IST-004527 ARTIST2
Network of Excellence
on Embedded Systems Design

Activity Progress Report for Year 3

JPRA-Cluster Integration

Dynamic and Pervasive Networking

Clusters:

Adaptive Real-Time

Activity Leader:

Professor Eduardo Tovar, Polytechnic Institute of Porto, Portugal

http://www.dei.isep.ipp.pt/~emt

Policy Objective (abstract)

There is a consistently growing role of networking in various fields of applications of embedded computing, such as the provision of pervasive access to multimedia and telecommunication networks, the deployment and operation of large-scale sensor networks or even the construction of vehicles, industrial machinary, medical equipment, etc. This activity looks at platforms, communication protocols, quality-of-service provision, efficiency, etc, of these networks. Both COTS and research-based technologies are considered. Current efforts have been essentially devoted to various aspects related to wireless sensor networks, to re-configurability and on-line adaptation mechanisms in networked embedded systems and to deeply-embedded systems where the actual physical dynamics is tightly tied with computations and communications.

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1. Overview of the Activity

1.1 ARTIST Participants and Roles

Professor Eduardo Tovar – Polytechnic Institute of Porto (Portugal)
Wireless Sensor Networks (WSN); dynamic Medium Access Control (MAC) protocols; deeply-embedded networked systems with emphasis on the integration of physical dynamics with computations and communications.

Professor Luís Almeida – University of Aveiro (Portugal)
Dynamic reconfiguration in distributed embedded systems.

Professor Giorgio Buttazzo – University of Pisa (Italy)
Advanced scheduling methodologies and overload management.

Professor Alan Burns – University of York (UK)
QoS in networks of embedded systems, modelling knowledge in sensor networks.

1.2 Affiliated Participants and Roles

Professor Lucia Lo Bello – University of Catania (Italy)
Real-time networks in factory communication and automotive environments; Soft real-time communication and QoS support over wireless networks, in particular, 802.11, 802.15.4 and Bluetooth; Energy-aware real-time protocols for wireless sensor networks.

Professor Pau Martí – Polytechnic University of Catalonia (Spain)
Network-based control systems; feedback control of communication systems.

Professor Marisol García-Valls – Universidad Carlos III de Madrid (Spain)
Dynamic reconfiguration architectures in networked embedded applications.

Professor Julián Proenza – University of Balearic Islands (Spain)
System-wide integration of fault tolerance mechanisms in distributed embedded systems with dynamic reconfiguration.

Professor Wilfried Elmenreich – Technical University of Vienna (Austria)
Sensor fusion; time-triggered architectures.

Professor José Maria Giron – Complutense University of Madrid (Spain)
Dynamic reconfiguration in distributed computer control systems based on smart components.

1.3 Starting Date, and Expected Ending Date

This activity officially started on September 2006. It is planned to develop to the end of the project in August 2008.

1.4 Baseline

Looking at the current scenario in embedded systems we see a *consistently* growing role of networking, ranging from the interconnection of autonomous devices such as cellular phones, Personal digital assistants (PDAs), laptops and their peripherals, to the provision of pervasive access to multimedia and telecommunication networks, to the deployment and operation of

large-scale sensor networks, to intelligence distribution in complex embedded systems, or even, at a small physical scale, to connect multiple processing cores within Systems-on-Chip (SoCs).

In this vast horizon, the ongoing Artist2 NoE's activity on Dynamic and Pervasive Networks of the ARTIST2 Adaptive Real-Time Systems (ART) cluster focuses on **Wireless Sensor Networks** (WSNs), **Mobile Ad-hoc Networks** for mobile autonomous robots (MANETs) and **Networked Embedded Systems** (NESs), areas in which many open challenges remain, and many new problems arose in the past few years.

For example, **energy-aware communication** is turning out to become a major research challenge for WSNs, imposing innovative and efficient networking protocols that manage communications periodicity, nodes' synchronization and transmitting power. As WSNs grow into very large-scale networks with thousands of nodes and more, **efficient data aggregation** becomes essential being imperative that its time-complexity does not depend on the number of sensor nodes. This is particularly important in the recently coined Cyber-Physical Systems or Deeply-Embedded Systems in which the actual physical dynamics is tightly associated with computations and communications. (The reader is refered to the following relevant event held last year in the US: http://varma.ece.cmu.edu/cps/).

Quality-of-Service (QoS) adaptation and the collaborative computing paradigms in NES require protocol mechanisms to monitor instantaneous bandwidth usage, enforce minimum agreed QoS levels (e.g. through contracts and traffic policing) and leverage the access to free bandwidth (to increase QoS whenever possible).

Higher software integration in NES requires integrated global resource management together with effective and efficient temporal partitioning (e.g., using hierarchical scheduling techniques), as well as flexible mapping between software and hardware architectures.

Replacement and/or extension of wired with wireless networking technologies, requires coping with more error-prone channels and security risks but profiting from simplified deployment and elimination of cabling.

