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ART-WiSe

a communication architecture for large-scale critical applications based on standard and COTS technologies

Mário Alves (mjf@isep.ipp.pt)

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CISTER Research Centre in Real-Time Computing Systems
FCT Research Unit 608

isep instituto superior de engenharia do porto

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 8 PhD), 12 different nationalities
  - 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)

focus

Buzzwords

- ubiquity
- pervasiveness
- wireless
- mobility
- smart spaces
- M2M
- distributed
- embedded
- dynamic
- energy

Future will witness…

- **People want**, demand, require
  - monitoring/controlling **everything/everywhere** in a pervasive fashion
  - living in "**ambient intelligence**" (homes, buildings, roads, factories, parks)
  - to be "**always connected**"
- so, **humans increasingly depend on "computers"**
  - for all their **daily life** activities
- thus, **computing systems** will tend to be
  - ubiquitous, embedded, distributed, networked, large-scale
  - more tightly connected to the physical world (humans, machines, environment) – **cyber-physical**
  - mobile, wearable, dynamic, scalable
  - more dependable – computers must be **reliable, safe, secure**

…more embedded computing systems …

- Since systems will tend to **scale**
  - number of nodes: **10^3…10^6…**
  - physical dimension of the monitored region: **10^3 …10^6… m^2**
- this implies
  - very low **node cost** (tending to 1 €/$ per node in 2 years?)
  - no **maintenance** (at least for most of the nodes)
  - long network/node **lifetime** (several years)
- and stringent node **resource limitations**
  - **processing/memory** – speed, size
  - **communications** – radio coverage, bit rate
  - **energy** – battery size vs. capacity

…bringing important challenges

- 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**
    - **real-time** computing
  - get messages transmitted **correctly** and **on time**
    - **real-time** communications
  - …
- and **this is what we are addressing**

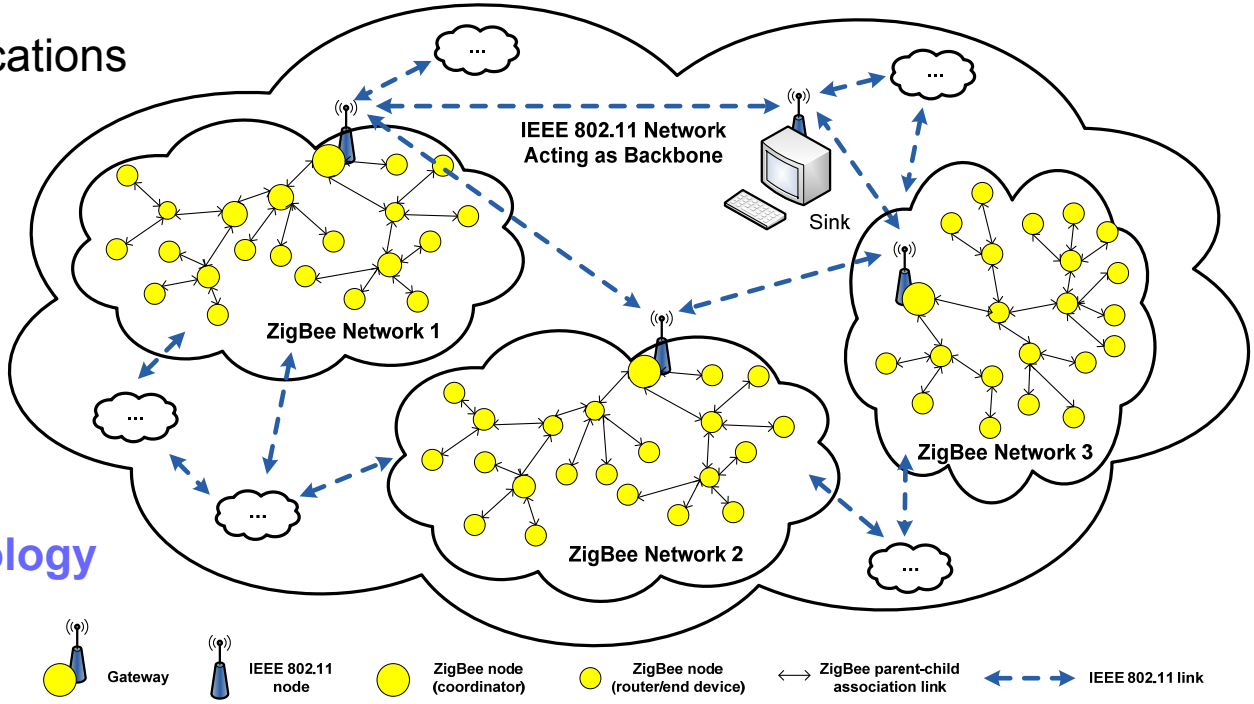
Which applications are we targeting?

