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

Activity Progress Report for Year 4

Real-Time Networks

Clusters:

Operating Systems and Networks

Activity Leader:

Luis Almeida (University of Porto, Portugal)

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	January 20th 2012

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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 Y3 deliverable --

No changes.

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.

Note: Along the duration of this activity, several collaborations took place with groups beyond those in ArtistDesign, either core or affiliated. In the description of the work, further on, we will refer to the groups in ArtistDesign using a short name and in boldface, and to the external groups using the full name and in normal font style.

-- Changes wrt Y3 deliverable --

No changes except for the note added at the end

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 Y3 deliverable --

No changes.

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.

-- Changes wrt Y3 deliverable --

No changes.

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.

-- Changes wrt Y3 deliverable --

No changes.

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 of 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.

-- Changes wrt Y3 deliverable --

No changes.

2. Work Achieved in the NoE

2.1 Synthesis View of the Main Overall Achievements

The objectives of this activity as stated in Section 1.4 include the development of timing analysis and temporal control mechanisms for dynamic networks, efficient temporal partitioning to support higher integration levels and global resource management, techniques to further reduce energy consumption in autonomous devices and in WSNs in particular, more robust wireless-based applications that are more tolerant to message losses as well as analyses that cope with the intrinsic limitations of the wireless medium. Finally, the objectives also include influencing industry through seminars, courses, standards and joint projects.

Therefore, we organized our work in two main lines, namely:

- protocols and middleware for robust and flexible real-time communication, with associated analytical tools
- protocols, tools and analysis methods for wireless sensor networks (including mobile ad-hoc networks)

Beyond the objectives, the work program in Section 1.6 also referred to two taxonomies, one on each of the lines referred to above. These have not been successfully completed which we believe to have been compensated for with a significant amount of outcomes at the scientific, technical, and outreach levels as we will explain later in this section. In particular, several state-of-the-art surveys were produced in the scope of related projects, which are publicly available as deliverables. For example, the iLAND (http://www.iland-artemis.org/) and EMMON (http://www.artemis-emmon.eu) ARTEMIS projects, which were proposed and triggered during this activity envolving several ArtistDesign partners, addressed exactly the two lines referred to above, respectively. In addition to these, the FlexWARE (http://www.flexware.at/) FP7 project also addressed real-time wireless communication in local area industrial networks as well as the CONET (http://www.cooperating-objects.eu/) FP7 Network of Excellence, more focused on ad-hoc wireless communication for cooperating objects, which produced a roadmap containing relevant material for our targeted taxonomy on real-time WSN. These materials are gathered in a wiki (http://twiki.fe.up.pt/bin/view/ArtistDesign/) that will persist beyond ArtistDesign with the main results of the Activity on Real-Time Networks.

It is also important to note that this activity bears strong connections to the Activity on Scheduling and Resource Management and the Activity on Design for Adaptivity. In fact, the work on traffic scheduling and bandwidth management fits the former while the work on flexible communication fits the latter. Nevertheless, in gross terms, in this activity we focus on the communication aspects, i.e., the protocols and associated analysis, and we try to reduce overlapping. It is possible, though, that occasional topics are referred to in more than one activity but still with a different focus.

Technically, the activity generated a strong set of outcomes that advanced the frontiers of the state-of-the-art in real-time communications, not only in terms of protocols and analysis but also their engineering, deployment and operation. It is interesting to observe the wide body of scientific literature that was produced over the years, a good part of which integrated consistent toolsets/frameworks that are now available for use. A few examples are:

- The toolset to design, analyse, configure and deploy dense WSNs, in part built within the EMMON project (http://www.artemis-emmon.eu), including the OpenZB ZigBee protocol stack (http://www.open-ZB.net) and the Z monitor (http://www.z-monitor.org). In this scope, a WSN experimental testbed with 300+ nodes has been recently deployed. In this process, several contributions were made to the ZigBee/IEEE802.15.4 and TinyOS standards;

- The RTDB middleware / wireless communication protocol for teams of collaborating robots (http://code.google.com/p/rtdb/);
- The (Re)CANcentrate framework essentially developed within the CANbids project (http://srv.uib.es/project/12) which provides duplex/simplex stars for CAN, which has now been fully verified and completed with a thorough quantitative characterization of the reliability benefits of stars versus buses and with star-based fault-injectors for testing CAN-based systems that open new possibilities;
- The Flexible Time-Triggered framework (FTT - http://www.fe.up.pt/ftt), particularly concerning the FTT-SE protocol for switched Ethernet and the FTT-enabled Ethernet switch, which received new enhancements mainly within the scopes of the iLAND (http://www.iland-artemis.org/) and HaRTES (http://www.ieeta.pt/lse/hartes) projects that open up their applicability to a wide range of applications, and which boost the robustness of the system providing a fully reconfigurable communications virtualization layer;
- The MAST modeling and analysis suite (http://mast.unican.es/), which was enhanced with more networking components and analysis, namely for switched networks such as AFDX;
- The DREQUIEMI middleware for developing distributed real-time Java applications (http://www.it.uc3m.es/drequiem/drequiemi/) which was enhanced with a programming abstraction based on message and queues and with a new communication protocol for RMI, beyond other improvements in the temporal behavior;
- The iLAND real-time service-oriented middleware which supports predictable online service composition and for which a reference implementation, fully featured with all reconfiguration capabilities, will be available soon (http://www.iland-artemis.org/);

Beyond these frameworks, many other analyses have been developed such as temporal and buffering analysis both deterministic and stochastic for wireless networks, protocols for reducing energy consumption in the wireless communication and considering the interaction with task scheduling, new analysis for CAN that is tuned to cope with features of common CAN device drivers and controllers, new analysis for distribution middlewares such as DDS, etc.

Altogether, these contributions are reported in 210 publications produced over the 4 years of the activity and distributed as follows:

- 1st year: 17 from individual groups and 12 joint publications
- 2nd year: 31 from individual groups and 26 joint publications
- 3rd year: 27 from individual groups and 21 joint publications
- 4th year: 46 from individual groups and 30 joint publications
- Total: 121 from individual groups and 89 joint publications

It is also worth noting that the overall impact of the group grew substantially beyond the boundaries of the activity participants. As an example, the 30 joint publications produced this year involved collaboration with 16 groups beyond those stated in Sections 1.1 and 1.2. Moreover, the partners involved in this activity also participated in several related projects, both at the European and national levels, some of which have already been referred to before:

- European level (FP7 and ARTEMIS): WASP, EMMON, iLAND, INDEXIS, MADES, FlexWARE;

- National level with international collaboration: IPERMOB (I), CANbids (E), HARTES (P), SENODS (P);

In this aspect, we believe that the activity played a significant role in promoting project submissions and cross-fertilization of ideas and results. This cross-fertilization was also fostered by several workshops on related topics organized with a strong involvement from activity partners. Some of these workshops were consistently organized over the years and others occurred on an event basis, as well as tracks and special sessions organized in related conferences, essentially in the areas of Real-Time Systems, Embedded Systems and Industrial Automation:

- Workshops: APRES 2008-2011 (in conjunction with the Activity on Design for Adaptivity), RTN 2008-2011, SOCNE 2010-2011, WARM 2010, NeRES 2011.
- Special sessions and tracks: ETFA 2009-2011, INDIN 2010-2011, IECON 2010-2011

Finally, the activity also carried out a considerable dissemination effort. In fact, activity members participated in almost all summer schools organized by ArtistDesign, either in Europe, China, South America and Morocco, with talks on cutting edge real-time communication topics. Adding to these, several participations also took place within other focused schools, students competitions, such as CyberRescue 2008-2009, as well as in PhD and MSc programs.

-- The above is new material, not present in the Y3 deliverable --

2.2 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). 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) (**Porto, Catania, Pisa, York, Prague)**.

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

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 addressed 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 (**Aveiro**).

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 (**Aveiro, Mallorca**, **CMU**).

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. Therefore, this line explored ways to improve this situation and bring Service-oriented Architectures to the real-time applications domain. An ARTEMIS project was submitted to address this issue. Moreover, this line 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 **(Madrid-UC3M, Aveiro)**.

Still under this line, work was carried out on the FRESCOR contracting middleware and having it supporting 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 (**Cantabria, Valencia**, **Prague**).

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 concerning composability with respect to timeliness by means of using server-based CPU scheduling techniques in the scope of traffic scheduling (**Aveiro**, **Mälardalen**).

-- No changes wrt Y3 deliverable --

This section was already presented in the Y3 deliverable, in section 1.7.

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

During the second year, the teams involved in this activity, together with new collaborations, 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 (**TUKL, CSEM, Philips, Pisa, York, Porto).**

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 **(Aveiro, UnivPorto, Pavia** plus University of Zaragoza and Zhejiang University**).**

b) Networked embedded systems

Robust communication with star topologies - Quantitative comparison of the error-containment capabilities of bus and star topologies **(Aveiro, UnivPorto, Mallorca, Mälardalen)**.

