Cooperating Objects NETwork of Excellence

7th Framework Programme

FP7-224053

The WSN standards and COTS landscape: can we get QoS and “calm technology”?

Tutorial@EWSN’09

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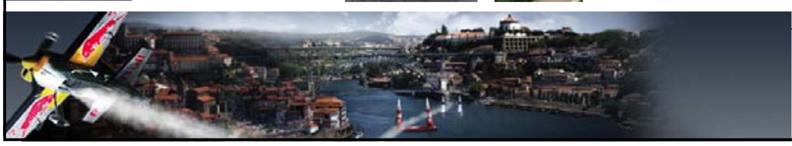
Where do I come from...

Somewhere around here

(Porto, Portugal)

knew about these?



About my research unit

CISTER

Research Centre in Real-Time Computing Systems

http://www.cister.isep.ipp.pt

About my research unit – research areas

- What are **Real-time Computing Systems**?
  - real-time computing systems are those systems where **correctness depends** not only of the correct production of logical results but also **on the time** when those results are produced
  - e.g. transportation, factory automation, medical, security, audio/video streaming, robotics
- Main research areas:
  - single/multi-core/multi-processor systems
  - real-time languages and operating systems
  - scheduling and schedulability analysis
  - **wireless sensor/actuator networks**
  - **cyber-physical systems**

About my research unit – other partnerships

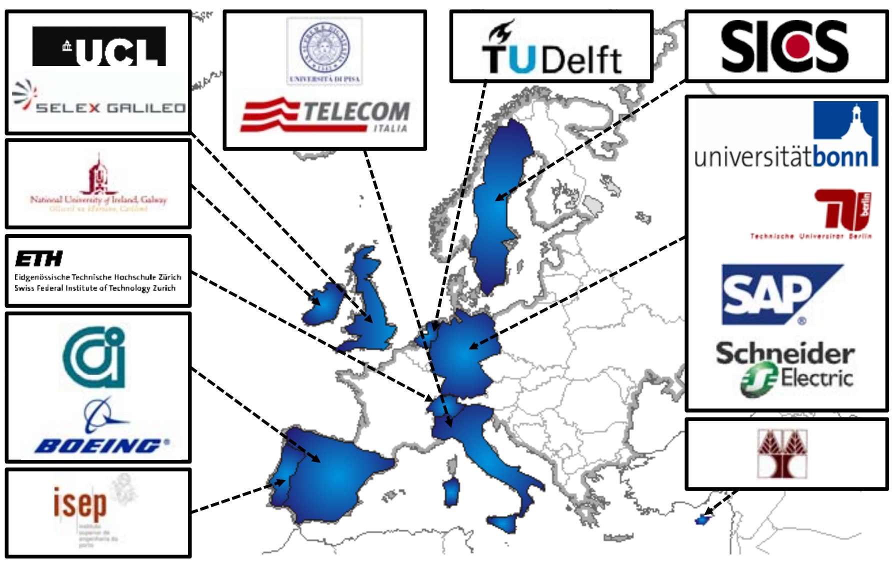
- EMMON (ARTEMIS programme)
  - large-scale embedded monitoring using WSNs
  - MAR/2009 – FEB/2012
  - 8 partners: Critical Software (PT), Intesys (UK), Trinity College Dublin (IR)…
- ARTISTDesign (EC NoE) http://www.artist-embedded.org
  - embedded systems design
  - JAN/2008 – JAN/2012 (4 years)
  - 30 partners: OFFIS (D), a PAREDES (I), Centre de Énergie Atomique (F), U. Uppsala (S), U. York (UK), U. Lund (S), U. Bolonha (I), U. Lausanne (CH), …
  - Headed by Prof. Joseph Sifakis, 2007 ACM Turing Award
- PT-CMU (Carnegie Mellon University) http://www.cmuportugal.org
  - networked sensor, communication and decision systems for monitoring critical physical infrastructures
  - JAN/2007 – FEB/2012 (5 years)
- TinyOS Net2, ZigBee and IEEE 802.15.4 Working Groups
  - leading IEEE 802.15.4/ZigBee protocol stack
  - since 2006 (in Net2 WG), since 2009 (802.15.4 and ZigBee WGs)
  - http://www.tinyos.net, http://www.open-ZB.net

About CONET

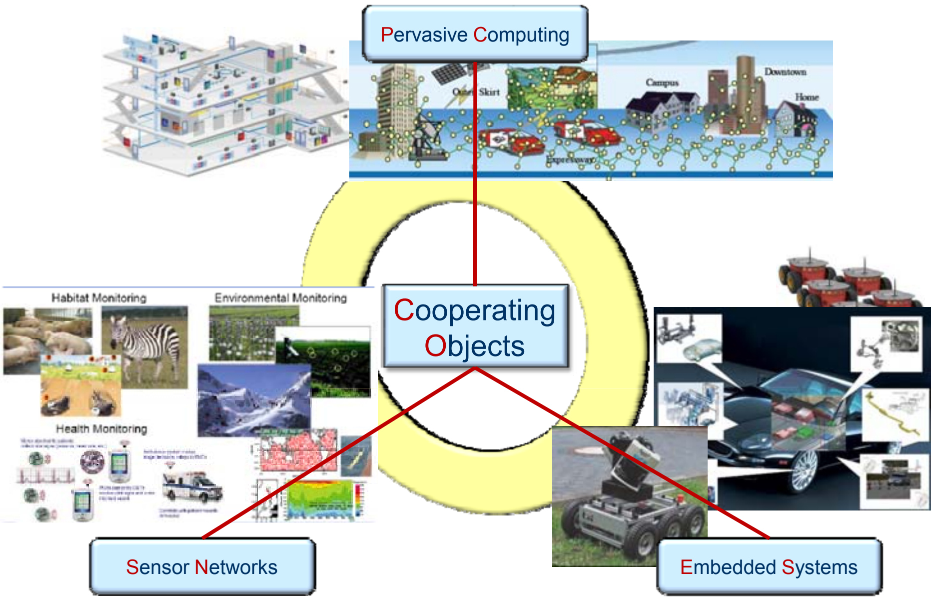
- Network of Excellence funded in FP7 (INFSO-ICT-224053)
  - **1/JUN/2008 – 31/MAY/2012** (48 months)
  - EC approved funding: **4 MEuro**
  - Total Budget: **10.4 MEuro**
  - **16 core** partners: key **academic** and **industrial** players
  - Very strong **Industrial and External Advisory Boards**
  - More information: http://www.cooperating-objects.eu

COOPERATING OBJECTS
NETWORK OF EXCELLENCE

About CONET – core partners



About CONET – areas



About CONET – current research clusters

Hardware

Testbed and Simulation Platforms for Cooperating Objects *

Mobility of Cooperating Objects *

Deployment and Management of Cooperating Objects *

Recognizing Emotions using WSNs

System

http://www.cooperating-objects.eu/research-clusters

Algorithms

Ubiquitous Integration of Cooperating Objects *

Scalable Data Processing *

Resource Management and Adaptation *

COTS-based Architecture for QoS

Non-functional Properties

Acknowledgements

- EWSN'09
  - **Cormac Sreenan**/Utz Roedig (General co-Chairs)
- CONET
  - **Pedro Marron** (CONET coordinator)
  - COTS4QoS research cluster (particularly **Gianluca Dini** and **Ida Savino**, UNIPI)
- CISTER
  - **Ricardo Severino**, **Anis Koubâa**, **Nouha Baccour**, **Nuno Pereira**, Petr Jurcik, Björn Andersson, Shashi Prabh, Eduardo Tovar

About the title of the talk (1)

- **The wireless sensor networks standards and COTS landscape: can we get QoS and "calm technology"?**

About the title of the talk (2)

- 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)

About the title of the talk (3)

- what are “wireless sensor/actuator networks”? (cont.)
  - **“actuator”**
    - devices which transform an input signal (mainly an electrical signal) into motion
    - e.g. electrical motors, pneumatic actuators, hydraulic pistons, relays, electro-valves, piezoelectric actuators, buzzers, lamps
  - **“network”**
    - a “computer network” is a group of interconnected computers

About the title of the talk (4)

- what are “wireless sensor/actuator networks”? (cont.)
  - **“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

About the title of the talk (5)

- what are “wireless sensor/actuator networks”? (cont.)
  - **“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.

SEVENTH FRAMEWORK PROGRAMME

About the title of the talk (6)

- what are "standard and COTS technologies"?
  - **"technology"**
    - "is a broad concept that deals with a **species' usage and knowledge of tools and crafts**, and how it affects a **species' ability to control and adapt to its environment**. In human society, **it is a consequence of science and engineering**"
  - **"standard"**
    - "A technical standard is an established norm or requirement. It is usually a **formal document that establishes uniform engineering or technical criteria, methods, processes and practices**."
  - **"COTS"**
    - "Commercial, off-the-shelf (COTS) is a term for software or hardware, generally **technology or computer products**, that are **ready-made and available for sale, lease, or license to the general public**."

About the title of the talk (7)

- but why using "**standard and COTS technologies**"?
  - for **reducing the development and maintenance costs**
    - we can buy them (or get them for free – open-source)
  - for **increasing interoperability**
    - with what other people (industry/academia) is doing
  - for **speeding up their utilization and deployment**
    - in real world applications
    - by system developers (love COTS)
    - by end-users (hate new/immature things)

About the title of the talk (8)

- what is "**Quality-of-Service (QoS)**"?
  - traditionally, **"QoS is the ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. …"**
    - "… For example., a required bit rate, delay, jitter, packet dropping probability and/or bit error rate may be guaranteed…"
    - "…QoS guarantees are important if the network capacity is a limited resource…" (isn't it always?)
    - "e.g. voice over IP, online games and IP-TV"
- but we will look at **QoS in a different way** (later on)

SEVENTH FRAMEWORK PROGRAMME

About the title of the talk (9)

- what is "**calm technology**"?
  - "**the most profound technologies are those that disappear**; they weave themselves into the fabric of everyday life until they are **indistinguishable** from it"
  - the term **"calm technology"** was coined by **Mark Weiser** ("The computer of the 21st Century", Scientific American, **1991**), in his early visions on ubiquitous computing
  - actually, **common people do not want to know how** a car, a pen or a computer works; they just want to be **served properly**, with the **best quality** possible.

