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Network of Excellence  
on Embedded Systems Design

Activity Progress Report for Year 4

JPRA-Cluster Integration  
**Flexible Resource Management for Real-time  
Systems**

2008-09-30

Clusters:

**Adaptive Real-time Systems**

Activity Leader:

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<http://rts.eit.uni-kl.de>

*Policy Objective (abstract)*

*Resource management in many embedded systems application domains (including consumer electronics, robotics, automotive and telecommunications) faces the challenges of highly variable resource demand, highly variable resource availability, distributed architecture, and strong requirements for resource.*

*Hence, the objective of the research is to exploit the excellence of the different teams for advancing the state of the art in the theory and practice of techniques leading to adding the required flexibility to the resource management in these systems. The challenge is to develop an efficient resource manager that can be adopted in next generation kernels to perform adaptive QoS control of time sensitive applications with dynamic characteristics.*

*The former activities "Flexible Scheduling Technologies" and "Adaptive Resource Management for Consumer Electronics" have been merged into this activity.*

## Table of Contents

|  |    |
|--|----|
| 1. Overview of the Activity .....  | 3  |
| 1.1 ARTIST Participants and Roles .....                                      | 3  |
| 1.2 Affiliated Participants and Roles .....                                  | 3  |
| 1.3 Starting Date, and Ending Date .....                                     | 3  |
| 1.4 Baseline .....   | 4  |
| 1.5 Problem Tackled in Year 4 .....  | 4  |
| 1.6 Comments From Year 3 Review .....  | 5  |
| 1.6.1 <i>Reviewers' Comments</i> .....                                       | 5  |
| 1.6.2 <i>How These Have Been Addressed</i> .....                             | 5  |
| 2. Summary of Activity Progress .....  | 6  |
| 2.1 Previous Work in Year 1 .....  | 6  |
| 2.2 Previous Work in Year 2 .....  | 6  |
| 2.3 Previous Work in Year 3 .....  | 9  |
| 2.4 Current Results .....  | 10 |
| 2.4.1 <i>Technical Achievements</i> .....                                    | 10 |
| 2.4.2 <i>Individual Publications Resulting from these Achievements</i> ..... | 15 |
| 2.4.3 <i>Interaction and Building Excellence between Partners</i> .....      | 18 |
| 2.4.4 <i>Joint Publications Resulting from these Achievements</i> .....      | 19 |
| 2.4.5 <i>Keynotes, Workshops, Tutorials</i> .....                            | 20 |
| 3. Milestones, and Future Evolution Beyond the NoE .....                     | 22 |
| 3.1 Milestones .....   | 22 |
| 3.2 Indicators for Integration .....   | 22 |
| 3.3 Main Funding .....   | 23 |
| 3.4 Future Evolution Beyond the Artist2 NoE .....                            | 23 |
| 4. Internal Reviewers for this Deliverable .....                             | 24 |

# 1. Overview of the Activity

## 1.1 *ARTIST Participants and Roles*

Activity Leader: Gerhard Fohler - Technische Universität Kaiserslautern

Role: resource management framework, video streaming, wireless networks

Team Leader Giorgio Buttazzo - Scuola Superiore S. Anna

Role: scheduling mechanisms for temporal isolation

Team Leader Michael Gonzalez Harbour - University of Cantabria

Role: end-to-end timing analysis of distributed systems

Team Leader Luis Almeida - University of Aveiro

Role: Bandwidth adaptation in networks

Team Leader Eduardo Tovar - Polytechnic Institute of Porto

Role: communication protocols for wireless networks

Team Leader Alejandro Alonso - UP Madrid

Role: adaptive techniques for QoS

Team Leader Alan Burns – University of York (UK)

Role: fixed priority schemes and real-time languages

## 1.2 *Affiliated Participants and Roles*

Team Leader Marisol García-Valls - U. Carlos III, Madrid

Role: QoS management

Team Leader Liesbeth Steffens - NXP

Role: consumer electronics, video streaming, multi resource management

Team Leader Ivo De Lotto – University of Pavia (Italy)

Role: dynamic priority schemes

Team Leader Lucia Lo Bello – Univ. of Catania (Italy)

Role: communication protocols and stochastic scheduling

## 1.3 *Starting Date, and Ending Date*

The activity started in Sept 2006 as the merger of the previous Cluster Integration Activities “Flexible Scheduling Technologies”, and “Adaptive Resource Management for Consumer Electronics”. The activity has ended in Sept 2008, with the identification of research topics of industrial relevance and example solutions. The subject of the activity is a hot research topic so work on its topics will continue in the future.

