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

Activity Progress Report for Year 2

Real-Time Networks

Cluster:

Operating Systems and Networks

Activity Leader:

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http://www.fe.up.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 Adhoc 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	February 4th 2010

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1. Overview of the Activity

1.1 ArtistDesign participants and their role within the Activity

Cluster Leader: Giorgio Buttazzo – Scuola Superiore S. Anna (Italy)
Role: real-time MAC protocols, wireless sensor networks.

Team Leader: Luis Almeida – University of Porto (Portugal)
Role: Activity coordinator, networking platform, development of distributed applications.

Team Leader: Gerhard Fohler – Technical University of Kaiserslauten (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.

-- Changes wrt Y2 deliverable --

The role of Scuola Superiore S. Anna has been updated.

1.2 Affiliated participants and their role within the Activity

Team Leader: Paulo Pedreiras – University of Aveiro (Portugal)
Role: real-time networks, dynamic quality of service management.

Team Leader: Hermann Haertig – Universtity 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: Real-time middleware, QoS-based resource management.

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

-- Changes wrt Y2 deliverable --

Dr Steffens from NXP has retired, with no replacement as yet. The role of University Carlos III of Madrid has been updated.

1.3 Starting Date, and Expected Ending Date

Starting date: January 1st, 2008

Ending date. December 31st, 2011.

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.

-- Changes wrt Y2 deliverable --

The ending date has been extended by one year.

1.4 Policy Objective

This activity addresses 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 such as WirelessHART (within ISA100 and IEC TC65 WG16), ZigBee/IEEE802.15.4, and through joint R&D projects.

-- No changes wrt Y2 deliverable --

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, as well as other technologies such as Bluetooth low power, 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.

Scalability issues in 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. But these are not the only challenges. For example, aggregating the enormous amounts of data into a small set of meaningful quantities in a scalable and efficient way, discovering services available or areas covered, routing the data efficiently and in time, developing interaction models that are adequate to support applications built on top of such infrastructures, are all challenges that need to be revisited having scalability in mind.

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 was 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 was 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.

-- No changes wrt Y2 deliverable --

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. Moreover, the activity also aims at providing more efficient networking support for distribution middleware, with improved bandwidth usage and timeliness, as well as to virtual resource middleware, with improved temporal isolation between hierarchical partitions. Finally, the activity also targets the development of adequate protocols for wireless-based NESs, capable of delivering the required QoS, comparable to that achieved with the wired counterparts but providing large benefits in terms of deployment and weight.

It is also foreseen the that joint research will be developed on: (i) the design distributed algorithms for computing basic operations in large-scale networked embedded sensor systems such that their time-complexity is independent of the number of sensor nodes

and; (ii) showing their usefulness in the application areas of control of physical systems and sensor fusion (taking into account the dynamic nature of such communication infrastructures); and (iii) the support of Quality-of-Service (QoS) in wireless sensor networks (such as the ART-WiSe framework) with the additional goal to contribute to the standardization process on IEEE 802.15.4/ZigBee suite of protocols.

The activity also aims at producing a taxonomy of WSNs and MANETs for time-sensitive applications, addressing the existing protocols, their features and limitations, as well as the respective middleware for application development. On the other side, a parallel thread of action will produce a taxonomy 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.

-- No changes wrt Y2 deliverable --

1.7 Work achieved in Year 1 *(Jan-Dec 2008)*

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.

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.

-- No changes wrt Y2 deliverable --

This section was already presented in the Y2 deliverable, in section 1.7.

1.8 Work achieved in Year 2 *(Jan-Dec 2009)*

During the second 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. Moreover, special attention was devoted to specific application domains for their current relevance, namely wireless communication in industrial scenarios, support to intelligent transportation and healthcare systems. The actual problems tackled in this period are briefly described below.

a) Wireless sensor networks

Timeliness in Wireless Sensor Networks – Time analysis that cope with the inherent non-deterministic data delivery in these networks, the structuring /clustering of such networks to reduce end-to-end delays, and access protocols with more efficient arbitration mechanisms, namely based on dominance properties.

Mobility issues in ad-hoc real-time wireless communication – Middleware to support real-time cooperation among autonomous agents, graceful degradation of real-time protocols with respect to interference caused by alien traffic and support to relative localization and navigation.

b) Networked embedded systems

Robust communication with star topologies - Quantitative comparison of the error-containment capabilities of bus and star topologies.

Real-time support to middleware and composability – Use of synchronous techniques within standard distribution middleware (CORBA, RMI, DDS...) to improve its timeliness.

Analysis for specific networks – Improvement of the analysis for CAN with dynamic bandwidth assignment, assessment of current DC-powerline technology for real-time communication, analysis for FlexRay and for general token-passing protocols.

c) Specific application domains

Wireless networks in industrial environments – Characterization and assessment of interferences in such environments, assessment of the effectiveness of the QoS mechanisms in IEEE802.11e within industrial environments and topological issues to cater for the needs of industrial systems.

Supporting Intelligent Transportation Systems – Integration of heterogeneous and pervasive components in a consistent real-time information system, heavily based on wireless networking.

Networked Embedded Systems for Healthcare – Integration of weareable wireless communication-enabled devices to monitor the condition of patients and the level of physical activity. Provision of the needed level of dependability in such systems.

-- No changes wrt Y2 deliverable --

This section was already presented in the Y2 deliverable, in sections 1.8 and 2.1.

1.9 Problem Tackled in Year 3 *(Jan-Dec 2010)*

Here we present the problems that were addressed during the third year, following a structure consistent with the one used in the previous year. Some specific topics continue to be active, a few topics faded (terminated or suspended) and several new issues were included as the activity progressed. In particular, there is still a large interest on real-time issues in wireless sensor networks, combined with energy efficiency and adaptive mechanisms, as well as on networked embedded systems, both in terms of protocol improvements for enhanced robustness, adaptivity and timeliness and in terms of middleware technologies to ease programming and composition of distributed real-time systems. In terms of specific application domains, the work of this year continued addressing the wireless communication in industrial scenarios and the support to intelligent transportation and included now the real-time video transmission as well as the networks-on-chip. These are briefly described below and further expanded in section 2.1 in the technical achievements. Note that some work on real-time

networks focused more on resource management or on adaptivity and are thus presented in the respective deliverables.

a) Wireless sensor networks

Timeliness in Wireless Sensor Networks – Time analysis that cope with the inherent non-deterministic data delivery in these networks, the structuring /clustering of such networks to reduce end-to-end delays, and access protocols with more efficient arbitration mechanisms that allow further energy savings.

b) Networked embedded systems

Robustness and timeliness in Controller Area Networks – replication management of duplex stars, clock synchronization and its formal verification, clockless synchronization of distributed control transactions.