Real-time support to middleware and composability – Use of synchronous techniques within standard distribution middleware (CORBA, RMI, DDS...) to improve its timeliness **(Aveiro, UnivPorto, Madrid-UC3M, Cantabria** plus University of the Basque Country-Bilbao**)**.

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 **(NXP, TUKL, Pavia**, **Aveiro, UnivPorto, Mälardalen, Pisa, Catalonia)**.

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 **(Catania)**.

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

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 **(Pisa, Evidence, Catania)**.

-- No changes wrt Y3 deliverable --

This section was already presented in the Y3 deliverable, in sections 1.8.

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

During the third year, the teams involved in this activity consistently continued addressing the same global research lines, namely real-time issues in wireless sensor networks, combined with energy efficiency and adaptive mechanisms, 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 continued addressing the wireless communication in industrial scenarios and the support to intelligent transportation and included real-time video transmission as well as networks-on-chip. These 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 that allow further energy savings **(TUKL, CSEM, Philips, Pisa, York, Porto, Prague)**.

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 **(Mallorca, UnivPorto, Catalonia** plus Institut Français du Petrole-IFP**)**.

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 **(Cantabria, Madrid-UPM, Madrid-UC3M, UnivPorto** plus University of the Basque Country-Bilbao**)**.

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 **(Madrid-UC3M, Pisa, Aveiro, UnivPorto, Malardalen, NXP, TUKL)**.

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 **(Madrid-UC3M)**.

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 **(Catania)**.

Supporting Intelligent Transportation Systems – using computer vision for transportation traffic assessment and its integration in resource-contrained wireless sensor networks **(Catania, Pisa, Evidence)**.

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 **(York, Pisa, Bologna** plus Pont. Catholic University of Rio Grande do Sul-PUCRS**)**.

-- No changes wrt Y3 deliverable concerning technical content --

This section resulted from merging sections 1.9 and 2.1 of the Y3 deliverable.

2.5 Work achieved in Year 4 (Jan-Dec 2011)

During the forth year, the research continued exploring the main lines defined in the objectives (Section 1.4) and work program (Section 1.6) and several significant outcomes were achieved from the continued integration of many individual results generated along the activity duration. These are briefly referred to and organized below while deeper explanations are presented in Section 3.1.

a) Protocols, tools and analysis methods for Wireless Sensor Networks

Engineering Wireless Sensor Networks – integrated toolset for semi-automatic deployment planning, worst-case analysis/dimensioning, simulation and nodes testing/programming using both the Open-ZB stack and the Z monitor; 300+ nodes demonstrator; beacons management and architecture for flexible deployment of beacon-enabled mode over cluster-tree topologies in industrial environments; use of opportunistic techniques to meet end-to-end delay and reliability requirements **(Porto, Catania, Pisa)**

Dependability, scalability and adaptability in WSNs – dependability analysis for WSNs using Bayesian Networks; definition of safety requirements conformance tests for online maintenance; instantiation of scalable sensing and data processing techniques in cyber-physical; multi-modal routing approach, exploiting the different strengths and weaknesses of individual protocols; adaptive dual-rate beacon approach for resource efficient target tracking with cluster-based WSNs **(York, Porto, UnivPorto,** Zhejiang University**)**

Protocols and analysis for specific applications of WSNs – architecture for large scale deployments, distributed resource constrained visual tracking, distributed localization, optimization of transmissions and real-time routing for intelligent transportation systems and ambient intelligence systems **(Pisa)**

b) Protocols and analysis for real-time wireless communication

Quality of service support in WLANs – improvements of 802.11e contention-based MAC protocol; bandwidth reclaiming mechanism that recovers unused transmission time; isochronous medium access control for industrial WLANs with bandwidth-efficient admission control based on EDF scheduling; survey of real-time WLANs for industrial automation **(Pisa, Catania,** Ostwestfalen-Lippe University of Applied Sciences, University of Idaho**)**

Mobility issues in real-time wireless networks –probabilistic schedulability analysis of an industrial WLAN consisting of multiple automation cells in the presence of mobile nodes; accurate end-to-end delay estimation for path tracking wireless control systems; synchronization in volatile ad-hoc networks of collaborating mobile robots **(Catania, Catalonia, UnivPorto)**

c) Analysis and tools for Controller Area Networks - CAN

New schedulability analysis for CAN considering practical constraints – response-time schedulability analysis that considers effects of FIFO queues and non-abortable transmission buffers in CAN device-drivers and controllers **(York,** University of Ulm and INRIA-Nancy**)**

Design and testing tools for CAN-based distributed systems – Genetic algorithm with a permutational solution encoding for solving the holistic assignment of fixed priorities in distributed real-time systems aided by the optimized segmentation of the network; sensitivity study of the reliability improvements of stars over buses in CAN; fault injectors for CAN-based systems; execution mechanisms for networked control loops that dynamically reduce the traffic while maintaining control performance **(UnivPorto, Cantabria, Mallorca, Catalonia,** University of the Basque Country-Bilbao**)**

d) New modeling, analysis and applications of real-time communications

Survey of real-time communication in industrial networks – **(Catania, Aveiro,** University of Klagenfurt**)**

Modeling switches and routers in MAST (Modeling and Analysis Suite for Real-Time Applications) – inclusion of schedulability analysis for applications using switched networks, particularly AFDX **(Cantabria)**

Schedulability analysis technique for AFDX networks – response-time analysis of the network including the scheduling of virtual links and contention in the end-systems and in the switches **(Cantabria)**

Dynamic hierarchical virtual channels over switched Ethernet – response time analysis for the hierarchical scheduling of virtual channels within the custom-designed HaRTES Ethernet switch **(Aveiro, UnivPorto, Malardalen)**

New tools for Flexible Time-Triggered Switched Ethernet – MTU optimization for improved schedulability; approaches to scale FTT-SE to large networks; timing analysis for FTT-SE in single master / multiple switches configuration; preliminary dependability analysis **(UnivPorto, Aveiro, Malardalen, Mallorca)**

Ethernet for automotive communications – study of Ethernet suitability for automotive embedded systems, with focus on Ethernet AVB and Time-Triggered Ethernet **(Catania)**

e) Real-time middleware and high-level modelling

Adaptation of a distribution middleware based on the end-to-end flow model to High-Integrity (HI) systems – API to develop HI distributed real-time systems in Ada integrating the real-time end-to-end flow model with the Ravenscar profile **(Cantabria)**

Integration of distribution middleware into an MDE development process for HI systems – MDE approach to ease the automatic generation of HI distributed real-time applications from high-level system models **(Cantabria, Madrid-UPM)**

Analysis of the real-time capabilities of DDS – study focusing on how DDS is able to guarantee real-time behaviour through the mechanisms included in the standard, and proposing some extensions to this standard **(Cantabria)**

Middleware for real-time reconfiguration – analysis of the difficulties and implications of real-time reconfiguration in distributed real-time systems; architecture for a reconfigurable real-time middleware and associated applications services component model; abstract model of the infrastructure including nodes and network; scheduling frameworks for real-time reconfiguration **(Madrid-UC3M, UnivPorto, Aveiro)**

Real-time service composition – hybrid approach for predictable service composition with video-surveillance demo for smart-phones **(Madrid-UC3M)**

Enhancements to distributed real-time Java – dual programming abstraction for distributed real-time Java, one based on remote invocations another on messages and queues; impact of non-functional transmission patterns on the end-to-end path of Java communications; enhanced communication protocol for RMI middleware **(Madrid-UC3M)**

-- The above is new material, not present in the Y3 deliverable --

3. Detailed view of the progress in Year 4 *(Jan-Dec 2011)*

3.1 Technical Achievements

a) Protocols, tools and analysis methods for Wireless Sensor Networks (Porto, Catania, York, UnivPorto, Pisa)

Engineering Wireless Sensor Networks (Porto, Catania, Pisa)

In this period substantial attention was devoted to the engineering of WSN, building on expertise on IEEE 802.15.4/ZigBee technologies and on previously developed tools such as the Open-ZB protocol stack (http://www.open-ZB.net). This work, coordinated by **Porto**, was essentially carried out within the EMMON ARTEMIS project (http://www.artemis-emmon.eu) and focused on designing, implementing and demonstrating a WSN system architecture for large-scale and dense real-time monitoring [ISEP+1][ISEP+3][ISEP+5]. Moreover, an integrated toolset was developed for “automatic” deployment planning, worst-case analysis/dimensioning, simulation and nodes testing/programming using both the Open-ZB stack and the Z monitor (http://www.z-monitor.org) [ISEP+2] [ISEP+4] [talk by Mário Alves]. A baseline version of the EMMON system architecture (encompassing communication network architecture, middleware architecture and command and control client/server applications) and integrated toolset have been experimentally validated through a 300+ nodes demonstrator in December 2010 in Porto, Portugal, which has been and still is the largest WSN test-bed in Europe to date. Currently, a final demonstrator with 400+ sensor nodes plus thousands of virtual nodes in a real-world scenario (monitoring of SANJOTEC building) is underway.

