IST-214373 ArtistDesign
Network of Excellence
on Design for Embedded Systems

Activity - Progress Report for Year 1

Real-Time Networks

Clusters:

Operating Systems and Networks

Activity Leader:

Professor Luis Almeida (University of Aveiro, Portugal)

http://www.ieeta.pt/~lda/

Policy Objective (abstract)
This activity addresses the problems posed by the growing role of networking within the frameworks of Networked Embedded Systems (NESs), Wireless Sensor Networks (WSNs) and Mobile Ad hoc Networks (MANETs). Its main objectives are the timing analysis of communication protocols, the development of new protocols that are analysable while being dynamically reconfigurable and adaptable, the support for higher integration levels within distributed embedded systems, the reduction of communication related energy-consumption and the support for a progressive replacement of wired with wireless networking technologies.

Versions

number	comment	date
1.0	First version delivered to the reviewers	December 19th 2008

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1. Overview of the Activity

1.1 ArtistDesign Participants and Roles

Cluster Leader: Giorgio Buttazzo – Scuola Superiore S. Anna (Italy)
Role: kernel maintenance, development of robotic applications.

Team Leader: Luis Almeida – University of Aveiro (Portugal)
Role: activity co-ordinator, networking platform, development of distributed applications.

Team Leader: Gerhard Fohler – Technical University of Kaiserslautern (Germany)
Role: video streaming applications, scheduling.

Team Leader: Michael Gonzalez Harbour – University of Cantabria (Spain)
Role: definition of the POSIX operating system interface.

Team Leader: Alan Burns – University of York (UK)
Role: feasibility analysis of fixed priority real-time systems.

Team Leader: Eduardo Tovar – Polytechnic Institute of Porto (Portugal)
Role: distributed applications and QoS over heterogeneous networks.

1.2 Affiliated Participants and Roles

Team Leader: Hermann Härtig – University of Dresden (Germany)
Role: microkernel architectures and virtualization techniques

Team Leader: Pau Marti – Universitat Politècnica de Catalunya (Spain)
Role: control applications and schedulability of event-driven control systems.

Team Leader: Marisol García Valls – Carlos III University of Madrid (Spain)
Role: memory management in real-time Java middleware.

Team Leader: Jean-Dominique Decotignie – CSEM (Switzerland)
Role: networks.

Team Leader: Lucia Lo Bello – University of Catania (Italy)
Role: QoS-oriented scheduling and management of communication and processing.

Team Leader: Julian Proenza – University of the Balearic Islands (Spain)
Role: fault-tolerance.

Team Leader: Dirk Pesch – Cork Institute of Technology (Ireland)
Role: adaptive wireless systems, wireless sensor networks

Team Leader: Liesbeth Steffens - NXP Semiconductors (the Netherlands)
Role: industrial partner, video streaming, in-car networks, sensor networks

Team Leader: Tullio Facchinetti – University of Pavia (Italy)
Role: embedded real-time systems and robotics applications.

1.3 Starting Date, and Expected Ending Date

Starting date: January 1st, 2008

Ending date. December 31st, 2010.

Despite the precise dates specified above, it is likely that this activity will continue beyond the end of ArtistDesign, given the growing role of networking within embedded system for the

foreseeable future and the needed research for new protocols and technologies that will allow integrating subsystems in a composable way, support cooperation among larger numbers of nodes, cope with variations in topology and resources availability, and provide truly physically dispersed interaction with the environment.

1.4 Policy Objective

This activity will address open research issues within the general framework of networked embedded systems, including not only the wired distributed embedded systems typically found in confined environments but also their extension to large-scale set-ups with wired/wireless mixed topologies including wireless sensor networks, and also the case of mobile ad-hoc networks with nodes that join and leave the network dynamically. Beyond such main framework, some attention will also be dedicated to networks-on-chip, particularly within multi-core systems-on-chip, and cyber-physical systems, given the growing importance of these topics.

Specifically, this activity aims at:

- analysing what kind of timeliness guarantees can be achieved across those frameworks and which mechanisms can be devised to grant such guarantees, particularly under the dynamic behaviour arising from load variations, topology changes, adaptation to the environment or other reconfigurations;
- fostering the currently increasing integration levels within distributed embedded systems, by means of efficient temporal partitioning and isolation, integrated global resource management and flexible architectures;
- pursuing further energy-consumption reduction in networking, particularly in wireless sensor networks and mobile devices in general, both from device and system perspectives;
- addressing the problems brought up by and devise solutions to the current trend towards the systematic and progressive replacement and/or extension of wired with wireless networking technologies, from embedded control applications to multimedia systems;
- influencing industry through courses and seminars to raise awareness to emerging techniques/technologies, through participation in emerging standardisation efforts, mainly ZigBee/IEEE802.15.4, and through joint R&D projects.

1.5 Background

Along the past decades, several network communication protocols have been developed with new capabilities, from an ever increasing throughput and support for traffic classes (including guaranteed latency and jitter), to different topologies, integration of heterogeneous segments, extensive use of wireless technologies, openness to dynamic arrival and departures of nodes, openness to larger networks (such as the Internet), etc. If, on one hand, many problems have been solved, with a significant number of successful embedded applications that rely on networking services, on the other hand new problems appeared, or some old problems persist, that still require adequate solutions. The following non-exhaustive list highlights some open research issues that will establish the baseline for this activity.