Real-time support to middleware and composability – automatic generation of high-integrity distributed real-time systems (particularly in Ravenscar source code) from high-level system models, integration of networking guarantees and middleware technologies, real-time support to service-oriented middleware, real-time functional composition mechanisms, and distribution middleware layers that support dynamic and timely reconfiguration and adaptation.

Protocol optimizations for embedded real-time communications – connectionless JRMP subprotocol, distributed real-time Java, traffic scheduling in IP routers, reducing energy consumption in real-time distributed embedded systems, and timeliness and robustness in switched Ethernet-based real-time communication.

c) Specific application domains

COTS middleware for real-time video transmission over DDS – real-time and QoS-based transmission of video over networked embedded nodes with timing requirements.

Wireless networks in industrial environments – integration of wireless sensor networks with wired networks, and open issues of using wireless LANs technology (particularly 802.11e) with respect to real-time behavior.

Supporting Intelligent Transportation Systems – using computer vision for transportation traffic assessment and its integration in resource-contrained wireless sensor networks.

Networks-on-Chip – evaluation of the performance and power overhead that NoC interconnects can impose on specific applications, and enhancing robustness of bus allocations in multi-core real-time systems.

-- The above is new material, not present in the Y2 deliverable --

2. Summary of Activity Progress in Year 3

2.1 Technical Achievements

a) Timeliness in Wireless Sensor Networks (TUKL, CSEM, Philips, Pisa, York, Porto, Prague)

The inherent properties of Wireless Sensor Networks (WSN) clash with the notion of timeliness adopted from classic real-time systems. It is practically unfeasible to impose strict deadlines on single messages in WSN without overdimensioning network capacity: mobility, irregular topology, ad-hoc infrastructure, energy constraints, and limited availability of resources, constitute an unfavorable environment for such timeliness guarantees. Therefore, the teams at **TUKL, CSEM** and **Philips** proposed a generalized notion of timeliness which suits the characteristics of WSN, based on the requirements in the EU IST project WASP. It allows to express the end-to-end timeliness requirements of message streams by means of target time intervals and confidence level [TUKL1].

Pisa has developed a novel TDMA MAC protocol that allows further saving energy in real-time wireless networks. The proposed method expoits elastic scheduling for balancing the residual energy among the nodes with the objective of prolonging the network lifetime while guaranteeing real-time constraints. In order to assess real-time aspects in WSNs, the team also developed a simulator [Pis+1]. A mechanism was also proposed to support adaptive bandwidth allocation in WSNs [Pisa4] while a component-based interface that is compliant with such adaptation is proposed in [Pisa2].

Pisa has also developed the WBuST communication protocol that allows real-time message communication in wireless distributed embedded systems. The protocol can guarantee both time and energy constraints and has been designed for cluster-based networks, where each cluster is managed by a master node. The channel access is synchronized by the transmission of a periodic beacon and scheduled with a weighted round robin algorithm. WBuST has been implemented for the Flex boards, under the RTOS Erika, and its performance has been widely assessed through a set of experiments.

York developed part of a protocol suite that delivers synchronization in cellular architectures aiming at reducing communication times across a network by making sure the appropriate node within each cell is transmitting at a time such that the message can hop across the network without waiting for the next available transmission slot to begin [York1].

York also carried out a detailed evaluation of whether variants of classical algorithms for simple stateless network protocols actually provide benefits. The work shows where a variant of an algorithm exists to deal with a particular situation, e.g. network voids, it might well deal with the void well but then performs worse in the more general cases. The specific case of a classical gossiping algorithm and its variants is analyzed in [York2] showing the situations in which the variants provide benefits and measuring the undesired behaviors that remain.

Porto and **Prague** have continued the development of the OpenZB framework to effectively support the design, analysis, dimensioning and engineering of WSN systems with stringent timing requirements, bridging the gap between traditional real-time embedded systems and large-scale wireless sensor networks. This has been reported in [Por+1] which was the 1st paper on real-time issues in WSNs published by TOSN. In the reporting period a PhD thesis was defended at CTU (Prague) [Por+2] presenting a comprehensive framework for the worst-case analysis and dimensioning of cluster-tree WSNs, instantiated in the widely adopted IEEE 802.15.4/ZigBee protocols, spanning over (1) an optimal time-division cluster scheduling

mechanism to avoid inter-cluster collisions; (2) analytical models and software tools for evaluating network resources and finding the best energy/bandwidth trade-offs; (3) OPNET simulation models for IEEE 802.15.4/ZigBee WSNs; (4) validation of theoretical and simulation models through extensive experimental work. The developed models and tools for worst-case network analysis and dimensioning (MATLAB) and for simulation (OPNET) of IEEE 802.15.4/ZigBee WSNs are available on the web (http://www.open-zb.net/) and are used worldwide, having received over 100 000 effective visits, with more than 6000 downloads of the toolset from all over the world (including top universities and companies). Notably, there are roughly 4 -5 downloads per day, 4 years after the first release in Noveber 2006. Further publications by Prague (CTU) include [CTU1] and [CTU2] the former was the most accessed paper on the 10th of November of 2010 (http://ieeexplore.ieee.org/xpl/topAccessedArticles.jsp?punumber=9424/).

These methodologies, models and tools are being used within the ARTEMIS project EMMON, aiming at real-time monitoring using large-scale and dense WSNs, as a baseline to sustain the WSN architecture.

b) Robustness and timeliness in Controller Area Networks (Mallorca, UnivPorto, Catalonia, IFP)

Mallorca and **UnivPorto** continued the development of the (Re)CANcentrate stars for CAN, aiming at improved error containment with respect to the common bus topology. In this reporting period, a co-supervised PhD thesis on the topic was successfully presented [Mall1]. A first protoype of the replication management mechanisms in ReCANcentrate was built and experimentally assessed [MaUP].
http://dmi.uib.es/~mbarranco/srvlsestars

Mallorca also developed a novel approach for the formal modeling and verification of clock synchronization algorithms with timed automata that allows including drifting clocks in this framework. This approach was applied to a specific fault-tolerant algorithm for CAN that is compliant with existing systems, provides high precision and is low cost [Mall2].

Catalonia and **IFP** (Institut Français du Pétrole) have developed a novel approach to networked control systems analysis and design that provides increased control performance for a set of control loops that share a single CAN network. First, standard periodic messaging is guaranteed to ensure stability, and second, non-periodic additional messaging is added whenever bandwidth is available in such a way that the aggregated control performance for all control loops is improved. A proof-of-concept system was implemented showing the practicality of the proposal as well as its benefits [CatIFP1][CatIFP2].