Moreover, distributed sensing, actuation and cooperative computing **involving low-power and tiny computing platforms** appear as a basilar functionality in an ever crescent range of applications, including surveillance, environment and critical infrastructures monitoring, disaster recovery operations, distributed control, military operations, etc. The requirements imposed by these diverse applications necessarily imply different trade-off options on supported functionality, quality of service, efficiency, platforms, protocols, architectures, etc.

1.5 Problems Tackled in Year 3

Overview

In this first year of the activity, we devoted main research efforts to aspects related to *wireless sensor networks*, to *re-configurability and on-line adaptation* mechanisms in networked embedded systems and to the use and improvements in standard and COTS communication technologies for WSNs, MANETs and NESs.

A substantial part of this work was based on the following two wireless protocol standards:

IEEE 802.15.4 is a protocol standard that defines the Physical Layer (OSI layer 1) and Data Link Layer (OSI layer 2) for Low-Rate Wireless Personal Area Networks (LR-WPAN). The Zigbee Specification (elaborated by the ZigBee Alliance), specifies the Network Layer (OSI layer 3) and the Application Layer (OSI layer 7) that build on top of the IEEE 802.15.4 protocol, providing a full protocol stack. The consortium has been working towards the effective use of these protocols as federating communication technologies for large-scale Wireless Sensor Networks with critical Quality-of-Service (QoS) requirements.

IEEE 802.11 is a family of standards for the Physical Layer (OSI layer 1) and Data Link Layer (OSI layer 2) for Wireless Local Area Networks (WLAN). The IEEE 802.11e extension provides additional mechanisms (e.g. different traffic classes) for improved QoS. The consortium has been working on these technologies for tackling time-sensitive applications.

Problems Tackled on Wireless Sensor Networks

a) Use of ZigBee/IEEE 802.15.4 technologies for supporting large-scale wireless sensor network applications with timeliness guarantees.

This problem has been addressed within the ART-WiSe framework (involving researchers from **Porto** and **Prague**) and RTPAW (Real-Time Power-Aware) framework (involving researchers from **Catania**), includes the provision of timeliness guarantees, evaluation models, simulation tools, routing protocols, energy-efficiency, cluster tree topologies, network dimensioning, adaptability and admission control, etc. Notably, results attained during this year have been published recently in top-ranked scientific events and deserved best-paper awards in competitive forums such as the recent Euromicro Conference on Real-Time Systems (ECRTS'07).

b) Keeping low the time-complexity of distributed computations of physical quantities in large-scale and very dense sensor systems.

WiDom (Wireless Dominance protocol) and WiSe-CAN (Wireless Sensor Networks protocol based on the Controller Area Network protocol) are two related research efforts that have evolved through this year involving researchers from **Porto**, **Vienna**, **Barcelona** and **Lund**. We believe that important results have already been attained, namely on the actual MAC provision (binary countdown protocols for wireless channels), a collaboration that also involves **CMU** and **UIUC** in the US, and on efficient uses of such MAC approaches for computing aggregate quantities.

c) Using a knowledge-theoretic framework for developing, verifying and analysing WSN protocols.

This framework (developed at **York**) can be used to analyse and enhance existing WSN protocols, modeling them as a KBP (Knowledge-Based Protocol) and investigating whether nodes can learn certain facts in a more energy efficient way. The expectation is that it is then possible to derive an enhanced, more energy effective version of the protocol. This approach will then benefit other partners working on WSN protocols development/enhancement: **Porto**, **Catania**, **Prague**, **Barcelona**, **Aveiro**. Actually, Porto has started in March 2007 a joint cooperation with **UFSC**, Brazil, on using mobile agents in WSN protocols.

Problems Tackled on Reconfigurability in Distributed Real-Time Systems

d) Network support for reconfigurability.

In this scope, the target for this year was to advance existing network protocol frameworks that attempt to provide high flexibility with real-time and safety guarantees and to devise adequate connections between such protocols and the middleware layers above, providing the mechanisms to efficiently exploit such reconfigurability. This was essentially tackled by **Aveiro** and **Madrid**, exploring the use of the flexible time-triggered (FTT) paradigm to support service-oriented middlewares in distributed real-time domains, and also **Aveiro** and **Cantabria** exploring the use of the same paradigm to support a contract middleware, particularly the one being developed within the FRESCOR project.

e) Impact of reconfiguration mechanisms on overall system dependability.

This impact was analysed by **Aveiro** and **Mallorca**. In fact, reconfiguration mechanisms may increase system complexity and turn out to reduce reliability. An architecture has been

proposed, based on enforcing important consistency properties at its lowest levels, e.g., fail silence behavior and atomic broadcast, to simplify the development of system-wide dependability mechanisms.

f) Adaptive traffic scheduling mechanisms.