Energy-efficient communication

Energy-efficient communication, particularly in WSN, is still an open issue requiring innovative networking protocols that manage communications periodicity, nodes synchronisation, transmission power and routing. Several research protocols exist but ZigBee and its data link layer IEEE802.15.4 need particular attention given their growing popularity in the wireless sensor networks arena.

Networks of nodes with scarce resources
Nevertheless, energy is not the only concern. In fact, there is currently a trend in distributed sensing, actuation and co-operative computing, be it for surveillance, environment and critical infrastructures monitoring, disaster recovery operations, distributed control or military operations, towards using small and tiny platforms. Moreover, a new area is emerging, the so-called Body Area Networks (BANs – IEEE802.15.6) that integrate tiny communicating nodes embedded in personal objects, clothes, shoes and even medical implants. The scarce resources of these platforms and the requirements imposed by such diverse applications necessarily imply different trade-offs on supported functionality, quality of service, efficiency, platforms, protocols, architectures, etc.

Data aggregation in and management of large sensor systems
Sensor networks with 1000 sensor nodes are already being planned today but tens of thousands of nodes are foreseeable within a few years. Planning, installing, commissioning and operating such networks is a challenging task given their dimension. On the other hand, despite the enormous amount of data that can be generated, applications are typically only interested in a few sensor readings or an aggregated quantity of the sensor readings. This poses the challenge on how to combine all these sensor readings to useful aggregated quantities and to do this efficiently, in a scalable way.

Networking support to middleware
Another challenge that remains open is the efficient integration of network protocols into higher level middleware, e.g., to efficiently support properties like transparent distribution, true multicasting, publisher-subscriber interaction models, integrated distributed resource management or service composition and interaction for service-oriented computing. One specific middleware that will be considered is the contract-based framework that is being developed within the FRESCOR project, aiming at providing a uniform approach for the application to express its QoS and timing requirements with respect to any system resource. The challenge will be to provide the required network services at the lowest possible levels of the architecture, to efficiently support the pursued virtual resource abstraction. Similarly, special attention will be devoted to the support of the service-oriented paradigm and its use to facilitate development of distributed embedded systems.

Quality-of-Service adaptation and graceful degradation
QoS adaptation and the collaborative computing paradigms are challenges that will require protocol mechanisms that 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). This issue is also addressed by the FRESCOR project and also by other approaches such as the Flexible Time-Triggered (FTT) framework, which carry out such adaptation at the data link level, where it can be more resource efficient than solutions based on the Internet Protocol, such as RSVP. On the other hand, these adaptation techniques can also be applied to provide graceful degradation in distributed systems, thus supporting cost effective fault-tolerance mechanisms that rely on replicas providing different levels of service using spare resources (unintended redundancy).

Higher software integration
Another challenge is to support higher software integration in distributed embedded systems requiring integrated global resource management together with effective and efficient temporal partitioning as well as flexible mapping between software and hardware architectures. Hierarchical scheduling and component-based techniques seem particularly adequate to this purpose but they need proper support from the networking infrastructure. Some attention will be devoted to related frameworks like AUTOSAR in the automotive industry, IEC61499 in industrial automation and ARINC 653 in the avionics domain.

Wireless communication everywhere
Another issue that remains open is the replacement and/or extension of wired with wireless networking technologies in domains requiring timing guarantees, e.g., industrial automation, coping with more error-prone channels but profiting from simplified deployment and elimination of cabling (see the on-going ISA 100 standardisation efforts). Note that the use of wireless technologies, as openness in general, poses many challenges related to security, such as intrusion avoidance and tolerance as well as enforcement of data privacy. Despite their high importance, these challenges will not be addressed in this activity but awareness to them will allow following the relevant research results developed elsewhere.

1.6 Technical Description: Joint Research

The work-programme for this activity includes the development of specific protocols and associated analysis tools to provide some level of timeliness guarantees and minimize energy consumption in WSNs and MANETs, protocols to enforce agreed QoS levels in NESs (wired/wireless) and also to support dynamic QoS management, dynamic reconfiguration and other run-time adaptation methods to achieve efficient resource usage and less expensive fault tolerance.
The first 18 months targeted research along the above referred lines, carried out collaboratively by several groups, with a special target on producing two taxonomies, one of WSNs for time-sensitive applications, addressing the existing protocols, their features and limitations, as well as the respective middleware for application development, and the other of flexibility in NES, addressing several perspectives of the concept, from design flexibility to configuration flexibility, operational flexibility etc, but also within the scope of real-time distributed applications with more or less criticality.