Another issue that was tackled by **Catalonia** was the synchronization of nodes in Networked Control Systems (NCS). These systems often require imposing periodic execution for the sampling and/or actuation operations to enforce synchronized constant time delays, which is typically achieved using clock synchronization. Conversely, this work proposed a mechanism that implements these synchronized operations in an NCS without global time and which has been experimentally validated [Cat1].

c) Real-time support to middleware and composability (Cantabria, Madrid: UPM and UC3M, Bilbao, UnivPorto)

Building High-integrity Distributed Real-Time (HDRT) systems requires a rigorous methodology to assist in the design and development of verifiable software. Work has been done in cooperation between **Cantabria** and **Madrid (UPM)** to develop an approach based on the Model-Driven Engineering (MDE) paradigm to ease the automatic generation of HDRT

applications from high-level system models. Since those applications must be amenable to stringent timing analysis, such as the determination of worst-case execution time or schedulability analysis, a set of timing analysis tools has been integrated with a toolset for MDE. In addition, a new approach has been explored to integrate the real-time end-to-end flow model with the automatic generation of Ravenscar-compliant source code in distribution middleware [Cant1]-[Cant3] [CaUPM].

Madrid (UC3M) has been cooperating with other partners to improve the real-time support to distribution middlewares. **UC3M** as technical coordinator of iLAND has worked on the integration of networking gurantees and middleware technologies (concerning DDS, ICE, and Distributed RTSJ and their prototype implementations as iLAND middleware v0.1 and DREQUIEMI, respectively). This topic of the iLAND ARTEMIS project includes mainly UC3M and it aims at developing a common middleware for real-time and dynamically reconfigurable applications. Currently, UC3M has produced the first iLAND Reference implementation v0.1 http://www.iland-artemis.org

UC3M has also designed and implemented the architecture of a service oriented middleware. For this activity, special interest is focused the design and implementation of a *common communication bridge* over DDS middleware and RTSJ [UC3M7]. Also, this bridge supports other underlying middlewares as RT-CORBA and WS*. Also, **UC3M** is extending the DDS real-time characterization parameters.

UC3M has also continued the work on functional composition mechanisms over real-time networks focusing at the level at which compositional middleware is integrated closely with the network and their synchronization mechanisms [UC3M1], interaction with remote communication protocols and development of new composition and reconfiguration algorithms for service-based applications [UC3M4] [UC3M5]. Also, this work has been integrated with work on mode changes on single platforms to obtain better dynamic performance results in multimedia systems. **UC3M** is also involved in a Spanish National Project of the Ministry of Industry for building gateways for the DDS standard of the OMG.

UnivPorto and **Bilbao (UPV/EHU)** developed distribution middleware layers that support dynamic timely reconfiguration and adaptation in distributed systems. Two middlewares were developed, one directly on top of the FTT-SE protocol by **UnivPorto** [UP1] (http://www.fe.up.pt/~ftt) and another on top of RT-CORBA that also follows the FTT paradigm by **UPV/EHU**, also in collaboration with **UnivPorto** [EHUUP]. This work was partly developed within the iLAND ARTEMIS project.

d) Protocol optimizations for embedded real-time communications (Madrid, Pisa, Aveiro, UnivPorto, Malardalen, NXP, TUKL)

Madrid (UC3M) analyzed the performance of the connection-less JRMP subprotocol which was designed originally for distributed real-time Java. The validation showed performance improvements in comparison to currently used infrastructures. The performance has been reported to a journal in an article which now in accepted status.

UC3M also tested a priority-based scheduling strategy for distributed real-time Java applications which is also valid for other distributed real-time applications. The policy is deployed now in common-off-the-shelf routers (IP traffic) that prioritize packets using a non-preemptive fixed-priority policy [UC3M3].

Pisa developed an integrated energy-aware algorithm for scheduling packets and tasks for reducing energy consumption in real-time distributed embedded systems. The method exploits DVS and DPM techniques to enhance the amount of saving for different system configurations.

Aveiro, UnivPorto and **Malardalen** have continued the work on improving timeliness and robustness in switched Ethernet-based real-time communication by using specific switch built-

in features. In particular, heterogeneous asynchronous traffic flows are handled by built-in servers that constitute virtual channels and can be associated to ports, layers 2 or 3 information, or even application semantics. A working prototype was developed, capable of dynamically creating/removing servers and adapting the servers hierarchy [AvUPMa]. A work was triggered concerning the interconnection of multiple of these switches and the protocol for reserving servers (virtual channels) from end-to-end [AvMaUP]. This work was partially developed in the scope of the HaRTES project.
http://www.ieeta.pt/lse/hartes

NXP and **TUKL** continued their collaboration within the ARTEMIS project INDEXYS – INDustrial EXploitation of the genesYS cross-domain architecture, aiming at in-vehicular networks with focus on TTEthernet and FlexRay [TN1].
http://www.indexys.eu

e) COTS middleware for real-time video transmission over DDS (Madrid)

Madrid (UC3M) has developed architectures for enabling real-time and QoS-based transmission of video over networked embedded nodes with timing requirements. This work ranges from the study of the suitability of certain middleware paradigms for this purpose. Precisely, **UC3M** has developed a demonstrator for transmission over DDS and ICE middlewares [UC3M6].

f) Wireless networks in industrial environments (Catania, Torino)

Industrial wireless sensor networks are different from typical WSNs as in industrial deployments WSNs usually have to be integrated with wired industrial networks because there are critical data flows that cannot be transmitted over the wireless medium. In this scope, **Catania** investigated the use of a chain-based protocol, called Circular Chain Data Forwarding (CCDF), that not only supports the integration with a wired industrial infrastructure but also takes advantage of such an integration to deliver real-time performance even to nodes that could not be directly covered by a sink [CT1]. To was achieved using a chain-based mechanism that integrates data forwarding with the channel access strategy. Theoretical results, confirmed by in-depth simulations, have shown the enhanced performance of the protocol in both error-free and error-prone channels [CT2].

Catania has also provided a comprehensive overview on Wireless LANs on the factory floor and on the open issues of this technology as far as the real-time support is concerned, with a special focus on the IEEE 802.11e standard [CTTo]. This work was partially developed within the flexWARE project.
http://www.flexware.at

g) Supporting Intelligent Transportation Systems (Catania, Pisa, Evidence)

Automatic traffic monitoring and surveillance have become essential for effective road usage and management. Various sensors have been used to estimate traffic parameters, but their installation and maintenance is often difficult and costly. Among the technologies being investigated, computer vision promises the most flexible and reliable solutions to estimate traffic parameters. In this context, **Catania** proposed wireless sensor network architecture for autonomous traffic monitoring, based on computer vision techniques for automatic scene analysis and interpretation. A discussion on relevant design issues, the proposed architecture and the relevant modules, with experimental results that show the accuracy of the proposed approach can be found in [CT3].

