ARTIST 2

Network of Excellence

IST-004527 ARTIST2:
Embedded Systems Design

Cluster Progress Report for Year 2

Cluster:

Adaptive Real Time

Cluster Leader:

Prof. Giorgio Buttazzo (Scuola Superiore S. Anna)
http://feanor.sssup.it/~giorgio/

Policy Objective (abstract)

Adaptive real-time is a new discipline that developed to provide support to emerging applications (e.g., multimedia systems, robotics, telecommunications) characterized by reactive behaviors in highly dynamic environments. Achieving adaptivity in embedded real-time systems is a complex task that requires expertize from several disciplines, including operating systems, scheduling theory, network communication, control theory, quality of service management, and programming languages. To cover these issues, the ART cluster is organized into 5 activities:

1. JPIA Platforms: A common infrastructure for adaptive real-time systems
2. JPRA NoE: QoS Aware Components
3. JPRA Cluster: Flexible Scheduling Technologies
4. JPRA Cluster: Adaptive Resource Management for Consumer Electronics
5. JPRA Cluster: Real-Time Languages

A new JPRA Cluster activity on Dynamic and Pervasive Networking will be started on October 2006 to address the numerous research challenges in the frameworks of Wireless Sensor Networks, Mobile Ad-hoc Networks and Embedded Networked Systems.

Table of Contents

1. Overview

1.1 High-Level Objectives

The high level objective of the ART cluster is to build the fundamental bases of a new real-time software technology that can provide a more efficient and predictable support to the development of future embedded systems, characterized by high complexity and dynamic behavior. In particular, the new software technology should

- support scalability to facilitate the porting of control applications to different platforms;
- simplify the management of resources to control the growing complexity of embedded systems;
- increase programming flexibility, for specifying functional and performance requirements to simplify test and verification;
- increase system adaptivity to react to environmental changes, still providing a sufficient level of performance;
- be robust to tolerate transient and permanent overloads conditions due to wrong design assumptions or unpredictable changes.

Such features would have a concrete impact on European industry to reduce time to market, and improve software realiability and testabilty. To support industry in such a transition phase, new tools, algorithms and kernel mechanisms must be also provided. In this respect, the ART cluster is playing an active role, acting as a bridge between the academic and the industrial world, especially in the domain of consumer electronics, robotics, and telecommunications.

A means to achieve such a goal was to develop a research platform for real-time systems to share competencies, resources, and tools targeting at the development of control applications with performance and timing requirements. The use of a shared platform is essential for experimenting new real-time software technology, including novel scheduling algorithms, resource management techniques, energy-aware policies and overload handling approaches to increase robustness and predictability. A shared platform also facilitates the transfer of research results to industry, as it allows teaching practical knowledge of concepts and techniques. In addition, several solutions can be developed and tested in parallel in different partner sites, allowing the evaluation of the most appropriate approach for specific applications.

To better achieve this objective, two new activities have been started in the ART cluster: one related to programming languages, to support real-time functionality via language constructs rather than operating system calls, and the other related to networks, to provide real-time support to distributed applications.

1.2 Industrial Sectors

The most important industrial fields that can benefit from adaptive real-time technology include Consumer Electronics, Industrial Automation, and Telecommunications.

Consumer Electronics (CE) products range from miniature cameras and MP3 players to advanced media servers and large displays. Mainly driven by Moore's law, the evolution in the CE industry is very fast. The software content, measured in ROM size, grows one order of magnitude every 6 to 7 years [Bou05]. Utilizing available hardware and software resources in an optimal fashion is crucial both to save costs and to keep the competitive edge. Moreover, multimedia systems exhibit a highly dynamic behavior, since task execution times are often dependent on input data that are difficult to predict [Riz06]. As a consequence, these systems

are prone to intermittent overload conditions that could degrade the performance in an unpredictable fashion [Wus05, Loo03]. To address these problems, the ART cluster aims at integrating the most recent research results achieved in the real-time community to build flexible as well as predictable real-time systems that can react to load changes and perform QoS adaptation in a controlled fashion.

In the area of Industrial Automation there is a trend to search distributed solutions and to prepare hardware and software for connecting the general plant actuators, sensors and the controllers. Distributed solutions give a natural automation condition to common industrial needs as usually such plants are physically and topologically distributed. At the same time, there is an increase of demands for new options and improvements in the automation results, fetching more control of plant secondary data. This imposes a continuous increment in processing power and memory capacity that requires adaptivity at different levels of system operation. The contribution of the ART cluster in this domain is to investigate how to achieve predictability and adaptivity in distributed systems.

Embedded systems for telecommunications applications are mainly targeted to the interfaces between communication technologies and to coding/decoding operations. They may be considered real-time as they have timeliness requirements for some of the critical operations they must perform. The referred systems are microprocessor based platforms, often integrating a second processor (e.g., a DSP) devoted to specific functions, like MPEG coding. From the software point of view, a modern mobile phone typically consists of several million lines of code with use-cases involving large number of concurrent activities. A system supporting ``memory and temporal protection'' would allow safely mixing real-time and non real-time applications with the benefit of achieving a more scalable platform. The work on resource reservation carried out in the ART cluster is of crucial importance to manage the increased complexity of the applications in this domain.

1.3 Main Research Trends

Most of today's embedded systems are required to work in dynamic environments, where the characteristics of the computational load cannot always be predicted in advance. Still timely responses to events have to be provided within precise timing constrains in order to guarantee a desired level of performance. The combination of real-time features in dynamic environments, together with cost and resource constraints, creates new problems to be addressed in the design of such systems, at different architecture levels.

To cope with dynamic environments, a system must be adaptive; that is, it must be able to adjust its internal strategies in response to a change in the environment, to keep the system performance at a desired level [Loo03, Eke05]. Implementing adaptive embedded systems requires specific support at different levels of the software architecture.

The most important component affecting adaptiveness is the kernel, hence specific research efforts are being devoted to flexible, as well as predictable real-time scheduling and resource management policies [But06]. However, flexibility can also be introduced above the operating system, in a software layer denoted as a middleware. To investigate such a possibility, other research groups are working on this level to introduce adaptivity and QoS management [Sch03, Wan05, Sch06, Gar02].

Some embedded systems are large and distributed among several computing nodes. In these cases, special network methodologies are investigated to achieve adaptive behavior and predictable response [Alm03] [Ped05]. Several research efforts have also been placed in addressing wireless sensor networks (WSN) [Sta03], mobile ad-hoc networks MANET [Joh96, Wu04, Fac05] and other networked systems for which, albeit the dynamic nature and resource

scarcity of the infrastructure, timeliness is still a requirement. Often such a support cannot be found in today's commercial systems.

Finally, as the complexity of real-time systems increases, high demand will be placed on the programming abstractions provided by languages. Unfortunately, current programming languages are not expressive enough to prescribe certain timing behavior and hence are not suited for realizing predictable real-time applications. As a consenquence, most of the work on programming languages for real-time applications is aimed at providing real-time functionality via language constructs rather than operating system calls.

2. State of the Integration in Europe

2.1 Other Research Teams

The ART cluster had several interactions with the following research teams:

- University of Illinois at Urbana Champagne (reference persons: Prof. Lui Sha, Prof. Tarek Abdelzaher, and Prof. Marco Caccamo) on wireless communication protocols for real-time distributed emebedded systems.
- University of Virginia (reference persons: Prof. John Stankovic and Prof. Sang Son) on adaptive real-time systems for sensor networks.
- University of Lund (reference persons: Karl-Erik Arzen and Anton Cervin) on feedback control tecniques for adaptive real-time systems.
- University of California at Berkeley (reference person: Alberto Sangiovanni Vincentelli) on the design of component-based operating systems.
- ARTIST2 cluster on Modelling and Components, for modelling, composition, and verification of timing properties.
- Philips Research Eindhoven (reference persons: Dr. Liesbeth Steffens and Dr. Sjir van Loo) on resource management for consumer electronics.
- Ericsson Mobile Platforms (reference person: Dr. Johan Eker) on resource reservation and adaptive QoS management.
- Microchip Technology (reference person: Dr. Antonio Bersani) on real-time embedded platforms for monitoring and control.
- Carnagie-Mellon University (reference person: Prof. Raj Rajkumar) on wireless sensor networks, cooperative computing, andQoS adaptation.
- Seoul National University (reference persons: Dr. Jungkeun Park, Dr. Kanghee Kim) on distributed embedded systems and stochastic analysis of periodic task sets.
- Malardalen University, Sweden (reference person: Dr. Thomas Nolte) on integration of networked subsystems in resource constrained environments and on stochastic analysis of hybrid task sets.

2.2 Interaction of the Cluster with Other Communities

Interaction with the control community

There are at least two reasons that motivate a tight collaboration of the ART cluster with the control community. From the operating system prespective, the use of feedback control techniques allow making real-time embedded systems more reactive to environmental changes, hence system adaptivity can be improved by integrating control theory and real-time scheduling [Sta99]. From the control perspective, using flexible scheduling technologies allows making control systems more robust and predicatable: integrating feasibility analysis in the design of complex control systems allows the system designer to better analyze/control/compensate for delays and jitter caused by concurrency and intertask interference [Arz00].

Thanks to the ARTIST2 network of excellence, the ART cluster got in contact with the cluster on Control for Embedded Systems. In particular, since the first year, the two cluster leaders,

Giorgio Buttazzo (ART) and Karl-Erik Arzen (Control) organized a number of meetings and workshops to exchange ideas and propose more concrete actions to make progress in this area.

A joint work involving people from Pavia, Pisa and Lund has been carried out to integrate feedback control schemes into the Shark operating system (used as a shared platform) and to investigate the effects of different scheduling policies on delays and jitter in control loops.

Another strong collaboration has been established with the hybrid systems community. As a result of this connection, Giorgio Buttazzo has been invited as a co-Program Chair to organize the International Conference on Hybrid Systems: Computation and Control (HSCC 2007).

A joint work involving people from UPC (affiliated to TUKL) and Lund has been carried out to investigate feedback scheduling techniques. A PhD student from UPC spent 5 months in Lund working on the project.

Interaction with the cluster on compilers and timing analysis

A collaboration has been started with the cluster on compilers and timing analysis to investigate the problem of enhancing the predictability of real-time systems by reducing the variability of task execution times. In fact, internal kernel mechanisms, such as scheduling, mutual exclusion, interrupt handling and communication, can heavily affect task execution behaviour and hence the timing predictability of a system. For example, preemptive scheduling reduces program locality in the cache, increasing the worst-case execution time of tasks compared with non preemptive execution.