1.7 Problems Tackled in Year 1

During the first year, the teams involved in this activity explored several of the specific lines referred in section 1.5 that are related to the two main topics covered in the activity, i.e., WSNs and flexibility in NES. The actual lines addressed are briefly described below, while the results achieved, mainly in terms of scientific publications, are presented later in section 2.1.

a) Issues in WSNs using standard protocols and COTS technologies

This problem has been addressed mainly within the ART-WiSe framework (http://www.hurray.isep.ipp.pt/ART-WiSe), involving researchers from **Porto, Catania, Pisa, York** and **Prague**. Main focus is on how to use IEEE 802.15.4 and ZigBee as federating communication protocols for WSN applications with QoS requirements (e.g. real-time, reliability, energy-efficiency, scalability, topology management). Research includes the provision of timeliness guarantees, evaluation models, simulation tools, energy-efficiency, cluster tree topologies, network dimensioning and admission control. The objective is to use not only standard communication protocols (IEEE 802.15.4/ZigBee), but also COTS technologies such as operating systems (e.g. TinyOS and ERIKA) and hardware platforms (e.g. MICAz, TelosB, Stargate SBC).

b) Scalable data aggregation in WSNs

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** and **Vienna**. We target at dealing with sensor faults and using the approach to perform localisation.

c) Mobility in real-time wireless networks

Mobility in wireless networks adds to the complexity of achieving real-time communication given the dynamic topology and dynamic communication links. This problem was addressed by **Aveiro**, concerning the self co-ordination of teams of mobile units with variable number of team members and resilience to uncontrolled traffic, external to the team. The technology considered was plain DCF IEEE 802.11.

d) Robust communication with star topologies

In wired networks, star topologies are typically associated to a higher level of robustness because, in one hand, they reduce the multiple points-of-failure typically present in a bus to one single point-of-failure, i.e., the star hub, and in the other hand the star hub is also a natural point for error containment, be it in the value or time domains. However, typical wired networked embedded systems use either bus topologies or star topologies that have limited confinement capabilities. For example, CAN buses, which are commonly found in embedded systems due to their low cost and simplification of cabling, exhibit low error confinement capabilities and thus a simple fault in the medium or in a transceiver may render the network useless.

On the other hand, current COTS Ethernet switches also have relatively poor traffic scheduling capabilities (FIFO queues and very few priority levels) and poor protection against misbehaving nodes, namely in the time domain. Therefore, it is possible that a node suffering from a time domain fault, such as a babbling idiot, can cause a substantial negative impact system wide. Improving this aspect by including more protection capabilities in the switches, mainly in the time domain, was considered an important aspect. Both the stars for CAN and Ethernet were addressed by **Aveiro** and **Mallorca** with support from **CMU** in the case of Ethernet.

e) Real-time network support to middleware layers.

The development of complex distributed applications requires appropriate support from a middleware layer that provides an adequate abstraction level. There are nowadays several types of middleware that abstract away certain properties of the underlying platforms and facilitate application development. Service-oriented middleware is one such case that improves functional flexibility at run-time. However, existing service-oriented middlewares do not support real-time guarantees. Improving this situation and bringing Service-oriented Architectures to the real-time applications domain has been tackled by **Madrid** (UC3M) and **Aveiro**. These groups have also tackled the problem of supporting synchronisation of distributed communications based on the Java language, allowing to control the relative phase of remote methods invocations and thus the level of contention at the servers access, resulting in improved timeliness and lower queuing requirements for server requests.

Cantabria, Valencia and **Prague**, on the other hand, focused on the FRESCOR contracting middleware and have added support to it in several communication networks: CAN bus, as a representative of fieldbuses, WiFi, as a representative of wireless networks, wired Ethernet, and switched Ethernet using industrial switches.

f) Providing network support for safe integration

When increasing the integration levels in distributed applications, the risk for mutual interference among different streams and tasks increases. One way to mitigate such risk at the network level consists in using protocols that support composability. This has been tackled by **Aveiro** and **Mälardalen** concerning composability with respect to timeliness by means of using server-based CPU scheduling techniques in the scope of traffic scheduling.

2. Summary of Activity Progress

2.1 Technical Achievements

a) Worst-case analysis and dimensioning of cluster-tree wireless sensor networks

Porto and **Prague** have developed a methodology for modelling cluster-tree WSNs where the sink can either be static or mobile [POc1][POc2]. This methodology enables the computation of the worst-case end-to-end delays, buffering and bandwidth requirements across any source-destination path in a cluster-tree WSN, under the assumption of error-free communication. It was instantiated for the particular case of IEEE 802.15.4/ZigBee cluster-tree WSNs and validated through a comprehensive experimental study using commercially available technology, namely TelosB motes running TinyOS.

Catania addressed the problem of routing in long-distance wireless mesh networks (LDWMNs) [CT1]. In this context, the main features and relevant design challenges of LDWMNs were analyzed and a novel wireless routing technique was proposed. The router is based on a modular architecture that provides fault tolerance and gracefully degrading performances in case of fault, while full-duplex capability of its wireless links provides higher throughput and reliability.

The work in **York** has been following three principal, but complementary, routes. Firstly we have been developing an experimental infrastructure for large-scale evaluation. This has resulted in Yet Another Sensornet Simulation (YASS) [YK1] which features a multi-phase radio analysis model and a novel means of processing the findings. This results in an infrastructure supporting realistic simulations an order of magnitude greater than what is possible with *ns2* and other current simulators. The results have been validated. Secondly, we have looked at ways using principled experimental methods of tuning existing protocols, rather than continually inventing new ones, using a technique called Design of Experiments [YK2]. This has shown significant benefits can be obtained that are robust to variations in network behaviour, node placement etc.. The current work is using the previous two areas of work to mine the available information to identify where protocols are deficient such that variants can be proposed. As part of this simple, in order to manage the resource usage, machine learning is being employed. Publications are being prepared in this area.

b) QoS add-ons to the IEEE 802.15.4 and ZigBee protocols

Porto has continued the ART-WiSe research framework around the use of IEEE 802.15.4 and ZigBee as federating communication protocols for WSN applications with QoS requirements (energy-efficiency, timeliness, throughput, reliability). In this context and in this reporting period, several mechanisms were proposed in order to improve QoS, such as a Hidden-Node Avoidance Mechanism for wireless sensor networks [PO1] and a Time Division Beacon Scheduling mechanism for ZigBee cluster-tree networks [PO2].