On a complementary direction, **Catania** researched the engineering of IEEE 802.15.4 industrial wireless sensor networks operating in beacon-enabled mode over cluster-tree topologies and focusing on two aspects, the beacons management [UniCT2] and the architecture for flexible deployment [UniCT4]. It is known that beacon collisions can undermine the reliability of cluster-tree networks, causing loss of synchronization between nodes and their coordinator. This research investigated a Multichannel Superframe Scheduling (MSS) algorithm that avoids beacon collisions by scheduling superframes over different radio channels, while maintaining the connectivity of all the clusters. The paper [UniCT2] describes the MSS algorithm and addresses the advantages it provides over the time-division superframe scheduling. Analytical results are shown which provide a quantitative estimation of how the schedulability space is improved, while simulation results show that the proposed technique increases the number of schedulable clusters and the maximum cluster density. The proposed approach was validated with an experimental implementation based on TinyOS. Concerning the architecture for flexible deployment, a two-tiered network architecture was proposed [UniCT4], in which the first tier is a field-level IEEE 802.15.4 network organized in Automation Cells, while the second tier is a real-time wired backbone, likely based on Real-Time Ethernet. The work focused on the wireless tier, in terms of industrial application requirements and possible solutions to meet them.

Finally, **Pisa** proposed a network design model [Pisa3] that combines opportunistic techniques aiming at meeting end-to-end delay and reliability requirements.

Dependability, scalability and adaptability in WSNs (York, Porto, UnivPorto, Zhejiang University**)**

As WSNs become a viable approach to practical large-scale monitoring, their dependability becomes more relevant. Therefore, **York** has been working on dependability analysis for

WSNs, using Bayesian Networks to provide detailed models of WSNs such that various analyses can be performed, providing a better understanding of the situations in which a WSN might be weak. This is complemented in two directions, on the one hand, a health monitoring infrastructure, which is based on a hazard analysis of the application from which key safety requirements are derived together with associated tests. The infrastructure supports such tests and orders maintenance when they fail. This has been presented in a paper submitted to the European conference on Wireless Sensor Networks (EWSN'12). On the other hand, it is important to understand the general and extremal behaviours of the protocols. The proposed approach is to check protocols across the expected operational profile and then stress test them to deduce the minimum failures that can induce a fault which is potentially hazardous. The work has already produced a search-based environment that allows stress testing the health-monitoring framework. A conventional failure analysis was functionally performed that allowed deducing the minimum failures, despite the complexity of the problem. A paper with these results is currently being produced.

Another property that is of major relevance in WSN is scalability. In this topic, **Porto** has extended previous work on scalable sensing and data processing and instantiated it in cyber-physical systems such as energy-efficiency in buildings and data centers as well as low carbon air travel using large-scale and dense sensor/actuator networks [ISEP+4] [talk by Nuno Pereira].

Finally, efficiency is another dimension in WSNs that requires special attention, given the strong resource constraints in the nodes. In this aspect, adaptive techniques become particularly interesting and provide a good compromise between resource efficiency and performance. Therefore, **York** proposed a multi-modal routing approach, exploiting the different strengths and weaknesses and individual protocols. The target is to detect which protocol would be most suitable in a particular situation and then switch to it. For instance AODV has variants with local repair, global (end-to-end) repair, etc. This is reported in [York1].

On the other hand, **UnivPorto** in collaboration with the Zhejiang University, China, proposed an adaptive beacon approach for target tracking cluster-based WSNs. In fact, the beacon rate has a direct impact on resource usage in the network but it also has an opposite impact in the quality of the tracking. Thus, a scalable inter-cluster synchronization mechanism was proposed that allows the coexistence of clusters operating with different beacon rates, a lower rate for low energy consumption and a higher rate for high tracking accuracy. The main idea is to have each cluster operating in the higher beacon rate mode when it is engaged in an active target tracking, only, and keeping it in the low beacon rate mode in all other circumstances. This work was experimentally assessed and reported in [UnivPorto-ZU+1].

Protocols and analysis for specific applications of WSNs (Pisa)

Some specific application domains present certain requirements that raise the demand for special protocols. That is the case of ambient intelligence, vision tracking, intelligent transportation and industrial systems.

In the scope of ambient intelligence, **Pisa** has been developing distributed protocols, validated either through simulation [Pisa5] or real hardware implementation [Pisa2]. In complementary lines, the same team has been addressing the intelligent transportation domain [Pisa9,12][Pisa+5], for which it proposed an innovative architecture [Pisa4] that allows large scale deployments, as well as distributed visual tracking with severly resource constrained nodes [Pisa6,11][Pisa+8], distributed localization [Pisa7], optimization of transmissions [Pisa10][Pisa+6] and real-time routing [Pisa8].

b) Protocols and analysis for real-time wireless networks (Pisa, Catania, Catalonia, UnivPorto, Ostwestfalen-Lippe University of Applied Sciences, University of Idaho**)**

Quality of service support in WLANs (Pisa, Catania, Ostwestfalen-Lippe University of Applied Sciences, University of Idaho**)**

Quality of Service and provisioning of real-time guarantees over wireless networks was addressed by **Pisa** concerning different IEEE 802.11e MAC scheduling policies [Pisa1]. Two different real-time scheduling algorithms were proposed that are suitable to improve the real-time and QoS support as required by multimedia applications with Variable Bit Rate (VBR) traffic. The first one [Pisa+7] is based on the coordinated use of resources assigned to the contention-based MAC protocol, whereas the second one [Pisa+2] integrates a bandwidth reclaiming mechanism that recovers unspent transmission time and assigns it to the next polled stations.

IEEE 802.11 Wireless Local Area Networks (WLANs) are not able to satisfy the requirements of industrial applications in terms of real-time communication because they have an unpredictable behaviour and introduce delays beyond acceptable bounds. In this context, **Catania** has researched ways to improve the support offered to real-time traffic. The paper [UniCT1] proposes a bandwidth-efficient admission control mechanism for EDF-scheduled factory communication cells which is able to encompass communication reliability and timeliness.

The paper [UniCT+2], developed within the flexWARE project (http://www.flexware.at), presents a new isochronous medium access control (IsoMAC) for WLANs along with a real-time scheduler and admission control mechanism specifically tailored for it. The paper [uniCT3] by **Catania** describes a middleware layer for soft real-time communication in wireless networks, devised and realized using standard WLAN hardware and software, that combines EDF scheduling with a dynamic adjustment of the maximum number of transmission attempts, so as to adapt the performance to fluctuations of the link quality, thus increasing the communication reliability, while taking deadlines into account.

Catania, in collaboration with the Ostwestfalen-Lippe University of Applied Sciences (Germany) and the University of Idaho (US), has also provided a comprehensive survey [UniCT+3] on research issues for Wireless LANs used for industrial communication, with a special focus on the IEEE 802.11 family.

Mobility issues in real-time wireless networks (Catania, Catalonia, UnivPorto)

Catania addressed the probabilistic schedulability of a real-time wireless factory automation network consisting of multiple automation cells in the presence of mobile nodes that roam from one cell to another one to accomplish application tasks along a set of predefined paths. The resulting paper [UniCT6] presents an offline analysis which, on the basis of information about the parameters of the real-time flows, the topology of the wireless network and the movement patterns of mobile nodes, allows the designer to obtain the probability that the network, at runtime, will be in a schedulable state. This probability has then to be evaluated by the designer against the application specifications to determine if the current network design is able to ensure the compliance with the application requirements or if some change in the design has to be made to meet such requirements. The analysis therefore provides a valuable support to the network designer in the offline dimensioning of the wireless network. The work [UniCT6] was partially developed within the flexWARE project. http://www.flexware.at/

On a complementary direction, **Catalonia** addressed the path tracking control of autonomous guided vehicles using wireless communication, mitigating the difficulty in achieving the timely and reliable transmission of messages over error-prone wireless channels. An autonomous guided vehicle (AGV) was built with a path tracking wireless control system where an accurate end-to-end delay estimation scheme is shown to be the key for successful operation. [UPC4].

A particular situation is that of relative localization of nodes in a team of collaborating autonomous robots. **UnivPorto** studied the potential of RF-ranging using the Chirp Spread Spectrum (CSS) modulation of 802.15.4. It was found that such technology presents a poor temporal behvior with unreliable/broken links, as those resulting from unsynchronized robots operation and frequent topology changes, imposing long latencies that are not adequate for a real-time localization system. Therefore, a synchronization mechanism that copes with volatile ad-hoc networks was developed and reported in [UnivPorto 2], which is based on maintaining information about the topology in a distributed manner so that RF-ranges in poor/broken links are avoided, improving the temporal predictability of the localization system.

c) **Analysis and tools for Controller Area Networks – CAN (York, UnivPorto, Cantabria, Mallorca, Catalonia,** University of Ulm, INRIA-Nancy, University of the Basque Country-Bilbao**)**

New schedulability analysis for CAN considering practical constraints (York, University of Ulm, INRIA-Nancy**)**

A collaboration between **York** and University of Ulm [York+1] investigated the case where CAN device drivers use FIFO rather than priority-based queues. This research provided response time analysis and optimal priority assignment policies for CAN messages in networks where some nodes use FIFO queues while other nodes use priority queues. It shows the detrimental impact that FIFO queues have on the real-time performance of CAN. The paper received the best paper award at ECRTS 2011. Subsequent work in this area, not yet published, investigates gateway applications; showing that if it is not possible to implement a priority queue, then it is preferable to use multiple FIFO queues each allocated a small number of messages with similar transmission deadlines.