- We are particularly interested in applications with stringent Quality-of-Service requirements, such as:
  - critical physical infrastructures (e.g. bridges, tunnels, railways, highways, metropolitan)
  - utilities transportation systems (e.g. electrical, gas, water, oil)
  - homeland security
  - 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. in a hospital)
  - intelligent transportation systems
  - precision agriculture

Did you mention “ART-WiSe”?

Architecture for Real-Time Communications in Wireless Sensor Networks

- **Objective**
  - large-scale critical applications
- **Main Design Goals**
  - Real-Time
  - Reliability
  - Scalability
  - Mobility
  - Energy-efficiency
  - Cost-effectiveness
  - **COTS standard technology**
- **Multiple Tiered Arch.**
  - Tier 2: backbone
    - IEEE 802.11 (WiFi) +… or
    - IEEE 802.16 (WiMAX) +… or…
  - Tier 1: sensor network
    - IEEE 802.15.4/**ZigBee** +…



- Tier 2 is composed of
  - *n* WiFi nodes, each including a
  - gateway to a Tier 1 ZigBee network
- Tier 1 is composed of
  - *n* ZigBee networks, each with
  - *m* clusters (cluster-tree, mesh)

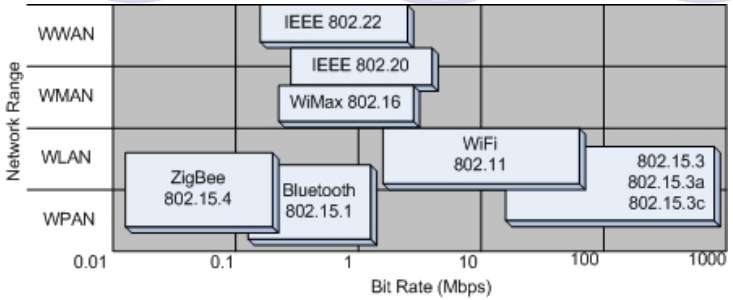
Why using IEEE 802.15.4/ZigBee?

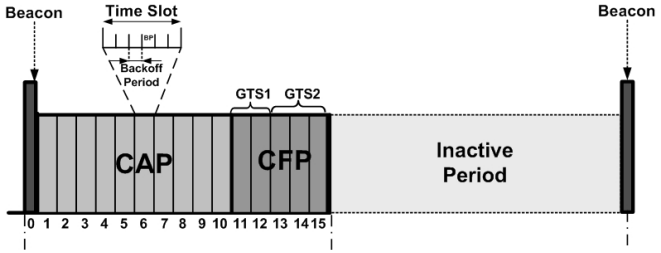
- **Energy-efficiency**
  - adaptable duty-cycles (100% → ≈ 0%)
  - low data rates (20-250 kbps)
  - low radio coverage (≈ 30 m)

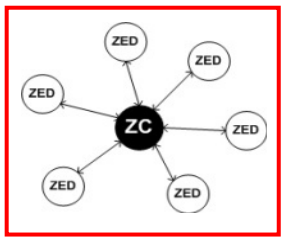
- **Traffic differentiation**
  - Real-Time traffic
    - Guaranteed Time Slots (GTS)
  - Best-effort traffic
    - CSMA/CA mechanism