About the title of the talk (10)

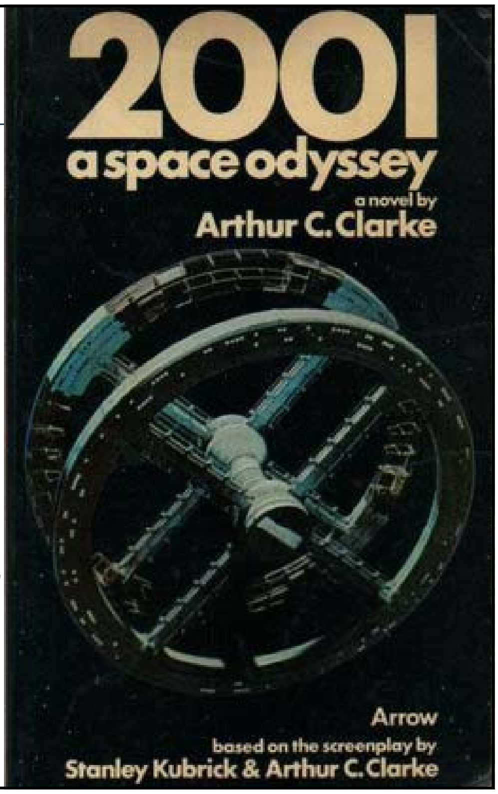
- So, wraping up:
  - we will reason about
    - how to achieve
      QoS and „calmness“
    - by using
      standard and COTS WSN technology

Tutorial outline

- **ICT trends**
  - some visions on the evolution and threats of ICT technology
- **WSN technology**
  - an outlook of WSN types, topologies, routing, MAC, PhL, motes, transceivers, RFID, MEMS, OS, comm. protocols
- **Quality-of-Service**
  - a holistic approach
- **On-going work**
  - related CONET activities

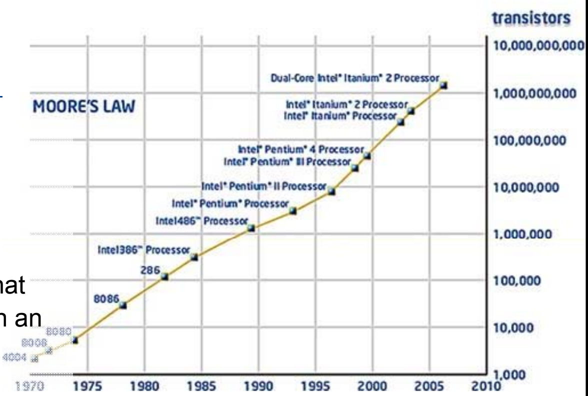
ICT trends (1)

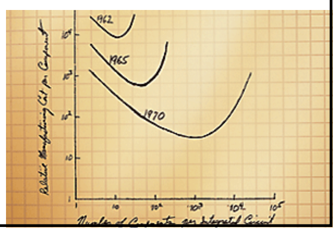
- Imagination is the limit…
  - **Arthur C. Clarke's Laws** (1917-2008):
    - "When a distinguished but elderly scientist states that **something is possible** he is almost certainly **right**. When he states that **something is impossible**, he is very probably **wrong**"
    - "The only way of **discovering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



ICT trends (2)

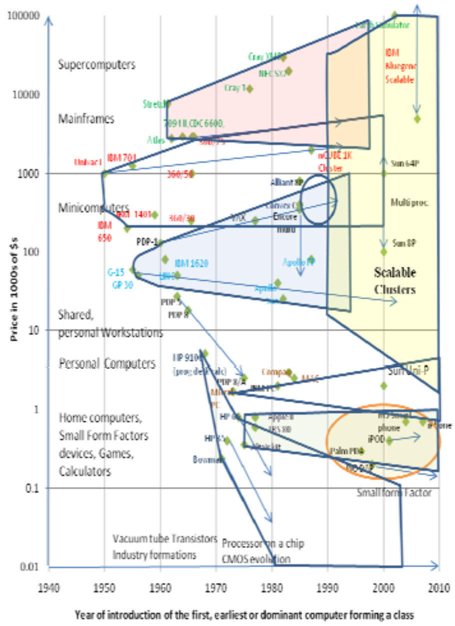
- and ICTs trend may help…
  - **Gordon Moore's Law** (born 1929):
    - "The **number of transistors** that can be inexpensively placed on an integrated circuit is **increasing exponentially**, doubling approximately every two years" (paper from **1965**)
    - In **2005**, he stated that **the law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





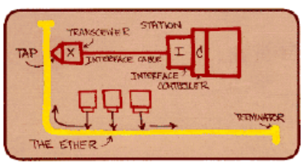
ICT trends (3)

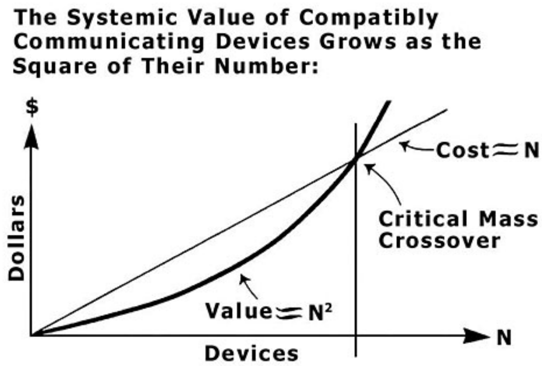
- and ICTs trend may help…
  - Gordon **Bell’s Law** (born 1934)
    - “Roughly **every decade a new**, lower priced **computer class forms** based on a new programming platform, network, and interface resulting in new usage and the establishment of a new industry” (paper from **1972**)
  - “**As of 2005**, 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**)”



ICT trends (4)

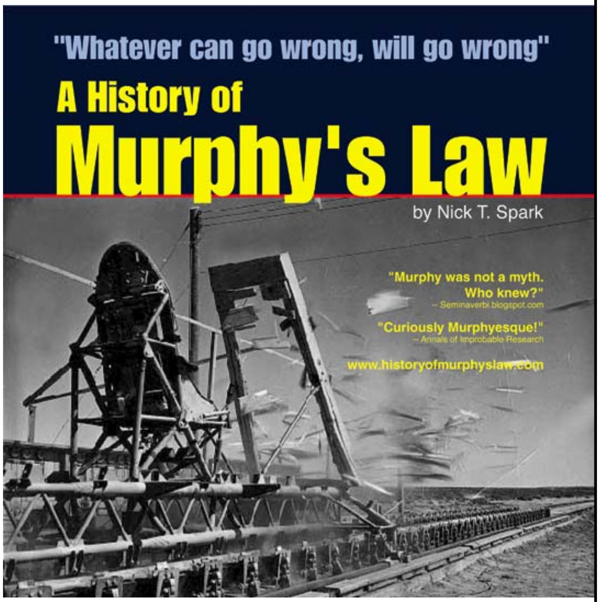
- and ICTs trend may help…
  - Robert **Metcalfe's Law** (born **1946**):
    - “**the value of a network grows as the square of the number of its users**”





ICT trends (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**)

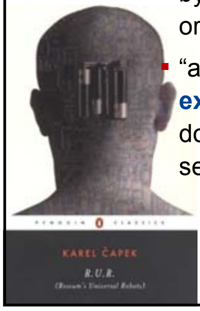


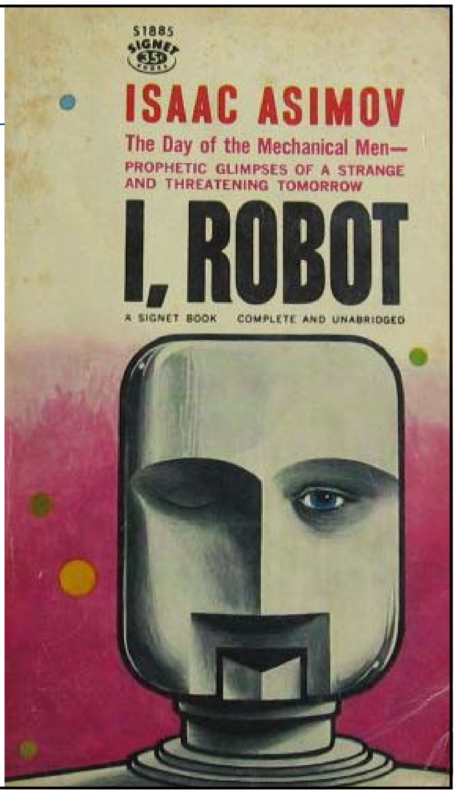
ICT trends (6)

- 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

ICT trends (7)

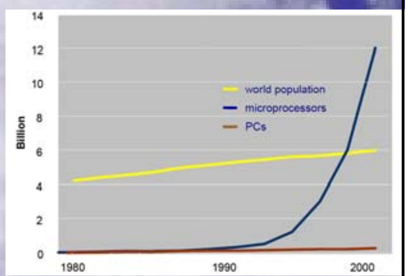
- but be very careful with the consequences…
  - Isaac **Asimov's Laws** (**1920-1992**):
    - “a robot **may not injure a human** being or, through inaction, allow a human being to come to harm”
    - “a robot **must obey orders** given to it by a human being except where such orders would conflict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

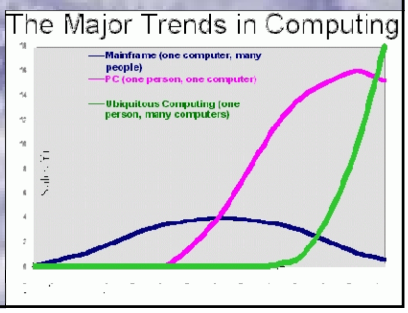




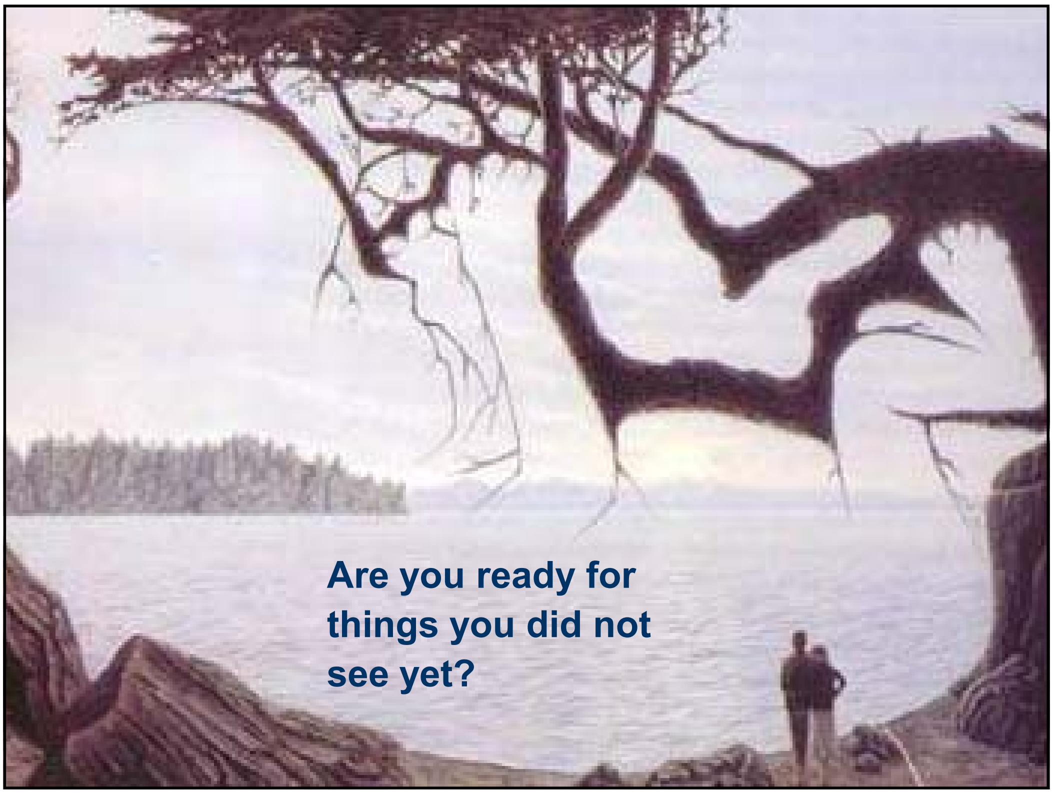
ICT trends (8)