To address these issues, a new research was initiated that looks at predictability and efficiency in a synergistic manner and that involves all levels of abstraction and implementation in embedded-system design.

Thanks to the ARTIST2 network of excellence, the ART cluster got in contact with the cluster on Compilers and Timing Analysis. The two clusters started working together to develop a new approach consisting of a combination of several methods, including (a) design-space exploration on the hardware architecture level to identify good designs offering combinations of strong performance with good predictability, (b) appropriate kernel mechanisms for task and resource management that are predictable and analyzable, and (c) a synergistic development of models, design methods and matching analysis tools that extract precise system-behaviour properties.

Interaction with the consumer electronics industry

Thanks to the International Collaboration Days organized within the ARTIST2 project, the ART cluster got in contact with two major companies, Philips and Ericsson, acting in the domain of consumer electronics. After a tight interaction with the engineers responsible for the software development process, a number of industrial needs have been identified, that would make new generation products more robust and flexible.

To cope with a constantly increasing complexity of software applications (already consisting of several million lines of code and hundreds of concurrent activities), a system supporting memory and temporal protection would allow safely mixing real-time and non real-time applications with the benefit of achieving a more scalable platform. Therefore, the work on resource reservation carried out within the ART cluster is of crucial importance to manage the increased complexity of the applications in this domain.

In addition, multimedia systems exhibit a highly dynamic behavior, since task execution times are often dependent on input data that are difficult to predict. As a consequence, these systems are prone to intermittent overload conditions that could degrade the performance in an unpredictable fashion. Again, the expertize existing in the ART cluster on overload

management is of high interest for these companies, since it allows building flexible as well as predictable real-time systems that can react to load changes and perform QoS adaptation in a controlled fashion.

Interaction with the electronics industry

A new interaction of the ART cluster with Microchip Technology has been started on real-time embedded platforms for monitoring and control. In particular, the expertize existing in the ART cluster on real-time embedded control applications and real-time operating systems is extremely actractive for Microchip, who is interested in pushing the development of real-time embedded applications using 16-bit microcontrollers (as the dsPIC30 and the dsPIC33).

In this context, a big opportunity for the ART cluster is to find an agreament with Microchip to define the characteristics of a small real-time embedded platform for sensory acquisition and motor control that can be used (in conjunction with a wireless card) as a node of a mobile wirelss network. This unit would be more powerful and flexible than a mote and could be used to carry out experiments on sensor networks, embedded control, mobile robot teams and distributed control systems.

Interaction with the language community

A new activity started this year looking at real-time languages and the role they play is the development of flexible real-time systems. Considerable expertise exists within the ART cluster for this activity. In particular members of ART have participated in the development of Ada, (Ada 2005), Java (RTSJ) and POSIX (for use with C and C++). This particupation has included membership of the associted standisation bodies. The focus of the this work on languages is to link work within the cluster with international efforts across a number of languages, including but not limited to, these languages.

Dissemination

The ART cluster has been quite active in disseminating the research results achieved in the context of the ARTIST2 network of excellence, as an overall strategy for reaching other research/academic/industrial communities with related interests.

The operating system platform developed in the context of the Joint Programme of Integration Activities (JPIA) has been extensively used in summer schools and graduate courses to teach how to develop embedded applications with real-time and performance requirements.

In additions, several scientific papers have been published and a number of workshops, conferences, and invited talks have been organized by the ART cluster to spread the acquired knowledge in the scientific community. The conferences and workshops in which the ART cluster has been involved include:

- OSPERT 2006: 2nd Workshop on Operating Systems Platforms for Embedded Real-Time applications, Dresden, Germany, July 4, 2006. A paper presentation and a keynote talk has been given by Giorgio Buttazzo (ART cluster leader) on predictability and efficiency in real-time operating systems for embedded systems. Gerhard Fohler (TUKL) was on the program committee.
- ETFA 2005: 10th IEEE International Conference on Emerging Technologies and Factory Automation, Catania, Italy, September 2005. Scuola Sant' Anna of Pisa, Pavia Aveiro and Catania presented scientific papers on real-time scheduling, communications and distributed embedded systems, and Lucia Lo Bello from Univ. Catania (affiliated to Pisa) acted as a Program Chair. Luis Almeida (Aveiro) was co-Chair of the Real-Time and Networked Embedded Systems track and Giorgio Buttazzo (Pisa) was a member of the Programm Committee.

- RTSS 2006: 27th IEEE Real-Time Systems Symposium, Rio de Janeiro, Brazil, December 5-8, 2006. Pisa will present a techical paper on real-time scheduling. Porto will present a paper on Modelling and Worst-Case Dimensioning of Cluster-Tree Wireless Sensor Networks. Gerhard Fohler from TUKL acted as a Program Co-Chair. Giorgio Buttazzo (Pisa), Alan Burns (York), Michael Gonzalez Harbour (Cantabria), Eduardo Tovar (Porto) and Pau Marti (affiliated to TUKL) were members of the Program Committee.
- OPODIS 2005: 9th International Conference on Principles of Distributed Systems, Pisa, Italy, December 12-14, 2005. Giorgio Buttazzo (ART cluster leader) gave a keynote speech on real-time issues in sensor networks. Porto presented a paper proposing the use of dominance protocols for the wireless domain.
- ECRTS 2006: 18th Euromicro Conference on Real-Time Systems, Dresden, Germany, July 5-7, 2006. Pisa, Pavia, Aveiro, Porto, York, and Cantrabria presented technical papers on real-time scheduling. Giorgio Buttazzo (Pisa), Pau Marti (Catalonia, affiliated to TUKL) and Lucia Lo Bello (Catania, affiliated to Pisa) were members of the Program Committee. Gerhard Fohler (TUKL) is Techical Committee Chair. Giorgio Buttazzo (Pisa), Alan Burns (York), Eduardo Tovar (Porto), Michael Gonzales Harbour (Cantabria), and Liesbeth Steffens (affiliated via TUKL), are also members of the Executive Board. UPC (affiliated to TUKL) presented a paper on adaptive resource management for control tasks.
- RTAS 2006: 12th IEEE Real-Time and Embedded Technology and Applications Symposium, San Jose, CA, USA, April ,4-7, 2006. Giorgio Buttazzo (Pisa), Eduardo Tovar (Porto), Luis Almeida (Aveiro), Michael González Harbour (Cantabria) and Gerhard Fohler (TUKL) were members of the Programm Committee. Cantabria, York, Malardalen and Pisa presented a paper on a frakework for flexible scheduling.
- HSCC 2007: 10th International Conference on Hybrid Systems: Computation and Control, Pisa, Italy, April 4-7, 2007. Giorgio Buttazzo (Pisa) acted as a Program Co-Chair. Pau Marti (affiliated to TUKL) was a member of the Program Committee.
- RTCSA 2006: 12th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications, August 2006. Pisa and Pavia presented a paper on energy-aware resource management and a paper on real-time scheduling for jitter reduction. Porto presented a paper on multiprocessor scheduling, a paper on the implementation of a dominance MAC protocol for wireless sensor networks and a third paper on QoS adaptation for service level agreements. Cantabria presented a paper on hierarchical scheduling of tasks with EDF on top of constant bandwidth servers.
- IFAC 2005: 16th IFAC World Congress, Praha, Czech Republic, July, 2005. UPC (affiliated to TUKL) presented a paper on probabilistic techniques for analysing real time control systems.
- IECON 2005: 31th Annual Conference of the IEEE Industrial Electronics Society, Raleigh, USA, November, 2005. UPC (affiliated to TUKL) presented a paper on stability analysis of control systems subject to varying resource allocation.
- WFCS06: 6th IEEE International Workshop on Factory Communication Systems, Torino, Italy, June 2006. UPC (affiliated to TUKL) presented a paper on a software tool for generating cyclic schedules.
- IECON 2006: 32th Annual Conference of the IEEE Industrial Electronics Society, Paris, France, November, 2006. UPC (affiliated to TUKL) organized a special session on Network-based Control Systems and presented a paper on dynamic resource allocation on a CAN-based distributed control system.

- JTR 2007: X Jornadas de Tiempo Real, Barcleona, Spain, February 2007 (Spanish Real-Time Workshop). UPC (affiliated to TUKL) chairs and organizes the workshop.
- RTN 2006: 5th International Workshop on Real Time Networks, Dresden, Germany, July 4, 2006. Porto presented two papers on wireless sensor networks, one on ZigBee and another on how to compute aggregate quantities with WiDom networks. Aveiro presented a paper on high integrity hard real-time Ethernet switches. Catania (affiliated to Pisa) presented one technical paper on subsystem integration. Lucia Lo Bello (Catania) was member of the Program Committee.
- OSERTS '06 – Workshop towards Off-the-Shelf Embedded Real-Time Software. Alejandro Alonso (Madrid) acted as Programmee Committee member and presented a technical paper.
- WPDRTS 2006: 14th International Workshop on Parallel and Distributed Real-Time Systems (In conjunction with IPDPS), Rhodes Island, Greece, April 25-26, 2006. Madrid presented a technical paper. Porto presented a paper on the GTS Allocation Analysis in IEEE 802.15.4 for Real-Time Wireless Sensor Networks. Cantabria presented a paper on the analysis of hierarchical scheduling for component-based systems. Michael González Harbour (Cantabria) was a Program Committee Member.
- Ada Europe 2006: 11th International Conference on Reliable Software Technologies, Porto, Portugal, June 5-9, 2006. Alejandro Alonso (Madrid) and Juan A. de la Puente (Madrid) were members of the Programme Committee and presented technical papers. Alejandro Alonso was member of the Ada-Europe Board. Luis Miguel Pinho (Porto) and Michael Gonzalez-Harbour (Cantabria) were Program Co-chairs. Cantabria presented a paper on Interchangeable Scheduling Policies in Real-Time Middleware for Distribution.
- ISORC'06, 9th IEEE International Symposium on Object and component-oriented Real-time distributed Computing, April 24-26, 2006, Gyengju, Korea. Miguel A. de Miguel (Madrid) was member of the Programmee Committee and presented a technical paper.
- DIPES 2006: 5th IFIP Working Conference on Distributed and Parallel Embedded Systems, Braga, Portugal, 11-13 October 2006. Luis Miguel Pinho was member of the Program Committee. Porto presented a paper on a Iterative Refinement Approach for QoS-aware Service configuration. Aveiro presented an invited paper on traffic scheduling anomalies within temporal partitions.
- WFCS 2006: 6th IEEE Workshop on Factory Communication Systems, Torino, Italy, 29th June – 1st July 2006. Eduardo Tovar (Porto) and Lucia Lo Bello (Catania, affiliated to Pisa) were members of the Program Committee. Porto presented a paper on the timeliness analysis of hybrid wired/wireless PROFIBUS networks. Aveiro presented several papers, on the implementation of the FTT paradigm over switched Ethernet networks, as well as on the bus replication and global system management within FTT-CAN networks. Catania presented a technical paper on clock synchronization in Bluetooth networks used in distributed automation domain.
- WTR 2006: 8th Brazilian Workshop on Real-Time Systems, Curitiba, Brazil, 2 June 2006. Luis Almeida (Aveiro) was Chair of the Program Committee.
- RTNS 2006 – 14th Int. Conf on Real-Time and Networked Embedded Systems, Poitiers, France, May 2006. Luis Almeida (Aveiro) was member of the Program Committee.
- INCOM 2006, 12th IFAC Simposium on Information Control for Manufacturing, St. Ettiene, France, May 2006. . Luis Almeida (Aveiro) was co-Chair of the Real-Time and Networked Embedded Systems track. Aveiro also presented two papers, one concerning the dual-rate switching control approach, together with Catalonia (affiliated

to TUKL), another concerning enhanced network drivers for real-time periodic communications, together with Pavia (affiliated to Pisa).