Pisa and **Evidence** also addressed the problem of gathering real-time information on mobility (infomobility) with visual information [Pis+2][Pis+4] and focused on the constraints imposed by the scarse resources of the wireless networks [Pisa5] particularly proposing the use of line sensors [Pisa1]. This work is partly developed within the project IPERMOB.
http://www.ipermob.org

h) Networks-on-Chip (York, PUCRS, Pisa, Bologna)

York has been collaborating with **PUCRS** (Brazil) on power estimation methods for on-chip networks. The collaboration used a rate-based power estimation method at RTL developed at **PUCRS** and adapted it to generate power macromodels that could be built into TLM models of Networks-on-Chip. The produced TLM models could be directly plugged in the lsi.noc evaluation framework, providing designers with early evaluation of the performance and power overhead that the NoC interconnects would impose on specific applications [Yor+1]-[Yor+4].

Pisa collaborated with **Bologna** to provide a unified approach for enhancing robustness in multi-core real-time systems using an adaptive TDMA allocation of an on-chip bus together with elastic scheduling [Pis+3].

-- The above is new material, not present in the Y2 deliverable --

2.2 Individual Publications Resulting from these Achievements

UnivPorto

[UP1] Ricardo Marau, Luis Almeida, Mario Sousa, Paulo Pedreiras. A middleware to support dynamic reconfiguration of real-time networks. ETFA 2010, 15th IEEE Conference on Emerging Technologies and Factory Automation. Bilbao, Spain, 13-16 September 2010.

Mallorca

[Mall1] Manuel Barranco (PhD Thesis). "Improving Error Containment and Reliability of Communication Subsystems Based on Controller Area Network (CAN) by Means of Adequate Star Topologies". University of the Balearic Islands, Palma, Spain. May 2010.

[Mall2] Guillermo Rodríguez-Navas (PdD Thesis). "Design and Formal Verification of a Fault-tolerant Clock Synchronization Subsystem for the Controller Area Network". University of the Balearic Islands, Palma, Spain. November 2010.

TUKL

[TUKL1] Ramon Serna Oliver, Gerhard Fohler, Timeliness in Wireless Sensor Networks: Common Misconceptions, Proceedings of the 9th International Workshop on Real-Time Networks RTN'2010, Brussels, Belgium, July 2010.

Cantabria

[Cant1] Daniel Sangorrin and Michael González Harbour. "Bandwidth Isolation for Composability in Fixed Priority Real-Time Networks." 9th International Workshop on Real-Time Networks RTN'2010, Bruselas, July, 2010.

[Cant2] Daniel Sangorrín, Michael González Harbour, Héctor Pérez, and J. Javier Gutiérrez. "Managing Transactions in Flexible Distributed Real-Time Systems". 15th Int. Conf. On

Reliable Software Technologies, Ada-Europe'2010, Valencia (Spain), in Lecture Notes in Computer Science, LNCS Vol. 6106, pp. 251-264, June 2010.

[Cant3] Héctor Pérez Tijero, J. Javier Gutiérrez, and Michael González Harbour. "Support for a Real-Time Transactional Model in Distributed Ada". 14th International Real-Time Ada Workshop, Porto Venere (Italy), ACM SIGAda Ada Letters, Volume XXX, Number 1, pp. 91-103, April 2010.

Catania

[CT1] E. Toscano, L Lo Bello, “The case for Chain-Based Routing in Industrial Wireless Sensor Networks”, In Proceedings of the 8th IEEE International Workshop on Factory Communication Systems, WFCS’10, Nancy, Francia, 19-21 May 2010, pp.189-192, ISBN 978-1-4244-5461-7.

[CT2] E. Toscano, L. Lo Bello, “A novel approach for data forwarding in Industrial Wireless Sensor Networks,” IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), Spain, Sept. 2010, ISBN: 978-1-4244-6849-2.

[CT3] G. Iannizzotto, F. La Rosa, L. Lo Bello. “A wireless sensor network for distributed autonomous traffic monitoring”, 3rd IEEE/IES Conference on Human-System Interaction, HSI 2010, Rzeszow, Poland, May 2010, pp.612-619, ISBN 978-1-4244-7561-2.

Pisa

[Pisa1] M. Chitnis, C. Salvadori, M. Petracca, P. Pagano, G. Lipari, “Traffic related observations by Line Sensing techniques” Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems (SenSys 2010), Zurich, Switzerland, November 3-5, 2010.

[Pisa2] L. Santinelli, M. Chitnis, C. Nastasi, F. Checconi, G. Lipari, P. Pagano, “A Component-Based Architecture for Adaptive Bandwidth Allocation in Wireless Sensor Networks”, Proceedings of the 5th IEEE Symposium on Industrial Embedded Systems (SIES 2010), Trento, Italy, July 7-9, 2010.

[Pisa3] D. Alessandrelli, P. Pagano, C. Nastasi, “MIRTES: MIddleware for Real-time Transactions in Embedded Systems”, Proceedings of the 3rd IEEE International Conference on Human System Interaction 2010 (HSI 2010), Rzeszow, Poland, May 13-15, 2010 (WSN track, best paper award).

[Pisa4] Nastasi, M. Marinoni, L. Santinelli, P. Pagano, G. Lipari, G. Franchino, “BACCARAT: a Dynamic Real-Time Bandwidth AllocationPolicy for IEEE 802.15.4”, Proceedings of IEEE Percom 2010, International Workshop on Sensor Networks and Systems for Pervasive Computing (PerSeNS 2010), Mannheim, Germany, March 29-April 2, 2010.

[Pisa5] M. Chitnis, P. Pagano, G. Lipari, C. Salvadori, M. Petracca, L. Santinelli “Distributed visual surveillance with resource constrained embedded systems”. (accepted) Visual Information Processing in Wireless Sensor Networks: Technology, Trends and Applications. Publisher: IGI Global.

Catalonia

[Cat1] P. Martí, A. Camacho, M. Velasco, P. Marés and J.M. Fuertes. Synchronizing Sampling and Actuation in the Absence of Global Time in Networked Control Systems. In 15th IEEE International Conference on Emerging Techonologies and Factory Automation (ETFA10), Bilbao, Spain, September 2010.

York

[York1] J. Tate and I. Bate. A Feedback-Driven Timing Synchronisation Protocol For Cellular Sensornets. Proceedings of the 7th IEEE International Conference on Mobile Ad-hoc and Sensor Systems, 2010.