- 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**”

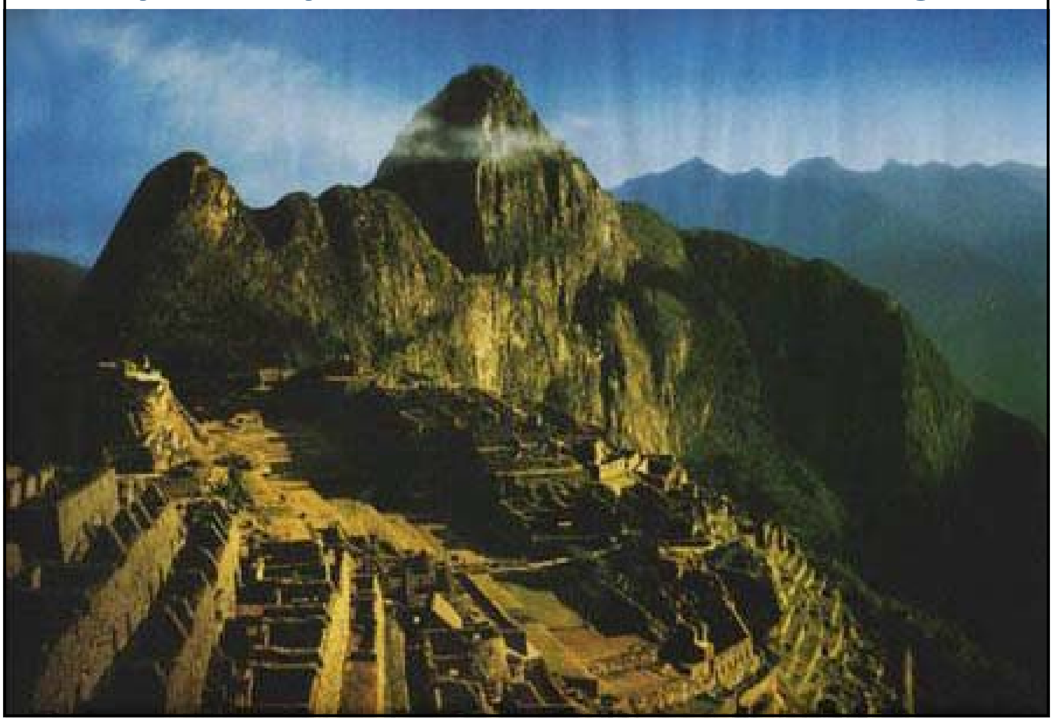




[Mark Weiser, "The Computer for the 21st Century" - Scientific American Special Issue on Communications, Computers, and Networks, September, 1991]



Are you ready to watch the world from a ≠ angle?



WSN technology

WSN technology – WSN types

- From “traditional” WSN to other “forms”:
  - Body Sensor Networks (**BSN**)
  - Vehicular Sensor Networks (**V2V, V2I**)
  - Machine-to-Machine (**M2M**)
  - Underwater (Acoustic) Sensor Networks (**UW-ASN**)
  - Internet-of-Things (pervasive Internet)
  - Urban/social/participatory Sensor Networks
  - Interplanetary Sensor Networks
  - Fieldbus Networks (the good oldies are getting wireless/mobile capabilities and scaling up)
  - Networks-on-Chip (**NoC**)
  - Near-Field Communications (**NFC**)

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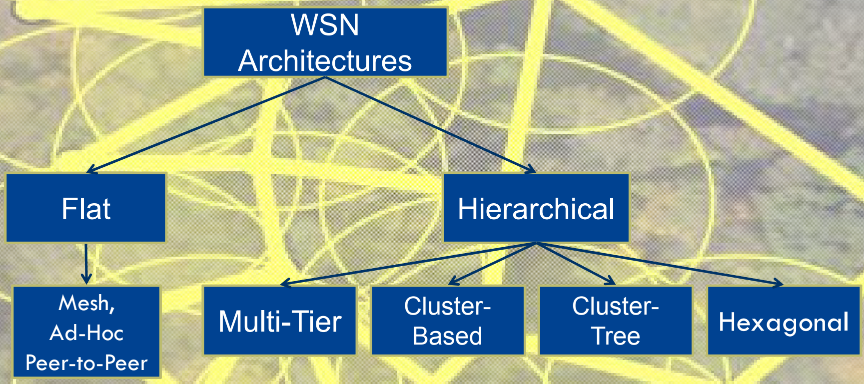
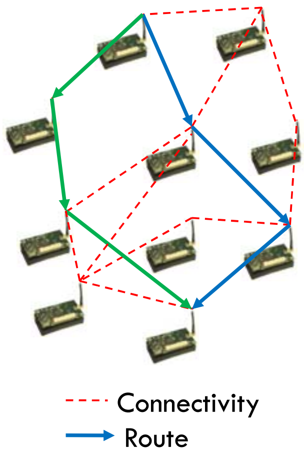
WSN technology – WSN topologies

- Overview



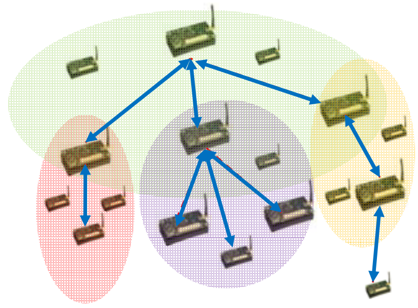
WSN technology – WSN topologies

- **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 (e.g. CSMA/CA, Aloha)
  - unsynchronized or synchronized (e.g. S-MAC)



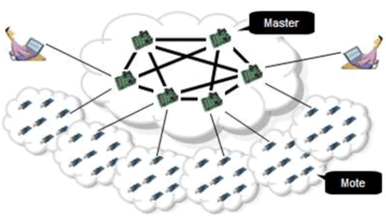
WSN technology – WSN topologies

- **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 rolesm, e.g. coordinator, sink, router, leaf



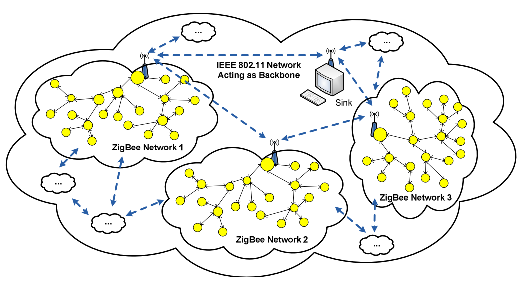
WSN technology – WSN topologies

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



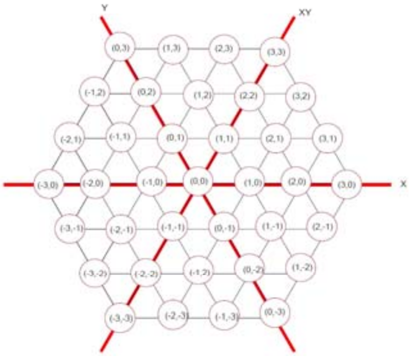
http://research.cens.ucla.edu/projects/2007/Systems/Tenet

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



WSN technology – WSN topologies

- **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

WSN technology – routing aspects

- 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); e.g. AODV
  - **deterministic**
    - unique routing path from any source to any destination (though nodes connectivity may be much larger); e.g. tree routing

WSN technology – routing aspects

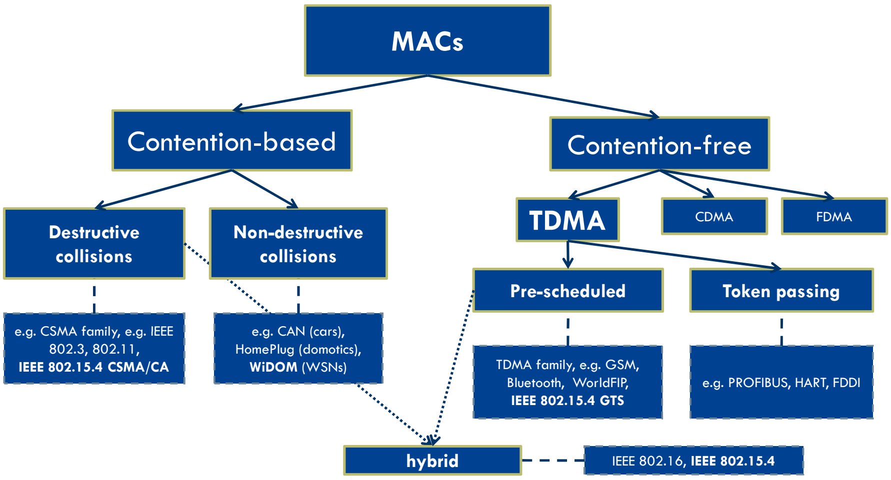
- Routing classification – **dynamics**
  - **proactive** (first compute all routes; then route)
  - **reactive** (compute routes on-demand)
  - **hybrid** (first compute all routes; then improve while routing)
- Routing classification – **architecture**
  - **direct** (node and sink communicate directly)
    - fast drainage; small scale
  - **flat** (equal; random indirect route)
    - fast drainage around sink; medium scale
  - **clustering** (hierarchical; route through distinguished nodes)

WSN technology – routing aspects

- 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.

WSN technology – MAC aspects

- MAC classification (do you like this one?)