A collaboration between **York** and INRIA-Nancy [York+2] investigated the case where it is not possible to abort a message once it has been placed in one of a CAN controller's transmission buffers. This behaviour breaks the classical model of purely priority-based queuing behaviour. Schedulability analysis was developed enabling accurate worst-case response times to be computed for messages sent on networks containing nodes with such non-abortable transmit buffers.

Design and testing tools for CAN-based distributed systems (UnivPorto, Cantabria, Mallorca, Catalonia, University of the Basque Country-Bilbao**)**

The segmentation of a network can contribute positively to the schedulability of distributed real-time systems. In this context, the University of the Basque Country (Bilbao) in collaboration with **UnivPorto** and **Cantabria** have developed a genetic algorithm with a permutational solution encoding that solves the holistic assignment of fixed priorities in distributed real-time systems aided by the optimized segmentation of the network. The experimental results show that the genetic algorithm can find good solutions for complex distributed real-time architectures in reasonable times. [UP-UC+1] [UP-UC+2]

On a different note, **Mallorca**, in collaboration with **UnivPorto**, has been studying the use of stars as design blocks to improve robustness in CAN systems, which led to the development of

(Re)CANcentrate, a (replicated) star topology for CAN (http://srv.uib.es/project/11). This work has been essentially carried out within the CANbids project (http://srv.uib.es/project/12). This year, the work completed the first known quantitative comparison between stars and buses concerning reliability [UIB-UP-1] and produced a full sensitivity study, which has been submitted to a journal, with a preliminary version reported in [UIB3]. A device driver for ReCANcentrate was also designed and the star replication scheme verified. Particular importance was given to the testing tools, particularly fault injectors [UIB2] [UIB4], which are lacking in the design tool chain of CAN-based systems. Finally, preliminary steps were taken to include semantic (temporal) information of the application in the star by using the Flexible Time-Triggered paradigm [UIB1]. A working demo of ReCANcentrate can be see at http://www.youtube.com/watch?v=dd6sCmLJkMc

Finally, **Catalonia** has researched Networked Control Systems (NCS) in ways to reduce the amount of control data exchanged between sensors, controllers and actuators nodes without sacrificing the control performance specifications given to each networked control loop. The typical periodic execution of each loop helps meeting the control specifications but imposes a static network traffic. To overcome this limitation, this year the work has focused on deriving novel execution mechanisms. First, an alternative execution mechanism for each networked control loop that can dynamically lower the traffic while ensuring the same or better control performance than the achieved by the periodic case has been developed. Second, application of event-driven self-triggered techniques to sliding mode control over networks as a means for reducing the bandwidth utilization has also been studied. [UPC1] [UPC2] [UPC3]

d) New analysis and applications of real-time communications (Catania, Aveiro, Cantabria, UnivPorto, Malardalen, Mallorca, University of Klagenfurt**)**

Survey of real-time communication in industrial networks (Catania, Aveiro, University of Klagenfurt**)**

Catania, in collaboration with **Aveiro** and the University of Klagenfurt**,** wrote a comprehensive survey [UniCT+1] on research about providing real-time support over networks used for industrial communication, with a special focus on design paradigms, performance metrics and design challenges.

Modeling switches and routers in MAST (Modeling and Analysis Suite for Real-Time Applications) (Cantabria)

Switched networks have an increasingly important role in real-time communications. The IEEE Ethernet standards have defined prioritized traffic (802.1p) and other QoS mechanisms (802.1q). The Avionics Full-Duplex Switched Ethernet (AFDX) standard defines a hard real-time network based on switched Ethernet. In the process of defining the new MAST 2 model for real-time systems, the network elements have been enhanced to include switches and routers. We have introduced the schedulability model that will enable an automatic schedulability analysis of an application using switched networks, in particular, AFDX networks are supported [UC-1]. MAST can be accessed at http://mast.unican.es/

Schedulability analysis technique for AFDX networks (Cantabria)

The ARINC-664, Part 7 (AFDX) standard defines a communications network based on Ethernet and the UDP/IP protocols. Its timing behavior is deterministic due to the use of special network switches and end-systems with static routing tables and traffic regulation at the sending end, through mechanisms called virtual links. We have developed a response-time analysis of the network including the scheduling of the virtual links and contention in the end-systems and in the switches. This response time allows us to obtain worst-case latencies and output jitter for the network messages. These results can be integrated with the response time analysis in other resources to obtain end-to-end response times in complex distributed systems [UC-2].

Dynamic hierarchical virtual channels over switched Ethernet (Aveiro, UnivPorto, Malardalen)

The provision of dynamic virtual channels with guaranteed bandwidth and latency in networks such as Ethernet is becoming more appealing to cater for distributed real-time applications and high integration levels with temporal isolation. This target was achieved with an enhanced Ethernet switch developed at **Aveiro** and **UnivPorto** with collaboration of **Malardalen** that follows the flexible time-triggered paradigm and within which a hierarchical scheduling framework was setup. This was generally reported in the resource management deliverable and is referred here as a networking component for the sake of completeness. The construction of the switch is thoroughly reported in a PhD thesis defended at **Aveiro** [UnivPorto+2] and involved collaboration between **Aveiro**, **UnivPorto** and **Malardalen**. An analysis of the hierarchical composition of virtual channels is reported in [UnivPorto+1]. The development of the switch was essentially carried out within the HaRTES project (http://www.ieeta.pt/lse/hartes).

New tools for Flexible Time-Triggered Switched Ethernet (UnivPorto, Aveiro, Malardalen, Mallorca)

The Flexible Time-Triggered Switched Ethernet (FTT-SE) protocol has been developed by **Aveiro** and **UnivPorto** for some time and was the subject of recent evolutions carried out essentially within the iLAND ARTEMIS project. This year, the following significant developments took place. Firstly, the impact of the choice of MTU was analysed and a method was proposed to obtain a near optimal value [UnivPorto+4]. Secondly, an analysis of the scalability of the protocol was carried out identifying and comparing three possible approaches [UnivPorto1]. One of these approaches enabled the use of a single master controlling a network of several cascaded switches. A preliminary analysis for this approach was carried out in collaboration with **Malardalen** and reported in [UnivPorto+3]. Finally, a preliminary dependability study was carried out in collaboration with **Mallorca** and reported within the iLAND project. More information on FTT-SE can be found at http://www.fe.up.pt/ftt

Ethernet for automotive communications (Catania)

Stimulated by the interest shown by industries and supported by ongoing projects such as the SEIS project, **Catania** has been investigating the suitability of Ethernet for automotive embedded systems, with a special focus on the Ethernet ABV and Time-Triggered Ethernet technologies as possible candidates for the automotive industry.The research, still in progess, has already resulted in a position paper which provides an overview on facts and trends towards the introduction of Ethernet in automotive communications and discusses how and to what extent Ethernet technology is likely to step in and provide benefits to the different automotive functional domains. This research was also the topic of Prof. Lo Bello's keynote speech at the Tenth International Workshop on Real-Time Networks RTN'11 on July 5, 2011, Porto, Portugal [UniCT5]. http://www.rtn2011.org/

e) Real-time middleware and modelling (Cantabria, Madrid-UPM, Madrid-UC3M, Pisa, UnivPorto, Aveiro)

Adaptation of a distribution middleware based on the end-to-end flow model to High-Integrity (HI) systems (Cantabria)

We have proposed an API to develop High-integrity Distributed Real-Time (HDRT) systems in Ada by integrating the real-time end-to-end flow model with the Ravenscar profile (widely used for single-processor systems but not for distributed ones). The work is built upon the endpoints pattern, a technique that we have used to integrate the end-to-end flow model into Ada's Distributed Systems Annex (DSA). We adapted our previous work to the requirements of the Ravenscar profile. We made a step forward and discuss the modifications needed to make a specific instance of the endpoints pattern compatible with the Ravenscar profile [UC-3].

Integration of distribution middleware into an MDE development process for HI systems (Cantabria, Madrid-UPM)

Building High-integrity Distributed Real-Time (HDRT) systems requires a rigorous methodology to assist in the design and development of verifiable software. We have dealt with an approach based on the Model-Driven Engineering (MDE) paradigm to ease the automatic generation of HDRT applications from high-level system models. We have explored the integration of the real-time end-to-end flow model with the automatic generation of Ravenscar-compliant source code in distribution middleware. Furthermore, 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 also been integrated with a toolset for MDE [UC-UPM-1].