[York2] J. Tate and I. Bate. Do sensornet protocol variants yield real benefits. Proceedings of the 17th IEEE International Conference on the Engineering of Computer Based Systems, 2010.

Madrid (UC3M)

[UC3M1] Pablo Basanta-Val, Marisol García-Valls and Iria Estévez-Ayres. *No-Heap Remote Objects for Distributed Real-time Java* ACM Transactions in Embedded Computing Systems. Volume 10 Issue 1, August 2010.

[UC3M2] Pablo Basanta-Val, Marisol García-Valls and Iria Estévez-Ayres. *Fine tuning of the multiplexing facilities of Java's Remote Method Invocation*. [Accepted] in Concurrency and Computation Practice and Experience

[UC3M3] Pablo Basanta-Val, Marisol García-Valls and Iria Estévez-Ayres. *Using Switched-Ethernet and Linux-TC for Distributed Real-Time Java Infrastructures*. IEEE RTAS-2010 WiP Session.

[UC3M4] Iria Estévez-Ayres, Marisol García-Valls and Pablo Basanta-Val. On the reconfiguration of service-based real-time applications. In Proc. Of WiP session of IEEE RTAS-2010, Stockholm, Sweden, 12-15 April, 2010.

[UC3M5] J. Díez-Sánchez (advisor: I. Estévez-Ayres). Implementation and evaluation of composition algorithms for distributed real-time service-based applications. Master Thesis, Universidad Carlos III de Madrid. March 2010

[UC3M6] M. García-Valls, Pablo Basanta-Val, Iria Estévez-Ayres. *Adaptive real-time video transmission based on DDS* . 8th IEEE International Conference on Industrial Informatics. (IEEE INDIN 2010). IEEE Computer Society Press. Osaka, Japón. 13-16 de julio, 2010.

[UC3M7] M. García-Valls, et al. Middlewares as platform. Deliverable 4.5. version 1.5 (month 20). iLAND ARTEMIS Project. Dec. 15th, 2010.

Prague

[CTU1] Zdenek Hanzálek, Petr Jurcik, "Energy Efficient Scheduling for Cluster-Tree Wireless Sensor Networks With Time-Bounded Data Flows: Application to IEEE 802.15.4/ZigBee", IEEE Transactions on Industrial Informatics, vol. 6, nº3, August 2010.

[CTU2] Petr Jurcik, Zdenek Hanzalek, "Simulation study of energy efficient scheduling for IEEE 802.15.4/ZigBee cluster-tree Wireless Sensor Networks with time-bounded data flows", 15th IEEE Int. Conf. on Emerging Technologies and Factory Automation (ETFA 2010), Bilbao, Spain, 13-16/SEP/2010.

-- The above are new references, not present in the Y2 deliverable --

2.3 Interaction and Building Excellence between Partners

The technical achievements reported in section 2.1 already pointed implicitly to a relatively large set of collaborative work among the project partners and others, which could hardly be

done in isolation. Among these, we highlight the following, most of which resulted in concrete exchanges and research results. Moreover, it is important to refer that the partners involved in this activity were involved in several **R&D project proposals,** involving **other academic and industrial partners**, which were submitted, either within the FP7 ICT, ARTEMIS and ITEA2 calls, some of which being successful and having started in this period.

Madrid (UC3M) and **Madrid (UPM)** have been collaborating in the provision of real-time networking support to service-oriented middleware, **UC3M** working at the level of distribution middleware and **UPM** at the level of QoS management and modeling.

Madrid (UC3M) and **Pisa** have started collaboration on resource management from a vertical perspective including the networking issues. A PhD student from Pisa, Gaetano Anastasi, visited UC3M for 9 months to develop joint work in this topic.

Ricardo Marau, a researcher from **UnivPorto,** visited **UC3M** for a week to discuss the design and implementation of combined resource management, mainly within the scope of the iLAND project.

Mallorca, **Aveiro** and **UnivPorto** continued their collaboration towards the definition of flexible yet dependable mechanisms for distributed real-time systems, namely using star topologies. In this scope, Julia Proenza from Mallorca visited UnivPorto for one month to analyze the potential benefits of integrating both (Re)CANcentrate and FTT-CAN frameworks.

Aveiro, UnivPorto and **Mälardalen** followed their collaboration towards implementing server-based scheduling within enhanced Ethernet switches. During this period Rui Santos, a student from Aveiro/UnivPorto, spent 5 months at Malardalen University to develop response-time analysis for the hierarchical server composition. Also in this framework, Manuel Barranco from **Mallorca** is now at UnivPorto for a 5 months stay to carry out dependability analysis of the enhanced switches.

Bilbao (EHU/UPV) and **UnivPorto** continued the collaboration on improving the timing behavior of RT-CORBA by synchronizing the methods invocation instants and using it to support service-based applications.

UnivPorto hosted Augusto Oliveira, a PhD student from University of **Waterloo**, Canada, for one month, to develop a versatile tagging system for use in distributed systems, particularly for supporting distributed resource management. UnivPorto also hosted for 3 months a student from **Zhejiang** University, China, to develop an adaptive WSN for tracking applications.

York, **Porto**, **Uppsala** and **Malardalens** are starting collaborative work in the domain of cell-structured networks and their synchronization.

Luis Almeida from **UnivPorto** visited **Pisa** for a week to deliver a course on Real-Time Networks and discuss on-going research work, particularly addressing adaptivity in WSNs.

TUKL, **Philips**, and **CSEM** have continued work on timeliness notions for WSN, with a focus on accurate simulations and realistic requirements.

Porto and **Prague** have continued the collaboration on methodologies for analysing, modelling and engineering cluster-tree WSNs, instantiated in the PhD work of Petr Jurcik, jointly supervised by Porto(ISEP) and Prague which successfully ended this year.

-- Changes wrt Y2 deliverable --

With respect to Y2, several collaborations continued, some faded, while new ones appeared, involving organizations of ArtistDesign as a whole and from outside, too.

2.4 Joint Publications Resulting from these Achievements

[EHUUP] Isidro Calvo, Luis Almeida, Federico Pérez, Adrián Noguero, Marga Marcos. Supporting a Reconfigurable Real-Time Service-Oriented Middleware with FTT-CORBA. ETFA 2010, 15th IEEE Conference on Emerging Technologies and Factory Automation. Bilbao, Spain, 13-16 September 2010.

[AvUPMa] Rui Santos, Paulo Pedreiras, Luis Almeida, Alexandre Vieira, Thomas Nolte, Ricardo Marau, Arnaldo Oliveira. Flexible, Efficient and Robust Real-Time Communication with Server-based Ethernet Switching. WFCS 2010 – 8th IEEE Workshop on Factory Communication Systems. Nancy, France. 19-21 May 2010.