WSN technology – MAC aspects

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

WSN technology – MAC aspects

2. contention-free

- transmissions 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 guarantees; ~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, HART, FDDI
  - **pros**: energy efficient; timing guarantees; ~100% network throughput
  - **cons**: not very flexible; very error-prone (token losses) in harsh environments

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WSN technology – MAC aspects

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 technology – MAC aspects

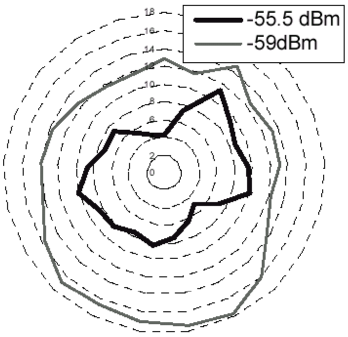
- Characteristics of a good MAC/DLL protocol for WSNs
  - **energy efficiency** (to prolong the network lifetime)
    - flexible enough to **adapt duty-cycles** (100% → 0%)
      - dynamically
      - in a per-cluster basis
    - must resolve some causes of energy loss:
      - **collisions** (due to retransmissions)
      - **hidden-nodes** and **exposed-nodes** (lead to unnecessary extra collisions)
      - **overhearing** (wasted effort in receiving a packet destined to another node)
      - **idle listening** (sitting idly and trying to receive when nobody is sending)

WSN technology – MAC aspects

- Characteristics of a good MAC/DLL protocol for WSNs (cont.)
  - **scalability and adaptability**
    - changes in network size, node density and topology should be handled rapidly, transparently and effectively
  - **reliability**
    - error detection/correction mechanisms; order inversion avoidance
  - **traffic differentiation**
    - support higher/lower priority traffic classes; support best-effort and real-time traffic
  - **minimized frame overhead**
    - but still support network management, security, error detection/correction

WSN technology – Physical Layer aspects

- radio link characteristics
  - **Link asymmetry**
    - node A is connected to Node B does not mean that Node B is connected to node A
  - **non-isotropic 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



*Zhou et. al. 04

WSN technology – Physical Layer aspects

- propagation phenomena
  - **reflection**
    - is the change in direction of a wave front at an interface between two different media so 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

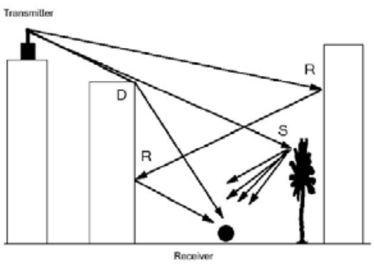


Figure 2.5 Reflection (R), diffraction (D) and scattering (S)

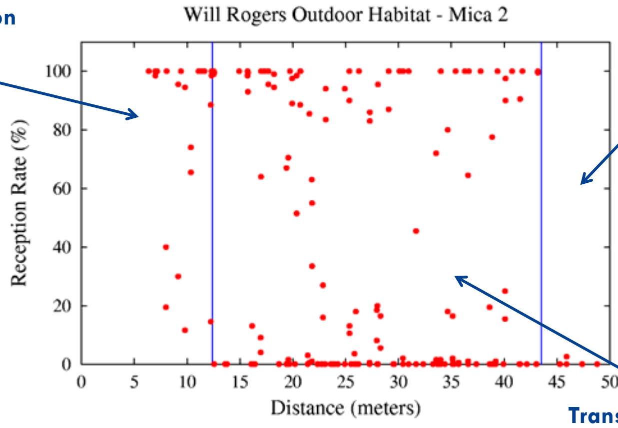
Source: **Wireless Networks**, P. Nicopolitidis, A. S. Pomportsis, G. I. Papadimitriou, M. S. Obaidat Publisher John Wiley & Sons, Inc. New York, NY, USA (2003)

WSN technology – Physical Layer aspects

- spatial characteristics

Connected region (PRR > 90%)

Disconnected Region (PRR < 10%)

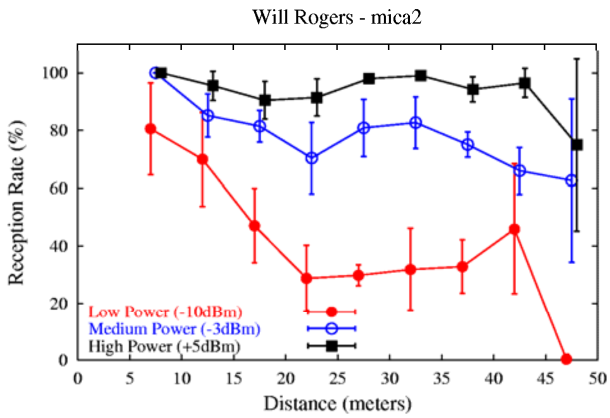


Transitional region (Gray area)

Cerpa et. al. 03

WSN technology – Physical Layer aspects

- packet reception rate vs. distance



Cerpa et. al. 03

WSN technology – motes (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, computation node or gateway

WSN technology – transceivers (examples)

	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

WSN technology – ZigBee transceivers

FREAKLABS updated 2008-12-05

Zigbee Chip Comparison - Transceivers

MANUFACTURER	PART NUMBER	SUPPLY VOLTAGE (V)	SLEEP CURRENT (UA)	TX CURRENT (MA)	RX CURRENT (MA)	TX POWER (DBM)	RX SENSITIVITY (DBM)	SECURITY	PACKAGE	DIMENSIONS (MM)	TEMPERATURE RANGE (DEG C)	COMMENTS
ATMEL	AT86RF230	1.8-3.6	.02 (TYP)	16.5 @ 3DBM	15.5	3	-101	NONE	32 QFN	5X5	-40 TO 85	NICE SPECS. NO SECURITY.
	AT86RF231	1.3-3.6	0.02	14.3 @ 3DBM	13.2	3	-101	AES	32-QFN	5X5	-40 TO 85	SECURITY MODULE ADDED. ANTENNA DIVERSITY. UP TO 2 MBPS.
FREESCALE	MC13201	2.0-3.4	1 (TYP), 22 (MAX)	30 @ 0DBM	37	4	-91	NONE	32 QFN	5X5	-40 TO 85	MC13201 - NON-ZIGBEE/802.15.4 APPS, PA AND LNA OUTPUT PINS FOR EXT AMPS, TX/RX SWITCH
	MC13202/3	2.0-3.4	1 (TYP) 6 (MAX)	30 @ 0DBM	37	4	-91	NONE	32 QFN	5X5	-40 TO 85	MC13202 - 802.15.4 ONLY MC1303 - 802.15.4 + ZIGBEE STACK
	MC13191/2/3	2.0-3.4	1 (TYP) 6 (MAX)	30 @ 0DBM	37	4	-92	NONE	32 QFN	5X5	-40 TO 85	MC13191 - NON 802.15.4/ ZIGBEE, MC13192 - 802.15.4 ONLY, MC13193 - 802.15.4 + ZIGBEE
TEXAS INSTRUMENTS	CC2420	2.1-3.6 (VREG) 1.6-3.6 (IO)	20	17.4 @ 0DBM	18.8	0	-95	CTR CCM AES	48 QLP	7X7	-40 TO 85	ONE OF THE FIRST 802.15.4 CHIPS OUT
	CC2520	1.8-3.8	.03(LPM1) 175(LPM2)	25.8 @ 0DBM 33.6 @ 5DBM	22.3 (NORMAL) 18.8 (LOW CURRENT)	5(TYP) 7(MAX)	-98	AES	28 QFN	5X5	-40 TO 125	SEE MY REVIEW ABOUT THIS CHIP'S SPECS
OKI	ML7065	2.5	NO INFO	NO INFO	NO INFO	0	-90	AES	48 QFN	7X7	-25 TO 70	POSSIBLE BUG ON WEBSITE WHERE DATASHEET LINK GIVES PRODUCT INTRO ONLY.
UBEC	UZ2400	2.4-3.6	2	23 @ 0DBM	19	0	-95	AES CTR CCM	40 QFN	6X6	-40 TO 85	CHECK ERRATA ON COMPANY WEBSITE FOR ISSUES WITH SECURITY ENGINE AND ZIGBEE 2006 SPEC.

WSN technology – ZigBee MCU+transceiver

FREAKLABS

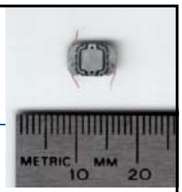
Zigbee Chip Comparison - Integrated MCU + Transceiver

MANUFACTURER	PART NUMBER	SUPPLY VOLTAGE (V)	MCU RAM SIZE (KB)	FLASH SIZE (KB)	GPIO	SLEEP CURRENT (UA)	TX CURRENT (MA)	RX CURRENT (MA)	TX POWER (DBM)	RX SENSITIVITY (DBM)	SECURITY	PACKAGE	DIMENSIONS (MM)	TEMPERATURE (DEG C)	COMMENTS
ATMEL	ATMEGA-64/128/256-RZXX	1.8-3.6	4, 8, 8	64, 128, 256	32, 54, 86	1 (MCU SLEEP) .02 (RF)	10 (MCU ACTIVE) 16.5 @3DBM (RF)	10 (MCU ACTIVE) 15.5 (RF)	3	-101	NONE	44 64 QFN 44 64 TQFP	QFN 7X7 9X9 TQFP 12X12 16X16	-40 TO 85	MULTI-CHIP MODULES USING THE AVR + AT86RF230
FREESCALE	MC-13211/2/3	2.0-3.4	1, 2, 4	16, 32, 60	32	.02 - .675 (MCU) 1 (RF)	.8 - 6.5 (MCU) 30 @ 0DBM (RF)	.8 - 6.5 (MCU) 37 (RF)	4	-92	NONE	71 PIN LGA	9X9		MULTI-CHIP MODULES USING THE HCS08 + MC1319X, SLEEP CURRENT DEPENDS ON SUPPLY VOLTAGE AND STOP MODE, ACTIVE CURRENT DEPENDS ON SUPPLY VOLTAGE AND CLOCK FREQ.
	MC13224	2.0-3.6	96	128	64	UP TO 5 UA	29	24	5	-100	AES	145-PIN LGA	9.5X9.5	-40 TO 105	SERIAL FLASH MIRRORED IN RAM. INCLUDES ROM WITH FULL 802.15.4 MAC. ARM7 MCU.
TEXAS INSTRUMENTS	CC2430	2.0-3.6	8	32, 64, 128	21	0.5	27 @ 0DBM	27	0	-92	AES	48 QFN	7X7	-50 TO 150	IEEE 802.15.4 TIMER, RANDOM NUMBER GENERATOR, ONBOARD TEMP SENSOR
	CC2431	2.0-3.6	8	128	21	0.5	27 @ 0DBM	27	0	-92	AES	48 QFN	7X7	-50 TO 150	SAME AS CC2430, INCLUDES LOCATION ENGINE
EMBER	EM250/260	2.1-3.6	5	128	17	1	33 @ 5DBM	29	5 (BOOST MODE)	-98	AES	48 QFN	7X7	-40 TO 140	BOOST MODE INCREASES TX 2 DBM AND RX, EM260 SAME AS EM250 BUT RUNNING IN ZIGBEE COPROCESSOR MODE
JENNIC	JN5121	2.2-3.6	96	0	21	5	45 @ 0DBM	50	0	-90	AES	56 QFN	8X8	-40 TO 85	JENNIC STACK IS IN ROM. REQUIRES EXTERNAL SERIAL FLASH FOR APPS.
	JN513X	2.2-3.6	8-96	0	21	0.4	39 @ 3DBM	39	3	-97	AES	56 QFN	8X8	-40 TO 85	SEE ABOVE

WSN technology – RFID

- RFID **tag** (or transponder)
  - object that can be applied to or incorporated into a **product, animal, or person** for identification using radio waves
    - from centimeters to meters distance (RFID 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

WSN technology – RFID



- RFID 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

SEVENTH FRAMEWORK PROGRAMME

WSN technology – RFID

- Example applications
  - cards (passports, bank, transportation)
  - asset management
  - identification/tracking (objects/people/animals)
  - security/access control
  - toll payment
  - race timing

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

WSN technology – RFID

- Challenges
  - **reliability**
    - certain materials distort or absorb RFID signals, harsh environment, EMI, product packaging and handling, tags/reader relative speed
  - **cost**
    - passive tags: $0.20 - $10 per tag now → < $0.05 per tag in the future
  - **reinventing processes/applications**
    - much beyond bar code replacement
  - **standardization/integration**
    - hardware, communication protocols, system integration
  - **wearable tags**
    - implantable, injestible, digestible,...
  - **RFID/WSN convergence**
    - trend for undefined border (or not) between RFIDs and motes...