Catania carried out the analysis of the existing energy-aware protocols, at the various levels of the protocol stack, to provide a better understanding of the most relevant approaches, with a look into the advantages and the disadvantages of each of them, and the suitability of the protocols for certain classes of applications. This work resulted in two book chapters. A survey of the most widely known energy efficient routing protocols for WSN is given in [CT3], while [CT4] focuses energy-efficient MAC protocols for WSNs.

Another issue that has been addressed by **Catania** is cross-channel interference in co-located IEEE 802.15.4 networks in industrial environments [CT2]. The problem is tackled from two

different perspectives and provides both analytical and experimental results. The latter were obtained through an extensive series of measurements run in order to assess the performance of IEEE 802.15.4 networks under different critical operating conditions. The analytical results are based on the properties of the coding used at the Physical layer of the IEEE 802.15.4 protocol, in particular the power spectral density of the signal.

c) Supporting real-time communications in wireless sensor networks over the ERIKA real-time operating system

IEEE 802.15.4/ZigBee and TinyOS have been playing an important role in leveraging a new generation of large-scale networked embedded systems. However, based on previous experience (from **Porto** and **Prague**) on the implementation and use of the IEEE 802.15.4/ZigBee protocols over TinyOS (http://www.open-ZB.net), several problems (producing loss of synchronisation and even inability of communication) emerge due to some limitations of TinyOS, namely related to the lack of task pre-emption and prioritisation [PO4]. This unreliability is not a major concern for non-critical environments where the nodes are supposed to guarantee best-effort services. However, when real-time guarantees are required, different software solutions must be used to support real-time services in such networked applications. In this context, researchers from **Porto** and **Pisa** are implementing the IEEE 802.15.4/ZigBee protocol stack over ERIKA [POc3], a real-time operating system for resource constrained embedded systems that nevertheless provides pre-emptive scheduling and support for priorities. The current work focuses on the assignment of priorities to the different protocol tasks, on performing an efficient and prioritised message queue management and control, and on achieving an accurate control over transmissions instants to meet the protocol strict timing requirements.

d) Low time-complexity data aggregation 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) [PO3] are two related research efforts that have evolved through this year involving researchers from **Porto** and **Vienna**. We have (i) shown how the approach can be used to perform localisation [PO5] and (ii) how the approach can be used with the CAN bus [POc4], using the message identifiers to encode the magnitude of physical quantities allowing a straight forward derivation of MAX, MIN, and other aggregation functions.

e) Mobility issues in real-time wireless communication.

In this line, **Aveiro** continued the work of providing a solution for co-ordinating a dynamic team of mobile units in the presence of uncontrolled traffic external to the team. This work is based on the IEEE 802.11 technology and proposes complementing it with an adaptive TDMA approach with reconfigurable slot structure that adjusts on-line to the delays caused by the external traffic and to the actual number of active team members [AV2].

f) Robust communication with star topologies

Pursuing the superiority of stars over buses with respect to error containment, **Aveiro** and **Mallorca** developed two star topologies for CAN, namely CANcentrate (simplex) and ReCANcentrate (replicated), which maintain the shared medium characteristics of original CAN and thus can be applied to existing applications as a simple replacement of cabling. In this reporting period this work resulted in a book chapter [AVc1] as well as an article accepted for publication in IEEE Computer [AVc2]. Special attention was also devoted to data consistency

issues in ReCANcentrate, during dynamic phenomena associated to transient errors [AVc3] [AVc4].

On the other hand, **Aveiro**, with the collaboration from **CMU**, designed a new Ethernet switch that carries out traffic scheduling with resource reservation, controlling the transmissions, and verifying at the input the compliance of the incoming streams with their negotiated properties. Non-compliant packets can be promptly confined to specific time windows or eliminated, thus not interfering with the remaining system. A preliminary version of such switch is presented in [AV1].

g) Analysis for specific networks

In the particular case of Networks-on-Chip, wormhole routing is a commonly used technique. **York** carried out scheduling analysis of wormhole switching in NoCs to support priority based allocations of virtual channels. Work extended to deal with priority assignment and the energy and space saving obtained by minimising the number of priorities and hence virtual channels needed [YK3].

Pavia, **Aveiro** and **Mälardalen** (which is external to this activity) started collaboration in the scope of automotive systems concerning the use of DC powerline networking technology. Two seminars were organised in this scope and initial work has been reported in [AVc7].

h) Real-time support to middleware and composability

Providing real-time support to existing middlewares requires appropriate architectures and platforms. In this case, **Aveiro** has provided the FTT-SE platform that has been used in **Madrid** (UC3M) to support composition of service-based applications [AVc5]. This latter group has also developed different enhancements for RTSJ (Real-Time Specification for Java), both in memory management [MA1] [MA2] and architectural [AVc6], that introduce higher predictability and efficiency towards implementing the Distributed RTSJ. These extensions have been implemented in their DRTSJ prototype named DREQUIEMI.

Cantabria analysed the integration of distribution middleware with contract-based scheduling, with results reported in [CA1].