- SAE World Congress 2006, Detroit, USA, April 2006. Aveiro presented a paper on the experimental evaluation of the master replicaiton mechanisms of FTT-CAN and Baleares (affiliated to Aveiro) presented a paper on the experimental assessment of the replicated star topology for CAN, ReCANcentrate.

Participation in Standards

Some ART cluster members are actively involved in the following standardization activities:

- UML Profile QoS and Fault Tolerance
  URL: http://www.artist-embedded.org/artist/UML-Profile-QoS-and-Fault.html
  Member: Alejandro Alonso, UP Madrid.

- Ada
  URL: http://www.artist-embedded.org/artist/UML-Profile-QoS-and-Fault.html
  Member: Alan Burns, Univ. of York.

- POSIX 1003
  URL: http://www.artist-embedded.org/artist/POSIX-IEEE-1003.html
  Member: Michael Gonzalez Harbour, Univ. of Catabria.

- MPEG Multimedia Middleware (M3W)
  URL: http://www.artist-embedded.org/artist/MPEG-Multimedia-Middleware-M3W.html
  Member: Alejandro Alonso, UP Madrid.

- ETHERNET powerlink
  URL: http://www.artist-embedded.org/artist/ETHERNET-Powerlink.html
  Member: Lucia Lo Bello, Univ. of Catania (affiliated to Pisa).

2.3 Main Aims for Integration and Building Excellence through Artist2

Achieving adaptivity in embedded real-time systems is a complex task that requires expertize from several disciplines, including operating systems and kernels, scheduling theory, distributed systems, network communication, control theory, quality of service management, and programming languages. Combining the results achieved in such different domains and orchestrating the various groups active in these fields is only possible by a tight interaction among the cluster participants. Hence, the aim of the integration through Artist2 is to facilitate communication among cluster members in order to:

- Improve the understanding of the key features to be added at different architecture levels (operating system, network, middleware, and language) to support adaptive real-time systems;
- Clarify the terminology to provide a common language for exchanging information between different cluster and research communities;
- Build a common operating system platform to perform experiments and develop tools that can be shared by the different research teams;

- Identify new research directions aimed at overcoming the problems encountered during the integration phase;
- Interact with industries to understand their problems and identify possible solutions;
- Form new consortia and make concrete project proposals to address specific research problems or develop critical applications of industrial interest.

3. Overall Technical View

3.1 Brief State of the Art

The main reason for investigating adaptive real-time systems is to provide predictability and flexibility for systems and environments where requirements on resources are inherently unstable and difficult to predict in advance. Such a difficulty is due to different causes. First of all, modern computer architectures include several low-level mechanisms that are designed to enhance the average performance of applications, but unfortunately introduce high variations on tasks' execution times. In other situations, as in multimedia systems, processes can have highly variable execution times that also depend on input data [Riz06]. As a consequence, the overall workload of a computing system is subject to significant variations, which can produce an overload and degrade the performance of the entire system in an unpredictable fashion [Loo03, Eke05]. This situation is particularly critical for small embedded devices used in consumer electronics, telecommunication systems, industrial automation, and automotive systems. In fact, in order to satisfy a set of constraints related to weight, space, and energy consumption, these systems are typically built using small microprocessors with low processing power and limited resources.

For most of these systems, the classical real-time approach based on a rigid off-line design, worst-case assumptions and a priori guarantee would keep resources unused for most of the time, therefore it is not acceptable for efficiency reasons. When resources are scarce, they cannot be wasted. On the other hand, an off-line design based on average-case behavior is also critical, because it would be difficult to guarantee timing constraints when resources are overloaded.

To prevent unpredictable performance degradations due to overloads, a real-time system must react to load variations, degrading its performance in a controlled fashion acting on system, as well as application parameters. The process of controlling the performance of a system as a function of workload variations is referred to as Quality of Service (QoS) Management. Performing efficient QoS management requires specific support at different levels of the system architecture. Hence, new software methodologies are emerging in Embedded Systems, which strictly relate to Real-Time Operating Systems (RTOS), Middleware, and Networks.

Real-time scheduling is the kernel mechanism having the most impact on RTOS performance. Most scheduling algorithms have been developed around one of three basic schemes: table driven [Foh95], fixed priority [Aud95], or dynamic priority [Spu96]. Depending on whether scheduling decisions are resolved before or during runtime, they are classified as offline or online.

Adapting to changing environmental situations may involve changes to task parameters at runtime. System wide changes, e.g., for changing operational modes in the system, have been addressed by mode change algorithms [Foh93].

Feedback scheduling changes task parameters, in particular periods [But02], to respond to online variations in the environment and current load conditions of the system. As both conditions can vary frequently, too frequent responses, which in turn influence the conditions, can introduce instability in the system. Feedback control scheduling applies control theory to estimate effects of changes and to choose parameters to provide for smooth responses and avoid instability [Cas06].

Each of the basic scheduling paradigms has specific advantages. When advantages of different schemes are demanded in the same system, more than one scheme could be used for different tasks. For example, in a complex system including hard periodic and soft aperiodic tasks, two scheduling schemes need to be integrated for satisfying the different requirements of each task class.

In hierarchical scheduling [Reg01] a meta algorithm arbitrates between a set of diverse scheduling algorithms. Thus, it can appear to the individual scheduling algorithms and their applications that they execute alone in the system. Furthermore, the amount of the CPU portion can be set individually for each scheduler and application. Special attention has to be given to shared resources.

In those systems subject to higly varialble workload, an overload condition could degrade the system performance in an unpredictable fashion. Novel scheduling methodologies have been recently proposed to cope with transient and permanent overload conditions. Transient overloads due to execution overruns can be effectively handled using resource reservation techniques [Mer94], according to which each activity consumes a fraction of the processing resource, independently of the actual execution demand. Permanent overload conditions, typically occurring in a periodic environment, can be efficiently handled by sporadic job skipping [Kor95] or by rate adaptation techniques (like elastic scheduling) [But02], which keep the load below a given threshold by acting on task periods.

Major needs for flexible scheduling techniques are typical of industries working in consumer electronics, industrial automation, and telecommunications, as resulted from a study carried out within the ARTIST 5FP project [Bou05].

For example, mobile terminals today are getting more and more advanced and their source code consists of several million lines of code involving a large number of parallel activities. For these applications, the use of flexible real-time scheduling techniologies would allow to safely mix real-time and non real-time processes. The benefit of such a solution would be a much more scalable platform. Adding and removing features would become predictable and less hazardous, allowing configuring the system without worrying about unpleasant surprises.

In the area of Industrial Automation, the continuous increment in processing power and memory capacity in local processors gives the opportunity to add new tasks into them, increasing system complexity in terms of supervision, diagnostics, presentation, communication, etc. Adaptive tasks scheduling that preserves the real-time constraints is a possible way to handle such situation and manage the complexity of the application.

In telecommunication companies, the main current interest seems to be in exploring the use of real-time extensions for the Linux OS. It also seems that QoS mechanisms are starting to be recognized as important for these embedded applications to increase the efficiency of subsystems and to support the possibility to serve more clients with similar levels of resources.

3.2 Ongoing Work in the Partner Institutions

The Scuola Superiore Sant'Anna (SSSA) of Pisa is investigating advanced scheduling methodologies for increasing the predictability of real-time systems characterized by a highly variable workload and execution requirements. Resource reservation mechanisms have been analyzed and implemented in the Shark kernel and currently under evaluation. The objective is to reduce intertask interference and provide temporal protection among the concurrent activities. The reserch team is also analyzing rate adaptation strategies to handle permanent overload conditions in periodic task systems, which are typical in control and multimedia applications. Another strong research line deals with energy-aware scheduling in processor with dynamic voltage scaling capabilityes, with the objective of guaranteeing a desired level of

performance while minimizing energy consumption. This is crucial problem in all embedded systems operated by batteries.

The Univeristy of Pavia (affiliated to the Scuola Superiore Sant'Anna) is working on new methodologies for integrating overload management techniques with energy-aware strategies, in the context of small embedded systems for battery operated devices. New scheduling mechanisms have been proposed and analysed to guarantee timing constraints while minimizing energy consumption, and a kernel infrastructure has been developed into the Shark operating system in order to facilitate their implementation. The work will proceed to extend the proposed kernel infrastructure to include other devices other than the CPU, such as I/O devices, memory, actuators, and wireless communication boards.

Evidence s.r.l. (affiliated to the Scuola Superiore Sant'Anna) is working on the implemention of novel scheduling techniques on a small real-time kernel (Erika Enterprise) that runs on small microprocessors with scarce resources. Specific kernel mechanisms (as stack sharing protocols) are being investigated to optimize memory usage and reduce runtime overheads. In addition, Evidence is developing design tools for supporting the application programmers in specifying task requirements, generating code, and analyzing the schedulability of complex real-time applications.

University of Catania (affiliated to the Scuola Superiore Sant'Anna) is continuing in its work on network architectures and transmission protocols for real-time wireless networks used in factory communication. This activity now run across several research threads, which involve different standards, such as, 802.11b/g/e, Bluetooth, 802.15.4. The common aspect is investigating and/or providing QoS and real-time support offered to real-time traffic flows. A novel activity recently started deals Wireless Sensor Networks under real-time constraints. The application field is land monitoring and the main focus is on energy-aware routing techniques. The team is also continuing the work on the stochastic analysis of hybrid task sets in the context of priority-driven soft real-time systems and on flexible scheduling and resource management in networked embedded systems.