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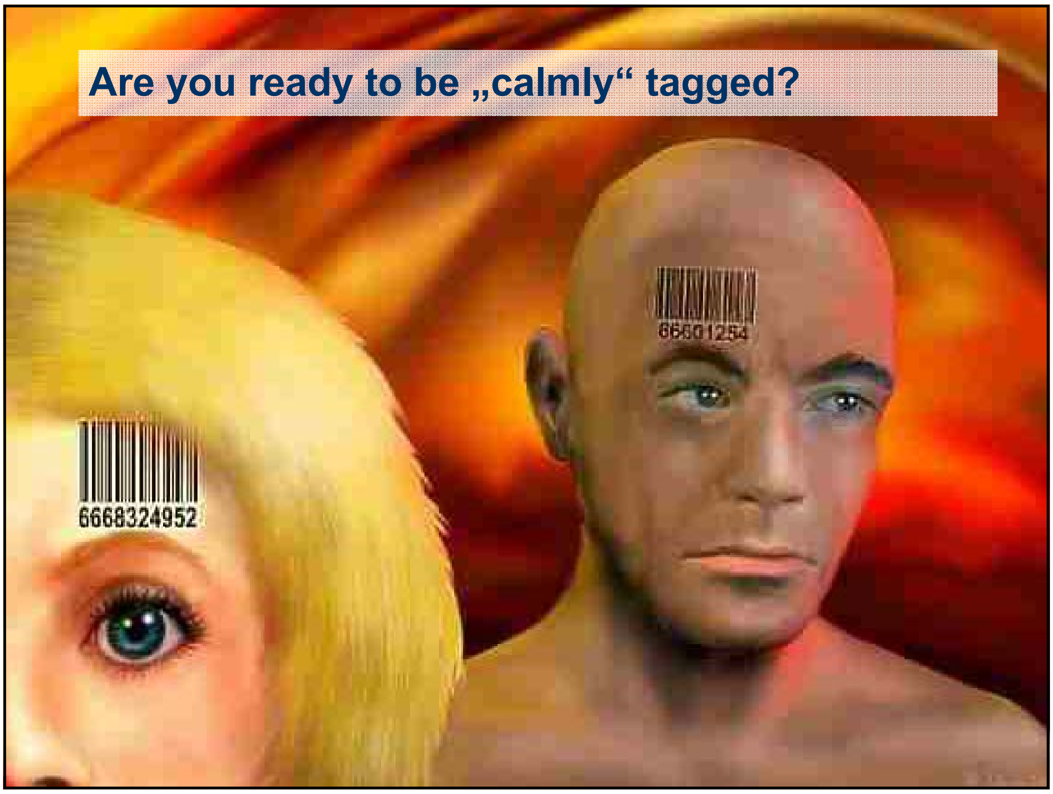
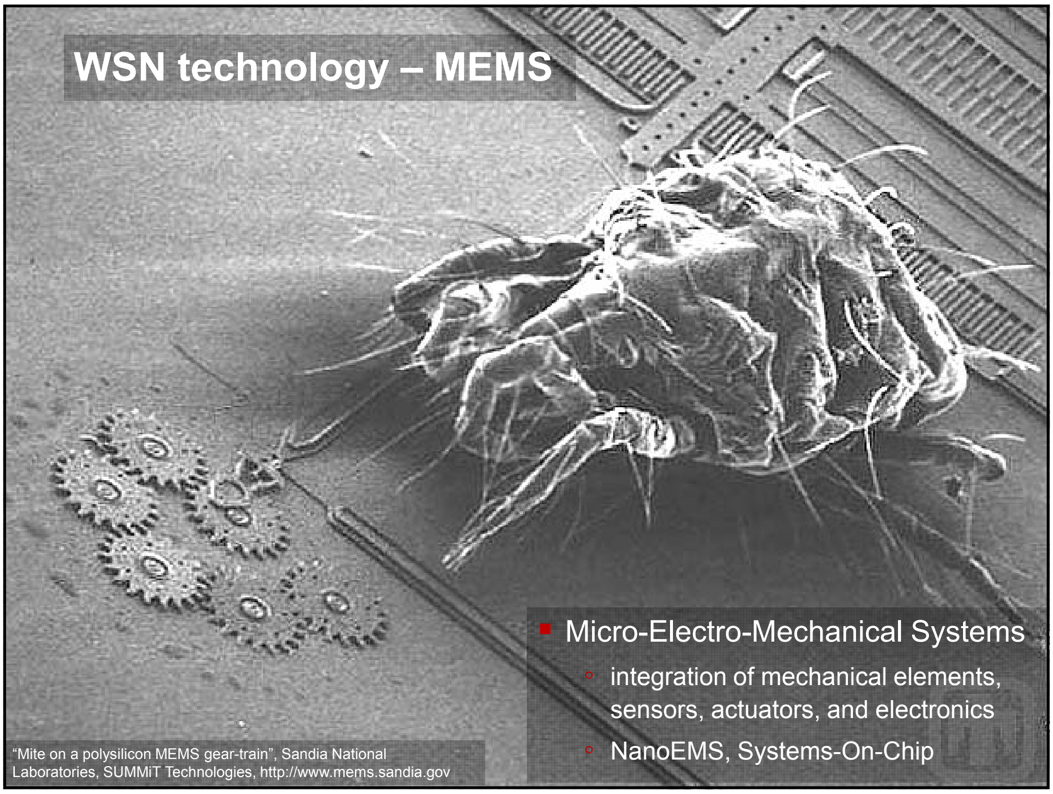
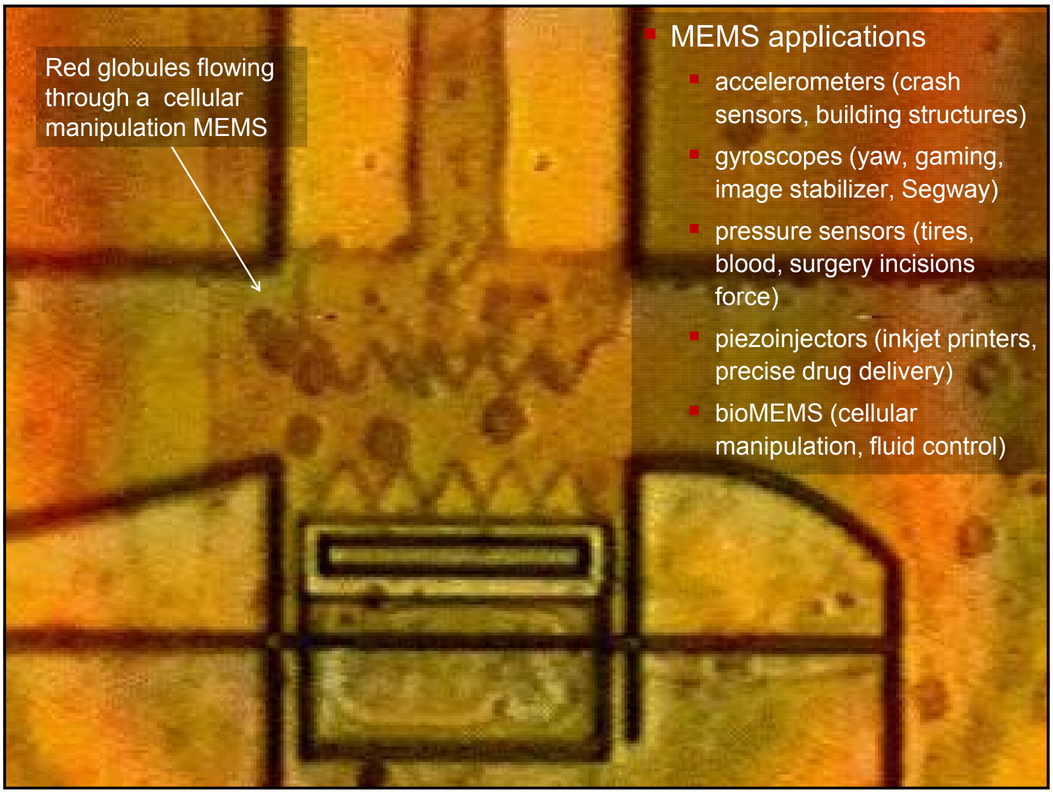

Are you ready to be „calmly“ tagged?
6668324952


WSN technology – MEMS
Micro-Electro-Mechanical Systems
integration of mechanical elements, sensors, actuators, and electronics
NanoEMS, Systems-On-Chip
“Mite on a polysilicon MEMS gear-train”, Sandia National Laboratories, SUMMiT Technologies, http://www.mems.sandia.gov



WSN technology – 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

WSN technology – 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

SEVENTH FRAMEWORK PROGRAMME

WSN technology – network ranges/types

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 Bluetooth Low Energy
x m – x0 m	Room	PAN (Personal Area Networks)	IEEE 802.15.1/Bluetooth IEEE 802.15.4/(ZigBee) IEEE 802.15.3/UWB (6lowpan), USB, FireWire
x0 m – x00 m	Building, Campus	LAN (Local Area Networks)	IEEE 802.11/WiFi IEEE 802.3/Ethernet WirelessHART, ISA100 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…

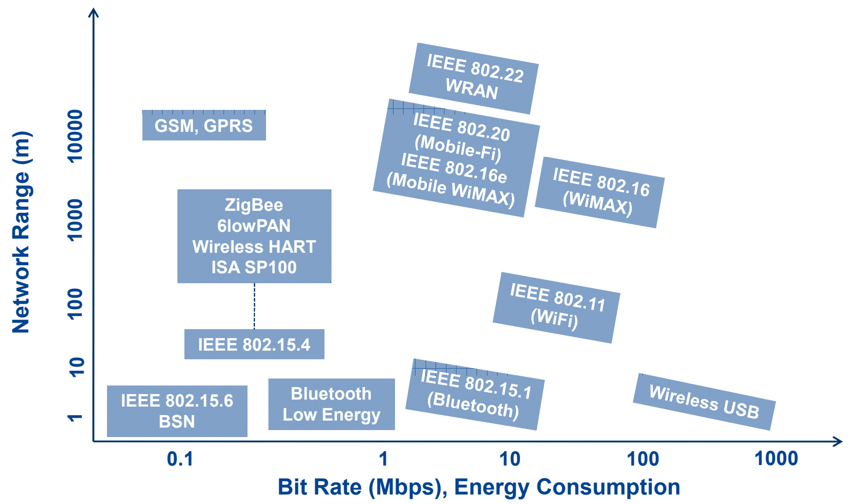
WSAN can span over all of these…

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

WSN technology – wireless standards landscape



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WSN technology – tiered comm. architectures