Moreover, **Aveiro** and **Mälardalen** have explored the use of server-based CPU scheduling to schedule traffic in a protected way, with temporal isolation among different streams, thus granting a high level of composability with respect to timeliness. Such a protocol was developed, Server-SE, which exploits the flexibility in traffic scheduling granted by the FTT-SE protocol [AVc8].

i) Educational test-beds

Aveiro has continued with the series of Student Design Competitions in the scope of the IEEE Real-Time Systems Symposium, generally called CiberMouse@RTSS200x. This year the competition specifically addressed the issue of mobile ad-hoc networks, proposing a problem in which a team of communicating mobile robots must co-ordinate their movements to maintain radio connection while maximising the area coverage. The competition site has all the necessary tools to participate (http://www.ieeta.pt/lse/ciberRTSS08/).

2.2 Individual Publications Resulting from these Achievements

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

[PO1] A. Koubâa, R. Severino, M. Alves, E. Tovar, "H-NAMe: A Hidden-Node Avoidance Mechanism for Wireless Sensor Networks", submitted to an international journal.

[PO2] A. Koubâa, A. Cunha, M. Alves, E. Tovar, "TDBS: A Time Division Beacon Scheduling Mechanism for ZigBee Cluster-Tree Wireless Sensor Networks", to be published in the Real-Time Systems Journal, Springer.

[PO3] E. Tovar, B. Andersson, N. Pereira, M. Alves, S. Prabh and F. Pacheco, "Highly Scalable Aggregate Computations in Cyber-Physical Systems", 7th International Workshop on Real Time Networks (RTN'08), Prague, Czech Republic, 2nd July, 2008.

[PO4] A. Cunha, R. Severino, N. Pereira, A. Koubâa, M. Alves, "ZigBee over TinyOS: implementation and experimental challenges", 8th Portuguese Conference on Automatic Control (CONTROLO'2008), Invited Session on "Real-Time Communications: from theory to applications", 21-23 July, 2008, Vila Real, Portugal.

[PO5] B. Andersson and S. Prabh, "Localizing an Object in Large-Scale Cyber-Physical Systems", in International Workshop on Cyber-Physical Systems Challenges and Applications (CPS-CA'08)}, Santorini Island, Greece, June 11, 2008, in conjunction with the 4th IEEE Inter. Conference on Distributed Computing in Sensor Systems (DCOSS'08), invited paper.

Aveiro

[AV1] R. Santos, R. Marau, A. Oliveira, P. Pedreiras, L. Almeida. Designing a Customized Ethernet Switch for Safe Hard Real-Time Communication. WFCS 2008 – 7th IEEE Workshop on Factory Communication Systems. Dresden, Germany. 21-23 May 2008.

[AV2] F. Santos, L. Almeida, L. S. Lopes. Self-configuration of an adaptive TDMA wireless communication protocol for teams of mobile robots. ETFA 2008, 13th IEEE Conference on Emerging Technologies and Factory Automation. Hamburg, Germany, 15-18 September 2008.

Catania

[CT1] O. Mirabella, L. Lo Bello, A. Raucea, Improving routing in Long Distance Wireless Mesh Networks via a Distributed Embedded Router. Journal of Parallel and Distributed Computing, 68(3):361-371, ISSN: 0743-7315, Academic Press Inc., Orlando, FL, USA, Mar 2008.

[CT2] E. Toscano, L. Lo Bello, "Cross-Channel Interference in IEEE 802.15.4 Networks". In Proceedings of the 7th IEEE International Workshop on Factory Communication Systems, WFCS'08, Dresden, Germany, May 2008, pp. 139-148, IEEE 2008, ISBN 978-1-4244-2349-1.

[CT3] L. Lo Bello, E. Toscano, Power-Efficient Routing in Wireless Sensor Networks", Networked Embedded Systems Handbook, CRC Press/Taylor & Francis, US (in press).

[CT4] L. Lo Bello, M. Collotta, E. Toscano, "Energy-Efficient MAC Protocols for Wireless Sensor Networks", Networked Embedded Systems Handbook, CRC Press/Taylor & Francis, US (in press).

Madrid

[MA1] P. Basanta-Val, M. García-Valls, and I. Estévez-Ayres. Simplifying the Dualized Threading Model of RTSJ Proc. of the 11th IEEE International Symposium on Object/component/service-oriented Real-time distributed Computing, ISORC 2008. May 5 - May 7, 2008. Orlando, Florida, USA.

[MA2] P. Basanta-Val, M. García-Valls, I. Estévez-Ayres y J. Fernández-González. Integración de capacidades de multiplexación en el conjunto de subprotocolos JRMP. IEEE América Latina, ISSN 1548-0992. In Spanish. (to appear)

York

[YK1] J. Tate, I. Bate and S. Poulding. Tuning Protocols to Improve the Energy Efficiency of Sensornets. Fourth UK Embedded Forum, 2008.

[YK2] J. Tate and I. Bate. YASS: A Scaleable Sensornet Simulator for Large Scale Experimentation. Communicating Process Architectures, pp411-430, 2008.

[YK3] S. Zheng and A. Burns. Real-time communication analysis for on-chip networks with wormhole switching. Proceeding of the IEEE International Symposium on Networks-on-Chip(NoCS), 2008.