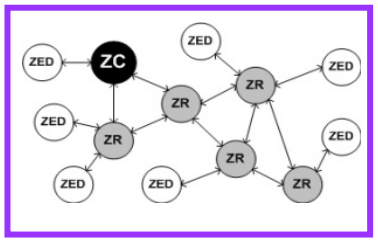
- **Scalable network topologies**
  - star, mesh, cluster-tree
  - up to 65000 nodes per PAN

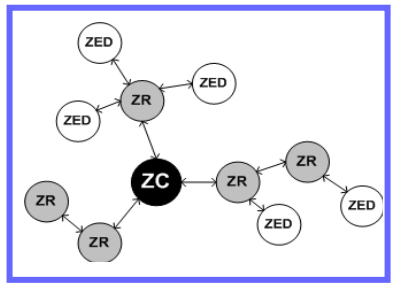
- **COTS standard technology**
  - many different motes
  - many manufacturers
  - simulation/debugging tools
  - fast growing market

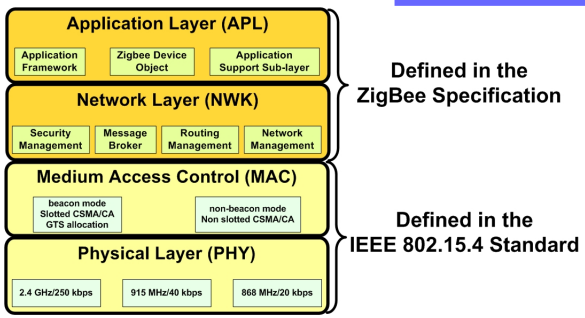






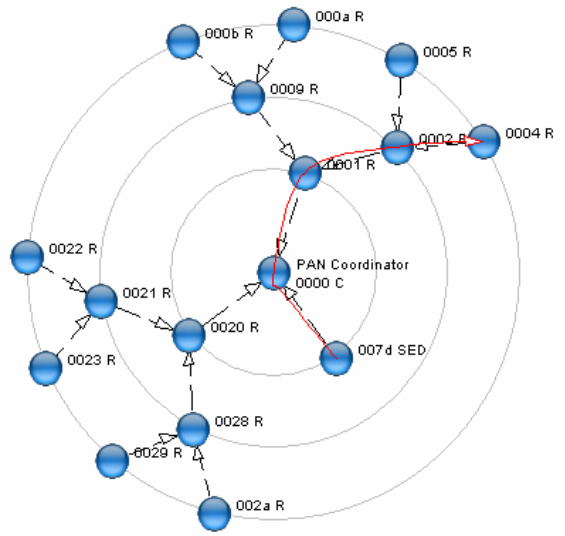


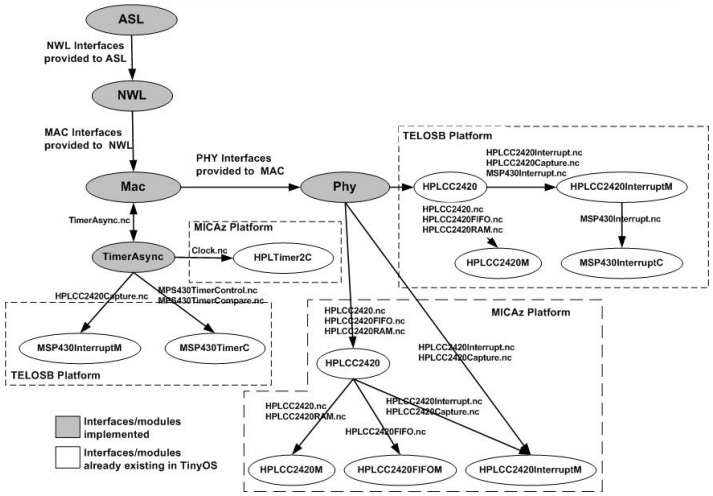


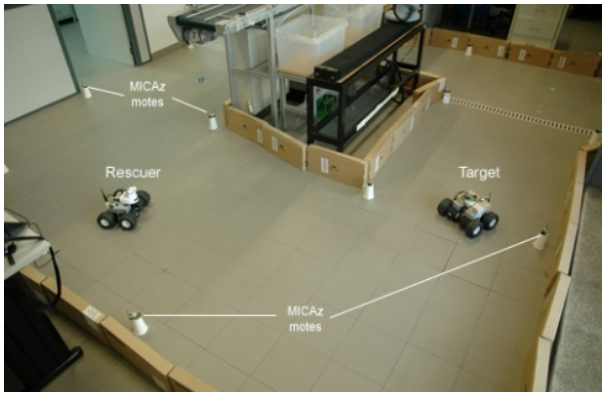


What have we done?

- Developed a **complete toolset for ZigBee**
  - to analyse, simulate, dimension and test IEEE 802.15.4/ZigBee networks (star and cluster-tree)
    - system planning tools: **MATLAB**
    - simulation models: **OPNET**
    - protocol stack: nesC/**TinyOS** over MICAz and TelosB motes
- Engineered **ZigBee cluster-tree WSNs**
  - efficiently scheduling cluster (beacon/superframe) active periods
  - providing worst-case timing analysis and network dimensioning
  - energy/bandwidth tradeoff
    - **respecting backward compatibility with the standard**
- Proposed and validated **novel methodologies** to
  - increase bandwidth utilization by multiple nodes sharing time slots
  - mitigate the hidden-terminal problem
  - tolerate router failure/degradation via proactive re-association
  - differentiate between low/high priority traffic in CSMA/CA
    - **respecting backward compatibility with the standard**
- Opened our **source code** to the scientific community
  - http://www.open-ZB.net: over **30000 visits** and **1000 downloads** (since DEC/2006)
  - http://www.hurray.isep.ipp.pt/ART-WiSe: over **15000 visits** (since DEC/2006)
- Validated our results over **realistic application** scenarios
  - namely a search&rescue robot-based application
  - http://www.hurray.isep.ipp.pt/ART-WiSe/testbed







Where have we been publishing?

- **Our work has been recognized at the highest level**