Aveiro, and **Barcelona** tackled the issue of applying feedback (adaptive) scheduling techniques to networked control systems (NCS). The goal was to optimize the aggregated control performance achieved by all tasks by efficiently using the scarce resources at run-time, particularly through rate adaptation and sampling period selection. During this year adequate architectures were defined, together with adequate schedulability analysis. In this line, **Porto** also carried out studies on admission control and dynamic scheduling for the ZigBee protocol that resulted in the i-GAMe proposal (first published at ECRTS'06). Finally, **Catania worked** on the framework of traffic smoothing, particularly in the use of dynamic contention window adapters**.**

COTS Technologies Tackled

While in some cases we were investigating new protocols and technologies (essentially in the area of wireless sensor networks) in some other cases, the activity targeted general improvements in networking technologies and techniques for distributed real-time applications, namely on improving analysis/tools and protocol mechanisms. Particular concern was devoted to popular networking technologies, such as Ethernet (**Aveiro**, **Mallorca and Catania**), CAN (**Aveiro**, **Porto**, **Catania**, **Vienna** and **Mallorca**), IEEE 802.11 (**Aveiro**, **Pisa**, **Catania** and **Mälardalen)**, IEEE 802.15.4 (**Porto**, **Catania**, **Prague**, **York**), Bluetooth (**Catania**) or PROFIBUS (**Porto**).

1.6 Comments From Year 2 Review

1.6.1 Reviewers' Comments

Not applicable

1.6.2 How These Have Been Addressed

Not applicable

2. Summary of Activity Progress

2.1 Previous Work in Year 1

Not applicable

2.2 Previous Work in Year 2

Not applicable

2.3 Current Results

2.3.1 Technical Achievements

Below is a synthesis of the main technical achievements related to the major research areas (Problems Tackled) as identified in Section 1.5: wireless sensor networks, reconfigurability in distributed real-time systems and COTS communication technologies. These achievements, despite relating to different application scopes and technologies, are all **consistent contributions** to the main goal of providing **timeliness, efficiency and robustness** to the **dynamic and pervasive networks** that interconnect the growing embedded world.

ON WIRELESS SENSOR NETWORKS

Partners (**Porto**, **York, Catania, Prague**, **Vienna**) have proposed wireless sensor network protocols focusing on **energy-efficient and real-time operation**, based on both the IEEE 802.15.4/ZigBee [CT3, PO01, PO04, PO07, PO10, PO12, PO15, PO16] and on a new prioritized medium access control protocol [PO3, PO8, PO9, PO14, PO17, PO18]. A knowledge-theoretic framework [YK1] and the prioritized medium access control protocol [PO17] have been exploited in the design of protocols for WSN.

Importantly, out of the several relevant works in WSNs, we would like to highlight a **best paper award** [PO10] at the most important European event in the area of Real-Time and Embedded Computing Systems (ECRTS'07), in the context of the ART-WiSE (Architecture for Real-Time communications in Wireless Sensor networks, http://www.hurray.isep.ipp.pt/art-wise) research frameworks. Also some important **technological breakthroughs** under the open-ZB (http://www.open-zb.net) framework were achieved. The open-ZB open-source toolset web site already witnessed over 16000 visits and over 600 downloads in less than one year.

RECONFIGURABILITY IN DISTRIBUTED REAL-TIME SYSTEMS

Partners (Aveiro, UC3M, Cantabria, Mallorca, Barcelona, Catania) have worked on reconfigurability in distributed real-time systems. The Flexible Time-Triggered **framework** has been further developed and its properties have been exploited by middleware [AV2, AV3]. **Solutions** have been proposed to deal with the extra complexity caused by reconfigurability in distributed systems [MA2, MA3] [MAL01]. A **protocol for reconfigurable bandwidth allocation** in networked embedded control systems has been proposed [BA1, BA2]. A **traffic smoother** for Switched Ethernet and IEEE 802.11 networks was also developed [CT1, CT6].

COTS TECHNOLOGIES

Partners (Aveiro, Pisa, Porto, Catania, Mälardalen) have worked on COTS technologies to improve certain properties. Specifically, an efficient method was developed for handling

aperiodic messages in **master-slave switched Ethernet** networks [AV2]. **Further developments for CAN** were carried out including (i) techniques for multi-packet transmission [PIS1], (ii) schedulability analysis [PO13], (iii) data aggregation protocols [PO17, PO18] and (iv) star-topologies (http://dmi.uib.es/~mbarranco/srvlsestars/).
Developments for hybrid wired/wireless communication include (i) an approach that uses bridges instead of repeaters [PO5, PO6], (ii) methods for guaranteeing timeliness and (iii) simulation models [PO6] – a http://www.hurray.isep.ipp.pt/activities/HW2PNETSIM. For **IEEE 802.11**, a broadcast framework [AV1] and a traffic smoother [CT6] have been developed and an **improvement to IEEE 802.11e** has been proposed [CT4, CT12]. The use of IEEE 802.11 to support real-time communications over UAV-based (Unmanned Autonomous Vehicles) disaster management systems has also been explored [CT5, CT9, CT10]. For **Bluetooth**, a deadline-aware scheduling algorithm has been developed [CT2, CT11].

2.3.2 Individual Publications Resulting from these Achievements

Porto (available to download from http://www.hurray.isep.ipp.pt/asp/list_docs2.asp)

[PO1] Koubaa, A., Alves, M., Tovar, E.,"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, Germany, pp. 19 – 49, Jan. 2007.