Cantabria

[CA1] H. Pérez, J. J. Gutiérrez, D. Sangorrín, and M. G. Harbour. Real-Time Distribution Middleware from the Ada Perspective. 13th International Conference on Reliable Software Technologies, Ada-Europe, Venice (Italy), in Lecture Notes on Computer Science, Springer, LNCS 5026, June, 2008, ISBN: 3-540-68621-7.

2.3 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.

Porto has also been involving other activity partners in the collaboration with the **TinyOS community**, for developing implementations of the IEEE 802.15.4 and ZigBee protocols over TinyOS for commercially available mote platforms.

Porto and **Pisa** have been collaborating since late 2007 on the provision of technologies and tools for achieving real-time communications in wireless sensor networks. Particularly, Porto and Pisa have been working on the migration of the open-ZB IEEE 802.15.4/ZigBee protocol stack (http://www.open-ZB.net) to the ERIKA (http://erika.sssup.it) real-time operating system.

Madrid and **Aveiro** have been collaborating for a couple of years in the provision of real-time networking support to service-oriented middleware, opening the way to use this kind of technology with its inherent functional flexibility in real-time applications [AVc5]. In this year, Aveiro hosted for one month Iria Estevez, a professor from Madrid (UC3M), to develop a working prototype of her dynamic service composition framework based on the FTT-SE protocol. Further collaboration is being carried out in the scope of the DREQUIEMI framework developed at UC3M to support distributed real-time Java applications, using principles from the FTT framework.

Mallorca and **Aveiro** continued their collaboration towards the definition of flexible yet dependable mechanisms for distributed real-time systems and on the use of star topologies to boost robustness, particularly CANcentrate and ReCANcentrate for CAN networks.

Pavia, **Aveiro** and **Mälardalen** started a collaboration in the scope of automotive systems concerning the use of DC powerline networking technology to save cabling. Two workshops were organised on this topic, in Pavia, bringing together industrial and academic partners.

Aveiro and **Mälardalen** started a collaboration towards designing protocols to support compositionality in networked embedded systems exploring the server-based scheduling concept from CPU scheduling and applying it to networks.

Valencia (Alcoy branch) and **Aveiro** continued on-going co-operation towards dynamic QoS management of industrial video surveillance systems. Particularly, Ricardo Marau, a PhD student from Aveiro, visited Alcoy to carry out tests on a specific system.

During the reporting period, the partners involved in this activity set up several **R&D project proposals** together with several **other academic and industrial partners**, which were successfully submitted, either within the FP7 ICT, ARTEMIS and ITEA2 calls.

2.4 Joint Publications Resulting from these Achievements

Porto and Prague

[POc1] P. Jurcik, A. Koubâa, R. Severino, M. Alves, E. Tovar, Real-Time Communications over Cluster-Tree Sensor Networks", submitted to an international journal.

[POc2] P. Jurcik, R. Severino, A. Koubâa, M. Alves, E. Tovar, "Real-Time Communications over Cluster-Tree Sensor Networks with Mobile Sink Behaviour", 14th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA 2008), Kaohsiung, Taiwan, 25-27/AUG/2008.

Porto and Pisa

[POc3] P. Pagano, M. Chitnis, A. Romano, G. Lipari, R. Severino, M. Alves, P. Sousa, E. Tovar, "ERIKA and OpenZB: a tool suite for realtime wireless networked applications", submitted to an international conference.

Porto and Vienna

[POc4] B. Andersson, N. Pereira, N. Cruz, W. Elmenreich and E. Tovar, "A Scalable and Efficient Approach to Obtain Measurements in CAN-based Control Systems", in IEEE Transactions on Industrial Informatics, Vol 4, No 2, May 2008.

Mallorca and Aveiro

[AVc1] J.Pimentel, J.Proenza, L.Almeida, G.Rodríguez-Navas, M.Barranco, J.Ferreira. Dependable Automotive CAN Networks. in Automotive Embedded Systems Handbook, N. Navet and F. Simonot-Lion (ed). CRC Press / Taylor and Francis, ISBN: 9780849380266, November 2008.

[AVc2] M. Barranco, J. Proenza, L. Almeida. Boosting robustness in CAN systems with new star topologies: CANcentrate and ReCANcentrate, IEEE Computer. (to appear)

[AVc3] M. Barranco, J. Proenza, L. Almeida. Maintaining data consistency in ReCANcentrate during hub decouplings. Work-in-Progress Session of WFCS 2008 – 7th IEEE Workshop on Factory Communication Systems. Dresden, Germany. 21-23 May 2008.

[AVc4] M. Barranco, J. Proenza, L. Almeida. Management of Media Replication in ReCANcentrate. ICC 2008, International CAN Conference, Barcelona, Spain, March 2008.

Madrid and Aveiro

[AVc5] I. Estevez-Ayres, M. Garcia-Valls, L. Almeida, P. Basanta-Val. Solutions for Supporting Composition of Service-Based Real-Time Applications. 11th IEEE Symp. on Object/component/service-oriented Real-time distributed Computing, ISORC 2008. Orlando, USA. May 2008.

[AVc6] P. Basanta-Val, I. Estevez-Ayres, M. Garcia-Valls, L. Almeida. A synchronous scheduling service for distributed real-time Java. Submitted to IEEE Transactions on Parallel and Distributed Systems.