The real-time systems research group at the University of York is continuing in its work on scheduling (focusing specifically on fixed priority systems and server-based implementations), real-time languages (including standardisation efforts with Ada 2005 and the real-time specification for Jave – RTSJ), embedded systems implementations on SoC and FPGA platforms, and general modelling work for temporal systems (including wireless sensor nets).

The Technical University of Kaiserslautern (TUKL) is continuing to work on adaptive resource managment for media processing and, in particular, on adaptation methods for both streams and resourced on 802.11 wireless networks. A key challenge here is the provision of methods indicating bandwidth availability during system runtime. Ideally, predictions about availability in future time interval can be given with meaningfull confidence, but notion of achievable Qualit-of-Service will be usefull already. The issue of multi resource management is also being investigated at TUKL. In particular, modern multiprocessor architectures for media processing demand the integration of CPU scheduling and cache/memory handling for predictable timing. Finally, TUKL continues the work on flexible scheduling, with emphasis on the integration of offline and online scheduling, e.g., for integration of time triggered and event triggered systems.

University of Cantabria is working in basic and applied research in the area of real-time technology, and its application to the development of real-time systems for industrial controllers, robots, and intelligent instrumentation. The group focuses on fixed priority systems, like those based on POSIX operating systems or those developed in the Ada programming language. The Group is also developing methodologies and tools for software engineering of real-time systems in which a mixture of soft and hard deadlines can be found. The tool currently being developed, called MAST, allows the design of a real-time system using a UML

tool, modeling its real-time performance, and making the schedulability analysis automatically from the UML description. The group is also actively participating in the development of the Real-time POSIX operating systems standards. As a result of this participation, several of the chapters of the latest real-time POSIX standards have been authored by members of the group. The group is currently developing a hard real-time kernel, called MaRTE OS, that is compliant with the POSIX minimum real-time system profile.

The team at the University of Aveiro is involved in the design and analysis of network protocols for distributed embedded systems, with particular emphasis on supporting dynamic QoS management, mainly for multimedia systems, flexible scheduling, dynamic reconfiguration, graceful degradation and survivability for embedded control systems, particularly robots and vehicles. The used network technologies are mainly Ethernet and CAN, with some work on WiFi and Bluetooth. The team is also addressing the architectural aspects of such systems to provide flexible architectures that are easy to deploy, reconfigure and operate but still fulfiling the application timing and safety requirements and using the systems resources efficiently. One of the main lines of work in this direction develops around the Flexible Time-Triggered (FTT) paradigm. Currently, this paradigm is being adapted to micro-segmented switched Ethernet networks, allowing to overcome the deficiencies of COTS switches in terms of real-time behaviour.

Universidad Politécnica de Madrid (UPM) is working on communication mechanisms for distributed real-time systems in Java and Ada. With respect to Java, UPM has designed and implemented two versions of RMI: one focused on hard real-time systems and the other intended for business-critical systems. On relation with Ada, UPM has developed an enhanced version of the RT-EP protocol, and has implemented drivers for hard real-time systems based on the Ravenscar profile. UPM has also been active in the production of the new version of the language Ada 05, which has been just approved as an ISO standard. Work on adapting the Open Ravenscar Kernel (ORK) to Ada 2005 has also begun. UPM is still working on HOLA-QoS, which is a middleware for managing QoS and resources, based on a layered and modular architecture. During the last year, a new version of HOLA-QoS has been developed to provide resource reservation and management facilities. The work on QoS-aware components is focusing on the specification of QoS properties in system models, to have functional and non-functional information in the same UML model. Finally, UPM is continuing with the experimentation and evolution of the resource and QoS management facilities in ROBOCOP, which is a component framework.

Universidad Carlos III de Madrid (UC3M), affiliated to UPM, closely relates to the UPM team working on QoS support in middleware, QoS management for flexible embedded distributed environments and QoS-aware modelling and components. UC3M is actively working on the adaptation of the Java distribution middleware (RMI) to support real-time and QoS features. It has developed a framework for the flexible composition of real-time applications, named CoSeRT, to create applications based on services. CoSeRT is now being adapted to support flexibility and QoS support for distributed environments. UC3M has collaborated with the University of Aveiro to start the adaptation of CoSeRT to suit embedded networking domains to provide fault tolerance to applications and real-time distributed communications.

The team of the Technical University of Catalonia (affiliated to TUKL) is focusing on feedback scheduling techniques for adaptive real-time systems. In particular, two scenarios are being treated: maximization of application performance within the available computing resources, and gracefull degradation in overloaded systems. Both scenarios are of special interest of industry of mass market products (e.g., automotive or multimedia) for providing more and better services to the end user with no cost increments. Specifically, the team is investigating new control methods for networked control systems with adaptive resource management. Finally, the team is defining a new application profile for the CAN network aimed at optimizing application performance in networked embedded systems.

The team of the IPP-HURRAY research group at the Polytechnic Institute of Porto (ISEP-IPP) is involved in the design and analysis of innovative communication protocols for networks of embedded systems (WiDOM, TDMA-SS, HYDRA and ART-WiSe). WiDOM is a wireless medium access control (MAC) mechanism based on dominance protocols that has been explioited to efficiently perform computations of aggregate quantities. A major goal has being in analysing and proposing mechanisms to technologies going currently through standardization processes, such as the IEEE 802.15.4, which is being implemented on the MICAz motes using TinyOS operating systems. Some of the already attained achievements within this framework have been the development of tools able to evaluate the timeliness abilities of cluster-based IEEE 802.15.4 networks and the proposal of admission control mechanisms to improve and turn more flexible the real-time properties of the guaranteed allocation schemes in such technologies. Another quite active area within the research group has been on collaborative computing, programming languages and OS run-time monitoring. Collaborative QoS-aware coalitions of nodes have been studied and proposed to support resource intensive service requests in devices with limited resources supported by hybrid wired/wireless communications. The group is now starting to tackle higher level support of multiprocessor systems and stochastic timeliness analysis of distributed systems.

3.3 Interaction and Building Excellence between Partners

The expertize within the ART cluster and the interaction among the partners is being extremely helpful for building a general view of the existing embedded systems panorama, with the advantage of perceiving the approaches followed by the partners under different perspectives. This generates interesting discussions that are extremely constructive in the process of integrating several algorithms together in the same system. In some case, such interactions generate new ideas on applying existing algorithms to different domains (e.g., from processor to networks, or viceversa) or extending the algorithms to more general scenarios.

All the partners in the ART cluster actively contributed to the development of a shared operating system platform for testing and evaluating novel kernel mechanisms suitable for supporting adaptive real-time embedded systems.

In particular, the interaction between Pisa, Pavia, Evidence, Aveiro, and Catania was very constructive for defining the characteristics of a small real-time embedded platform for sensory acquisition and motor control, which can also be used (in conjunction with a wireless card) as a node of a mobile wirelss network. Microchip is very interested in commercializing such a product for a number of industrial applications and academic research.

York, Cantabria, Porto, and Madrid (UPM and UC3M) are tightly collaborating in the real-time languages activity, which also involves other international researchers, particularly in the US. One of the main aims of such a collaboration is the development of a web-based repository for Ada 2005 patterns.

Pavia, Pisa, Catania and Aveiro are addressing the issue of achieving flexibility in networked systems through an integrated approach, where several subsystems are encapsulated and later integrated on a shared hardware architecture. This is valuable in many industrial contexts, among which, distributed robotics and automotive. As the network is a resource shared by all subsystems in the distributed architecture, its role in the integration process is particularly important, and the usage of an efficient and flexible network scheduler is essential. The core activity thus focuses on assessing the suitability of Server-CAN, a network scheduler for the Controller Area Network, in the context of subsystem integration.

Philips and TUKL have been working on integrating real-time scheduling and cache management for next generation execution platforms in a joint PhD student project. Together

with partners within and outside ARTIST2, TUKL has started work on an EU project on flexible scheduling, which continues the work carried out within the FIRST project.

University of Cantabria is leading the FRESCOR project, which is aimed at developing a framework that integrates advanced flexible scheduling techniques directly into an embedded systems design methodology, covering all the levels involved in the implementation, from the OS primitives, through the middleware, up to the application level. The FRESCOR project brings together a strong consortium of 11 leading members of industry and academia. Six of its partners are university groups that are strong in different research topics in embedded systems, and are members of the ARTIST2 NoE: Cantabria (real-time distributed systems), York (real-time scheduling), SSSA (real-time operating systems), TUKL (flexible and hierarchical scheduling), University of Valentia (embedded real-time operating systems), and Czech Technical University in Prague (network protocols, reconfigurable architectures). The other five partners are industrial companies. Two of them are large companies with different business areas: ENEA is participating as a developer of a real-time operating system and Thales is contributing with their expertise in component-based design methodologies. The other three companies are SMEs with a lot of experience in the area, and they will contribute to the development, evaluation and exploitation of different parts of the project: Visual Tools S.A. on digital media applications, Rapita Systems Ltd on simulation tools, and Evidence srl on real-time kernels for reconfigurable multiprocessor platforms.

UP-Madrid has a tight collaboration with the Universidad of Cantabria for the development of the enhanced version of the RT-EP protocol and for the adaptation of HOLA-QoS to the MaRTE operating system. Similarly, UPM had a close interaction with SSSA for doing the equivalent job on top of the SHARK operating system. UPM has continued its collaboration with UC3M in the development of the improvements of HOLA-QoS and some of the activities on QoS-aware components. Finally, UPM has based the work on RMI-HRT on the definition of a Java profile for high integrity systems done by the University of York.

Universidad Carlos III de Madrid (UC3M) has collaborated in a very close way with the University of Aveiro during this period of time. Two of the members of UC3M have carried out a 5 months stay each at the University of Aveiro to work on the avobe mentioned topics. On one side, the knowledge on real-time communications, sensor networks and fault tolerance of the Aveiro group and, on the other side, the knowledge of middleware architectures, QoS management and RTSJ-RMI of UC3M has been joined. This has allowed the enhancement of the work of UC3M towards the network level in order to build real-time communications and fault-tolerance inside middleware technology. Also, UC3M collaborates continuously with UPM in the enhancement of the HOLA-QoS architecture and on some aspects of QoS-aware component technology.