## 1.4 Baseline

In some application domains, such as multimedia, applications are very expensive in terms of resource consumption. In other applications domains, such as automotive, mobile telephony or even building automation, the resources are scarce and there is a growing pressure to integrate resources even further and optimize their use. In both cases, timeliness directly relates to user perceived quality, e.g., smoothness of the video stream. Furthermore, efficient resource usage is key issue not only for cost considerations, but also for competition on a feature bases: better resource usage – more features.

Both resource demands, e.g., MPEG-2 video streams, and resource availability, e.g., available bandwidth on wireless links, fluctuate rapidly and unpredictably; worst case assumptions will lead to extreme over provisioning. Consequently, methods for adaptive resource management are required.

Trading resource usage (processing, communication and memory/storage, inter-device and intra-device) against offered output is known as QoS (Quality of Service). The different resources cannot be considered separately, interferences and inter-resource tradeoffs have to be taken into account because they affect the application output. The tradeoffs have to be made at different time scales, in order to match the time scales of the system dynamics.

Theory for independent scheduling algorithms is well defined in the areas of event triggered and time triggered systems, but few theoretical results have been achieved in trying to integrate these approaches. Some partial results exist for simplified architectures, but it is necessary to enhance them by taking into account all of the requirements of modern real-time systems including distributed ones. In addition to the development of theory, a framework needs to be built in order to allow a flexible way to handle different scheduling algorithms for different kinds of resources, and evaluate their applicability to real application domains.

## 1.5 Problem Tackled in Year 4

The objectives of the activity in the second year crystallised around the following issues:

- **Application requirements.** The characteristics of adaptive applications diverge significantly from the classic, static models: the amount of resources needed varies largely and differently for resource. In a joint effort with the FRESCOR project, application domains covered in the activity were considered.
- **Adaptive Management of Multiple Resources.** The resources typically used in end-to-end delivery of streams often exhibit fluctuating availability and interdependencies. Wireless networks, for example, are influenced by interference, mobility, or physical structures, which cannot be known before system deployment.

Even on single devices, a number of resources will be interdependent making the issue of multi resource management important. The focus of efforts has been put towards integrating CPU scheduling and cache management for efficient cache use and predictability.

- **QoS Middleware.** In addition to these effects on single devices, the fluctuating resource availability has to be dealt with on a system wide level as well, allowing the system to make QoS adaptation decisions in response to fluctuations in the nodes' service load, under the control of the user. Since complex dynamic real-time scenarios may prevent the possibility of computing optimal service configurations before execution, iterative refinement approaches with the ability to trade off deliberation time for the quality of the solution will be more practical. Another issue is the adaptation of distributed QoS negotiation policies and the integration of this middleware with communication protocols.

- **Flexible scheduling Technologies.** Handling multiple concurrent activities with different criticality and timing constraints (e.g., periodic, aperiodic, time driven, event driven tasks) in the same system requires a development of an integrated flexible scheduling framework. Work on the first three years of this activity has focused on the integration of diverse scheduling schemes, such as fixed priority based, dynamic priority based, and offline construction into a single coherent set, on the development of new theory for the case of energy-aware scheduling, and on the requirements for the flexible scheduling framework. Work in the current year has focused on the integration of different resources into the same flexible scheduling framework, by extending and further refining the requirements for the framework, and by starting its implementation.
- **Overload management techniques.** A number of overload management techniques have been tested to evaluate their impact on real-time systems. In particular, *Resource Reservations* and *Elastic Scheduling* techniques have been evaluated to cope with transient and permanent overload conditions. *Resource Reservations* techniques basically isolate the temporal behaviour of a task (or subset of tasks) protecting the rest of the systems from potential overruns. On the other hand, *Elastic Scheduling* provides an effective solution to cope with permanent overload conditions. According to this method, task utilizations are treated as flexible springs that can be compressed (by enlarging periods) to reduce the load up to a desired value. Such novel techniques (not yet available in commercial operating systems) have been implemented into Shark as basic scheduling modules to be tested and evaluated in actual control applications.

## 1.6 Comments From Year 3 Review

### 1.6.1 Reviewers' Comments

*"The document is very well written even if it would have benefited from a more concise style on section 2.2 and perhaps 2.3. The list of publication is important. The actions of cooperation between partners could be presented in more detail. The work plans for year 4 are quite clear. The indications in the last paragraph of section 2.3.1 that repeat "Describe the Technical Achievement here in clear and concise terms" is appreciated from a reviewer's point of view but must be removed Page 10 of 19 in the final version. The deliverable is accepted taking into account the modification done after the pre-review."*

### 1.6.2 How These Have Been Addressed

- Section 2.2 has been revised for a more concise style, sections 2.3 (in this year's deliverable) and 2.4 written with the comment in mind
- The mentioned paragraph in section 2.3.1 has been removed.