[AvMaUP] Rui Santos, Paulo Pedreiras, Farahnaz Yekeh, Thomas Nolte, Luis Almeida. On Hierarchical Server-based Communication with Switched Ethernet. (Work-in-Progress session) ETFA 2010, 15th IEEE Conference on Emerging Technologies and Factory Automation. Bilbao, Spain, 13-16 September 2010.

[MaUP] Manuel Barranco, David Gessner, Julián Proenza, Luís Almeida. First Prototype and Experimental Assessment of Media Management in ReCANcentrate. ETFA 2010, 15th IEEE Conference on Emerging Technologies and Factory Automation. Bilbao, Spain, 13-16 September 2010.

[TN1] Andreas Eckel, Paul Milbredt, Zaid Al-Ars, Stefan Schneele, Bart Vermeulen, György Csertan, Neeraj Suri, Abdelmajid Khelil, Gerhard Fohler, INDEXYS, a Logical Step beyond GENESYS, SAFECOMP 10, September 2010.

[Pis+1] P. Pagano, M. Chitnis, G. Lipari, C. Nastasi, Y. Liang, “Simulating Real-Time Aspects of Wireless Sensor Networks”, EURASIP Journal on Wireless Communications and Networking, Volume 2010, 2010.

[Pis+2] M. Magrini, D. Moroni, C. Nastasi, P. Pagano, M. Petracca, G. Pieri, C. Salvadori, and O. Salvetti, “Visual Sensor Networks for infomobility”, accepted for the special issue of the international journal "Pattern Recognition and Image Analysis: Advances in Mathematical Theory and Applications", MAIK "Nauka/Interperiodica" Pleiades Publishing, Moscow, distributed worldwide by Springer, 2011.

[Pis+3] P. Burgio, M. Ruggiero, F. Esposito, M. Marinoni, and G. Buttazzo, L. Benini, "Adaptive TDMA bus Allocation and Elastic Scheduling: a unified approach for enhancing robustness in multi-core RT systems", Proceedings of the 28th IEEE International Conference on Computer Design (ICCD 2010), Amsterdam, the Netherlands, October 3-6, 2010.

[Pis+4] M. Magrini, D. Moroni, C. Nastasi, P. Pagano, M. Petracca, G. Pieri, C. Salvadori, and O. Salvetti, “Image mining for infomobility”, Proceedings of the 3rd International Workshop on Image Mining Theory and Applications. Angers, France, INSTICC Press, pp. 35-44, 2010.

[Pis+5] G. Cecchetti, A.L. Ruscelli, A. Alifano, G. Lipari, “Improving the QoS support in HCCA-EDCA mixed IEEE 802.11e networks”, Proceedings of the 21st CNIT International Tyrrhenian Workshop on Digital Communications (ITWDC), Ponza Island, Italy, September 2010.

[Pis+6] A.L. Ruscelli, G. Cecchetti, S. Gopalakrishnan, G. Lipari, “A model for the design of Wireless Sensor Networks using Geographic Routing”, IEEE UbiCoNet 2010, Miami, Florida, December 2010. [Pis+1] Haibo Zeng, Marco Di Natale, Paolo Giusto Alberto Sangiovanni-Vincentelli “Statistical Analysis of Controller Area Network Message Response Times”, SIES Conference, Lausanne July 8-10, 2009 (winner of best paper award).

[Yor+1] L. S. Indrusiak, L. C. Ost, F. G. Moraes, Sanna Maatta, J. Nurmi, L. Moller, M. Glesner. Evaluating the impact of communication latency on applications running over on-chip multiprocessing platforms: a layered approach. Proceedings of the 8th IEEE Int Conference on Industrial Informatics (INDIN), 2010, pp148-153.

[Yor+2] L. Moller, P. Fischer, F. G. Moraes, L. S. Indrusiak, M. Glesner. Improving QoS of Multi-Layer Networks-on-Chip with Partial and Dynamic Reconfiguration of Routers. 20th Int Conf on Field Programmable Logic and Applications (FPL), 2010.

[Yor+3] L. Moller, A. Rodrigues, F. Moraes, L. S. Indrusiak, M. Glesner. Instruction Set Simulator for MPSoCs based on NoCs and MIPS Processors. Int Workshop on Reconfigurable and Communication-centric Systems-on-Chip (ReCoSoC), 2010.

[Yor+4] L. Ost, G. Guindani, L. S. Indrusiak, F. Moraes. Model-Based Power Estimation of NoC-Based MPSoCs. 25th South Symposium on Microelectronics (SIM), 2010, pp125-128.

[CaUPM] Héctor Pérez, J. Javier Gutiérrez, Esteban Asensio, Juan Zamorano, and Juan A. de la Puente "Validating the End-to-End Flow Model to Develop High-Integrity Distributed Real-Time Systems" Submitted to 16th International Conference on Reliable Software Technologies – Ada-Europe 2011.

[CTTo] L. Lo Bello, E. Toscano, S. Vittorio, “A perspective on the IEEE 802.11e Protocol for the Factory Floor”, in Dr. Javier Silvestre-Blanes Ed., Factory Automation, Chapter 9, pp.177-200, InTech, Vukovar, Croatia, ISBN 978-953-307-024-7, Mar 2010.

[CatIFP1] P. Martí, A. Camacho, M. Velasco, M.M. Ben Gaid. Run-Time Allocation of Optional Control Jobs to a Set of CAN-based Networked Control Systems. In IEEE Transactions on Industrial Informatics, Vol.6, N. 4, November 2010.

[CatIFP2] P. Martí, A. Camacho, M. Velasco, M.M. Ben Gaid. Efficient Utilization of Bus Idle Times in CAN-Based Networked Control Systems. In 2nd IFAC Workshop on Distributed Estimation and Control in Networked Systems (NecSys2010), Annecy, France, September 2010.

[Por+1] P. Jurcik, R. Severino, A. Koubaa, M. Alves, E. Tovar, “Dimensioning and Worst-case Analysis of Cluster-Tree Sensor Networks”, ACM Transactions on Sensor Networks, Volume 7, Issue 2, Article 14, August 2010.

[Por+2] Petr Jurcik, “Real-Time Communications over Cluster-Tree Wireless Sensor Networks”, PhD Thesis in Electrical Engineering and Information Technology, Faculty of Electrical Engineering of the Czech Technical University in Prague (Czech Republic) in collaboration with CISTER-ISEP Research Unit, Polytechnic Institute of Porto (Portugal). Submitted in January 2010 and defended in October 2010.