Technical University of Catalonia had a strong interaction with many ART cluster teams that has taken place with several cluster meetings, visits to other partners' institutions, as well as joint publications in top conferences and journals. The team interacted with the University of Lund to modify the Truetime simulator to better study new feedback scheduling theoretical results. It also interacted with SSSA to implement feedback scheduling mechanisms in the Shark kernel.

During year2, the team at the University of Aveiro developed interactions with Pavia concerning a flexible Ethernet network driver to be applied in SHaRK, which, beyond the common immediate packet send and receive services is capable of transmitting packets at predefined instants in time, thus providing improved support for timed protocols, with Catalonia for the design of the "dual-rate switching control" approach that consists in reducing drastically the sampling rate of feedback control loops when they are close to the stationarity to reclaim resources, with Carlos III concerning the development of a dynamic service composition framework in distributed real-time systems and the combination of the FTT paradigm with RMI to improve predictability in this middleware. and with the University of the Balearic Islands,

concerning the development and analysis of active hubs for CAN (CANcentrate/ReCANcentrate).

References

[Alm03] L. Almeida. A Word for Operational Flexibility in Distributed Safety-Critical Systems. WORDS 2003, 8th IEEE Workshop on Object-oriented, Real-time and Dependable Systems, Guadalajara. Mexico, January 2003.

[Arz00] Karl-Erik Årzén, Anton Cervin, Johan Eker, Lui Sha, “An Introduction to Control and Scheduling Co-Design”, *39th IEEE Conference on Decision and Control,* Dec. 2000

[Aud95] N.C. Audsley and A. Burns and R.I Davis and K.W Tindell and A.J. Wellings, “Fixed Priority Preemptive Scheduling: An Historical Perspective”, Real-Time Systems, Vol. 8, pp. 173-198, 1995.

[But02] G. Buttazzo and L. Abeni, "Adaptive Workload Management through Elastic Scheduling", Real-Time Systems, Vol. 23, No. 1-2, pp. 7-24, July-September 2002.

[Bou05] Embedded Systems Design, The ARTIST Roadmap for Research and Development, Lecture Notes in Computer Science, Vol. 3436, Edited by Bruno Bouyssounouse and Joseph Sifakis, Springer, 2005.

[But06] G. Buttazzo, "Research trends in real-time computing for embedded systems", ACM SIGBED Review archive, special issue on major international initiatives on real-time and embedded systems, Vol. 3, No. 3, pp. 1-10, July 2006.

[Cas06] Rosa Castañé, Pau Martí, Manel Velasco, Anton Cervin and Dan Henriksson, “Resource Management for Control Tasks Based on the Transient Dynamics of Closed-Loop Systems”, 18th Euromicro Conference on Real-Time Systems 2006

[Eke05] “Embedded Software for Mobile Terminals”, Keynote Speech by Johan Eker; Ericsson Mobile Platforms AB. Euromicro Conference on Real-Time Systems (ECRTS 2005), Palma de Mallorca, Balearic Islands, Spain, July 6-8, 2005.

[Fac05] T Facchinetti, G. Buttazzo, L. Almeida. Dynamic Resource Reservation and Connectivity Tracking to Support Real-Time Communication among Mobile Units, EURASIP Journal on Wireless Communications and Networking, 2005(5): 712-730, December 2005.

[Foh93] G. Fohler. Changing operational modes in the context of pre run-time scheduling. IEIC transactions on information and systems, special issue on responsive computer systems, Nov 1993.

[Foh95] G. Fohler, "Joint Scheduling of Distributed Complex Periodic and Hard Aperiodic Tasks in Statically Scheduled Systems", in IEEE Real-Time Systems Symposium, December, 1995.

[Gar02] Marisol García-Valls, Alejandro Alonso, José F. Ruiz, Ángel Groba, “An Architecture for a Quality of Service Resource Manager Middelware for Flexible Multimedia Embedded Systems”, In Proceedings of the International Workshop on Software Engineering and Middleware - SEM 2002. Orlando, Florida (2002)

[Joh96] D. B. Johnson and D. A. Maltz, “Dynamic Source Routing in Ad Hoc Wireless Networks”, In Mobile Computing, pp. 153-181, Kluwer Academic Publishers, 1996.

[Kor95] G. Koren and D. Shasha, “Skip-Over: Algorithms and Complexity for Overloaded Systems that Allow Skips”, *Proceedings of IEEE Real-Time System Symposium*, December 1995.

[Loo03] "Living with uncertainty: A systems architect's view on real-time", Keynote Address by Sjir van Loo, Principal systems architect, responsible for the Philips Research long-term objectives for the Embedded Software Technology, Euromicro Conference on Real-Time Systems (ECRTS03), Porto, Portugal, 2-4 July 2003.

[Mer94] C. Mercer, S. Savage, and H. Tokuda, "Processor Capacity Reserves: Operating System Support for Multimedia Applications", IEEE International Conference on Multimedia Computing and Systems, 1994.

[Ped05] P. Pedreiras, P. Gai, L. Almeida, G. Buttazzo. FTT-Ethernet: A Flexible Real-Time Communication Protocol that Supports Dynamic QoS Management on Ethernet-based Systems. IEEE Transactions on Industrial Informatics, 1(3):162-172, August 2005.

[Reg01] John Regehr, John Stankovic, "HLS: a framework for composing soft real-time systems", Proc. RTSS 2001, London 2001.

[Riz06] L. Rizvanovic and G. Fohler, "Real-time Architecture for Networked Multimedia Streaming Systems", MiNEMA Workshop, 2006, Leuven, Belgium, February 2006.

[Sch03] Richard E. Schantz, Joseph P. Loyall, Craig Rodrigues, Douglas C. Schmidt, Yamuna Krishnamurthy, and Irfan Pyarali, "Flexible and Adaptive QoS Control for Distributed Real-time and Embedded Middleware", Middleware 2003, the ACM/IFIP/USENIX International Middleware Conference, Rio de Janeiro, Brazil, June 2003.

[Sch06] Richard E. Schantz, Joseph P. Loyall, Craig Rodrigues, Douglas C. Schmidt, "Controlling quality-of-service in distributed real-time and embedded systems via adaptive middleware", Software: Practice and Experience, Wiley, Vol. 36, No. 11-12, pp 1189-1208, 2006

[Spu96] M. Spuri and G. Buttazzo, "Scheduling Aperiodic Tasks in Dynamic Priority Systems", The Journal of Real-Time Systems, Vol. 10, No. 2, pp. 179-210, March 1996.

[Sta03] J. Stankovic et al. "Real-Time Communication and Coordination in Wireless Sensor Networks", In Proceedings of the IEEE, Vol. 91, N.7, July 2003.

[Sta99] J. Stankovic, C. Lu, S. Son, and G. Tao, "The Case for Feedback Control Real-Time Scheduling", *Euromicro Conference on Real-Time Systems*, June 1999.

[Wan05] X. Wang, D. Jia, C. Lu and X. Koutsoukos, Decentralized Utilization Control in Distributed Real-Time Systems, IEEE Real-Time Systems Symposium (RTSS'05), December 2005.

[Wu04] J. Wu and I. Stojmenovic, "Ad-Hoc Networks", IEEE Computer, vol. 37, no. 2, February 2004.

[Wus05] C. C. Wüst, L. Steffens, W. F. Verhaegh, R. J. Bril, and C. Hentschel, "QoS Control Strategies for High-Quality Video Processing", Real-Time Systems, Vol. 30, No. 1-2, pp. 7-29, May 2005.

4. Overall Assessment and Vision for the Cluster

4.1 Assessment

During this second year of work, all the partners actively contributed to the progress of the research activities planned by the cluster. Affiliated partners gave also a substantial contribution by attending meetings, workshops, by participating in joint publications and by exchanging human resources.

The intercluster meetings and the plenary meetings organized by the project coordinator, including the review meetings, were also very fruitful for establishing new relations and opening novel interdisciplinary research directions, as the activiities with the cluster on compilers and timing analysis and with the cluster on control (as reported in Section 2.2). Indeed ARTIST2 has contributed to creating the necessary critical mass to set up the FRESCOR EU project that started in June 2006 and coordinated by University of Cantabria. Many of the ART partners involved in the activity on flexible scheduling are also partners of the project. Given such common goals, the role of the flexible scheduling activity in ARTIST2 is to:

- Bring together a wide body of expertise from the whole ARTIST2 community to come out with a broad and ambitious set of requirements for the flexible scheduling framework;
- Use that expertise to establish and later evaluate the usefulness and applicability of a contract-based specification for the framework, that allows applications to express their requirements, and the scheduler to satisfy them in the most optimal way;
- Use the ARTIST2 community as one of the ways of disseminating the results of the FRESCOR project.

With these roles in mind, this is a great situation in which the FRESCOR project can benefit from the ARTIST2 NoE expertise, and the network can benefit from being able to influence the project, and from being able to exploit its results.

Other two consortia were formed thanks to the ARTIST2 network, which made two project proposals that are still in phase of preparation, PREDATOR (coordintated by University of Saarlandes) and QUAEST (coordintated by Philips Research), both involving several members of the networks.

Another merit of the ARTIST2 network was to create a concrete opportunity for a joint research involving the ART cluster and the Control cluster. Feedback scheduling has been proven to be an efficient technique for adaptive resource management in real-time systems. It combines two disciplines: real-time systems and control systems. Although both disciplines are well stablished, a stronger interaction between them is required to fully exploit the potential benefits.

During this second year, the two clusters closely collaborated to investigate research issues that can have a significant impact in the embedded community. Moreover, the teams were also quite active in disseminating the results through workshops, scientific publications and summer schools.

A new activity on real-time languages (led by Universtity of York) was started and a series of workshops and meetings were organized. This is proving a successful way of coordinating a broad base of research on different languages taking place at a number of institutions.

The work on networks has reached several encouraging technical and scientific results during year2. The most significant results correspond to further evolutions within the FTT framework, particularly, the successful development of FTT-SE (FTT over Switched Ethernet), which has been successfully applied to dynamic QoS management with video streams and to dynamic

service composition and which seems adequate to support the contract model efficiently in distributed environments. Additionaly, a significant amount of work has been done in the design, analysis and implementation of protocols, mechanisms and paradignms for wireless sensor networks (WSN) and Mobile Ad-hoc Networks (MANETs), notably WiDOM, ART-WiSe and HYDRA.

Two problems faced during these period, which are common in research, are the difficulties in installing and understanding a complex piece of software that is an operating system and the complexity of some research jobs, which makes it difficult for a single research group to provide solutions to some industrial needs. The complementary research activities of different partners has been of primary importance for the accomplishments done during this period: the advanced resource management facilities from SHARK and MARTE could allow the development of more sophisticated QoS management algorithms.