## 2. Summary of Activity Progress

### 2.1 Previous Work in Year 1

In the first period, the technical results were achieved in the following areas: video stream demand analysis, identification of scheduling algorithms and kernel mechanisms for stream adaptations based on integrated, flexible scheduling; adaptive resource management for network bandwidth management, multi resource management, in particular with respect to cache aware scheduling; middleware support for QoS management.

Furthermore, the ART cluster has been in active contacts with relevant industry to gather understanding of realistic requirements and to identify research topics and baselines relevant for industrial and academic research. Partners has been giving presentations at the Philips Software Conference – Real-time Workshop and had meetings with Nokia, Ericsson mobile platforms and Visual Tools from Spain. The goal has been to go as far as possible towards the actual engineers for better understanding and prepare for a specific industry – academia workshop with selected participants.

New scheduling mechanisms for integrating overload management techniques with energy-aware strategies were investigated in the context of real-time systems. The new scheduling mechanisms were analysed to guarantee timing constraints while minimizing energy consumption, and a kernel infrastructure was developed into the Shark operating system in order to facilitate their implementation. Moreover, the assessment of the (m,k)-firm model was done for its implementation over the FTT-Ethernet protocol.

### 2.2 Previous Work in Year 2

#### Temporal Constraints for Video streaming

Philips and TUKL have studied temporal constraints of video streaming. As sources for the constraints we looked into semantic stream dependencies from MPEG decoding, as well as the temporal impact of devices and their resources in the end-to-end delivery chain of a stream. The work was carried out with industrial partners in the area. The results have been fed into other activities in the cluster, in particular w.r.t. to scheduling and networking. <http://rts.eit.uni-kl.de/research/mediaprocessing>

#### Integrated real-time scheduling and cache management

Philips and TUKL continued work on integrating real-time scheduling and cache management on multiprocessor platforms. To this end, we carried out experiments to study cache behaviour on the actual platform and formulated a number of scenarios with increasing complexity. A joint PhD student has carried out the work.

#### Adaptive service configuration for Quality-of-Service aware middleware

In order to support dynamic services with adaptive QoS requirements, we proposed a dynamic scheduler which is able to react to load variations. Isolation between different services is still achieved by guaranteeing a minimal service quality to accepted services and by an efficient overload control that considers the challenges and opportunities of dynamic distributed embedded systems. This scheduler was also extended taking into consideration simple dependencies between services' QoS attributes.



## Server Based Flexible Scheduling

Schedulability analysis techniques were developed for server-based systems that can be used to schedule different kinds of flexible timing requirements, such as those needed to integrate control systems with multimedia activities. In particular, this work focused on hierarchical scheduling analysis and design techniques. A further issue was the dimensioning of the parameters of a server for minimizing the average response time of the served activities. A statistical approach was addressed in order to compute the probability of missing a given deadline. Partners were SSSA, Cantabria, TUKL of the cluster and the partners of the FIRST and FRESCOR EU STREP consortia. [www.frescor.org](http://www.frescor.org)

## Adaptive resource management for networks

Work concerned the analysis of the achievable QoS guarantees in wireless networks. The achievable end-to-end QoS guarantees were investigated as a function of the guarantees provided by the underlying resource schedulers. Further activities dealt with network protocols to efficiently support dynamic bandwidth management with strict QoS guarantees in Ethernet-based networks, a wireless time-token communication protocol that allows providing real-time guarantees for real-time messages and tune the allocated bandwidth according to the required QoS was developed. Aveiro, Porto, SSSA, and TUKL carried out work.

<http://www.hurray.isep.ipp.pt/activities/art-wise/>

<http://rts.eit.uni-kl.de/research/mediaprocessing>

## Adaptive service configuration for Quality-of-Service aware middleware

An iterative refinement approach with the ability to trade off deliberation time for the quality of the solution was specified. The work also addressed the problem of dynamically changing system conditions, allowing the system to make QoS adaptation decisions in response to fluctuations in the nodes service load, under the control of the user. Monitoring the stability period and resource load variation of Service Level Agreements for different types of services was used to dynamically adapt future stability periods, according to a feedback control scheme. Work was done by Madrid and Porto ([www.hurray.isep.ipp.pt/activities/qos](http://www.hurray.isep.ipp.pt/activities/qos)).