-- The above are new references, not present in the Y2 deliverable --

2.5 Keynotes, Workshops, Tutorials

Invited talk: Luis Almeida, *Hierarchical Distributed Architectures for Autonomous Mobile Robots: A Case Study*
Institution: Singapore Polytechnic
Singapore – 16 March 2010

Addresses the benefits of using hierarchical approaches in the design of distributed embedded systems and focuses on a specific case study that refers to a team of mobile robots.

Conference: ETFA 2010 – 15th IEEE Conference on Emerging Technologies in Factory Automation
Bilbao, Spain – September 14-17, 2010

This conference included several tracks with directed involvement of activity members, namely Lucia Lo Bello from **Catania** that co-chaired the track on Information Systems in Automation, Julian Proenza from **Mallorca** that co-chaired the track on Industrial Communication Systems and Josep Fuertes from **Catalonia** that co-chaired the track on Automation Manufacturing Systems. Two special sessions were organized at this conference by Marisol Garcia-Valls from **UC3M** on reconfigurable networked embedded systems and QoS resource management, respectively.
http://www.etfa2010.org

Workshop : RTN 2010 – 9th Workshop on Real-Time Networks
Conference name : ECRTS 2010 – 22nd EUROMICRO Conference on Real-Time Systems
Brussels, Belgium – June 30, 2009

This workshop was the 9th in its series and focused on the current technological challenges of developing communication infrastructures that are real-time, reliable, pervasive and interoperable. It provides a relaxed forum for discussing those challenges taken has basis a restricted set of papers and a couple of invited keynotes.
http://www.hurray.isep.ipp.pt/rtn10/index.php/

Workshop : SOCNE 2010 – 5th IEEE Workshop on Service Oriented Architectures in Converging Networked Environments
Perth, Australia – April, 2010

Lucia Lo Bello from **Catania** was the Program co-Chair of the workshop.
http://www.socne.org

Workshop : WARM 2010 –Workshop on Adaptive Resource Management
Conference name : CPSWEEK 2010 – Cyber-Physical Systems Week
Stockholm, Sweden – April 12, 2010

This workshop was co-organized by the activities in this cluster and the activity on Designing for Adaptivity.
http://www.artist-embedded.org/artist/New-article,2075.html

Track: Distributed and Embedded Networked Control
Conference name : INDIN 2010 – 8th IEEE Conference on Industrial Informatics
Osaka, Japan –*13-16 July, 2010*

This Track was co-chaired by Josep Fuertes from **Catalonia**
http://indin2010.ist.osaka-u.ac.jp/

Special Session: Networked-based Control Systems
Conference name : IECON 2010 – 36th IEEE Conference on Industrial Electronics
Phoenix, USA – 7-10 November, 2010

This Special Session was co-chaired by Josep Fuertes from **Catalonia**
http://iecon2010.njit.edu/index2.html

Special Session: Networked-based Control Systems
Conference name : ICIT 2010 – IEEE Conference on Industrial Technology
Viña del Mar, Chile – 10-12 December, 2010

This Special Session was co-chaired by Josep Fuertes from **Catalonia**
http://www.icit2010.usm.cl/

Special Session: Human System Interaction and Wireless Sensor Networks
Conference name : HSI 2010 – 3rd Int. Conference on Human System Interaction
Rzeszow, Poland – 13-15 May, 2010

This Special Session was co-chaired by Lucia Lo Bello from **Catania**
http://hsi.wsiz.rzeszow.pl

Conference name : ICESS 2010 – 7th IEEE Conf. on Embedded Software and Systems
Bradford, UK– June 29th - July 1st, 2010

Marisol Garcia-Valls from **UC3M** was Workshop co-chair.
http://www.scim.brad.ac.uk/~ylwu/ICESS2010/

Tutorial : Luis Almeida, *Real-Time Communication for Embedded Systems*
Institution: Course at ENSIAS, Ùniversity Mohammed V
Rabat, Morrocco – 20-22 December, 2010

20h course covering the concepts, techniques, technologies and applications of real-time networks.

Tutorial : Luis Almeida, *Real-Time Networks*
Event: ArtistDesign Summer School in Morocco, 2010
Rabat, Morocco – 11-16 July, 2010

6h course covering the techniques, technologies and applications of real-time networks with a focus on traffic scheduling issues.
http://www.artist-embedded.org/artist/-ARTIST-Summer-School-in-Morocco.html/

Tutorial : Luis Almeida, *Real-Time Networks*
Event: Graduate Course on Real-Time Networks 2010
Scuola Superiore Sant'Anna, Pisa, Italy – 26-30 April, 2010

30h course (20h lectures + 10h lab) covering the techniques, technologies and applications of real-time networks with a focus on traffic scheduling issues.

-- The above is new material, not present in the Y2 deliverable --

3. Milestones, and Future Evolution

3.1 Problem to be Tackled over the next 12 months (Jan 2011 – Dec 2011)

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 by means of architectural and protocol solutions while reducing resource requirements (e.g. energy, memory and CPU) and supporting scalable data aggregation.*
- *Support for dynamic reconfiguration in wireless networks arising from mobility as well as changes in the set of active nodes and provision of graceful degradation in the timeliness and reliability of data delivery.*
- *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.*
- *Analysis of specific application domains, including assessment of operational environments, suitability of protocols, deployment issues, integration in larger systems.*

-- Changes wrt Y2 deliverable --

Minor change with respect to Y2. Work on DC powerline was currently suspended.

3.2 Current and Future Milestones

Year 1

• Contributions to the Zigbee specification **(achieved)**

• Educational tools supporting teaching of wired/wireless networked embedded systems **(achieved)**

• Taxonomy of WSN and MANET within real-time applications **(partially achieved).**

• Taxonomy of flexibility within distributed real-time applications **(partially achieved).**

Year 2

- ***Summer school on Real-Time Networks.***

Achieved. **Porto** is involved in the organization of the SensorNets 2009 school (http://www.sensornets-school.org) dedicated to Cyber-Physical Systems and Sensor Networks and also involving other teams. Moreover, other similar activities were organized along the period, namely the ArtistDesign Summer School in China (http://www.artist-embedded.org/artist/Overview,1630.html/) and the ArtistDesign Graduate Course on Embedded Control Systems (http://www.artist-embedded.org/artist/Overview,1673.html/), both covering the topic of Real-Time Networks by **UnivPorto** and **Aveiro**. The ArtistDesign Summer

School in Europe (http://www.artist-embedded.org/artist/Programme,1636.html/) also included several talks related to that topic.