Another problem experienced in the activity on Adaptive Resource Management for Consumer Electronics came from the fact that Philips is in the process of disentangling its semiconductor division. As a consequence, research actively involved in ARTIST are spread over both parts and it is not clear who will be where. Consequently, some of the work has been slowed down or stalled. Once the issue is settled, we expect continuation of the activities. To compensate in part, Ericson Mobile Platforms has agreed to get involved, in particular in the adaptive resource management activity. Consquently, the activity has been broadened from “consumer electronics” to “media processing”, and the number of partners involved has been reduced.

4.2 Vision and Long Term Goals

The long term goal of the ART cluster is to build the fundamental bases of a new real-time software technology that can provide a more efficient and predictable support to the development of future embedded systems, whose complexity is constantly increasing. In particular, the new software technology should

- support scalability to facilitate the porting of control applications to different platforms;
- simplify the management of resources to control the growing complexity of embedded systems;
- increase programming flexibility, for specifying functional and performance requirements that simplify test and verification;
- increase system adaptivity to react to environmental changes, still providing a sufficient level of performance;
- be robust to tolerate transient and permanent overloads conditions due to wrong design assumptions or unpredictable changes.

Using such a novel software technology would be of paramount importance for European industry, because it would allow to have a better control of complexity, so reducing the time to market. Moreover, it would improve software realiability and testabilty, so reducing the time spent in debugging.

Scientific research would also benefit from such an evolutionary change, because new tools, algorithms and kernel mechanisms will be necessary to support industry in such a transient period. In this respect, the ART cluster will play an essential role for suggesting the appropriate research directions, acting as a bridge between the academic and the industrial world.

4.3 Future Work and Evolution

4.3.1 Technical Description

Concerning the JPIA activity on A Common Infrastructure for Adaptive Real-Time Systems, in the next 18 months we are planning to use Shark for understanding how to build a component-based operating system, where most of the available kernel features can be composed together to create several user-defined configurations.

In particular, a component based approach should separate mechanisms from policies in order to replace a scheduling algorithm or a resource management protocol without affecting the applications and the others components. In addition, it should allow combining different scheduling disciplines to support the development of hierarchical software architectures.

There are several benefits in adopting a component based approach at the operating system level. First of all, it would be possible to enhance the functionality of the kernel by adding new blocks, depending of the application requirements, so tailoring the kernel to the specific system to be developed. Secondly, it would facilitate and speed up the integration of novel research results, which could increase efficiency and/or predictability. Finally, it would simplify the process of porting the kernel on different platforms, so reducing the time to market and the development costs on upgrades (since only small parts should be developed).

To achieve these goals, there are several practical and theoretical problems to be solved, since most of the mechanisms implemented in a kernel (like scheduling, resource protocols, interrupt handling, aperiodic servers, synchronization and communication) heavily interact with each other and have a high degree of inter-dependencies. We plan to treat such problems by decoupling scheduling algorithms from applications, scheduling mechanisms from scheduling policies, scheduling algorithms from resource management protocols, and combining resource reservation with resource management protocols.

As for the activity on Flexible Scheduling Technologies, the first step in the work over the next period is the definition of a set of concrete requirements that provide the widest possible coverage of the needs described. Once the final set of requirements has been established, it is necessary to develop an architectural model of the framework and the applications, and describe the interfaces among them. The new framework will include all system resources in addition to the threads and networks: dynamically reconfigurable modules, multiple processors, interrupts with time protection, shared resources with time protection, memory protection, and energy/power-aware scheduling. Another goal in this period is to start the design of a quality of service manager that understands about the quality concepts of the application and translates them to the scheduling domain information that the underlying system can understand and implement, generating the contracts in an automatic or semiautomatic way.

In the next 18 months, the activity on Adaptive Resource Management for Consumer Electronics will expand the application domain to more general media processing, to provide for more industrial input, including non mass market video processing and telecommunication. It will continue to collect requirements to feed input to development of our adaptive methods, including the expanded application domain. It will expand the integration of resources to be managed jointly. With respect to scheduling and cache, it will develop algorithms to reflect on both scheduling and cache management. It will also develop algorithms for adaptation of fluctuating resources, in particular wireless bandwidth and stream transformations. Work on the use of kernels developed by partners for HOLA-QoS will continue and focus in particular on the integration of communication aspects.

As for the activity on QoS-Aware Components, the next period of time will start with the precise evaluation of the different methods achieved so far. For example, it is needed to test and measure the performance overheads caused by the new QoS management frameworks based

on HOLA-QoS, MARTE and SHARK. The adaptation capabilities of HOLA-QoS will be refined in order to take advantage of the advanced resource management techniques of these kernels. The support to distribution for Java and Ada will be subject of worst-case execution analysis, in order to have a precise knowledge of the required parameters needed to make response time analysis. It may be needed to develop specific analysis techniques for some of the potential communication protocols to be used. The results of these evaluation will guide the work of the final nine months. It is expected that some design adjustments will be done to improve the properties of these software.

For the activity on Real-Time Languages, a number of workshops are planned for the coming period, including the next International Real-Time Ada Workshop (IRTAW13) which will take place in the US (Boston area) in March 2007. This will be sponsored by ARTIST" and involve a number of ARTIST2 participants (see earlier discussion). ARTIST2 is also co-organising JTRES – the 4th Workshop on Java Technology for Real-time and Embedded Systems. This is scheduled for 11-13 October 2006 in Paris. The Work will continue on the evaluation of Ada 2005 including the use of new Ada 2005 real-time capabilities for EDF-based server scheduling (including capacity sharing and capacity stealing servers), and the use of proof-carrying code in Embedded Systemsr. Much of this work will be reported to IRTAW13. A further ARTIST meeting to look at implementation issue will occur in Spain in October 2006. Both of the above events will be used to define and extend the pattern of use that will allow these languages to be used in the programming of effective, adaptive and flexible real-time systems.

A new activity on Dynamic and Pervasive Networking is planned from October 2006 to September 2008, to address numerous research challenges in the frameworks of Wireless Sensor Networks (WSN), Mobile Ad-hoc Networks (MANETs) and Embedded Networked Systems. Within the next 18 months four tasks will be carried out. WSNs and MANETs will receive a special emphasis. Energy-awareness is turning out to become a major research challenge for wireless sensor networks, drawing into innovative and efficient networking protocols. There are already some breakthroughs achieved recently by teams within the ART cluster, which will be further exploited taking advantage of the inter-team work within the cluster. Examples are the works on dominance protocols (WiDOM) and on ZigBee/IEEE802.15.4 (ART-WiSe). On MANETs, various teams within the cluster have already made progress to the state-of-the-art concerning routing protocols, QoS adaptation and collaborative computing paradigms. Work in this area will be fostered within this activity. The task on wired networked systems will address the issues arising from the currently increasing integration within distributed embedded systems. Such issues include integrated global resource management, dynamic QoS management, on-line reconfiguration, open connections and flexible architectures. Several teams within the cluster have made recent proposals in related topics, such as the FTT paradigm and ServerCAN. The work in this task will foster the generation of new results that will allow improving design and resource efficiency as well as safety by means of adaptation, QoS contracts, traffic policing and active temporal isolation. A task on taxonomy will also be performed. Distributed sensing, actuation and cooperative computing involving small and tiny computing platforms appear as a basilar functionality in an ever crescent range of applications, including surveillance, environment and critical infrastructures monitoring, disaster recovery operations, distributed control, military operations, etc. The requirements imposed by these diverse applications necessarily imply different trade-off options on supported functionalities, quality of service, efficiency, platforms, protocols, architectures, etc. In this task we plan to elaborate on exemplificative applications, on their requirements and on how these map into technology design issues. This task will run throughout the next 9 months, although a first document will be produced by February 2007, with the purpose of early identifying research opportunities and opportunities to contribute to the diverse ongoing standardization processes. This will enable to better tune the efforts to put in the other tasks to be developed within this activity.

4.3.2 Current and Future Milestones

A Common Infrastructure for Adaptive Real-Time Systems

1. Year1 **(achieved)**: Initial definition of the operating system and network features. *The SHARK operating system developed at the Scuola Superiore Sant'Anna of Pisa has been identified (for the reasons explained in* Deliverable 2-2 JPIA-a-ART-Y1*) as the most suited kernel for building a common infrastructure to perform advanced experiments on real-time systems.*
2. Year2 **(achieved)**: Deploy a working platform for experimenting RTOS and network development. *The SHARK operating system was upgraded according to the partners' needs and deploied on each partner site. A specific workshop has been organized in Pontedera (Pisa) to teach partners how to use the kernel for writing a real-time application and how to write new scheduling and resource modules.*
3. **Year3: Participate in the evolution of RTOS and networking standards, by introducing advanced scheduling methods for enhancing the predictability of real-time systems and handle their increased complexity.**
4. **Year4: Identify the problems to be solved for developing a component-based real-time operating system.**

Adaptive Resource Management for Consumer Electronics

1. Year1 **(achieved)**: Identify case studies and perform preliminary assessment. *Inputs from ongoing projects in which partners are involved and industrial partners, in particular Philips, have been collected.*
2. Year2 **(achieved)**: Define a set of case studies and from them deduce the QoS requirements and their mapping into operational parameters of the computing and communication infrastructures. *Temporal requirements for video streaming from stream demands and the temporal impact of devices have been identified. Adaptive methods for resource management and QoS middleware have been developed. Relations have been identified, e.g., on wireless networks. The work has been carried out with inputs from projects and a workshop.*
3. **Year3: Expend these into a meaningful set of requirements of dynamic application domains (for instance, multimedia) that allow the creation of global mechanisms for resource management.**
4. **Year4: Integration of the application adaptation processes into a general QoS resource management structure.**

Flexible Scheduling Technologies

1. Year1 **(achieved)**: Preliminary work on the integration of diverse scheduling schemes. *Achieved for the case of CPU and energy, and CPU and network*
2. Year2 **(achieved)**: Demonstrate the combination of specific scheduling schemes applied both to CPU as well as to the network, to suit diverse application requirements in the same system. *This has been achieved both in theoretical developments for server-based hierarchical scheduling, and in practice through the FIRST scheduling framework.*

3. **Year 3: Define a set of requirements and an architectural model for the framework for flexible scheduling that integrates multiple resources, including CPUs and networks: dynamically reconfigurable modules, multiple processors, interrupts with time protection, shared resources with time protection, memory protection, and energy/power-aware scheduling.**

4. Year4: Provide a framework that allows the seamless integration of flexible scheduling schemes for integrated resources, allowing the choice of appropriate scheduling methods for individual activities in the different resources.