Cluster partners have developed kernels that provide these facilities and, hence, could be suitable to act as the lower layer of a HOLA-QoS based system. Work that it was under development was to port HOLA-QoS on top MARTE (Cantabria) and SHARK (Pisa) kernels. One result of this work is the possibility of experimenting with the adaptation techniques that these advanced resource kernels provide. Some publications on HOLA-QoS can be found at <http://www.dit.upm.es/str>.

## Resource availability prediction

The resources typically used in-home entertainment applications (e.g., video/audio streaming) exhibit fluctuating availability. It is desirable to have mechanisms for indicating the available bandwidth during system runtime.

A comparative analysis of bandwidth estimation techniques for WiFi links has been carried out. In particular, the analyzed estimation techniques include several statistical and control-based algorithms. The analysis has identified the best suitable techniques taking into account the specific behavior of WiFi links. Work was carried out by UPC and TUKL. Analysis available at

[http://www.upcnet.es/~pmc16/nde\\_06.pdf](http://www.upcnet.es/~pmc16/nde_06.pdf).

## Requirements for integrated-resource scheduling framework

A workshop on “Requirements for Flexible Scheduling in Complex Embedded Systems” was

held in Massy (Paris) in June 2006, with the objective of developing a set of requirements for building a flexible scheduling framework for applications demanding various types of tasks, constraints, and scheduling paradigms within the same system, and paying attention to the integration of multiple resources. The workshop was very successful and brought together 20 participants.

### **Baselines for integrated-resource scheduling framework**

The FIRST (Flexible Integrated Real-Time Scheduling Technologies) IST project that finished in 2005 produced as its main result a contract-based scheduling framework, called FSF that was capable of scheduling multiple application components with various kinds of requirements for CPUs and, to a limited extent, for networks in distributed systems. This framework was selected as the baseline for the more ambitious framework that is being developed in this activity and that will take into account the integrated scheduling of multiple resources.

The FTT framework, in which a master manages the synchronous activities in a distributed system or cluster, was also extended to micro-segmented switched Ethernet-based distributed systems, having revealed potential to provide efficient support to the contract model, to dynamic QoS management and to integrated resource scheduling in distributed environments. The VTPE protocol (Virtual Token-Passing Ethernet), which supports event-triggered communication with real-time guarantees and high bandwidth utilization, was also extended with appropriate mechanisms to support isochronous traffic, more adequate for some applications, e.g. multimedia transmission.

### **New theoretical developments**

The contract-based scheduling framework needs to be implemented using a specific scheduling strategy, and the most effective approach for this case is the server-based hierarchical scheduling in which an application or application component is scheduled over a protected bandwidth-preserving server (such as a periodic server, a sporadic server, or a constant bandwidth server) and individual threads in that component are scheduled by a higher-level scheduler that uses the bandwidth provided by the server. Theory was developed towards being able to analyze such scheduling schemes. Work was done by the University of York together with Technische Universiteit Eindhoven (TU/e) on the analysis underpinning the use of CAN in real-time systems.

SSSA developed the following theoretical results: energy-aware scheduling algorithms for processors with dynamic voltage scaling and discrete frequency levels; a method for minimizing the deadline of periodic tasks with the objective of reducing delay and jitter; a general methodology for performing sensitivity analysis of fixed priority periodic systems with configurable periods and computation times, allowing the system designer to derive the feasibility region of a task set and compute the maximum parameter variations that keep the system feasible

Work carried out at the University of Aveiro also exposed a couple of anomalies related to the definition of critical instant in hierarchical scheduling scopes found in communication systems that led to optimistic worst-case response time analysis in the past. Adequate methods were devised to cope with such anomalies.

The Polytechnic Institute of Porto provided new theoretical developments on: a new multiprocessor scheduling approach with a higher utilization bound and with few preemptions, able to trade the utilization bound for preemptions; new flexible admission control algorithms for IEEE 802.15.4 networks improving the bandwidth utilization compared to the explicit allocation used in the IEEE 802.15.4 protocol; a new server-based scheduling approach for handling isolation and overload control on distributed cooperative systems;



**Flexible architectures and communication protocols for networks used in distributed embedded real-time systems**

This research was partly done in collaboration between the following ARTIST 2 partners: University of Pavia, University of Catania (affiliated partner) and Malardalen University, Sweden. It consists of the following activities:

- Integration of networked subsystems in a resource constrained environment.
- Facilitating subsystem integration by decoupling priority and identifier in CAN messages.
- Interconnection of real-time networks in factory automation and in the automotive domain.
- Design issues and transmission protocols for wireless networks used in factory communication
- Bluetooth to support real-time traffic in factory communication.
- Modelling of wireless real-time communications for land monitoring systems.