WSN technology – higher/lower comm. tiers

- higher communication tiers (backbone network)
  - **IEEE 802.11/WiFi** (QoS limitations)
  - **IEEE 802.16/WiMAX** (COTS not mature yet)
  - IEEE 802.15.3/UWB (COTS not mature yet)
  - GSM/GPRS
  - wired: switched Ethernet, ATM,FDDI,…
- lower communication tiers (sensor network)
  - **Bluetooth Low Energy** and **IEEE 802.15.6** (formed NOV/2007) – BAN
  - **IEEE 802.15.4** (Physical and Data Link Layers) – PAN
  - **ZigBee** (Network and Application Layers over IEEE 802.15.4)
  - **6lowPAN** (light IPv6 over IEEE 802.15.4)
  - **Wireless HART** and **ISA SP100** (over IEEE 802.15.4 PhL)
  - wired: Lon Works, HART, ASi, PROFIBUS, Foundation Fieldbus, DeviceNet, ModBus,…

Quality-of-Service

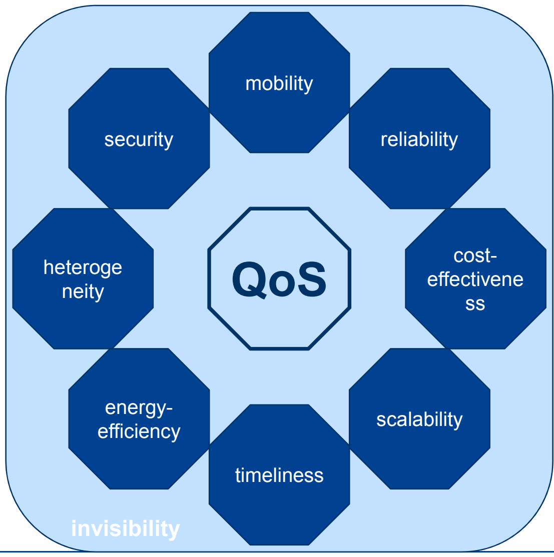
Quality-of-Service – question

- Please recall Slide #14 (Wikipedia definition of QoS):
  - "QoS is the ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. …"
- QoS is thus traditionally associated to:
  - **bit rate, network throughput, delay, bit/packet error rate**
  - which reflect the "**performance**" properties (timing & error rate)
- So, what do **YOU** think?
  - do these properties **alone** reflect the **overall quality** of the **service** provided to the **user/application**?

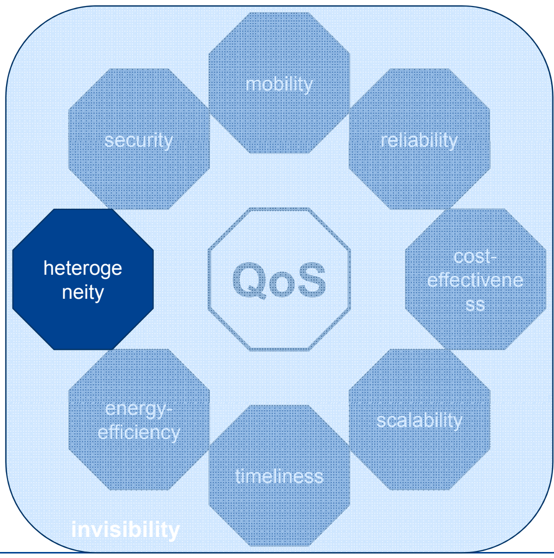
Quality-of-Service – a different perspective

- We consider that **this concept of QoS is too strict**
  - when taking into the consideration **the complexity and scale** of emerging computing systems
- Computing systems and particularly WSN applications should be designed taking into consideration **other QoS properties**, e.g.
  - energy-efficiency/system lifetime
  - dependability (reliability, availability, maintainability, security, safety,…)
  - timeliness (throughput, delay, traffic differentiation, real-time/best effort)
  - scalability, mobility, heterogeneity and cost-effectiveness
- thus, **QoS can be viewed in a holistic perspective**
  - as ellaborated next...

Quality-of-Service – a holistic approach



Quality-of-Service – heterogeneity



Quality-of-Service – heterogeneity

- **Heterogeneity emerges from:**
  - **≠ networking hardware & software**
    - ≠ sensor/actuator-level communication protocols (wired/wireless)
    - ≠ higher-level nodes (e.g. gateways, data processing sinks)
    - ≠ higher-level communication protocols
    - ≠ network planning/management tools
  - **≠ embedded system nodes hardware/software architectures**
    - ≠ sensors and sensor boards, design diversity, calibration
    - ≠ operating systems (for resource-constrained net. embedded systems)
    - ≠ programming languages ("idem") simulation/modelling
    - ≠ middleware (e.g. security and fault-tolerance mechanisms)

Quality-of-Service – heterogeneity

- **Heterogeneity emerges from (cont.):**
  - **≠ cyber/pervasive/host computing devices**
    - HMIs (in general), wearable computing (e.g. mobile phones, PDAs, handheld terminals, HMDs, RFID readers)
    - industrial computers (e.g. PLCs, NCs, RCs) and machinery, mobile robots, transportation vehicles, data-base servers
  - **≠ applications/services/users in the same system**
    - same network infrastructure may support several applications/services
    - potentially several/many human users, eventually playing at ≠ levels and with ≠ cultures, ≠ technical skills,...

Quality-of-Service – heterogeneity

- Research challenges
  - **new classes of resource-constrained embedded system nodes must be identified**
    - defining (or not?) **frontiers between nodes with ≠ characteristics and ≠ capabilities**
      - MEMS, active/passive RFID, "general-purpose" motes (e.g. Mica, Telos, Firefly), powerful motes (e.g. iMote, SunSPOT, Stargate)
    - trend for **miniaturization will turn this task harder** (or easier?)...

Quality-of-Service – heterogeneity

- Research challenges (cont.)
  - **interoperability btw sensor/actuator-level comm. protocols**
    - experience: there will be **no "single" standard protocol for WSNs**
    - **≠ wireless protocols will have to coexist**
      - e.g. IEEE 802.15.4, IEEE 802.15.6, ZigBee, 6loWPAN, IEEE 802.15.1 & Bluetooth Low Power, ISA100 or WirelessHART
    - **WSN protocols will have to coexist wih wired protocols**
      - such as for domotics (e.g. KNX, LonWorks), process control (ASi, DeviceNet, HART), industrial automation (PROFIBUS, FF) and automotive (e.g. FlexRay, CAN, LIN, MOST) systems

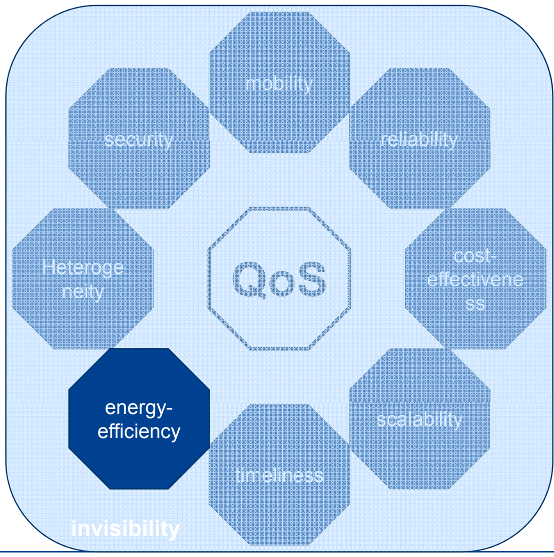
Quality-of-Service – heterogeneity

- Research challenges (cont.)
  - **interoperability btw sensor/actuator-level and higher-level protocols**
    - wireless: IEEE 802.11/WiFi, IEEE 802.16/WiMAX, IEEE 802.15.3/UWB
    - wired: Switched/Industrial Ethernet, ATM
    - guaranteeing end-to-end QoS is even more complex!
  - **dealing with ≠ embedded system nodes hardware/software**
    - **≠ sensor technology**
      - for measuring different physical quantities
      - same physical parameter measured by n sensor nodes
        - = type: redundancy, accuracy, functional (e.g. MAX) needs
        - ≠ types: “design diversity” needs
    - **≠ operating systems** (e.g. TinyOS, Contiki)
      - ≠ programming languages (e.g. nesC, C, JAVA)
      - ≠ simulation/programming environments/tools

Quality-of-Service – heterogeneity

- Research challenges (cont.)
  - **≠ applications/services/users in the same system**
    - same network infrastructure may support several applications/services
      - **≠ applications/services will impose ≠ QoS requirements**
        - will dynamically change depending on **spatiotemporal** issues
      - system designers must adequately **devise mechanisms** such as MAC/routing, admission control and scheduling, security, fault-tolerance, data aggregation/processing
        - **to encompass such applications/services coexistence**
    - **several/many human users, playing at ≠ levels and with ≠ cultures, ≠ technical skills,...**
      - further research on Human-Computer Interaction, HMIs, ergonomics, psychology and **semantics** is required

Quality-of-Service – energy-efficiency



Quality-of-Service – energy-efficiency

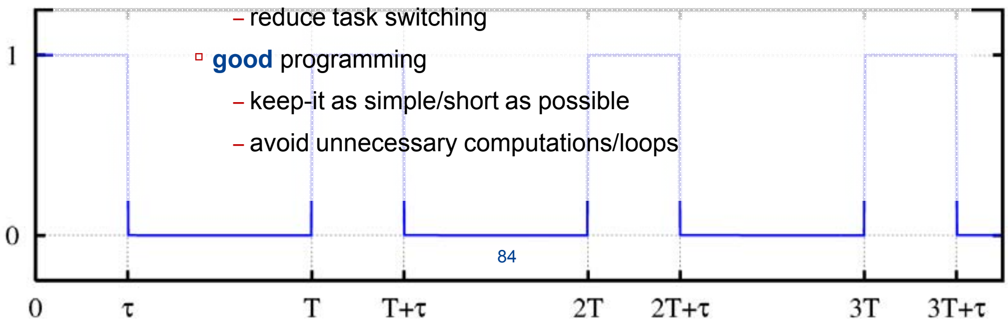
- Energy concerns must always be present
  - WSNs = embedded devices at large-scale
    - most will be **communicating through air** (wireless
    - some will be mobile
    - additional energy **cables are a real burden** of even impossible
  - therefore
    - most of the devices must be energetically **self-sustainable**
  - but this does **not** mean that all devices need to be autonomous in terms of energy
    - **some devices** can (must) be **powered by the electrical grid**
      - due to special duties (e.g. routers/gateways, data processing)
    - **some devices** can (must) be **powered by special energy sources** (micro-generators or high capacity batteries/fuel cells/supercapacitors)
      - due to innaccessible location, mobility features, etc.