Pavia, Aveiro and Mälardalen

[AVc7] F. Benzi, T. Facchinetti, T. Nolte, L. Almeida. Towards the Powerline Alternative in Automotive Applications. Work-in-Progress Session of WFCS 2008 7th IEEE Workshop on Factory Communication Systems. Dresden, Germany. 21-23 May 2008.

Aveiro and Mälardalen

[AVc8] R. Marau, N. Figueiredo, R. Santos, P. Pedreiras, L. Almeida, T. Nolte. Server-based real-time communications of Switched Ethernet. CRTS 2008 - 1st Workshop on Compositional Theory and Technology for Real-Time Embedded Systems (satellite of RTSS 2008), Barcelona, Spain, November 30, 2008.

2.5 Keynotes, Workshops, Tutorials

Workshop: Fieldbuses for Automotive and the Powerline Alternative
Pavia, Italy - January 24, 2008

Organizers:

- Tullio Facchinetti, University of Pavia, Italy
- Francesco Benzi, University of Pavia, Italy

Objectives: The workshop focused on the aspects, both from the physical and communication protocol side, about the use of powerline for the communication in the automotive domain. The main technologies for automotive communication have been presented (LIN, CAN, FlexRay) to compare a possible solution based on powerline. The discussion established the guidelines to conduct further research and experiment on the topic, mainly towards evaluating the timing characteristics of available powerline components. This workshop counted with participation of both academic partners (Pavia, Aveiro and Mälardalen) and industrial ones (Magnetti-Marelli).

Workshop: 1st International Workshop on Cyber-Physical Systems Challenges and Applications (CPS-CA'08)
Workshop Chair: Eduardo Tovar (Polytechnic Institute of Porto)
Santorini, Greece – 11/JUN/2008
This workshop was held in conjunction with the 4th IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS'08). http://www.hurray.isep.ipp.pt/cps-ca08

Workshop: 7th International Workshop on Real Time Networks (RTN'08)
Workshop Chair: Anis Koubaa (Polytechnic Institute of Porto)
Prague, Czech Republic – 2/JUL/2008
This workshop was held in conjunction with the 20th Euromicro International Conference on Real-Time Systems (ECRTS'08). HomePage: http://www.hurray.isep.ipp.pt/rtn08/index.php

Workshop: Operating Systems and Networks
Pisa, Italy – October 2-3, 2008

Objectives: The purpose of the workshop was to refine the research objectives of the cluster on Operating Systems and Networks and coordinate the collaboration among the different groups. Discussed topics included: architecture effects on worst-case execution times, taxonomy of resources, real-time networks, and real-time and control issues.

Organizers:

- Giorgio Buttazzo - Scuola Superiore Sant'Anna, Italy
- Alan Burns – University of York, UK
- Luis Almeida, Univ. of Aveiro, Portugal

Workshop: International Meeting on Powerline for - but not limited to - Automotive
Pavia, Italy – November 4, 2008

Organizers:

- Tullio Facchinetti, University of Pavia, Italy
- Francesco Benzi, University of Pavia, Italy

Objectives: This was a continuation of the workshop held in January and focused on establishing a lasting collaboration among interested partners from academia (namely Pavia, Milan, Aveiro, Mälardalen) and industry (Magnetti-Marelli, Yamar) towards using the DC powerline technology in vehicles. The event has been endorsed by the IEEE EMC-S IT Chapter.

URL: http://robot.unipv.it/component/content/article/64

Seminar: Open-ZB: an open-source implementation of the IEEE 802.15.4/ZigBee protocol stack for TinyOS
Lecturer: André Cunha (Polytechnic Institute of Porto)
Pisa, Italy – 26/FEB/2008
Seminar given to a diverse audience in the SSSUP (http://retis.sssup.it/lab_events/openzb1).

Keynote: Time for Cyber-Physical Systems
Lecturer: Alan Burns (University of York)
Santorini, Greece – 11/JUN// 2008
Keynote talk at the International Workshop on Cyber-Physical Systems Challenges and Applications (CPS-CA'08). http://www.hurray.isep.ipp.pt/cps-ca08

Seminar: Mobility Issues in Cyber-Physical Systems
Lecturer: Luis Almeida (U. Aveiro)
Stockholm, Sweden – 16/JUN/2008
Seminar given at the EU-US Workshop on Networked Information and Control Systems (http://www.access.ee.kth.se/EU-US08/)

Seminar: Enabling ubiquitous computing and cyber-physical systems with wireless sensor/actuator networks: what is at stake?
Lecturer: Mário Alves (Polytechnic Institute of Porto)
L'Aquila, Italy – 4/SEP/2008
Seminar given in a doctoral school for PhD students in Computer Engineering (http://gii2008.dei.polimi.it)

Seminar: Guaranteeing QoS in large-scale distributed embedded systems using standard and COTS technologies: ongoing research at IPP-HURRAY

Lecturer: Mário Alves (Polytechnic Institute of Porto)
L'Aquila, Italy – 4/SEP/2008
Seminar given in a doctoral school for PhD students in Computer Engineering (http://gii2008.dei.polimi.it)

Keynote: Highly Scalable Aggregate Computations in Cyber-Physical Systems: Physical Environment Meets Communication Protocols
Lecturer: Eduardo Tovar (Polytechnic Institute of Porto)
Rennes, France – 16/OCT/ 2008
Keynote talk at the 16th International Conference on Real-Time and Network System