In addition, a joint work was done by Pavia, Pisa and Aveiro to support connectivity tracking in mobile ad-hoc wireless networks subject to real-time constraints.

**2.3 Previous Work in Year 3**

The collection of application requirements has been extended beyond the video streaming domain. Activities were carried out in particular together with the FRESCOR project, including a joint requirements workshop and a meeting with the industrial advisory board of FRESCOR on the topic.

Algorithms for the integration of CPU scheduling and cache management have been developed and analysed for their effectiveness on actual boards.

An architecture for flexible functional composition on networked real-time applications was developed.

An architectural model of a flexible scheduling framework has been developed. The framework is capable of handling multiple concurrent activities with different criticality and timing in the same system, integrating the management of different kinds of resources such as processors, networks, memory, energy, and shared objects with time protection.

The flexible scheduling framework has been implemented for different execution platforms and networks.

A number of new theoretical results have been developed.

The feedback control approach has been applied to server-based real-time systems, in order to automatically control the partial utilization of each server and for online adaptation for networks.

The HOLA-QoS and the AquoSA framework have been continued and adapted for use with other kernels by cluster partners.

An architecture to support dynamic service composition has been devised

Methods for soft real-time systems based on stochastic response time analysis has been developed, including for overrun handling.

## **2.4 Current Results**

### **2.4.1 Technical Achievements**

#### **Application requirements (all)**

The delayed workshop in the domain of media processing with engineers has finally taken place in the form of a two-day workshop organized by Liesbeth Steffens of NXP at the NXP premises in November 2007. It brought together members of the ARTIST cluster and various NXP/Philips groups from different locations.

#### **Integrated CPU scheduling and cache management (TUKL, NXP (formerly Philips))**

NXP and TUKL have continued work on integrating real-time scheduling and cache management on multiprocessor platforms. We have carried out thorough experiments to study the impact of cache usage and scheduling on predictability on the actual platform. We developed a first algorithm with exhibits encouraging behaviour. Previous work has been extended to include Bus dependencies.

A joint PhD student is carrying out the work. Publications have been submitted. [TUKL1-3]

#### **Architectural model of the flexible scheduling framework (All)**

An architectural model of a flexible scheduling framework had been developed in previous years and has been extended in the current reporting period. The framework is capable of handling multiple concurrent activities with different criticality and timing in the same system, integrating the management of different kinds of resources such as processors, networks, memory, energy, and shared objects with time protection. The framework is independent of the underlying implementation, and can run on different underlying scheduling strategies. It is based on establishing service contracts that represent the complex and flexible requirements of the applications, and which are managed by the underlying system to provide the required level of service

Based on the experience gained during previous years the contract model has been updated and its API has been redesigned. The main changes made to the contract model have been:

- Updated energy management API to add operations to get more information from the system.
- New disk-bandwidth management services. A very simple module has been added to the framework to explore the possibility of handling contracts related to disk bandwidth.
- New feedback control API. The API of the feedback control module has been totally rewritten, based on the implementation and usage experience.
- Memory management. New services have been defined to be able to distribute spare capacity relative to memory resources..

**Implementation of the flexible scheduling framework (UC, UPVLC, CTU, SSSA, Aveiro, York, Thales Communications France)**

The main implementation effort in the flexible scheduling framework has been on the Integration of new resources. New communication networks have been added: CAN bus, as a representative of field busses, Wifi, as a representative of wireless networks, wired Ethernet [UC1], and switched Ethernet using industrial switches. An implementation to manage disk bandwidth is underway. Implementations on FPGAs and multiprocessor systems are also underway. In addition, the effects of power management are being introduced in one of the implementations.

The framework has been designed to be implementable on different platforms and work has been carried out to implement the framework on POSIX RTOSs (Partikle/RT-Linux, MaRTE OS), a commercial RTOS used in telecommunications (OSE), and in main-stream Linux kernels. An analysis module developed in the University of York was integrated in the framework to provide advanced schedulability analysis capabilities. [York4]

Work has been performed in cooperation with Thales Communications France (TCF) to Integration the contract-based scheduling framework with a component-based framework. The component based technology is the microCCM framework, that implements the component-container model with an infrastructure that is independent of CORBA. The integration with the contracts is provided by adding two kind of services: one managing task creation (called ThreadActivationService), and another one managing scheduling attributes (called SchedulingAttributeService). The contracts are declared in the deployment and configuration plan, and therefore the corresponding tool has been modified to read this information and automatically generate the code to create the contracts and manage the interceptors that bind threads to the corresponding contracts. [UC2][UC3][UC4].