Quality-of-Service – energy-efficiency

- Research challenges
  - **hardware design**
    - **reduce hardware's energy consumption**
      - microprocessors, microcontrollers, DSPs
      - memories, ADC/DAC
    - **reduce energy losses**
      - mechanical (e.g. friction), electrical (Joule's), magnetic (Foucault's)
      - trend for MEMS (when appropriate)
    - **favouring active sensors** (vs. passive)
      - active sensors produce their own energy
      - thermocouple, piezoelectric, photocell

Quality-of-Service – energy-efficiency

- Research challenges (cont.)
  - **resources utilization**
    - **sleep** as much as possible
      - low duty-cycle computations and communications
    - **efficient** computations
      - try to reach **100%** CPU(s) utilization
        - optimal scheduling algorithms
        - reduce task switching
      - **good** programming
        - keep-it as simple/short as possible
        - avoid unnecessary computations/loops



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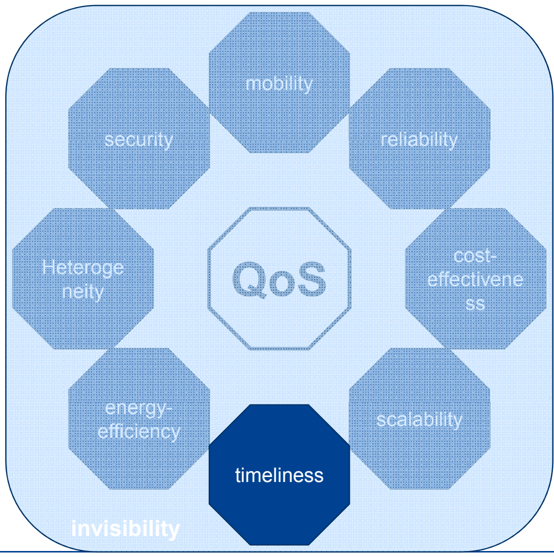
Quality-of-Service – energy-efficiency

- Research challenges (cont.)
  - resources utilization (cont.)
    - **efficient** communications
      - **energy-aware PhL/MAC/routing protocols**
        - use **adequate TX/RX power level** (→ location-awareness)
        - avoid **idle listenning & hidden/exposed terminal** problems
        - use **appropriate routes**, the shorter the better (not always)
        - avoid **collisions** (group nodes in CSMA, contention-free MACs)
      - **cross-layer design**
        - **lighter** protocol stacks (< memory footprint, < proc. delays)

Quality-of-Service – energy-efficiency

- Research challenges (cont.)
  - resources utilization (cont.)
    - **efficient** communications (cont.)
      - communicate **only when really needed**
        - **data aggregation/distributed data processing** if possible
        - do **not waste bandwidth** (specially in TDM-like MACs)
        - operate at **low duty cycles** (→ synchronization)
      - **reduce overheads**
        - OSI layer headers (e.g. security and reliability-related),
        - network management messages
  - **energy harvesting**/scavenging techniques
    - grab energy **from environment**
      - (e.g. thermal, vibration, light, humidity, wind, waves)

Quality-of-Service – timeliness



Quality-of-Service – timeliness

- Timeliness **= timing behaviour** of a system
  - is reflected in properties such as
    - network **throughput**
      - effective bit rate
    - message **delays**
      - how long does it take for a message to be transmitted from a source to be received by the destination
    - traffic **differentiation**
      - assign traffic classes/priorities, e.g. real-time/best effort traffic
  - these must be **balanced with other QoS properties**
    - e.g. to increase throughput it might be necessary to increase the “hardware” bit rate or nodes duty cycle
      - leading to more energy consumption

Quality-of-Service – timeliness

- Timeliness is **of increasing importance**
  - in a **cyber-physical world**, computing entities closely interact with their physical environment, thus their **timing behaviour is of paramount importance**
  - In some applications, some tasks are imposed to finish within a certain **deadline** – dubbed as “**real-time applications**”
    - need **RT computation**
      - requiring RT operating systems and programming languages
    - need **RT communication**
      - requiring RT communication protocols
    - usually require **over-allocation of resources**
      - resulting of the inherent pessimism of the analysis (e.g. WCET)
      - a problem for dynamic and energy-efficient systems

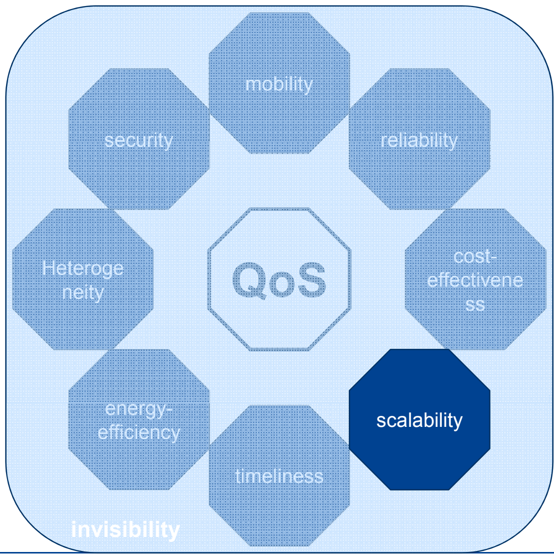
Quality-of-Service – timeliness

- Network **resources must be predicted in advance** (pre-run-time)
  - to support the applications with a predefined timeliness
  - to guarantee that the system will behave as expected
- **Network dimensioning methodologies/tools**, for computing
  - performance limits (throughput)
  - worst-case **message delays** (end-to-end or per-hop)
  - worst-case routers’ **buffers size**
- Real-time communications require
  - **deterministic** MAC and routing protocols
  - **hierarchical** network models (hexagonal, grid or cluster-tree)

Quality-of-Service – timeliness

- Research challenges
  - **biggest challenge is to balance all contradictory QoS properties**
  - explore hierarchical network architectures (already referred)
  - investigate how **aggregate computations** can be used to achieve a **time complexity that is independent of the number of nodes**
  - design algorithms and protocols in a **cross-layer approach**; bad thing is that software gets more difficult to maintain and update
  - **consider timeliness both at the network and node levels**; nodes hardware design, OS, prog. language and style impact timeliness
  - investigate **existing OSs** (particularly TinyOS and Contiki) **to incorporate real-time features** (e.g. preemption, priority-inheritance)
  - find **innovative MAC and routing schemes** (e.g. to reduce collisions, increase throughput and bandwidth utilization,...)

Quality-of-Service – scalability



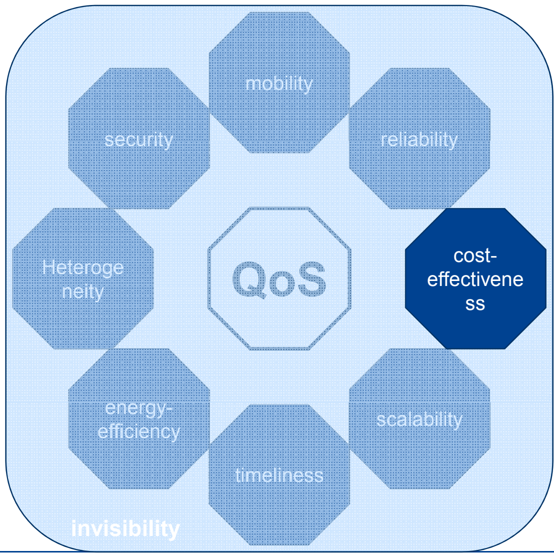
Quality-of-Service – scalability

- Scalability refers to the **capability of a system to easily/transparently adapt itself to variations** in the
  - **number of nodes** (fewer or more nodes in the overall system)
  - **nodes' spatial density** (fewer or more nodes in a restricted region)
  - **geographical region under coverage** (smaller/wider, 2D/3D)
- So far, largest WSN systems comprise some hundreds of nodes
  - e.g. VigilNet, ExScal
- **Computational and sensing power grows linearly with the number of sensor nodes**
  - **communication capabilities do NOT** (they get worse)
  - 1000 nodes reporting 1 ms message = **20 minutes!**

Quality-of-Service – scalability

- Research challenges
  - efficient **scale-aware MAC/routing mechanisms** (e.g. **WiDOM**)
  - efficient **data processing, aggregation, storage and querying**
  - explore hierarchical (tiered) network architectures
  - support **multiple data sinks** (need or load balancing)
  - investigate **how standard and COTS technologies can be used** and interoperate to support scalable systems

Quality-of-Service – cost-effectiveness



Quality-of-Service – cost-effectiveness

- **System cost** usually includes issues such as
  - system design/development
  - hardware cost
  - deployment and commissioning
  - exploration and maintenance
- Research challenges
  - cost/node target **< $1 threshold** (current cost €10-€50)
  - go for **mass production** (demand-supply snowball)
  - bet on **cheaper designs/materials/production processes**
  - bet on **components reduction/miniaturization** (e.g. MEMS)

Quality-of-Service – reliability

SEVENTH FRAMEWORK PROGRAMME

Quality-of-Service – reliability

- In WSN applications, **operational and environmental conditions may be unfavourable**
  - vibration/mechanical impacts
  - extreme (high/low) temperatures
  - extreme (high/low) pressures
  - water, humidity, moisture, dust
  - other RF sources, EMI
- Data delivery in WSN is inherently faulty and unpredictable (much more than in wired networks or even in other wireless networks)
  - sensor nodes are fragile and have weak resources
  - radio links are error-prone (EMI, obstacles, environment, mobility)
  - network congestion (event data bursts) may lead to packet loss
  - multi-hop nature of WSNs

Quality-of-Service – reliability

- WSN equipment must be **robust** and **reliable**
  - to overcome all these harsh conditions
  - to reduce or eliminate maintenance actions
  - to have a lifetime of years
- **Robustness** (hardware/software) refers to
  - a component or a system that performs well not only under ordinary conditions but also under abnormal conditions that stress
- **Reliability** is
  - the ability of a component or system to perform its required functions under stated conditions for a specified period of time
    - requires the use of robust hardware/software
    - requires the support for fault-tolerance mechanisms

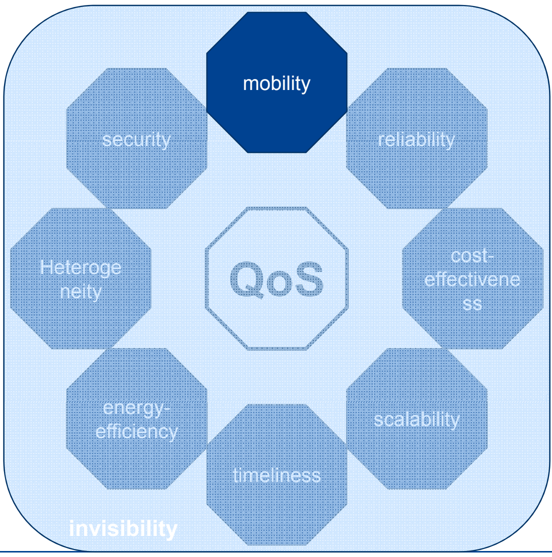
Quality-of-Service – reliability

- Research challenges
  - hardware robustness
    - investigate on robust, cheap, ecological materials/components
    - miniaturization & cost/node should not prejudice hardware robustness
  - robust software/algorithms
    - write "generic" code, to accommodate wide range of situations and thereby avoid having to insert extra code just to handle special cases
    - using formal techniques, e.g. fuzz testing, to test algorithms
    - providing each application with its own memory area (avoiding interference with the memory areas of other applications and kernel)
    - explore advanced programming paradigms (e.g. collaborative computing, reflection mechanisms)