Analysis of the real-time capabilities of DDS (Cantabria)

We have performed an analysis of the Data Distribution Service for Real-Time Systems (DDS), a data-centric distribution middleware, from the schedulability point of view, to support predictable applications. The study focuses on how DDS is able to guarantee the real-time behaviour through the mechanisms included in the standard, and proposes some extensions to this standard. Furthermore, we have compared DDS with other approaches to build distributed systems based on object distribution and remote procedures calls that can guarantee predictability, and we have showed how to use DDS to build real-time applications. A set of concepts defined in the Modelling and Analysis of Real-Time and Embedded systems (MARTE) standard has been integrated into DDS in order to allow Model-Driven Engineering (MDE) and schedulability analysis techniques to be used. Finally, to emphasize the results obtained from the analysis, we have also performed an evaluation to validate the predictability of a particular DDS implementation [UC-4].

Middleware for real-time reconfiguration (Madrid-UC3M, UnivPorto, Aveiro, University of the Basque Country-Bilbao**)**

UC3M has been primarily working on mechanisms, techniques, middleware architectures, and software frameworks for providing real-time reconfiguration in distributed real-time systems. An analysis of the difficulties and implications of real-time reconfiguration was made [UC3M+a]. UC3M has defined and implemented an architecture for a middleware that supports real-time reconfiguration carried out in the context of the iLAND project (ARTEMIS-Call1-100026 http://www.iland-artemis.org/). The architecture has been elaborated in different publications that are under review. A component model for the real-time application services managed by the middleware has also been further elaborated [UC3M-b]. Moreover, **UC3M** developed an architecture of a common bridge component to increase the portability of the iLAND middleware [UC3M-c]. Currently, the middleware implemented at **UC3M** is being ported to industrial demonstrators. A QoS registry for real-time SoAs was also developed by **Pisa** in collaboration with **UC3M** [Pisa4+].

Also within iLAND, the University of the Basque Country-Bilbao in collaboration with **UnivPorto** and **Aveiro** developed an abstract model of the system infrastructure including different types of devices and applications. The proposed approach allows modeling: (1) the devices that compose the distributed system with respect to four types of resources, namely CPU, memory, network interface and energy; (2) the properties of the communication infrastructure that connects the devices [Aveiro+1].

Finally, **UC3M** has also worked on the creation of scheduling frameworks for real-time reconfiguration using a contract-based paradigm refining the imprecise computation task model [UC3M-d] [UC3M-e].

Real-time service composition (Madrid-UC3M)

UC3M continued its effort in defining new algorithms for predictable service composition. As a result of this research, a novel hybrid approach for service composition was evaluated [UC3M-f] and compared against other available techniques.

UC3M developed a service-oriented video surveillance system for Android. In this system smart-phones participate in the video surveillance process [UC3M-g].

Enhancements to distributed real-time Java (Madrid-UC3M)

UC3M revised the programming abstraction of distributed real-time Java, which now considers a dual programming abstraction: one based on remote invocations and another on messages and queues. All the development was done on DREQUIEMI, its conceptual framework for distributed real-time Java [UC3M-h]. UC3M also worked on improved the programming model of real-time Java, avoiding priority inversion introduced by the garbage collector [UC3M-i]. Moreover, UC3M revised the non-functional transmission patterns for distributed real-time Java, evaluating the impact of different approaches on the end-to-end path of Java communications [UC3M-j]. Moreover, the team worked on enhancing the communication protocol used by the RMI middleware, which was extended with special tags for multiplexing and de-multiplexing [UC3M-k], and improving the end-to-end predictability of OSGi [UC3M-l].

-- The above is new material, not present in the Y3 deliverable --

3.2 Individual Publications Resulting from these Achievements

Cantabria

[UC-1] Michael González Harbour, J. Javier Gutiérrez, J. María Drake, Patricia López, y J. Carlos Palencia. "Modeling Real-Time Networks with MAST2". 2nd International Workshop on Analysis Tools and Methodologies for Embedded and Real-time Systems, WATERS 2011, Porto (Portugal), July, 2011, pp. 51,56.

[UC-2]J. Javier Gutiérrez, J. Carlos Palencia, y Michael González Harbour. "Response time analysis in AFDX networks". XIV Jornadas de Tiempo Real, JTR 2011, Madrid (Spain), February, 2011. Available at http://polaris.dit.upm.es/~str/jtr11/papers/011.pdf

[UC-3] Héctor Pérez Tijero, J. Javier Gutiérrez y Michael González Harbour. "Adapting the end-to-end flow model for distributed Ada to the Ravenscar profile". 15th International Real-Time Ada Workshop (IRTAW), Liébana (Spain), September, 2011

[UC-4] Héctor Pérez Tijero, y J. Javier Gutiérrez. "On the schedulability of a data-centric real-time distribution middleware". In press, Computer Standards and Interfaces Journal, Elsevier, August, 2011, ISSN 0920-5489.

Catalonia

[UPC1] J. Yépez, M. Velasco, P. Martí, E.X. Martín. One-Step Finite Horizon Boundary with Varying Control Gain for Event-Driven Networked Control Systems. In 37th Annual Conference of the IEEE Industrial Electronics Society (IECON11), Melbourne, Australia, November, 2011.

[UPC2] P. Martí, M. Velasco, J. Yépez, E.X. Martín. Lowering Traffic without Sacrificing Performance in Networked Control Systems. In 16th IEEE International Conference on Emerging Techonologies and Factory Automation (ETFA11), Toulouse, France, September, 2011

[UPC3] P. Martí, M. Velasco, A. Camacho, E. X. Martín, J.M. Fuertes. Networked Sliding Mode Control of the Double Integrator System Using the Event-driven Self-triggered Approach. In 20th IEEE International Symposium on Industrial Electronics (ISIE10), Gdansk, Poland, June, 2011.

[UPC4] C. Lozoya, P. Martí, M. Velasco, J. M. Fuertes, E. X. Martín, Simulation Study of a Remote Wireless Path Tracking Control with Delay Estimation for an Autonomous Guided Vehicle. International Journal of Advanced Manufacturing Technology, Vol. 52, Numbers 5-8, pp. 751-761, February, 2011.

Catania

[UniCT1]E. Toscano, L. Lo Bello, “Bandwidth-Efficient Admission Control for EDF-Based Wireless Industrial Communication”, 20th IEEE International Symposium on Industrial Electronics, ISIE 2011, 27-30 June 2011, Gdansk, Poland.

[UniCT2] Toscano E, Lo Bello L., “Multichannel Superframe Scheduling for IEEE 802.15.4 Industrial Wireless Sensor Networks”, IEEE Transactions on Industrial Informatics, vol. 58, ISSN: 1551-3203, doi: 10.1109/TII.2011.2166773 (published online Aug. 2011).

[UniCT3] E. Toscano, L. Lo Bello, “A Middleware for Reliable Soft Real-Time Communication over IEEE 802.11 WLANs”, in Proc. of the IEEE 2011 IEEE International Symposium on Industrial Embedded Systems (SIES’11), 15-17 June 2011, Vasteras, Sweden.

[UniCT4] M. Collotta, L. Lo Bello, E. Toscano, “A Flexible architecture for Wireless industrial Communications based on the IEEE 802.15.4 Protocol” (“Uma arquitetura flexivel para redes sem fio IEEE 802.15.4”), RTI – Redes, Telecomm e Installacoes, pages: 38-49, Aranda Editora, Sao Paulo, Brasil, ISSN:1808-3544, Feb 2011.

[UniCt5] L. Lo Bello, “The case for Ethernet in Automotive Communications”, ACMSIGBED Review, 27th Issue, Special Issue on the Tenth International Workshop on Real-Time Networks, Vol. 8, n.4, ISSN: 1551-3688, Dec.2011.

[UniCT6] E. Toscano, L. Lo Bello, “Probabilistic feasibility assessment of real-time wireless networks for factory automation with mobile nodes”, In Proceedings of the 16th IEEE

International Conference on Emerging Technologies and Factory Automation, IEEE ETFA'11, Sept.5-9 2011, Toulouse, France.

Madrid-UC3M

[UC3M-b] M. García-Valls, P. Basanta-Val , I. Estevez-Ayres. Supporting service composition and real-time execution through characterization of QoS properties. In 6th International Symposium on Software Engineering for Adaptive and Self-Managing Systems Sponsored by ACM SIGSOFT, IEEE TCSE May 2011.

[UC3M-c] I. Rodríguez-López, M. García-Valls, Marisol. Architecting a Common Bridge Abstraction over Different Middleware Paradigms. 6th International Conference on Reliable Software Technologies. Edinburgh, UK. June, 2011.