The work has been carried out by the members of the FRESCOR EU project, together with other members of the ART cluster, in particular UPM and Aveiro.

**New theoretical developments (York, SSSA, UC)**

A number of theoretical developments have continued to be made during this last year.

- For hierarchical scheduling, the resource sharing model has extended to include EDF scheduling. [York11]
- For standard fixed priority scheduling, the Multi-Frame extension (to the standard model) has been investigated and exact analysis developed for a number of variations in the model including arbitrary deadlines and release jitter. [York1],[York5]
- For systems that allow online/dynamic admissions, the efficient scheduling algorithms for fixed priority scheduling that were developed and verified last year have now been implemented and tested. These algorithms allow spare capacity to be allocated to applications in an effective and efficient way, thereby enhancing the adaptability of such applications. [York4],[York12]
- Means by which an application can obtained the correct parameters for its virtual resource has been developed. [York2],[York3],[York6],[York9],[York10]
- The application of fixed priority scheduling to wormhole NoE protocols has been investigated. This work includes priority assignment and buffer size reductions. [York7]
- For hierarchical systems that are implemented on an EDF scheduler, necessary and sufficient analysis has been developed that mirrors the fixed priority approach, and thereby allow mixed EDF and fixed priority systems to be deployed. These algorithms,

that were initially developed during the previous year, have been improved and show to be optimal (in most cases). [York11]

- As a result of using the POSIX specification of the sporadic server scheduling algorithm in the context of a resource reservation framework, it has been discovered that this specification has a bug that causes that the timing behaviour of the policy is more intrusive than expected on lower priority tasks. Consequently, a new definition of the algorithm that is appropriate for operating systems and real-time networks has been defined and its timing properties have been proven. The new scheduling protocol has been implemented on an implementation of resource reservations on the CAN bus. [UC5]
- Dynamic resource reservations require the use of mode change protocols when new activities arrive at the system, or when changes to an existing resource allocation are needed. An effective mode change protocol that is usable in these dynamic systems is the idle-instant protocol, in which operation in the new mode is deferred until an appropriate instant in the schedule. While this protocol is usable in processing resources, it is very difficult to use in the networks due to the synchronization that would be needed to determine the idle instant. As a consequence a new mode change protocol has been developed that is usable in networks, and performs in a time interval that is not longer than the interval used in the idle-instant protocol. [UC6]

### **Featuring switched Ethernet with flexible traffic scheduling (Aveiro, Valencia, Malardalen, University of Pennsylvania, CMU)**

Switched Ethernet is, nowadays, used from office to industrial automation and even in embedded systems. However, COTS switches still present limited traffic scheduling capabilities, normally restricted to FIFO queues and a few fixed priority levels. This limitation makes distributed systems design more complex and less resource efficient or with less guarantees. This problem has been tackled by Aveiro, Valencia and Malardalen by putting together the FTT-SE protocol, channel bandwidth management techniques and server-based scheduling.

FTT-SE allows removing the traffic scheduling of switched Ethernet systems out of the switches and into a specific node. This grants a high flexibility to the traffic scheduling and opens the way to carry out advanced scheduling features such as dynamic QoS management and server-based scheduling. Concerning the former, Aveiro and Valencia (Alcoy group) have been cooperating in the scope of an industrial video surveillance application to setup a dynamic QoS management system that maximizes the channel bandwidth use and the QoS provided to the cameras [AV1]. On the other hand, the FTT-SE protocol was also used to implement a server-based traffic handling approach that increases system robustness with respect to nodes temporal misbehaviours. A preliminary implementation has been reported in [R8].

Dynamic bandwidth management grants a high level of resource utilization while server-based scheduling brings in a high level of isolation thus favouring composability. Moreover, to enforce continued timeliness even during reconfigurations or adaptations, prompt schedulability tests must be used. This issue was also tackled by the Aveiro group, also in collaboration with two US institutions, namely University of Pennsylvania and CMU. Concerning the admission control, or QoS management, adequate utilization-based schedulability tests were developed, namely the Local Utilization Bound [R9] that improves resource utilization, and the adaptation of existing bounds to a model that includes release jitter being thus applicable to the output ports of switches where this phenomenon frequently occurs.