Quality-of-Service – reliability

- Research challenges (cont.)
  - fault-tolerance
    - generically, investigate F-T mechanisms that are scalable, energy/time-efficient, adaptable to dynamic changes
    - F-T mechanisms must spread along different layers (DLL, NL, AL), in a cross-layer approach (exploring the interactions btw layers)
    - find more robust TL solutions that can recover from node/link failures and network congestion

Quality-of-Service – mobility



Quality-of-Service – mobility

- WSN applications may involve a diverse set of mobile entities
  - vehicles, equipment, animals, humans, fluids,…
- instantiated in
  - nodes' mobility
    - isolated or in groups, sensor nodes or gateways
  - data sinks' mobility
    - on purpose (e.g. data mules) or due to user/application requirements
  - event mobility
    - kind of mobility, e.g. event tracking (e.g. tsunami, gas leak, herd, fire)
- mobility speed
  - fast: > 20 km/h
  - slow: < 20 km/h

Quality-of-Service – mobility

- Radio-cell/cluster boundaries
  - intra-cell (or intra-cluster) mobility
    - mobile node moves without losing connectivity with base station (structured network) or peers (ad-hoc network)
    - requires no mobility management
  - inter-cell (or inter-cluster) mobility
    - mobile node moves outside the radio coverage of a certain cell/cluster into another cell/cluster
    - hand-off (or hand-over) management mechanism is required

Quality-of-Service – mobility

- Mobility support can be very helpful, e.g.
  - to maintain and repair network connectivity (self-configuration)
  - to improve network coverage
  - to balance energy consumption (e.g. rotating cluster-heads/routers)
  - to adapt to dynamic stimulus changes (collect data upon event)
  - to collect data (data mules), extending WSN lifetime
  - to **increase QoS in critical regions**, upon events
  - to encompass **new applications** or extend “current” applications’ boundaries with extra capabilities
  - ultimately, to increase **users’ satisfaction** ☺

Quality-of-Service – mobility

- Research challenges
  - mobility support in WSNs is still in its infancy
  - investigate on mechanisms for **transparent, energy-efficient and reliable mobility support** with **no network inaccessibility times**
    - usually, protocols (e.g. ZigBee) only support joining/leaving of nodes
  - analyse how **fast mobility** can be supported (even harder to tackle)
  - investigate new **MAC and routing** mechanisms that are **adaptive to dynamical changes** (traffic load, topology) caused by mobility
  - develop WSN **simulation tools/models encompassing mobility**
  - find **new localization mechanisms** that are energy/cost-efficient
  - propose **accurate radio link quality estimators**
    - a basic building block for mobility, for hand-off decisions

Quality-of-Service – security

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Quality-of-Service – security

- Security in WSN applications is much more complex than in today's"traditional" desktop and enterprise computing
  - systems' large-scale (nodes/region), wireless, embedded, heterogeneous, unattended, environmentally hostile, dynamic nature
  - systems may go beyond boundaries of "controlled" environments
  - no "central, trusted authority"
  - cost/node precludes robust tamper-resistant casing/protection
- WSN systems will require
  - customized solutions: per application, even per node type
  - dynamically adaptable mechanisms, reconfigurability

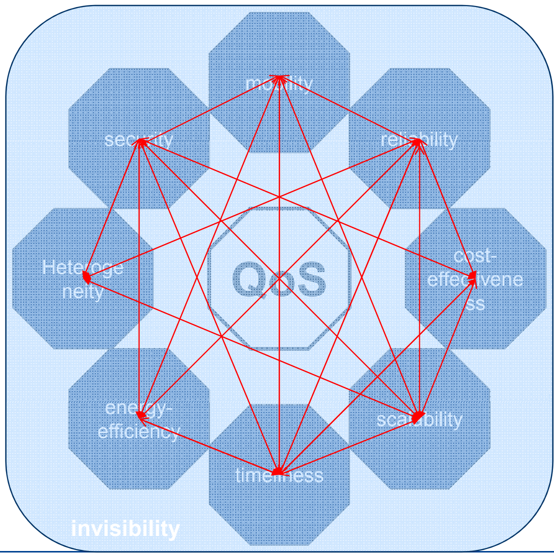
Quality-of-Service – security

- Security breaches
  - security bootstrapping
    - to ensure authenticity, confidentiality, freshness, integrity
    - how to setup secret keys among communicating nodes
  - key management: distribution and revocation
    - faulty or malicious devices must be logically removed from the network
    - to guarantee systems' reliability and safety
  - secure reconfiguration
    - e.g. remote downloading of authenticated components into a device upon its deployment of relocation
  - intrusion detection
    - to detect attempts to exploit insecurities and warn for malicious attacks
  - secure routing
    - to prevent malicious/faulty devices to perform actions on routed data/packets

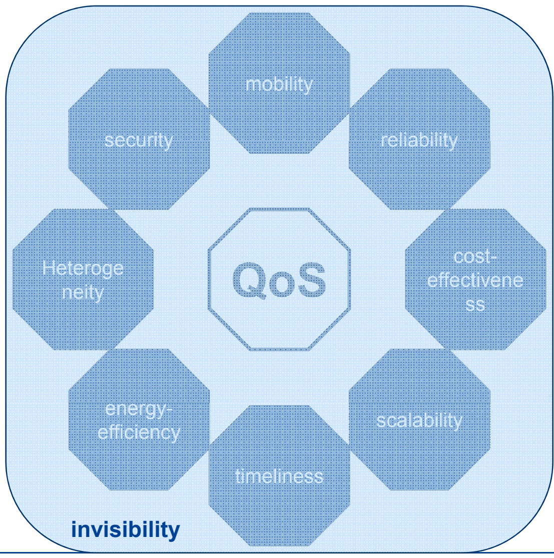
Quality-of-Service – security

- Research challenges
  - research on previous topics has **not reached maturity**
  - **low-cost, low power hardware** support to security
    - security mechanisms are computationally hungry
    - requires additional hardware to "current" WSN nodes
  - **remote program integrity** verification
    - existing tamper-resistant hardware is too expensive
    - "lighter" solutions (than existing ones) must be devised
  - balance security **with other QoS properties**
    - implementing security may imply additional hardware, additional computations, additional communications, longer messages,…

Quality-of-Service – multilateral impacts ☹



Quality-of-Service – invisibility



Quality-of-Service - invisibility

- Invisibility
  - recall Weiser's vision (Slide #25)
    - "**the best computer is a quiet, invisible servant**"
  - embedd system/components in the environment:
    - **invisible** (to the human eye)
    - **inaudible** (to the human ear)
    - ...
  - environmental impact
    - avoiding "buying new is cheaper than maintaining/repairing/recharging"
    - **recyclable** materials, **sustainable** systems
    - **ecologically friendly** (fauna, flora, land, sea, air)

Ongoing work – COTS4QoS research cluster

- Partners involved: ISEP, NUIG, TUB, UCL, UNIPI
- General Objective
  - achieving **Quality-of-Service** (QoS) in large-scale distributed embedded systems using **standard** and **Commercial-Off-The-Shelf** (COTS) technologies, namely concerning communication protocols, hardware platforms and operating systems
- Short-term (1st year) research
  - radio link quality estimation and characterization
  - integration of the open-ZB (CISTER) and TKN154 (TUBerlin) protocol stacks
  - adding Security functionalities to the open-ZB/TKN protocol stack
  - assessment of standard communication protocols for backbone
- Related links
  - open-ZB toolset: http://www.open-ZB.net
  - TinyOS Alliance: http://www.TinyOS.net
  - CONET: http://www.cooperating-objects.eu/research-clusters

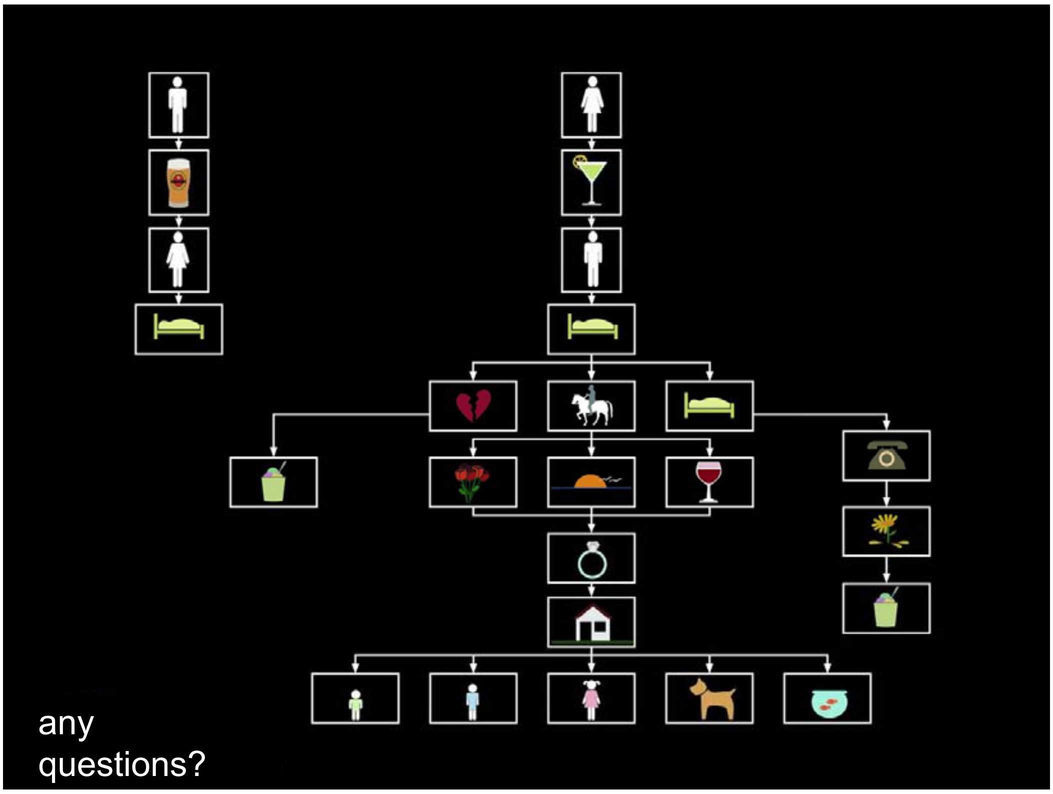
open-ZB

OpenSource Toolset for IEEE 802.15.4 and ZigBee

Ongoing work – CONET highlights

- CONET **roadmap** (http://www.cooperating-objects.eu/roadmap)
  - book on **SOTA and future directions** in the CO area
  - first edition to be released soon ☺
  - based on the Embedded WiSeNts roadmap
    - Coordination Action that finished on December 31st, 2006
    - **available for free download** (use link above)
- CONET **newsletter** (http://www.cooperating-objects.eu/newsletter)
  - monthly news from the consortium and CO related stuff
  - Issue #1 (January 2009), **available for free download** (link above)
    - guest column: "**When Sensor and Actuator Networks Cover the World**" by **John Stankovic**, University of Virginia
    - roadmap previews "**WSN Applications for Healthcare**" and "**Vision for Innovative Applications on the Aerial Transportation Domain**“

COOPERATING OBJECTS
NETWORK OF EXCELLENCE


any
questions?