[PO2] Alves, M., Tovar, E., "Engineering PROFIBUS Networks with Heterogeneous Transmission Media", Computer Communications, Vol. 30, No 1, pp. 17 – 32, Dec. 2006.

[PO3] Pereira, N., Andersson, B., Tovar, E., "WiDom: A Dominance Protocol for Wireless Medium Access", IEEE Transactions on Industrial Informatics, Vol. 3, No 2, pp. 120 – 130, May 2007.

[PO4] Koubaa, A., Alves, M., Tovar, E., "Energy/Delay Trade-off of the GTS Allocation Mechanism in IEEE 802.15.4 for Wireless Sensor Networks", International Journal of Communication Systems, Vol. 20, No. 7, pp. 791 – 808, John Wiley & Sons, Jul. 2007.

[PO5] Alves, M., Tovar, E., "Real-time communications over wired/wireless PROFIBUS networks supporting inter-cell mobility", Published in Computer Networks, Vol. 51, No. 11, pp. 2994 – 3012, Elsevier, Aug. 2007.

[PO6] Sousa, P., Ferreira, L., Alves, M., "Repeater vs. Bridge-Based Hybrid Wired/Wireless PROFIBUS Networks: a Comparative Performance Analysis", published in proceedings of the 11th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA'06), pp. 1065 – 1072, Prague, Czech Republic, Oct. 2006.

[PO7] Koubaa, A., Alves, M., Tovar, E., "Modelling and Worst-Case Dimensioning of Cluster-Tree Wireless Sensor Networks", published in proceedings of the 27th IEEE Real-time Systems Symposium (RTSS'06), pp. 412-421, Rio de Janeiro, Brazil, Dec. 2006.

[PO8] Andersson, B., Pereira, N., Tovar, E., "Exploiting a Prioritized MAC Protocol to Efficiently Compute Min and Max in Multihop Networks", published in proceedings of the 5th Workshop on Intelligent Solutions in Embedded Systems, Madrid, Spain, Jun 2007.

[PO9] B. Andersson, "Computing Aggregated Quantities Efficiently in Large-Scale Dense Sensor Networks", EU-US Workshop on Wirelessly Networked Embedded Systems Cyber-Physical Systems and Beyond, Edinburgh, UK, Jul. 2007, available at http://euusworkshop07.specknet.org/Programme.

[PO10] Koubaa, A., Cunha, A., Alves, M., "A Time Division Beacon Scheduling Mechanism for IEEE 802.15.4/Zigbee Cluster-Tree Wireless Sensor Networks", published in proceedings of

the 19th Euromicro Conference on Real-Time Systems (ECRTS 2007), pp. 125 – 135, Pisa, Italy, Jul. 2007, **Best Paper Award.**

[PO11] Pereira, N., Andersson, B., Tovar, E., "Exact Analysis of TDMA with Slot Skipping", published in proceeding of the 13th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA'07), pp. 63 – 72, Daegu, Korea, Aug. 2007.

[PO12] Cunha, A., Koubaa, A., Severino, R., Alves, M., "Open-ZB: an open-source implementation of the IEEE 802.15.4/ZigBee protocol stack on TinyOS", to be published in the 4th IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MASS´07), Pisa, Italy, Oct. 2007.

[PO13] Andersson, B., Pereira, N., Tovar, E., "A Two-Competitive Approximate Schedulability Analysis of CAN", to be published in the 12th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA'07), Patras, Greece, Oct. 2007.

[PO15] Koubaa, A., Alves, M., Tovar, E., Cunha, A., "An Implicit GTS Allocation Mechanism in IEEE 802.15.4 for Time-Sensitive Wireless Sensor Networks: theory and practice", Accepted for Publication at the Journal of Real-Time Systems, 2007.

[PO17] Andersson, B., Pereira, N., Tovar, E., "Exploiting a Prioritized MAC Protocol to Efficiently Compute Interpolations", to be published in the 12th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA'07), Patras, Greece, Oct. 2007.

Aveiro

[AV1] Santos, F., Currente, G., Almeida, L., Lau, N., Lopes, L. S., "Self-configuration of an Adaptive TDMA wireless communication protocol for teams of mobile robots", published in proceedings of the 2nd Workshop on Intelligent Robotics (IRobot 2007), Satellite event of EPIA 2007, the 13th Portuguese Conf on Artificial Intelligence, Guimaraes, Portugal. Dec 2007.

[AV2] Marau, R., Pedreiras, P., Almeida, L., "Asynchronous Traffic Signaling over Master-Slave Switched Ethernet protocols", published in proceedings of the 6th Workshop on Real-Time Networks (RTN'07), satellite event of ECRTS'07, Pisa, Italy, July 2007.

[AV3] Silva, V., Ferreira, J., Fonseca, J. A., "Dynamic Topology Management in CAN", published in proceedings of the 11th IEEE International Conference on EmergingTechnologies and Factory Automation (ETFA' 06), Prague, CZ, Sept. 2006.

York (available to download from http://www.cs.york.ac.uk/rts/bibtex/papers.html)

[YK1] Symeou, I., "Knowledge-Theoretic Protocols for Wireless Sensor Networks", published in proceedings of the 3rd IET UK Embedded Forum. pp. 3-9. April 2007.