## Dynamic QoS Adaptation (Porto)

Due to the growing complexity and dynamism of many embedded application domains (including consumer electronics, robotics, automotive and telecommunications), it is increasingly difficult to react to load variations and adapt the system's performance in a controlled fashion within a useful and bounded time. This is particularly noticeable when intending to benefit from the full potential of an open distributed cooperating environment, where service characteristics are not known beforehand and tasks may exhibit unrestricted QoS inter-dependencies.

Therefore, we have extended the adaptive resource framework, taking into account services' inter-dependencies and quality constraints, with an anytime QoS control policy in which the online search for the best set of QoS levels is combined with each user's personal preferences on their services' adaptation behaviour. We have also taken into consideration shared resources and precedence constraints in the scheduling of the real-time tasks. The concept of bandwidth inheritance is combined with a greedy capacity sharing and stealing policy to efficiently exchange bandwidth among tasks, minimising the degree of deviation from the ideal system's behaviour caused by inter-application blocking.

## Assessments on architectures and communication protocols for wireless networks used in factory automation (U. of Catania, SSSA)

This research was done by the University of Catania (affiliated partner) and addressed two main application scenarios, i.e., factory automation and wireless sensor networks. Part of the activity was done in collaboration with the Scuola Superiore Sant'Anna di Pisa. Joint publications dealing with flexible scheduling mechanisms for network based on well-known wireless standard protocols are in preparation.

The work in [CT1] proposes an approach to overcome some limitations on the way the IEEE 802.11e handles real-time industrial traffic through a dynamic adaptation of the back-off parameters for the different Access Categories. Such an adaptive control is performed by a fuzzy-logic controller, that takes into account both the throughput and frame retransmission count.

The paper [CT2] shows the performance of the IEEE 802.15.4 cluster-tree topology under large-scale RT WSNs scenarios. Simulation results in terms of throughput and delay are presented. Then, the key-aspects that limit the suitability for such kind of networks are discussed and viable solutions to the major problems are envisaged.

Another interesting aspect that was dealt with in this activity is the coexistence of multiple co-located IEEE 802.15.4 industrial networks, and particular attention was paid to cross-channel interference. The paper [CT3] summarises the results obtained on cross-channel interference in IEEE 802.15.4 networks.

## Relaxing task isolation in soft real-time periodic systems (U. of Catania)

This activity, continued from last year, showed that by "relaxing" task isolation, it is possible to efficiently deal with overruns in soft real-time systems with highly variable task execution times. The results obtained by the Randomized Dropping (RD) in [CT4] show that it is possible to bound task overruns in a probabilistic manner, thus providing "soft" task isolation while still maintaining system analyzability



**Stochastic response time analysis of hybrid task sets in priority-driven soft real-time systems (U. of Catania)**

This activity, continued from last year, focuses on a novel task model, where a task is characterised by an Arrival Profile (AP) and an Execution Time Profile (ETP), both given by random variables with known distributions. In [CT5] results are given on the calculation of stochastic Response Time Profiles (RTPs) of tasks hierarchically scheduled using server-based techniques in a stochastic analysis framework.

**Topology Management Protocols with Bounded Delay for Wireless Sensor Networks (U. of Catania)**

In Wireless Sensor Networks (WSNs) used in monitoring applications, the need to provide real-time traffic with an appropriate QoS typically clashes with the energy consumption constraints of the nodes, which have to work for long periods without the possibility of replacing their batteries. When both energy and QoS constraints are present, the role of topology control mechanisms is fundamental. This activity dealt with a topology control protocol to support energy-efficient real-time communication over WSNs. The aim of this work was to provide bounded delay for data traffic while reducing the energy consumption of the nodes. In [CT6] a detailed description of the protocol is given and both analytical and simulation results are presented that show the effects of the proposed topology control protocol in terms of reduced energy consumption, increased network capacity and reduced packet loss rate.

**Architecture for dynamic service composition and algorithms for QoS-based composition of services (UC3M, Aveiro)**

The group at UC3M (affiliated to UPM) explored using the service-oriented paradigm to develop distributed real-time applications and, together with Aveiro, devised an architecture to support dynamic service composition. This kind of architecture can also be an alternative to provide some level of flexible resource management by supporting different profiles of each service, with different QoS and resource usage, and allowing a dynamic recomposition of the services/profiles involved in an application according to a predefined objective, e.g., maximize QoS of an application given the currently available resources, minimize the resources needed by a set of applications, etc. The architecture is based on a global entity, called the composer, which, together with a QoS manager, decides when and how to recompose a given application. The real-time coordination of the composition changes in the distributed system is carried out with the FTT-SE protocol.