QoS aware Components

1. Year 1 **(achieved)**: Identification of the concrete integration topics: modeling of QoS properties in design models and components frameworks.

2. Year 2 **(achieved)**: Study and dissemination of the approaches from different partners. Definition of case studies for comparing the approaches and begin its modeling. *The work has concentrated on UML profiles for the description of extra-functional properties and on evolutions of CCM and Robocop as the components frameworks.*

3. **Year 3: Completion of the use cases using the different modeling approaches. Comparison and identification of guidelines on their use. Refinement of the modeling of some specific QoS properties and automatic model generation.**

4. **Year 4: Propose a modeling techniques that combines the best features of both for some selected extra-functional properties. Propose requirements for future QoS support on components framework. Develop proptotypes for proving the validity of some of the new identified new features.**

Real-Time Languages

Note that the activity on Real-Time Languages started in March 2006, so Year 3 milestones are after 18 months of activity:

Year2 **(achieved)**:

- Preliminary work in defining the future milestones and undertaking the necessary planning for future workshops, meetings, and joint work.

Year 3:

- **Organise and participate in the 13th IRTAW.**
- **Publish via a web site an initial set of patterns (repository) for use by Ada 2005 application programmers.**

Year 4.

- **Produce a white paper linking all real-time language work within ARTIST partners (including reference to external research effort where appropriate).**
- **Extend the repository**

Dynamic and Pervasive Networking

Note that this activity is going to start on October 2006:

Year 3

- **Organise a kick-off cluster meeting on this activity within the 4th quarter of 2006.**
- **Produce a white paper on taxonomy of Wireless Sensor Networks (WSNs) and Mobile Ad-Hoc Networks (MANETs), elaborating on exemplificative applications, on their requirements and on how these map into technology design issues (1st quarter of 2007).**
- **Identify and characterize network protocols to support integrated and dynamic resource management in distributed environments as necessary for on-line adaptation and reconfiguration.**
- **Organise and participate in the 6th International Workshop on RTN (3rd quarter 2007).**
- **Concrete contributions on MAC and Routing protocols for WSN, MANETs, systems of embedded systems and adaptive distributed embedded systems.(4th quarter 2007).**

Year 4

- **Contributions on distributed computing paradigms (e.g., computation of aggregate quantities, collaborative computing, reconfigurable systems) as well as on dynamic QoS management, flexible scheduling and generally resource management in distributed systems exploiting previously proposed mechanisms (e.g., MAC and routing protocols).**
- **Organize a summer school on Real-Time Networks, involving key players from industry and academia, possibly focusing on specific topics such as WSN and MANETs.**
- **A SOTA report on WSN and MANETs, with web publishing.**
- **Contributions to the standardization bodies (e.g., IEEE 802.15.4, IEEE 802.11.x, IEEE 802 AVBridges).**

5. Cluster Participants

5.1 Core Partners

Cluster Leader **Activity Leader for "NoE Integration: Low Power"**	
	Prof. Giorgio Buttazzo Scuola Superiore Sant'Anna (SSSA), Pisa (Italy) URL: http://feanor.sssup.it/~giorgio/
Technical role(s) within Artist2	Coordinating the ART cluster and the JPIA-Platform activity entitled "A Common Infrastructure for Adaptive Real-time Systems". Providing support on real-time scheduling, operating systems, resource management, overload handling, energy aware algorithms, and quality-of-service strategies.
Research interests	Real-time operating systems, dynamic scheduling algorithms, quality of service control, multimedia systems, advanced robotics applications, and neural networks.
Role in leading conferences/journals/etc in the area	Editor-in-Chief of the Journal of Real-Time Systems (Springer). Associate Editor of the Journal of Embedded Computing (Cambridge International Science Publishing). Executive Board Member of the Euromicro Conference on Real-Time Systems. Program Chair of RTSS'01, ECRTS'03, EMSOFT'04, HSCC'07. General Chair of RTSS'02, EMSOFT'04, ECRTS'07. Reviewer for Real-Time Systems, IEEE Transactions on Computers, ACM Transactions on Embedded Computing. Program committee member of most real-time related conferences.
Notable past projects	"FIRST: Flexible Integrated Real-time Systems Technology", IST-2001-32467 (2002-2005) investigated advanced scheduling for handling applications with various real-time requirements. "OCERA: Open Components for Embedded Real-time Applications", IST-2001-35102 (2002-2005) integrated advanced real-time mechanisms in open-source kernels. "FABRIC: Federated Applications Based on Real_time Interacting Components", IST-2001-37167 (2002-2003) investigated QoS management methods for home networks.

	"ARTIST: Advanced Real-Time Systems", IST-2001-34820 (2002-2005) investigated adaptive real-time systems for QoS management. "TRACS - Flexible Real-Time Architecture for Traffic Control Systems", ESPRIT III project No. 6373 (1992-1995) investigated real-time techniques for vessel control systems.
Awards	Best paper Award at the 10th Int. Conference on Real-Time and Embedded Computing Systems and Applications (RTCSA 2004), Gothenburg, Sweden, August 2004. Paper: "The Jitter Margin and Its Application in the Design of Real-Time Control Systems". Award for the best paper and presentation at the ANIPLA Workshop on Operating Systems for Industrial Control Applications, Milan, November 18, 1999. HUSPI Award given by Honeywell for the best journal publication on robotic systems, November 1987.
Further Information	Senior Member of IEEE

Team Leader **Activity Leader for "Real-Time Languages"**	
	Professor Alan Burns University of York, UK URL: www.cs.york.ac.uk/~burns
Technical role(s) within Artist2	Undertakes research in real-time systems scheduling, particularly for flexible systems. Also concerned with the development of programming languages for this domain.
Research interests	Scheduling, languages, modelling and formal logics.
Role in leading conferences/journals/etc in the area	Previous Chair of the IEEE Technical Committee on Real-Time Systems. Edited special issue of ACM Transactions on Embedded Systems (on education).
Notable past projects	DIRC – Dependability Interdisciplinary Research Collabroations – A large, UK, 6-year, multisite project looking at dependability of computer-based systems. Burns was a PI and manged the work on temporal aspects of dependability. FIRST – EU funded project concerninf flexibile scheduling FRESCOR – EU follow on project to FIRST

Team Leader **Activity Leader for "Adaptive Resource Management for Consumer Electronics"**	
	Prof. Gerhard Fohler Technical Univeristy of Kaiserslautern (TUKL) URL: www.eit.uni-kl.de/fohler
Technical role(s) within Artist2	The role of TUKL is to investigate resource management policies for controlling the quality of service in multimedia applications. The team is leading the activity on Adaptive Resource Management for Consumer Electronics and is involved in the development and analisys of algorithms for video streaming applications. A further focus is on flexible scheduling, with the aim of integrating offline and online approaches.
Research interests	Real-time scheduling, integration of offline and online scheduling, QoS management, video streaming and media processing.
Role in leading conferences/journals/etc in the area	Chairman, technical committee on real-time systems, Euromicro Member of executive board technical committees on, IEEE real-time systems, IE embedded systems Area editor real-time, Journal of System Architecture, Elsevier Program chair, IEEE Real-Time Systems Symposium, 2006 Program chair, subtrack real-time systems, DATE 2005-2007 Program committee member of most real-time related conferences
Notable past projects	FRESCOR - Framework for Real-time Embedded Systems based on COntRacts, EU IST STREP WASP - Wirelessly Accessible Sensor Populations, EU IST IP BETSY - BEing on Time Saves energY continuous multimedia experience with low battery power, EU IST STREP FIRST - Flexible Integrated Real-Time System Technology, EU IST STREP

Team Leader **Activity Leader for "Flexible Scheduling Technologies"**	
	Prof. Michael González Harbour Universidad de Cantabria http://www.ctr.unican.es
Technical role(s) within Artist2	The role of University of Cantabria is to provide support for schedulability analysis of embedded distributed systems with real-time requirements. The Group has also developed methodologies and tools for software engineering of real-time systems in which a mixture of soft and hard deadlines can be found and as such is leading the activity on Flexible Scheduling Technologies. The group is also actively participating in the development of the Real-time POSIX operating systems standards, and is active in real-time languages, (Ada) and therefore contributing to the platform being used in the Real-Time Languages activity. One important goal of the Group has always been to test the results of basic research in practical applications. As a consequence, the Group has contacts with industrial companies in the field of industrial automation.
Research interests	Real-Time Schedulability Analysis, Real-Time Operating Systems, Real-Time Languages, Real-Time networks
Role in leading conferences/journals/etc in the area	Program chair of ECRTS 07, Program Co-Chair of the International Conference on Reliable Software Technologies 2006, Program Committee Member of RTAS, RTSS, ECRTS, and various Workshops on real-time systems.
Notable past projects	FRESCOR, Framework for Real-time Embedded Systems based on COntRacts. The FRESCOR project is aimed at developing a framework that integrates advanced flexible scheduling techniques directly into an embedded systems design methodology, covering all the levels involved in the implementation, from the OS primitives, through the middleware, up to the application level (www.frescor.org)

Team Leader	
	Prof. Luis Almeida University of Aveiro URL: http://www.ieeta.pt/lse

Technical role(s) within Artist2	Leader of the team from the University of Aveiro, participating in the ART cluster.
Research interests	Real-time communication (traffic scheduling, protocols,…) Flexible architectures for distributed embedded systems
Role in leading conferences/journals/etc in the area	Usually participates in the Organizing and /or Program Committees of conferences in the fields of Real-Time Systems (e.g., RTSS, ECRTS, RTAS) and industrial communications (e.g., WFCS, ETFA, FET). Has chaired several workshops (e.g., RTN, WTR, WiP sessions). Reviewer for several related journals (e.g., IEEE TII, TIE, TC, ACM TECS, Kluwer JRTS)
Notable past projects	ARTIST (FP5 accompaning measure). CAMBADA – Cooperative Autonomous roBots with Advanced Distributed Architecture. Specification and development of a team of cooperating autonomous robots for the Robocup Middle-Size Soccer League. Particular focus has been devoted to the architecture of each robot and their communication for information sharing. http://www.ieeta.pt/atri/cambada/ DISCO, DIStributed embeddable systems for COntrol applications. The objectives of the project were to investigate techniques and to develop solutions to improve flexibility and adaptability in distributed embedded control systems in order to reduce operation and maintenance costs while maximising the utilisation of system resources. http://www.ieeta.pt/lse/DISCO_web.pdf CIDER, Communication Infrastructure for Dependable and Evolvable Real-time systems. The project pursued two objectives: to analyse the usability of Ethernet in dependable applications (static set-up) and to devise the necessary mechanisms to allow the set-up to change dynamically (dynamic set of services and hosts) while providing the required dependability. http://www.hurray.isep.ipp.pt/activities/cider/
Awards	Best Paper Award in WFCS 2004 Best Paper Award in SICICA 2000

