-time languages and operating systems
  - **Scheduling and Schedulability Analysis**
    - probabilistic scheduling
    - single, multicore and multiprocessor Scheduling
    - communication scheduling (TDMA/SS)
  - **Real-time Factory Communications**
    - wired/wireless real-time fieldbus communications
    - innovative communication protocols (TDMA/SS, WiseCan)

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and don’t run away from the next talk ☺

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