[UC3M-d] M. García-Valls, P. Basanta-Val, I. Estévez-Ayres. Real-time reconfiguration in multimedia embedded systems. IEEE Transactions on Consumer Electronics, 57(3):1280-1287, August 2011

[UC3M-e] Marisol García-Valls, Pablo Basanta-Val, and Iria Estévez-Ayres. Real-Time Software Framework for Supporting Reconfiguration in Consumer Electronics. 11th IEEE Conference on Consumer Electronics, pp.865-866, 9-12 Jan. 2011

[UC3M-f] Iria Estévez-Ayres, Marisol García-Valls, Pablo Basanta-Val, Jorge Díez-Sánchez: A hybrid approach for selecting service-based real-time composition algorithms in heterogeneous environments. Concurrency and Computation: Practice and Experience 23(15): 1816-1851 (2011)

[UC3M-g] Iria Estévez-Ayres, Marisol García-Valls, Pablo Basanta-Val and Iván Fernández-Pacheco. Using Android Smartphones in a Service-Oriented Video Surveillance System. 11th IEEE Conference on Consumer Electronics , pp.887-888, 9-12 Jan. 2011

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[UC3M-j] Pablo Basanta-Val, Marisol García-Valls and Iria Estévez-Ayres. Fine tuning of the multiplexing facilities of Java's Remote Method Invocation. Concurrency and Computation Practice and Experience. 23(11): 236-1260, August 2011.

[UC3M-k] Pablo Basanta-Val, Marisol García-Valls and Iria Estévez-Ayres. Extending the Concurrency Model of the Real-Time Specification for Java. Concurrency and Computation: Practice and Experience, 23(14): 1623-1645 (2011)

[UC3M-l] P. Basanta-Val, M. García-Valls and I. Estévez-Ayres. Real-Time Distribution Support For Residential Gateways Based on OSGi. 11th IEEE Conference on Consumer Electronics, 747-748, 9-12 Jan. 2011

Mallorca

[UIB1] Barranco, Manuel; Rodriguez-Navas, Guillermo; Gessner, David; Proenza, Julian; , "Towards the integration of flexible-time-triggered communication and replicated star topologies in CAN," Emerging Technologies & Factory Automation (ETFA), 2011 IEEE 16th Conference on, 5-9 Sept.2011 doi: 10.1109/ETFA.2011.6059170

[UIB2] Gessner, David; Barranco, Manuel; Ballesteros, Alberto; Proenza, Julian; , "Designing sfiCAN: A star-based physical fault injector for CAN," Emerging Technologies & Factory

Automation (ETFA), 2011 IEEE 16th Conference on, 5-9 Sept. 2011 doi: 10.1109/ETFA.2011.6059163

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[UIB4] Rodriguez-Navas, Guillermo; Winter, Christian; Proenza, Julian; , "Injection of aggregated error flags as a means to guarantee consistent error detection in CAN," Emerging Technologies & Factory Automation (ETFA), 2011 IEEE 16th Conference on, 5-9 Sept. 2011 doi: 10.1109/ETFA.2011.6059172

Pisa

[Pisa1] Gabriele Cecchetti and Anna Lina Ruscelli, “Real-Time Support for HCCA Function in IEEE 802.11e Networks: a Performance Evaluation”, Security and Communication Networks, Vol. 4, No. 3, pp. 299-315, 2011.

[Pisa2] M. Chitnis, C. Salvadori, M. Petracca, P. Pagano, G. Lipari and L. Santinelli. “Distributed Visual Surveillance with Resource Constrained Embedded Systems.” Visual Information Processing in Wireless Sensor Networks: Technology, Trends and Applications. IGI Global, 2012. 272-292. Web. 9 Nov. 2011.

[Pisa3] Gabriele Cecchetti and Anna Lina Ruscelli, “Improving the Design of Wireless Sensor Networks using QoS-Aware Opportunistic Techniques”, Proceedings of the IADIS Applied Computing 2011 (AP 2011), Rio de Janeiro, Brazil, November 6th - 8th, 2011.

[Pisa4] P. Pagano, M. Petracca, D. Alessandrelli, C. Nastasi, “Enabling Technologies and Reference Architecture for a EU-Wide Distributed Intelligent Transport System”, Proceedings of the 8th European ITS Congress, Lyon, France, June 6 - 9, 2011.

[Pisa5] C. Nastasi, A. Cavallaro, "Distributed target tracking under realistic network conditions" In Proc. of Sensor Signal Processing for Defence (SSPD), London, UK, 28-29 Sept., 2011.

[Pisa6] C. Nastasi, A. Cavallaro, "WiSE-MNet: an experimental environment for Wireless Multimedia Sensor Networks" Proc. of Sensor Signal Processing for Defence (SSPD), London, UK, 28-29 September, 2011.

[Pisa7] B. Abid, M. Petracca, P. Pagano, S. Bocchino and D. Alessandrelli, "Experimental validation of wireless localization techniques in IEEE802.15.4 networks", in Proceedings of 19th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split, Croatia, September 2011.

[Pisa8] S. Bocchino, M. Petracca, P. Pagano, M. Ghibaudi and F. Lertora, "SPEED routing protocol in 6LoWPAN networks", in Proceedings of IEEE 16th Conference on Emerging Technologies & Factory Automation (ETFA), Toulouse, France, September 2011.

[Pisa9] Paolo Pagano, Riccardo Pelliccia, Matteo Petracca, Marco Ghibaudi, “On Board Unit hardware and software design for Vehicular Ad-hoc NETworks” ITU-T, The Fully Networked Car @ Geneva International Motor Show (FNC 2011), Geneva, (CH), March 2011.

[Pisa10] M. Petracca, M. Ghibaudi, C. Salvadori, P. Pagano, D. Munaretto, “Performance Evaluation of FEC techniques based on BCH codes in Video Streaming over Wireless Sensor Networks”, IEEE Workshop on multiMedia Applications over Wireless Networks, July 2011

[Pisa11] C. Salvadori, M. Petracca, M. Ghibaudi, “On-board image processing in Wireless Multimedia Sensor Networks: a parking lot monitoring solution for Intelligent Transportation

Systems", Intelligent Sensor Networks: Across Sensing, Signal Processing, and Machine Learning (Eds.F. Hu), CRC Press, in press.

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[Pisa13] Mauro Marinoni, Mario Bambagini, Francesco Prosperi, Francesco Esposito, Gianluca Franchino, Luca Santinelli and Giorgio Buttazzo, "Platform-aware Bandwidth-oriented Energy Management Algorithm for Real-Time Embedded Systems", Proceedings of the 16th IEEE on Emerging Technologies and Factory Automation (ETFA 2011), Toulouse, France, September 5-9, 2011.

Porto

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UnivPorto

[UnivPorto1] Farahnaz Yekeh, Mostafa Pordel, Luis Almeida, Moris Behnam, Paulo Portugal. Exploring Alternatives to Scale FTT-SE to Large Networks, (Work-in-Progress) SIES 2011, 6th IEEE Symposium on Industrial Embedded Systems. Vasteras, Sweden, 15-17 June, 2011.

[UnivPorto2] Luis Oliveira, Luis Almeida, and Frederico Santos. A Loose Synchronisation Protocol for Managing RF Ranging in Mobile Ad-Hoc Networks. RoboCup Symposium 2011, Istanbul, Turkey. July 11, 2011.

York

[York1] T. H. Lim, I. Bate, J. Timmis "Multi-modal routing to tolerate failures", Proceedings of The International Conference on Intelligent Sensors, Sensor Networks and Information Processing 2011 (*ISSNIP 2011*), 2011.

-- The above are new references, not present in the Y3 deliverable --

3.3 Interaction and Building Excellence between Partners

The technical achievements reported in Section 2.5 and in more detail in Section 3.1 implicitly expose a relatively large set of collaborative work among the project partners and others, which could hardly be done in isolation. Similarly to the previous years, the partners involved in this activity were also involved in several R&D project proposals, involving other academic and industrial partners, which were submitted either within the FP7 ICT, ARTEMIS or ITEA2 calls. Moreover, it is noteworthy that a part of the collaborative work reported here resulted from participation in joint projects that were generated in the scope of this activity. The following are the collaborations developed in the reporting period.

Aveiro, Malardalen, Mallorca and **UnivPorto** continued their collaboration towards the definition of flexible yet dependable mechanisms for distributed real-time systems, namely using enhanced star topologies both in CAN and Ethernet. The teams were engaged in the national projects CANbids (Spain) and HaRTES (Portugal) and collaborated in the integration of the (Re)CANcentrate and FTT-CAN frameworks in the former case and in the FTT-enabled Ethernet switch in the latter. In this scope, Manuel Barranco from **Mallorca** visited **UnivPorto** as pos-doc for 5 months (2 months in this reporting period) to carry out dependability analysis of the FTT-enabled Ethernet switch. Moris Behnam from **Malardalen** also visited **UnivPorto** as post-doc, in the scope of the iLAND project, to work on the response-time analysis for the hierarchical server composition in that switch and further enhancements the the FTT-SE protocol.

UnivPorto, Cantabria and the University of the Basque Country-Bilbao initiated collaboration on optimized design automation of distributed real-time systems based on CAN using genetic algorithms. In this scope, Ekain Azketa, a PhD student from Bilbao, visited **Cantabria** to integrate the use of the MAST analysis suite in the optimization process.