Catania

[CT1] Lo Bello, L., Sgro', F., Kaczynski, G.A., Di Stefano, L., Mirabella, O.,"Improving Real-Time Behaviour of Ethernet switches using fuzzy Traffic Smoothing", In M. L. CHAVEZ ED. Fieldbus Systems and Their Applications (pp. 80-88). ISBN: 978-0-08-045364-4. Series: IPV – IFAC, Proceedings volume from the 6th IFAC International Conference. Elsevier (UK). (2006).

[CT2] Collotta, M., Lo Bello, L., Mirabella, O., "Deadline-Aware Scheduling Policies for Bluetooth Networks in Industrial Communications", published in proceedings of the 2nd IEEE International Symposium on Industrial Embedded Systems - SIES'2007, Lisbon, Portugal, Jul. 2007.

[CT3] Toscano, E., Mirabella, O., Lo Bello, L., "An Energy-Efficient Real-Time Communication Framework for Wireless Sensor Networks", published in the 6th International Workshop on Real-Time Networks (RTN'07) in conjunction with the 19th Euromicro International Conference on Real-Time Systems (ECRTS'07), Pisa, Jun. 2007.

[CT4] Vittorio, S., Lo Bello, L., “An Approach to Enhance the QoS Support to Real-Time Traffic on IEEE 802.11e Networks”, published in proceedings of the 6th International Workshop on Real-Time Networks (RTN'07) in conjunction with the 19th Euromicro International Conference on Real-Time Systems (ECRTS'07), Pisa, Jun. 2007.

[CT5] Buttazzo, G., Chiandussi, G., Demartini, C., Iannizzotto, G., Lo Bello L., Quagliotti, F., “Land control and monitoring system for fire prevention”, published in proceedings of the 50th International Congress on Methodologies for Emerging Technologies in Automation (ANIPLA 06), Special Session on Land Monitoring and Control, Nov. 2006.

[CT6] Lo Bello L., Kaczynski, G., Sgro', F., Mirabella, O., “A wireless traffic smoother for soft real-time communications over IEEE 802.11” published in proceedings of the 11th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 06), pp. 1073-1079, Sep. 2006.

[CT7] Lo Bello, L., Mirabella, O., “Efficient Full Duplex Links for Long Distance Wireless Mesh Networks”, published in proceedings 11th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA'06), pp. 598-601, ISBN/ISSN: 1-4244-0681-1, Sep. 2006.

[CT8] Mirabella, O., Lo Bello, L., Raucea, A.,”An integrated wired-wireless testbed for distance learning on networking”, published in Proceedings of the 1st IEEE International Conference on E-Learning in Industrial Electronics (ICELIE 06), pp. 74-79, Dec. 2006.

[CT11] M. Collotta, O. Mirabella, L. Lo Bello, “Comparison between RT scheduling techniques for Bluetooth Networks in DPCSs”. In Proceedings of the IEEE Second International Symposium on Industrial Embedded Systems - SIES'2007, Lisbon, Portugal, 4-6 July 2007.

[CT12] S. Vittorio, G. A. Kaczynski, L. Lo Bello (2007). Improving the real-time capabilities of IEEE 802.11e through a Contention Window Adapter. In Proceedings of RTAS'07 WIP. The 13th IEEE Real-Time and Embedded Technology and Applications Symposium, April 3 - April 6, 2007, (pg. 64-67), T.R. http://cse.seas.wustl.edu/Research/FileDownload.asp?733, Chenyang Lu (ed.), University of Washington (US).

Madrid

[MA1] Estévez Ayres, I., “Techniques for Supporting Functional Flexibility in Distributed Real-Time Embedded Systems”, PhD Thesis. Universidad Carlos III de Madrid. Directors: Marisol García-Valls, Luis Almeida, Sep. 2007.

[MA2] Estévez Ayres, I., Almeida, L., García Valls, M., Basanta Val, P., “An Architecture to Support Dynamic Service Composition in Distributed Real-Time Systems”, published at the 10th IEEE International Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing (ISORC 2007). Santorini Island, Greece. May 2007.

[MA3] Basanta Val, P., Almeida, L., García Valls, M., Estévez Ayres, I., “Towards a synchronous scheduling service on top of an unicast distributed real-time Java”, published in proceedings of the 13th IEEE Real-time Systems Application Symposium (RTAS'07).

[MA4] Breuer, P., García Valls, M., “Raiding the Noosphere: the open development of networked RAID support for the Linux Kernel Software”, Practice and Experience. ISBN: 0038-0644. Vol. 36, no. 4, pp. 365-395. Jonh Wiley & Sons, Ltd. Apr, 2006.

UPC Barcelona

[BA1] Velasco, M., Martí, P., Lozoya, C., “Distributed Feedback Scheduling of CAN-based Control Systems: Schedulability Analysis”, Submitted to 11th International Conference On Principles Of Distributed Systems (OPODIS), 2007.