3. Milestones, and Future Evolution

3.1 Problem to be Tackled over the next 12 months (Jan 2009 – Dec 2009)

For the next 12 months period, this activity will continue pursuing its objectives as stated in Section 1.4. In particular, we expect to pursue the following lines:

- Further analysis of network induced delays in diverse domains, from WSNs to NoCs as well as specific architectures, protocols and or traffic models.
- Improvements in the timeliness of the communication in WSNs and MANETs by means of architectural and protocol solutions while reducing resource requirements (e.g. energy, memory and CPU) and supporting scalable data aggregation.
- Dynamic reconfiguration issues in WSNs arising from changes in the set of active nodes.
- Architectures and protocols for NESs to support efficient QoS adaptation, dynamic reconfiguration, composability and higher robustness with respect to the coverage of assumptions on the desired behaviour of nodes and environment.
- Exploration of new media for NESs, particularly DC powerline, and its use in specific domains such automotive and aerospace, and analyse its combination with star/tree topologies.

3.2 Current and Future Milestones

Year 1

• Contributions to the Zigbee specification.

Achieved. Important scientific and technological achievements within the ART-WiSe and open-ZB frameworks have lead to a leap forward in the use of IEEE 802.15.4 and ZigBee protocols for Wireless Sensor Networks (WSNs), particularly concerning the worst-case analysis, dimensioning and real engineering of multiple cluster (cluster-tree) WSNs as well as the improvement of their Quality-of-Service (e.g. throughput, energy-efficiency). Importantly, these efforts have been developed in close synergy with the participation in the TinyOS Net2 Working Group. Note that TinyOS is the most widely used operating system for wireless sensor nodes.

• Educational tools supporting teaching of wired/wireless networked embedded systems.

Achieved. The know-how, tool-sets and test-beds emerging from the ART-WiSe and open-ZB frameworks (see 2.1 a, b and c), enabled and leveraged many academic courses and projects, ranging from hands-on lectures, short-term projects and MSc, PhD and post-doc studies. Also Aveiro has continued with the series of Student Design Competitions in the scope of the IEEE Real-Time Systems Symposium, having organised the CiberMouse@RTSS2008 edition and provided all the necessary tools (http://www.ieeta.pt/lse/ciberRTSS08/).

• Taxonomy of WSN and MANET within real-time applications.

Partially achieved. This taxonomy will survey the existing protocols, their features and limitations, as well as the respective middleware for application development in the scope of WSN and MANET. It will be completed in Year 2.

• Taxonomy of flexibility within distributed real-time applications.

Partially achieved. This taxonomy will survey the several perspectives of the concept, from design flexibility to configuration flexibility, operational flexibility etc, but also within the scope of real-time distributed applications with more or less criticality. It will be completed in Year 2.

Future milestones

- ***Summer school on Real-Time Networks.***
- ***Taxonomy of WSN and MANET within real-time applications (to be completed in Y2).***
- ***Taxonomy of flexibility within distributed real-time applications (to be completed in Y2).***
- ***Further educational tools to support teaching networked embedded systems***
- ***Contributions to communication protocols, their application and analysis.***

3.3 Main Funding

FRESCOR IST project, in which the following academic partners are involved: University of Cantabria, University of York, Scuola Superiore Santa Anna, Technical University of Kairserslautern, Technical University of Valencia and the Czech Technical University in Prague, together with the following industrial partners: Thales Communications France, ENEA EPACT, Visual Tools, Rapita Systems, EVIDENCE.

THREAD Spanish project, in which the following academic partners are involved: Technical University of Madrid, University of Cantabria, Technical University of Valencia

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.

REFLECT is a Portuguese project involving Porto, aiming at investigating generic frameworks for dynamic application monitoring and control. Porto also has a new proposal under evaluation for an adaptable framework for embedded systems to allow constrained devices to cooperate with more powerful (or less congested) neighbours.

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.

SSSA and Porto are involved in a FP7 IST STREP project proposal aiming at synthesising real-time applications for multicores based on software models of configurable software.

e-MAGERIT Emerging Applications for Next Generation Internet) - Region of Madrid S-0505/TIC/0251; 2006-2009.

WASP IST project, in which the following academic partners are involved: Technical University of Kairserslautern, RWTH Aachen, University of Paderborn, Imperial College London, Technical University of Eindhoven, Universiity of Lille, Ecole Polytechnique Fédérale de Lausanne together with the following research and industrial partners: IMEC, CSEM, Philips, Fiat, CEFRIEL, Microsoft Aachen, Fraunhofer IIS, IGD & Fokus, SAP.

MICS Swiss project, in which the following academic partners are involved: Ecole Polytechnique Fédérale de Lausanne, CSEM, ETHZ.

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

Catania is involved in the IST 7FP STREP project “Flexible Wireless Automation in Real-Time Environments”, FlexWARE, aiming at the implementation of a novel platform for the support of real-time communication over Wireless Local Area Networks based on the IEEE 802.11 standard,

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 behaviour.

Aveiro is also involved in the Portuguese project HaRTES – Hard Real-Time Ethernet Switching, which addresses the development of switches with enhanced traffic scheduling, policing and filtering that, nevertheless, are dynamically configurable and support dynamic QoS adaptation.

4. Internal Reviewers for this Deliverable

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Björn Andersson (ISEP - Portugal)