Cantabria and **Madrid-UPM** collaborated in the integration of distribution middleware into an MDE development process for high integrity systems.

York collaborated with University of Ulm and INRIA-Nancy in the development of new schedulability analysis for CAN considering practical constraints.

Catania, **Aveiro** and the University of Klagenfurt collaborated in a comprehensive survey on industrial real-time networks

Madrid-UC3M collaborated with both **Pisa and Madrid-UPM** in the scope of Quality of Service (QoS)-based resource management. In this scope, Gaetano Anastasi, a PhD student from **Pisa** visited **UC3M**. **UC3M** also collaborated with the University of Twente, in particular with the Pervasive Computing Lab, both within the iLAND project and on how to integrate real-time in ubiquitous computation environments through specialized middleware. Finally, **UC3M** also collaborated with the Factory Automation Group at the Technical University of Tampere in the scope of manufacturing and scheduling activities in enterprise resource management environments.

-- Changes wrt Y3 deliverable --

Collaborations updated

3.4 Joint Publications Resulting from these Achievements

Mallorca and UnivPorto

[UIB-UP-1] Barranco, M.; Proenza, J.; Almeida, L.; , "Quantitative Comparison of the Error-Containment Capabilities of a Bus and a Star Topology in CAN Networks," Industrial Electronics, IEEE Transactions on , vol.58, no.3, pp.802-813, March 2011.

Cantabria and Madrid-UPM

[UC-UPM-1] Héctor Pérez, J. Javier Gutiérrez, Esteban Asensio, Juan Zamorano, y Juan A. de la Puente. "Model-Driven Development of High-Integrity Distributed Real-Time Systems Using the End-to-End Flow Model". 37th Euromicro Conference on Software Engineering and Advanced Applications (SEAA), Oulu (Finland), Agosto, 2011, ISBN:978-0-7695-4488-5, pp. 209-216.

UnivPorto, Cantabria and University of the Basque Country-Bilbao

[UP-UC+1] Ekain Azketa, Juan Pedro Uribe, Marga Marcos, Luis Almeida, Jose Javier Gutierrez. Permutational genetic algorithm for fixed priority scheduling of distributed real-time systems aided by network segmentation. SOMRES 2011 – International Workshop on Synthesis and Optimization Methods for Real-Time Embedded Systems, a satellite event of RTSS 2011, Vienna, Austria, November 29, 2011.

[UP-UC+2] Ekain Azketa, Juan Pedro Uribe, Marga Marcos, Luis Almeida, Jose Javier Gutierrez. Genetic Algorithm for the Optimized Assignment of Priorities to Tasks and Messages in Distributed Real-Time Systems. ICESS 2011, The 8th IEEE International Conference on Embedded Software and Systems, Changsha, China, November 16-18, 2011.

Aveiro, UnivPorto and University of the Basque Country-Bilbao

[Aveiro+1] I. Calvo, E. Portillo, O. García, A. Armentia, M. Marcos, E. Estévez, R. Marau, L. Almeida, P. Pedreiras. Modelado de Infraestructura para la Composición y Reconfiguración de Sistemas Distribuidos. 32ª Jornadas de Automatica. Sevilla, Spain, 7-9 September 2011.

UnivPorto, Aveiro, Malardalen

[UnivPorto+1] Rui Santos, Paulo Pedreiras, Moris Behnam, Thomas Nolte, Luis Almeida. A Demonstration of Hierarchical Scheduling over Ethernet. RTSS@Work session of RTSS 2011, Vienna, Austria, November 29, 2011.

[UnivPorto+2] Rui Santos. *Enhanced Ethernet Switching Tecnology for Adaptive Hard Real-Time Applications*. PhD Thesis, University of Aveiro (Portugal), co-supervised with UnivPorto, July 2011.

[UnivPorto+3] Moris Behnam, Zahid Iqbal, Pedro Silva, Ricardo Marau, Luís Almeida, Paulo Portugal. Engineering and Analyzing Multi-Switch Networks with Single Point of Control. WCTT 2011 - Int. Workshop on Worst-Case Traversal-Time, a satellite event of RTSS 2011, Vienna, Austria, November 29, 2011.

[UnivPorto+4] Moris Behnam, Ricardo Marau, Paulo Pedreiras. Analysis and Optimization of the MTU in Real-Time Communications over Switched Ethernet. ETFA 2011, The 16th IEEE Conference on Emerging Technologies for Factory Automation, Toulouse, France, 5-9 Sep 2011.

UnivPorto, Zhejiang University

[UnivPorto-ZU+1] Shantao Chen, Luís Almeida, Zhi Wang. Analysis and Experiments for Dual-Rate Beacon Scheduling in ZigBee/IEEE 802.15.4. CPNS 2011 - 1st Int. Workshop on Cyber-Physical Networking Systems (satellite of INFOCOM 2011). Shanghai, China. 15 April, 2011.

Catania, Aveiro, University of Klagenfurt, Ostwestfalen-Lippe University of Applied Sciences (Germany), University of Idaho (US)

[UniCT+1] L. Lo Bello, J. A. Fonseca, W. Elmenreich," Real-Time Systems", in Prof. B. Wilamowski, J. D. Irvin – Industrial Electronics Handbook 2nd Edition, Vol2: Industrial Communication Systems, Ch.41, Taylor & Francis Group, LLC, ISBN: 978-1-4398028-9-2,Feb.2011.

[UniCT+2] H. Trsek, L.Wisniewski, E. Toscano, L. Lo Bello, "A flexible approach for real-time wireless communications in adaptable industrial automation systems", In Proceedings of the

16th IEEE International Conference on Emerging Technologies and Factory Automation, IEEE ETFA'11, Sept.5-9 2011, Toulouse, France.

[UniCT+3] H. Trsek, J. Jasperneite, L. Lo Bello, M. Manic,"Wireless Local Area Networks", in Prof. B. Wilamowski, J. D. Irvin, – Industrial Electronics Handbook 2nd Edition, Volume 2: Industrial Communication Systems, Chapter 43, Taylor & Francis Group, LLC, ISBN: 978-1-4398028-9-2, Feb.2011.

Madrid-UC3M and Visual Tools-Madrid

[UC3M+a] Marisol García-Valls, F. Gómez Molinero. Real-Time Reconfiguration: A Vision and its Reality . IEEE International Conference on Industrial Informatics (IEEE INDIN 2011). IEEE Computer Society Press. Caparica, Portugal. July 26 - 29, 2011.

Pisa and Madrid-UC3M

[Pisa+4] G. F. Anastasi, T. Cucinotta, G. Lipari, M. Garcia-Valls, "A QoS Registry for Adaptive Real-Time Service-Oriented Applications," in Proceedings of the IEEE International Workshop on Real-Time Service-Oriented Architecture and Applications (RTSOAA 2011), December 12-14 2011, Irvine, CA.

Pisa, Technical University of Munich, University of Ulm

[Pisa+1] Samarjit Chakraborty, Marco Di Natale, Heiko Falk, Martin Lukasiewycz, Frank Slomka: Timing and schedulability analysis for distributed automotive control applications. EMSOFT 2011: 349-350

Pisa, Evidence, University of Pisa, Politechnic of Torino

[Pisa+2] Anna Lina Ruscelli, Gabriele Cecchetti, Antonia Mastropaolo, and Giuseppe Lipari, "A Greedy Reclaiming Scheduler for IEEE 802.11e HCCA Real-Time Networks", Proc. of the 14th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWIM 2011), Miami, Florida, October 30th - November 4th, 2011.

[Pisa+3] E. D. Gutierrez Mlot, S. Bocchino, A. Azzarà , M. Petracca, and P. Pagano, "Web services transactions in 6LoWPAN networks," IEEE International Symposium on World of Wireless Mobile and Multimedia Networks (WoWMoM 2011), June 2011.

[Pisa+5] R. Mambrini, A. Rossi, P. Pagano, P. Ancilotti, O. Salvetti, A. Bertolino, P. Gai, L. Costalli, "IPERMOB: Towards an Information System to Handle Urban Mobility Data," Models and Technologies for ITS, Leuven, Belgium, Jun 22-24, 2011.

[Pisa+6] M. Petracca, P. Bucciol, A. Servetti and J.C. De Martin, "Adaptive Error Resilient Mechanisms for Real-Time Multimedia Streaming over Inter-Vehicle Communication Networks" DSP for In-Vehicle Systems & Safety, Springer-Verlag, in press.

[Pisa+7] Anna Lina Ruscelli, Gabriele Cecchetti, Angelo Alifano, and Giuseppe Lipari, "Enhancement of QoS Support of HCCA Schedulers Using EDCA Function", in IEEE 802.11e Networks. Ad Hoc Networks, Vol. 10, No. 2, pp. 147-161, 2012.

[Pisa+8] M. Magrini, D. Moroni, C. Nastasi, P. Pagano, M. Petracca, G. Pieri, C. Salvadori and O. Salvetti, "Visual Sensor Networks for Infomobility", Pattern Recognition and Image Analysis, Vol. 21, No, 1, pp. 20-29, 2011.