[BA2] Velasco, M., Martí, P., Castañé, R., Guardiã, J., Fuertes, J., "A CAN Application Profile for Control Optimization in Networked Embedded Systems", published in the 32th Annual Conference of the IEEE Industrial Electronics Society (IECON06), Paris, France, Nov. 2006.

2.3.3 Interaction and Building Excellence between Partners

Petr Jurcik, a PhD student at the Department of Control Engineering, Czech Technical University, Prague, has been in Porto (as a research fellowship) collaborating in the ART-WiSe and Open-ZB frameworks since the beginning of 2007. He has been addressing the implementation of a simulation model for the IEEE 802.15.4 GTS (Guaranteed Time Slot) MAC mechanism and the worst-case dimensioning of ZigBee cluster-tree wireless sensor networks.

Wilfried Elmenreich, Assistant Professor at the Technical University of Vienna, Austria, visited Porto during May-June 2007 with the purpose of developing data aggregation protocols for sensor networks. The work builds on his experience in sensor fusion and the experience from Porto researchers in prioritized medium access control protocols.

The collaboration between Aveiro and UC3M in the scope of the FTT framework implementation over RMI was carried out during a 5 months visit (2 months in this year) from a PhD student of UC3M (Pablo Basanta) to Aveiro and later supported by a few mutual short visits.

The collaboration Aveiro-Bilbao (external partner) during this year, in the scope of the synchronous scheduling over RT-CORBA, was carried out remotely with a one week visit of a professor from Bilbao (Isidro Calvo) to Aveiro to coordinate the work.

The collaboration Aveiro-Pisa in the scope of new CAN developments and analysis was carried out through a PhD student from Pisa (Cesare Bartolini) and mostly remote and with a meeting in Pisa.

The collaboration Aveiro-Mallorca in the scope of CAN star topologies and reconciling dependability with reconfigurability is carried out by Manuel Barranco (PhD student) in the former case and Julián Proenza (professor), in the latter case. During this year, Luís Almeida (Professor) spent one month in Mallorca in the scope of a sabbatical leave, which was used to foster the collaboration. After that, the collaboration was developed remotely with a few meetings in scientific events.

The collaboration between the partners at the University of Catania (Prof. Lucia Lo Bello, Dr. Giordano A. Kaczynski), Scuola S. Anna in Pisa (Prof. Giorgio Buttazzo) and Mälardalen University in Sweden (Dr. Thomas Nolte) focused on a land monitoring system especially devised to support prevention and on-line management of natural disasters and addressed the communications link between an UAV and the related ground station. On this activity, three joint papers have been written (reported below).

2.3.4 Joint Publications Resulting from these Achievements

Porto and CMU

[PO14] N. Pereira, B. Andersson, E. Tovar, A. Rowe, "Static-Priority Scheduling over Wireless Networks with Multiple Broadcast Domains", to appear in Proceedings of RTSS07, Tucson, USA.

Porto and Prague

[PO16] Jurcik, P., Koubâa, A., Alves, M., Tovar, E., Hanzalek, Z., "A Simulation Model for the IEEE 802.15.4 protocol: Delay/Throughput Evaluation of the GTS Mechanism", to be published in the 15th IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS´07), Istanbul, Turkey, October 2007.

Porto and Vienna

[PO18] B. Andersson, N. Pereira, W. Elmenreich, E. Tovar, F. Pacheco, N. Cruz, “A Scalable and Efficient Approach to Obtain Measurements in CAN-based Control Systems“, submitted to a Journal.

Aveiro and Madrid

[MAD01] I. Calvo, L. Almeida, A. Noguero, “A Novel Synchronous Scheduling Service for CORBA-RT Applications”, published at the 10th IEEE Symp. on Object/component/service-oriented Real-time distributed Computing, ISORC 2007. Santorini, Greece, May 2007.

[MAD02] P. Basanta-Val, L. Almeida, M. Garcia-Valls, I. Estevez-Ayres, “Towards a synchronous scheduling service on top of a unicast distributed real-time Java”, published at the 13th IEEE Real-Time and Embedded Applications Symposium (RTAS 2007), Bellevue, USA, Apr. 2007.

Pisa and Aveiro

[PIS01] Bartolini, C., Almeida, L., Lipari, G., “Using priority inheritance techniques to override the size limit of CAN messages”, to be published at the 7th IFAC Conf on Fieldbuses and Networks for Industrial and Embedded Systems (FET 2007), Toulouse, France, Nov 2007.

Mallorca and Aveiro

[MAL01] J. Proenza, L. Almeida. Position Paper on Dependability and Reconfigurability in Distributed Embedded Systems. RTN’07, 6th Workshop on Real-Time Networks, (satellite of ECRTS’07), Pisa, Italy, Jul. 2007.

Pisa and Catania

[PIS02] Buttazzo, G., Chiandussi, G., Demartini, C., Iannizzotto, G., Lo Bello L., Quagliotti, F., “Land control and monitoring system for fire prevention. In: Methodologies for Emerging Technologies in Automation”, published in proceedings of the 50th International Congress on Methodologies for Emerging Technologies in Automation (ANIPLA 06), Special Session on Land Monitoring and Control, Nov. 2006.