- ***Further educational tools to support teaching networked embedded systems***

Achieved. **Aveiro**, **UnivPorto** and **Pavia**, with Pavia leading, have continued with the series of Student Design Competitions in the scope of the IEEE Real-Time Systems Symposium. This year, this competition called CyberRescue@RTSS2009 focuses on the real-time control of a team of mobile autonomous agents, which involves, among other things, the development of an ad-hoc wireless communications protocol and an adequate middleware. All the necessary tools are available on-line (http://robot.unipv.it/cyberrescue-RTSS09) and the simulator became this year an open software project (http://sourceforge.net/projects/cpss/files).

- ***Contributions to communication protocols, their application and analysis***

Achieved. It is naturally a target of the activity to carry out the contributions referred in this milestone. In the current period many contributions have been made, which were described in Section 2.1.

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

Partially achieved. This taxonomy surveys the existing protocols, their features and limitations, as well as the respective middleware for application development in the scope of WSN and MANET. It is still an on-going effort that, for the sake of thoroughness, will be continued during Year 3. During the current period a draft was produced based on a collaborative document while a wiki is being prepared to support the completion of the process.

- **Taxonomy of flexibility within distributed real-time applications.**

Partially achieved. This taxonomy surveys 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 was found, however, that it was more adequate to merge this effort with a similar one being developed within the Transversal Activity on Design for Adaptivity and on the Activity for Scheduling and Resource Management, which is also on-going, based on a wiki, and will be continued during Year 3.

Year 3

- ***Summer school on Real-Time Networks.***

Achieved. Despite the absence of a Summer School specifically dedicated to Real-Time Networks, **UnivPorto** and **Pisa** were engaged in several educational events that included or targeted this topic namely a graduate course at the Scuola Superiore Sant'Anna in Pisa and the ArtistDesign Summer School in Morocco (http://www.artist-embedded.org/artist/-ARTIST-Summer-School-in-Morocco-.html/).

- ***Further educational tools to support teaching networked embedded systems***

Achieved. This year another related framework has been made available on the web as an open source project, namely the FTT-SE (Flexible Time-Triggered communication over Switched Ethernet) protocol (http://www.fe.up.pt/~ftt/). Despite being a research framework, it is also well suited to support teaching in real-time networks given that it works on top of Ethernet and allows any traffic scheduling policy. Moreover, frameworks developed and shared previously in the context of this activity for research purposes continue being updated and available, being also adequate to educational use, such as the OpenZB toolset for WSNs (http://www.open-zb.net/).

- ***Contributions to communication protocols, their application and analysis***

Achieved. In the current period many contributions have been made, which were described in Section 2.1.

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

Pending. This taxonomy surveys the existing protocols, their features and limitations, as well as the respective middleware for application development in the scope of WSN and MANET. The work in the current period saw relatively slow progress. A wiki was recently created containing the current draft. This milestone is carried on to year 4.

- **Taxonomy of flexibility within distributed real-time applications.**

Suspended. The effort towards this taxonomy was redirected to the Transversal Activity on Design for Adaptivity and, up to a certain extent, to the taxonomy developed within the Activity for Scheduling and Resource Management.

Future milestones

Continue the current efforts and achieve the following:

- ***Summer school on Real-Time Networks (or contributions on this topic to similar educational events).***
- ***Contributions to communication protocols, their application and analysis.***
- ***Taxonomy of WSN and MANET within real-time applications.***

3.3 Main Funding

The ArtistDesign NoE funds integration and building excellence with the partners, and with the European research landscape as a whole. Beyond this "glue" for integration and excellence, during Year 3 this activity has benefited from direct funding from:

- **iLAND – mIddLewAre for deterministic dynamically reconfigurable NetworkeD embedded systems.**
  (2009 – 2012), supported by the European Community through the Joint Undertaking ARTEMIS. **Madrid** (**UC3M**) is the **technical coordinator** of iLAND project and main contributor. The project also includes **UnivPorto**, among a total of 9 organizations. Aims at developing a middleware targeting dynamically reconfigurable and adaptive systems.
  http://www.iland-artemis.org
- **EMMON – Embedded Monitoring**
  (2009 – 2012) Project supported by the European Community through the Joint Undertaking ARTEMIS. Includes **Porto** among 9 partners. Aims at performing technological research on large scale distributed Wireless Sensor Networks.
  http://www.artemis-emmon.eu
- **INDEXYS – INDustrial EXploitation of the genesYS cross-domain architecture**
  (2009-2011) supported by the European Community through the Joint Undertaking ARTEMIS. 10 organizations including **NXP** and **TUKL.** Aiming at in-vehicular networks with focus on FlexRay.
  http://www.indexys.eu
- **HaRTES: Hard Real-Time Ethernet Switching**
  (2009 – 2011), supported by the Portuguese Government through Fundação para a Ciência e Tecnologia PTDC/EEA-ACR/73307/2006 and involving **Aveiro**, **UnivPorto**

and **Mallorca**. Aims at the design of a new type of Ethernet Switches that include flexible transmission control capabilities together with enhanced traffic classification and filtering that boost safety and timeliness while maintaining operational flexibility.
http://www.ieeta.pt/lse/hartes

- **MADES**
  (2010-2012) EU funded project for 30 months starting April1st, 2010, involving York among 6 partners. Aims to develop a UML / MARTE based model-driven approach for the design, validation, simulation, and code generation of complex embedded systems.
  http://mades-project.ning.com
- **FlexWARE: Flexible Wireless Automation in Real-Time Environments**
  ICT 7FP STREP project involving **Catania** and 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.
  http://weblink.weblink.weblink/webpage
- **IPERMOB: Pervasive and Heterogeneous Infrastructure to Control Urban Mobility in Real-time**
  Italian project (Regione Toscana) project involving **Pisa** and **Evidence** aiming at the implementation of an infrastructure to monitor and control mobility in urban centers.
  http://www.ipermob.org/
- **CANbids: CAN-based infrastructure for dependable systems**
  (2009-2011) Spanish project (PNIF, DPI2008-02195) developed by **Mallorca** and involving **UnivPorto** aiming at using operational flexibility and star topologies to build infrastructures that are highly-dependable but low cost.
- **WASP: Wirelessly Accessible Sensor Populations**
  (2006-2010) FP6-IST (IST- 034963) project involving **TUKL** and **CSEM** (among 18 partners) aiming at covering all the layers in WSNs, from hardware to the data dissemination and self-organization, to facilitate their deployment.

-- Changes wrt Y2 deliverable --

List updated with new projects (MADES, EMMON) having substantial industrial involvement.

4. Internal Reviewers for this Deliverable

- **Karl-Erik Arzen** (Lund University, Sweden)
- **Giorgio Buttazzo** (SSSA, Pisa, Italy)