  - A. Koubâa, M. Alves, E. Tovar, "i-GAME: An Implicit GTS Allocation Mechanism in IEEE 802.15.4", **18th Euromicro Conference on Real-Time Systems** (**ECRTS'06**) **European's premier conference in real-time and embedded systems – one of the 4 best papers**
  - A. Koubâa, E. Tovar, M. Alves, "Modelling and Worst-Case Dimensioning of Cluster-Tree Wireless Sensor Networks", **27th IEEE Real-time Systems Symposium** (**RTSS'06**) **most reputed conference in the area of real-time systems, with 10-12% acceptance ratio**
  - A. Koubâa, M. Alves, E. Tovar, "IEEE 802.15.4: a Federating Communication Protocol for Time-Sensitive Wireless Sensor Networks", **chapter of the book** "Sensor Networks and Configurations: Fundamentals, Techniques, Platforms, and Experiments", **Springer-Verlag**, January 2007.
  - A. Koubâa, A. Cunha, M. Alves, "A Time Division Beacon Scheduling Mechanism for IEEE 802.15.4/Zigbee Cluster-Tree Wireless Sensor Networks", **19th Euromicro Conference on Real-Time Systems** (**ECRTS'07**) **BEST PAPER AWARD**
  - P. Jurcik, A. Koubâa, M. Alves, E. Tovar, Z. Hanzalek, "A Simulation Model for the IEEE 802.15.4 protocol: Delay/Throughput Evaluation of the GTS Mechanism", **15th IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems** (**MASCOTS'07**) **the premier conference in the area of modeling and simulation of networks and computers**
  - A. Cunha, A. Koubâa, R. Severino, M. Alves, "Open-ZB an open-source implementation of the IEEE 802.15.4/ZigBee protocol stack on TinyOS", **4th IEEE International Conference on Mobile Ad-hoc and Sensor Systems** (**MASS'07**) **<5% (12/265) long paper accept. ratio**
  - A. Koubâa, M. Alves, E. Tovar, A. Cunha, "An Implicit GTS Allocation Mechanism in IEEE 802.15.4: theory and practice", **Real-Time Systems Journal** (**RTSJ**), Volume 39, Numbers 1-3, pp. 169-204, Springer, August 2008. Published on-line: 21/NOV/2007. **the RTSJ is the reference journal in the area of real-time and embedded computing systems**

With whom are we interacting?