Catania and Mälardalen

[CT9] Lo Bello, L., Kaczynski, G., Nolte, T., Sorbello, G., Sgro', F., Mirabella, O., “An approach to support UAV to ground station real-time communications in a land monitoring system”, published in proceedings of the 50th International Congress on Methodologies for Emerging Technologies in Automation (ANIPLA 06), Special Session on Land Control and Monitoring System for Fire Prevention, Nov. 2006

[CT10] Lo Bello L., Kaczynski, G., Nolte, T., “Towards a Robust Real-Time Wireless Link in a Land Monitoring Application”, published in proceedings of the 11th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 06), vol. I, pp. 449-452, ISBN/ISSN: 1-4244-0681-1, Sep. 2006.

2.3.5 Keynotes, Workshops, Tutorials

Invited Talks

Andersson, B., Tovar, E., "Computing Aggregated Quantities Efficiently in Large-Scale Dense Sensor Networks", EU-US Workshop on Wirelessly Networked Embedded Systems Cyber-Physical Systems and Beyond, Edinburgh, UK, Jul. 2007. (available at http://euusworkshop07.specknet.org/Programme).

L. Lo Bello, “Open Research Issues in Real-Time Networks”, WIRTES 2007, First Italian Workshop on Real-Time and Embedded Systems, July 2nd, 2007, Pisa, Italy. (available at: http://feanor.sssup.it/wirtes07/slides/session1/lobello.pdf)

Pereira, N., "A Prioritized Collision-Free MAC Protocol for Wireless Medium", Carnegie Mellon University, Dec. 2006.

Andersson, B. "Integration of WiDom in Real-Time Chains", University of Illinois Urbana Champaign, Mar. 2007.

Workshops, Tutorials and Seminar Offered

Workshop: NeRES 2007 – Networks for Reconfigurable Embedded Systems
Aveiro, Portugal – April 2007

This workshop was targeted to discuss the network requirements for supporting reconfigurability in distributed embedded systems, as well as the adequacy of current protocols and middlewares for that purpose. It gathered 26 participants from 15 institutions in 6 countries, with one industrial representative and several other academic participants presenting industrial case studies. There were 13 presentations covering aspects that ranged from flexible middleware, namely based on components, on resource contracts, on services and on the support for flexible scheduling, to dependability, integration, wireless mobile ad-hoc communication, intelligent telecommunication networks, industrial automation, automatic control systems, automotive and avionic systems.
http://www.artist-embedded.org/artist/Motivation-and-Goal.html

Tutorial: Real-Time Networks for Embedded Control Systems
Conference: 1st European South American School on Embedded Systems
Lecturer: Luis Almeida
Buenos Aires, Argentina – August 21 to 24, 2007

This tutorial was a module of the referred summer school, with 8 hours of lecturing focusing on the concepts, techniques, technologies and applications of networking for embedded control applications.
http://www.artist-embedded.org/artist/Objectives.html

Tutorial: Real-Time Networks for Distributed Embedded Systems
Lecturer: Luis Almeida
Pisa, Italy – May 2 to 4, 2007
Short course on the referred topic with 8 hours of lecturing and 4h labs.

Seminar: CAN and the challenge of designing Safety-critical automotive systems
Lecturer: Luis Almeida
Linköping, Sweden – June 11, 2007

Seminar given at the Linköping University

Seminar: Towards Flexible Distributed Computer Control Systems
Lecturer: Luis Almeida
Halmstad, Sweden – May 14, 2007

Seminar given at the Halmstad University

Tutorial: Designing Distributed Real-time Systems: a Focus on Holistic Time-Triggered Design
Lecturer: Luis Almeida
Philadelphia, USA – November 28, 2006

Lecture within the Real-Time Systems Course, Computer Science Departament, University of Pennsylvania, Philadelphia,
http://www.cis.upenn.edu/~lee/06cse480/lec-drts.pdf

Seminar: Traffic Scheduling Anomalies within Temporal Partitions
Lecturer: Luis Almeida
Philadelphia, USA – November 14, 2006

Invited Lecture at the Computer Science Departament, University of Pennsylvania, Philadelphia,
http://www.cis.upenn.edu/departmental/events/abstracts-2005/Luis.html

Tutorial: Brief Tour of Real-Time Embedded Networks
Lecturer: Luis Almeida
Philadelphia, USA – November 14, 2006

Lecture within the Real-Time Systems Course, Computer Science Departament, University of Pennsylvania, Philadelphia,
http://www.cis.upenn.edu/~lee/06cse480/lec-holistic-scheduling.pdf

3. Future Work and Evolution

3.1 Problems to be Tackled over the next 12 months (Sept 2007 – Aug 2008)

This activity did only start at the 3rd year of ARTIST2, and thus there is still obvious room for consolidating some of the achievements already attained in the past 12 months. This is particularly true concerning the efforts on **advancing the state-of-the-art in large scale deeply-embedded applications**. Advances already made on scalable approaches for computing aggregated quantities and on the networking protocols to support those have already proved worth to be exploited further. Aspects such as **protocol efficiency** (energy and time) are issues yet to be solved. Also for large-scale networked sensors the **exploitation of knowledge-based approaches** and the **assessment of COTS technologies** (e.g. IEEE 802.15.4 and ZigBee) will be further pursued. Notably, we expect to leverage on the opportunities already initiated concerning **contributions to the ongoing standardization efforts** on these technologies.