Team Leader	
	Professor Juan A. de la Puente Universidad Politécnica de Madrid URL: http://www.dit.upm.es/jpuente

Technical role(s) within Artist2	Team Leader of the Universidad Politécnica de Madrid, UPM leader on “Real-Time languages” and “Common infrastructure for Adaptive Real-Time Systems”
Research interests	Design of real-time systems, high-integrity systems, programming languages, scheduling, control systems and distributed systems
Role in leading conferences/journals/etc in the area	Associate editor of the Journal of Real-Time Systems. Participation in the Programme Committee of conferences such as Euromicro Real-Time Systems, International Conference on Reliable Software Technologies.
Notable past projects (optional – max 5)	ASSERT: Developmet of advance software techniques for high integrity systems for aerospace systems. TRECOM: Techniques for the development of advanced distributed real-time systems for safety and business critical systems. ORK (Open Ravenscar Real-TIme Kernel): Development of a kernel for safety-critical space systems.
Awards / Decorations	IFAC Fellow

Activity Leader for “Qos-aware components”	
	Prof. Alejandro Alonso Universidad Politécnica de Madrid. URL: http://www.dit.upm.es/aalonso
Technical role(s) within Artist2	Activity Leader for “Qos-aware components” UPM leader on Adaptive resource management for CE”
Research interests	Design of real-time systems, programming languages, scheduling, distributed systems and quality of service
Role in leading conferences/journals/etc in the area	Participation in the Programme Committee of conferences such as Euromicro Real-Time Systems, International Conference on Reliable Software Technologies.
Notable past projects	HIJA: High-Integrity Java Applications. The goal is to develop a new Java-based middleware platform fo the creation of Architecture-Neutral, high-integrity, distributed Real-Time Systems (ANRTS) ROBOCOP and Space4U. Development of component framework for embedded devices. It includes support for QoS and resource management. TRECOM: Techniques for the development of advanced distributed

	real-time systems for safety and business critical systems.

Team Leader **Activity Leader for "Dynamic and Pervasive Networking"**	
	Prof. Eduardo Tovar Polytechnic Institute of Porto (ISEP-IPP), Porto (Portugal) URL: http://www.hurray.isep.ipp.pt/asp/show_people.asp?id=1
Technical role(s) within Artist2	The role of ISEP-IPP team is to investigate distributed embedded systems, with a particular focus on communication protocols for WSN and MANETs. The team is leading the activity on Real-Time Networks and involved in flexible scheduling technologies, resource management policies and QoS-aware collaborative computing. The team has also a strong commitment in Real-Time Languages.
Research interests	Real-time systems, wireless sensor networks, multiprocessor platforms, communication networks, factory automation and system integration.
Role in leading conferences/journals/etc in the area	Executive Board Member of the Euromicro Technical Committee on Real-Time Systems. Program Chair ECRTS'05, RTN'02, WDES'06. General Chair of WFCS'00, ECRTS'03. Program committee member in several editions of ERCTS, RTSS, RTAS, RTCSA, ICDCS, SRDS, WFCS, ETFA, EMSOFT and other IEEE, ACM and Euromicro events on real-time systems, embedded systems and factory communication systems. Reviewer for Real-Time Systems, IEEE Transactions on Computers, ACM Transactions on Embedded Computing, IEEE Transactions on Industrial Informatics.
Notable past projects	"REMPLI: Real-time Energy Management via Power-lines and Internet", NNE5-2001-00825 (2003-2006) investigated advanced scheduling and protocols for power-line communication systems (PLC). "R-Fieldbus: High Performance Wireless Fieldbus in Industrial Multimedia-Related Environment", IST-1999-11316 (2001-2003), integrated advanced real-time mechanisms in hybrid wired/wireless fieldbus neworks. Mobility protocols and end-to-end deadlines.. "CABERNET: Network of Excellence in Distributed Computing Systems Architectures", IST-2000-25088 (2001-2003). "CIDER: Communication Infrastructure for Dependable Evolvable

	Real-time systems", POSI/1999/CHS/33139 (2001-2003), Portuguese Science Foundation project on real-time communication networks.
Further Information	Senior Member of IEEE

5.2 Affiliated Industrial Partners

Team Leader	
	Dr. Paolo Gai (Ph.D.) Evidence srl (Italy) URL: http://feanor.sssup.it/~pj/
Technical role(s) within Artist2	Support for the SHaRK kernel maintenance, consulting on POSIX and OSEK standards, real-time kernels, design and analysis tools.
Research interests	Real-time scheduling, operating systems, design and analysis tools.
Notable past projects	FIRST: Flexible Integrated Real-time Systems Technology, IST-2001-32467 (2002-2005) investigated advanced scheduling for handling applications with various real-time requirements. OCERA: Open Components for Embedded Real-time Applications, IST-2001-35102 (2002-2005) integrated advanced real-time mechanisms in open-source kernels. ARTIST: Advanced Real-Time Systems. (http://www.artist-embedded.org)

5.3 Affiliated Academic Partners

Team Leader	
	Prof. Lucia Lo Bello University of Catania (Italy) – Affiliated to SSSA, Pisa URL: http://www.diit.unict.it/users/llobello/
Technical role(s) within	Support for the SHaRK kernel maintenance. Implementation of

Artist2	industrial multimedia system using SHARK. Execution time measurement. Stochastic analysis of soft real-time tasks in the context of priority-driven soft real-time systems. Calculation of stochastic response time profiles of tasks that are hierarchically scheduled using server based techniques. Support for real-time communication in distributed embedded systems, with particular reference to networked embedded systems used in factory communication and in automotive environments. Real-time communication over wireless networks: modelling, timing analysis, and transmission scheduling to support soft real-time traffic over 802.11, 802.15.4 and Bluetooth networks. Design issues and protocols for wireless sensor networks and networked embedded systems.
Research interests	Real-time scheduling, overload handling, real-time communication protocols, factory communication, real-time communication over wireless networks, wireless sensor networks, automotive communications.
Role in leading conferences/journals/etc in the area	Program Chair of ETFA 05, ETFA 07. WIP Chair of ETFA 06. General Chair of ECRTS 04. PC member of many editions of ECRTS, RTSS;,RTAS,ETFA, WFCS, RTN , FET, RTNS ,WTR. Reviewer for the Real-Time Systems Journal, IEEE Transactions on Industrial Informatics, IEEE Transactions on Industrial Electronics, IEEE Transactions on Computers, Computer Standard and Interfaces, Journal of System Architectures. On the Editorial Board of the International Journal of Embedded Systems.
Notable past projects	Italian National project PRIN 04 entitled “Study and development of a realtime land control and monitoring system for fire prevention”, funded by the Italian Ministry of University and Research (http://www.prin.polito.it/) European project ESPRIT 26951 "NOAH - Network Oriented Application Harmonisation. Italian National COFIN 2001 inter-university project titled ‘’High-Performance Processing for Applications with High-Intensity Computational Requirements and Real-Time Constraints, funded by the Italian Ministry of University and Research (http://tsc.polito.it:7777/cofin2001/)
Further Information	Member of the International Electrotecnical Commission (IEC), Technical Committee SC65C, Working Group 11, Real-Time Industrial Ethernet (RTE), actively involved in standardization activities. Nominated expert member for the Italian Electrotechnical Committee (CEI-Comitato Elettrotecnico Italiano) in the Technical Committee

	SC65C “Digital Data Communications for Measurement and Control-Fieldbus for Use in Industrial Control Systems”, Maintenance Team 9, “High availability automation networks". Member of the Technical Committee on Factory Automation of the Industrial Electronics Society (IES). Co-chair of the Subcommittee 10 “Intelligent Sensors and Sensor Networks in Industrial & Factory Automation”.

Team Leader	
	Dr. Pau Martí Technical University of Catalonia, Barcelona, Spain URL: http://www.upcnet.es/~pmc16/
Technical role(s) within Artist2	Real-time systems and control systems co-design
Research interests	Real-time and control systems, overload handling, jitter analsyis and compensation, control theory.
Role in leading conferences/journals/etc in the area	Program committee member of major real-time and control conferences. Reviewer for the Real-Time Systems Journal.

Team Leader	
	Prof. Ivo De Lotto Robotic Lab, University of Pavia, Italy http://www.unipv.it/ingegneria/servizi/scheda.php?mat=000300
Technical role(s) within Artist2	Provide support for the development of real-time control applications in the domain of robotics and automation.
Research interests	Sensory systems, robotics applications, wireless communication, energy-aware computing.
Role in leading conferences/journals/etc in the area	Program committee member of major conferences on robotics. Reviewer of International journals on robotics. Member of the evaluation committee for national projects.
Awards / Decorations	Gold Medal of Italian Ministry of Education (1988)

Team Leader	
	Prof. Marisol García-Valls Universidad Carlos III de Madrid URL: http://www.it.uc3m.es/mvalls
Technical role(s) within Artist2	UC3M leader on Adaptive resource management for CE”
Research interests	Distributed embedded systems, design and modelling of real-time systems, real-time programming languages, quality of service
Role in leading conferences/journals/etc in the area	Member of the Programme Committee of conferences such as ARCS 06, EstiMedia 04-06, JTRES 03-04, EUC 05, EMSOFT 03-04 Reviewer of the Real-Time Systems Journal
Notable past projects	ARTIST: Advanced Real-Time Systems. URL: http://www.artist-embedded.org MUSE: MUlti Service Access Everywhere Everyware: Personalized services in ubiquitous environments

Team Leader	
	Prof. Julian Proenza University of the Balearic Islands URL: http://dmi.uib.es/research/SRV/jpa_ppl_en.htm
Technical role(s) within Artist2	Team leader of affiliated partner. Indirect participation in ART Cluster, with the core team University of Aveiro
Research interests	Dependable and Real-Time Systems, in particular, on fault-tolerant distributed systems, clock synchronization and field-bus networks, like CAN (Controller Area Network).
Role in leading conferences/journals/etc in the area	Chair of several workshops in his fields of interest. Participation in several Organizing and Program Committees of related events.