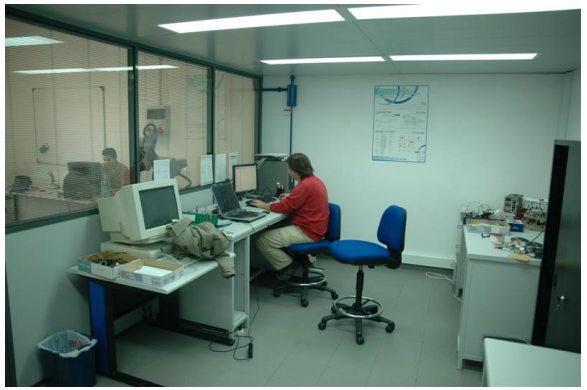
- **Our works have triggered strategic collaborations**
  - TinyOS Network WG (http://tinyos.stanford.edu:8000/Net2WG)
    - we are the **only non-USA partner**
    - together with top universities such as **UBerkeley, USouth California, UHarvard, UStanford, MIT**
  - SICS (Swedish Institute for Computer Science, http://www.sics.se)
    - migration to the **Contiki** (http://www.sics.se/contiki) Operating System
  - SSSUP (Scuola Superiore Sant'Anna, http://www.sssup.it)
    - migration to the **ERIKA** (http://erika.sssup.it) real-time Operating System
  - ARTIST2, ARTISTDesign and **CONET** NoEs
    - **16 partners,** including **UBONN, SICS, ETHZurich, UNIPI, TUDelft, UCLondon, SAP, Schneider Electric, Boeing R&T Europe, Telecom Italy**
    - **4 MEuros** EC funding
  - Carnegie-Mellon University (http://www.hurray.isep.ipp.pt/cmu-pt)
    - CISTER is the **only Research Unit from the Polytechnic**
  - EM&EM EU Project Proposal
    - Critical Software (PT), **Fraunhofer** (DE), Intesys (UK), **CEA** (FR),…

What about next?

- **Some current/envisaged RTD efforts**
  - On ZigBee networks
    - Supporting **mobility** (with RT and energy-efficiency)
    - Supporting **fault-tolerance** (with RT and energy-efficiency)
  - On the ART-WiSe network architecture
    - Assessing **candidate technologies for Tier 2** (WiFi, WiMAX, UWB)
    - Designing the **ART-WiSe architecture** (including the gateway)
  - On system engineering
    - Optimizing **deployment strategies** (logical over physical)
    - Developing **system planning/management** tools
  - On implementation and experimental work
    - Migrating the open-ZB protocol stack to **other OSs and platforms**
    - Applying ART-WiSe architecture to our **search&rescue test-bed**

Which Resources?

- Hands-On Lab



- Technological Resources
  - cents of motes (different platforms)
  - sensor and interface boards
  - single board computers
  - network/protocol analysers
  - mobile platforms (robotics and others)

Who are we?

- **ART-WiSe Team**
  - **Senior Researchers**
    - Mário Alves (PhD)
    - Anis Koubâa (PhD)
    - Eduardo Tovar (PhD)
  - **PhD researchers**
    - Petr Jürcik (MSc)
    - Nouha Baccour (MSc)
  - **MSc researchers**
    - Ricardo Severino
  - **Technical support**
    - Emmanuel Lomba
  - **Former collaborators**
    - Skender Ben Attia
    - Melek Attia
    - Anneleen Van Nieuwenhuyse
    - Bilel Znefi
    - Y-Q Song
    - André Cunha (MSc)