Pisa, McGill University, University of California (Berkeley)

[Pisa+9] Haibo Zeng, Marco Di Natale, Arkadeb Ghosal, Alberto L. Sangiovanni-Vincentelli: “Schedule Optimization of Time-Triggered Systems Communicating Over the FlexRay Static Segment”, IEEE Transactions on Industrial Informatics 7(1): 1-17, February 2011.

Porto, Technical University of Berlin, University of Pisa, Trinity College, SESM-Naples

[ISEP+1] S. Tennina, R. Gomes, M. Alves, M. Bouroche, F. Mirza, G. Carrozza, M. Santos, V. Ciriello, P. Braga, P. Oliveira, V. Cahill, “EMMON - A WSN System Architecture and Toolset for Large-Scale and Dense Real-Time Embedded Monitoring”, Poster Session of the 9th ACM Conference on Embedded Networked Sensor Systems (SenSys 2011), 1-4 November, 2011, Seattle, WA, USA.

[ISEP+2] Stefano Tennina, Ricardo Gomes, Mario Alves, Vincenzo Ciriello and Gabriella Carrozza, “The dark side of DEMMON: what is behind the scene in engineering large-scale wireless sensor networks”, 14th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2011), October 31- November 4, 2011, Miami Beach, FL, USA, pp. 41-50.

[ISEP+3] S. Tennina, M. Bouroche, P. Braga, R. Gomes, M. Alves, F. Mirza, V. Ciriello, G. Carrozza, P. Oliveira, V. Cahill, “EMMON: A WSN System Architecture for Large Scale and Dense Real-Time Embedded Monitoring”, 9th IEEE/IFIP International Conference on Embedded and Ubiquitous Computing (EUC), October 24-26, 2011, Melbourne, Australia.

[ISEP+4] J. Hauer, R. Daidone, R. Severino, J. Büsch, M. Tiloca, S. Tennina, “An Open-Source IEEE 802.15.4 MAC Implementation for TinyOS 2.1”, Poster Session of the 8th European Conference on Wireless Sensor Networks (EWSN 2011), February 23-25, 2011, Bonn, Germany.

[ISEP+5] S. Tennina, M. Bouroche, P. Braga, M. Alves, R. Gomes, M. Santos, F. Mirza, A. Garg, V. Cahill, G. Carrozza, V. Ciriello, “EMMON: A System Architecture for Large-Scale, Dense and Real-Time WSNs”, invited poster at the 8th European Conference on Wireless Sensor Networks (EWSN 2011), February 23-25, 2011, Bonn, Germany.

York, University of Ulm and INRIA-Nancy

[York+1] R.I. Davis, S. Kollmann, V. Pollex, F. Slomka “Controller Area Network (CAN) Schedulability Analysis with FIFO queues”. In proceedings 23rd Euromicro Conference on Real-Time Systems (ECRTS 2011), pages 45-56, July 5-8th, 2011.

[York+2] D.A. Khan, R.I. Davis, N. Navet “Schedulability Analysis of CAN with Non-abortable Transmission Requests”. In proceedings 16th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA'11), Sept 5-9th, 2011.

-- The above are new references, not present in the Y3 deliverable --

3.5 Keynotes, Workshops, Tutorials

Keynote talk: Lucia Lo Bello, The case for Ethernet in Automotive Communications
Event: RTN 2011 – 10th Workshop on Real-Time Networks
Porto, Portugal – 5 September 2011
Addressed challenges faced when trying to build an assurance in the autonomic computing

domain (including sensor networks, swarm robotics, systems of systems, cooperating objects etc.).

Invited talk: Luis Almeida, *A Network-centric Perspective on Cyber-Physical Systems*
Event: Dagstuhl Seminar on Cyber-Physical Systems
Dagstuhl, Germany – 2-4 November 2011
Addressed challenges posed on networks to efficiently support CPS.

Invited talk: Luis Almeida, *On Cyber-Physical Systems*
Event: EU-US Workshop on Networked Monitoring and Control
Brussels, Belgium – 28 June 2011
Addressed the definition of CPS and the group contributions to that field in terms of networking infrastructure.

Invited talk: Iain Bate, *Designing and Demonstrating Dependability in Autonomic Computing*
Institution: ISEP – Polytechnic Institute of Porto
Porto, Portugal – 20 September 2011

Addressed challenges faced when trying to build an assurance in the autonomic computing domain (including sensor networks, swarm robotics, systems of systems, cooperating objects etc.).

Special Section: Information technology in automation
Journal: IEEE Transactions on Industrial Informatics
Vol.7, n.4, – *November, 2011*

This Special Section was co-edited by Lucia Lo Bello from **Catania** and Georg Frey from Saarland University and contains nine papers focusing on the development, adoption and application of information technology in automation systems and presenting significant research works and new developments in several application domains including communication and middleware technologies.
http://tii.ieee-ies.org/ss/EditPast/1109_Editorial.pdf

Track: Industrial Communication Systems
Conference name: ETFA 2011 – 16th IEEE Conference on Emerging Technologies in Factory Automation
Toulouse, France – September 5-9, 2011

This track was co-chaired by Lucia Lo Bello from **Catania**.
http://www.etfa-2011.org/

Workshop : RTN 2011 – 10th Workshop on Real-Time Networks
Conference name : ECRTS 2011 – 23rd EUROMICRO Conference on Real-Time Systems
Porto, Portugal – July 5, 2011

This workshop was the 10th 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.rtn2011.org/

Workshop : NeRES 2011 –Workshop on Networks for Real-Time Embedded Systems
Porto, Portugal – November 10-11, 2011

This workshop was organized by Luis Almeida from **UnivPorto** within the scope of this activity and included talks of several other partners, namely **Porto** (Mário Alves), **Pisa** (Gianluca Franchino), **Catalonia** (Pau Marti), **Mallorca** (Julian Proenza), **Aveiro** (Paulo Pedreiras), **Cantabria** (Javier Gutierrez), Univ. Basque Country-Bilbao (Isidro Calvo).
http://www.artist-embedded.org/artist/Overview,2385.html

Workshop : SOCNE 2011 – 6th IEEE Workshop on Service Oriented Architectures in Converging Networked Environments
Toulouse, France – September 5, 2011

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

Special Session: Self recovery and real-time reconfiguration
Conference name : INDIN 2011 – 9th IEEE Conference on Industrial Informatics
Lisboa, Portugal –*26-29 July, 2011*

This Special Session was chaired by Marisol Garcia-Vals from **Madrid-UC3M** to define future trends in asset awareness, self recovery, and real-time execution and reconfiguration support in the context of industry
www.uninova.pt/indin2011/

Special Session: Networked-based Control Systems
Conference name : IECON 2011 – 37th IEEE Conference on Industrial Electronics
Melbourne, Australia – 7-10 November, 2011

This Special Session was co-chaired by Josep Fuertes from **Catalonia** in collaboration with Mo-Yuen Chow (North Carolina State University)
http://www.iecon2011.org/

Special Session: Networked-based Control Systems and Applications
Conference name : ISIE 2011 – 20th IEEE International Symposium on Industrial Electronics
Gdansk, Poland – 27-30 June, 2011

This Special Session was co-chaired by Josep Fuertes from **Catalonia** in collaboration with Mo-Yuen Chow (North Carolina State University)
http://www.isie2011.pl/

Tutorial : Luis Almeida, *Real-Time Communication for Embedded Systems*
Institution: Course at ENSIAS, Ùniversity Mohammed V
Rabat, Morrocco – 19-21 December, 2011

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

Tutorial: Luis Almeida, *Real-Time Communication for Embedded Systems*
Institution: Institute of Software – Chinese Academy of Sciences
Event: ArtistDesign Summer School in China 2011
Beijing, China – 11-12 August 2011

6 hour course covering the concepts, techniques, technologies and applications of real-time networks.

http://www.artist-embedded.org/artist/Overview,2239.html

Tutorial : Luis Almeida, *Real-Time Traffic Scheduling*,
Event: Course within the Master on Control Engineering, Automation and Robotics
Universidad del Pays Vasco, Bilbao, Spain – 3-4 May, 2011

6 hours of lectures covering techniques for message scheduling on networks and on the challenges of flexible communication.

Tutorial : Luis Almeida, *When Time becomes real*,
Event: Seminar within the MAP-Tele PhD program
Universidade de Aveiro, Portugal – 18 Feb, 2011

2 hour lecture introducing Distributed Real-Time Embedded Systems.
www.map.edu.pt/tele/

Tutorial : Nuno Pereira, *Densely Instrumented Energy-Efficient Physical Infrastructures*
Event: Advanced School on ICT for future energy systems
Trento, Italy – 25-29 July, 2011
Dedicated to applications of pervasive sensing technologies for densely instrumented energy-efficient physical infrastructures.
http://events.unitn.it/en/futureenergy2011

-- The above is new material, not present in the Y3 deliverable --

4. Internal Reviewers for this Deliverable

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