Aspects related to network requirements for supporting reconfigurability in distributed embedded systems received some special attention in the past 12 months within the framework of this activity. Middleware requirements and consideration of dependability requirements still pose a number of challenges and issues. Special emphasis will be given to proceed with the efforts related to **reconciling dependability with reconfigurability** and related with the **adequate support for middleware layers** that are predictable and provide extra flexibility in system design and operation.

3.2 Current and Future Milestones

Year 3 Milestones

• *Achieved*: Organise a kick-off cluster meeting on this activity within the 4th quarter of 2006. (*This was successful. It was not organised with a specific meeting but rather along the ARTIST2 audit meeting in 2006 and other events where a number of members were participating. The fact that some of the activities already started in each partner before the official start of the activity made things easier*).

• *Partially Achieved*: Produce a white paper on taxonomy of Wireless Sensor Networks (WSNs) and Mobile Ad-Hoc Networks (MANETs), elaborating on exemplificative applications, on their requirements and on how these map into technology design issues (1st quarter of 2007). (*A number of works have been produced concerning identification of the state-of-the-art in protocols for wireless sensor networks such as MAC protocols, data dissemination protocols, routing protocols, and applications, etc essentially in terms of wireless sensor networks. This involved a number of partners. We opted for this approach, instead of a one-document approach, given the heterogeneity in protocols, applications, concerns, etc. in those technological areas. Actually the organization of NERES 2007 – see 2.3.5 – did also contribute in this direction.*)

• *Achieved:* Identify and characterize network protocols to support integrated and dynamic resource management in distributed environments as necessary for on-line adaptation and reconfiguration. (*This has been successful as well, as reported in the sections concerning of this achievement*).

• *Achieved*: Organise and participate in the 6th International Workshop on RTN (3rd quarter 2007). (*This has been successfully organised in conjunction with ECRTS07, in*

Pisa, Italy, July 2007, and counted with the active participation of several members of this activity)

• *Achieved:* Concrete contributions on MAC and Routing protocols for WSN, MANETs, systems of embedded systems and adaptive distributed embedded systems. (4th quarter 2007). (*A huge number of contributions have been performed. Some of those are becoming seminal works. Contributions to standards are being exploited concerning ZigBee protocols*).

Milestones for Final Year (Year 4)

• Organize a summer school on Real-Time Networks, involving key players from industry and academia, possibly focusing on specific topics such as WSN, MANETs and reconfigurability issues.

• Contributions to the Zigbee specification.

• Educational tools supporting teaching of industrial wired/wireless networks.

• A SOTA report on Dynamic and Pervasive Networks, with web publishing.

3.3 Indicators for Integration

Although this activity has just started 12 months ago, there is already a substantial integration between participating partners. This is both reflected by the number of publications involving multiple partners (either core or affiliate) and by their joint involvement in successfully organised events such as the RTN'07 (http://rtn2007.loria.fr/), the NERES'07 (http://www.artist-embedded.org/artist/Motivation-and-Goal.html) or ARTIST2 Workshop on Basic Concepts in Mobile Embedded Systems (http://www.artist-embedded.org/artist/Objectives,679.html).

Also importantly, we firmly believe that this activity has helped research performed by the ARTIST2 partners on various aspects of networked-embedded systems to gain visibility worldwide and in that way improve its impact and influence within research communities typically more competitive in those aspects such as those from the USA.

3.4 Main Funding

CMU-PT is a five-year research program between Portuguese universities (Porto and Aveiro among them) and the Carnegie Mellon University. Porto is a core partner within the cluster on cyber-physical systems, aiming at advancing the state-of-the-art in the use of information and communication technologies for monitoring and providing risk assessment to physical critical infrastructures. Research will focus on aspects such as large-scale multi sensory systems.

GO-PLURATLITY is a Portuguese project involving Porto, which aims at the advancement of the state-of-the-art in Wireless Sensor Networks, QoS-Aware Computing and multiprocessor scheduling computing.

Catania is involved on a National Italian Project funded by the Italian Ministry of University and Research, PRIN 04, entitled: "Study and development of a real-time land control and monitoring system for fire prevention".

Catania is involved on the project "Flexible approaches to support QoS on soft real-time systems", funded by the University of Catania.

Barcelona is involved in Project C3DE ("Control, Communications and real-time Computing in Distributed Embedded nodes"), a Spanish-government funded project.

Aveiro is involved in the Portuguese project ACORD - Adaptative Coordination of Robotic Teams, which includes flexible wireless communication strategies that cope with dynamic team

composition, heterogeneity of team members, dynamic role assignement, while trying to provide some level of real-time behavior.

4. Internal Reviewers for this Deliverable

Luis Almeida (University of Aveiro)

Björn Andersson (Polytechnic Institute of Porto)