Also, UC3M group has developed a series of algorithms for composition of real-time applications that are based on services. Applications are represented as graphs, where the nodes are the functionality pieces and the interactions are messages. In these algorithms, we find suboptimal solutions as a means to trade-off composition time with the finding of a solution. The search on the graph is based on the QoS parameters that characterise the services. This work has been done in collaboration with the U. Aveiro. [R10]

**Distributed real-time middleware based on RTSJ – DRTSJ (UC3M)**

UC3M group has developed, in the starting phase of this project, extensions to RTSJ as a means to introduce more predictability in it to support the implementation of the distributed version of it (Distributed RTSJ – DRTSJ). Previous patterns as the NoHeapRemoteObject, Memory Area Pools, AGCMemory, threading model, etc., have been improved for their implementation in our prototype of DRTSJ called DREQUIEMI. Also, improvements to the communications protocol based on JRMP have been included in the prototype. [UC3M1] [UC3M2]



## Design of a quality of service manager (SSSA, TUKL, UPM, Cantabria, UC3M)

HOLA-QoS is a framework for managing QoS and resources and it has been used in media processing which UPM and UC3m have developed jointly. It is implemented as a layered architecture, so that layers can be replaced, as far as the API is kept. The work that has been finished is to replace the lower levels of HOLA-QoS with two kernels with resource management facilities (also called resource kernels): MARTE (Cantabria) and SHARK (Pisa). The integration has been validated with some test applications. The final part of this work is the integration of the higher levels of HOLA-QoS that is currently being redesigned. One result of this work is the possibility of experimenting with the adaptation techniques that these advanced resource kernels provide.

The objective of the in ISO/IEC 23004-1 standard (Multimedia middleware, M3W) is to allow applications to execute multimedia functions with a minimum knowledge of the middleware and to allow applications to trigger updates to the middleware to extend the middleware API. Part 3 defines a component model, so that it is possible to use third party software in a seamless way. UPM has cooperated in the definition of a set of facilities for supporting resource and QoS Management in such a standard. In addition, an implementation of the resource Management components has been developed, taking HOLA-QoS as the basis for this work. The work done by UPM in the ASSERT Project has also relied on some of these concepts. Some publications on HOLA-QoS can be found at <http://www.dit.upm.es/str>.

## Design of a quality of service manager (UPM, UC3M)

Budget accountant (BACC) is a software component that is able to handle resource budgets. In particular, it allows to assign budgets to entities, account for their usage on run-time and detect budgets overrun. There was a previous version of this component that has recently adapted to the linux kernel version 2.6. This work has been the basis for providing resource Management (CPU) facilities for the jamVM Java Virtual Machine (JVM). This will allow to provide CPU budgets to java threads. This approach is very relevant when due to different reasons (legacy code, libraries availability, ...) it is not possible to use a real-time JVM.

## 2.4.2 Individual Publications Resulting from these Achievements

### TUKL

[TUKL1] C. Otero-Perez, J v. Eindhoven, G. Fohler: "Execution-aware cache reservations for media applications", submitted

[TUKL2] C. Otero-Perez, G. Fohler Memory access impact on scheduling of media streaming applications on shared memory multiprocessor SoC submitted

[TUKL3] Raphael Guerra, Gerhard Fohler, "A Gravitational Task Model for Target Sensitive Real-Time Applications", ECRTS08 - 20th Euromicro Conference on Real-Time Systems, Prague, Czech Republic.

### Universidad de Cantabria

[UC1] Daniel Sangorrín, and Michael González Harbour. "Enhancing a Hard Real-Time Ethernet Protocol to support Distributed Contract-Based Bandwidth Reservation". Congreso Español de Informática (CEDI 2007), II Simposio de Sistemas de Tiempo Real, Zaragoza, September 2007.

[UC2] Patricia López Martínez, Julio Medina, & José María Drake. "Real-Time extensions to "Deployment and Configuration of Component-based Distributed Applications". OMG

Workshop on Distributed Object Computing for Real-Time Embedded Systems, Washington, DC, USA, July, 2008.

[UC3] Patricia López Martínez, Julio L. Medina, Pablo Pacheco and José M. Drake. "Ada-CCM: Component-based Technology for Distributed Real-Time Systems" 11<sup>th</sup> International Symposium on Component Based Software Engineering (CBSE-2008) Karlsruhe, Germany October 2008.

[UC4] J.L. Gilbert, O. Hachet, J. Chauvin, P. López, J.M. Drake, M. González Harbour, "Integration of Flexible Real-Time Scheduling Services in a Lightweight CCM-Based Framework". OMG Workshop on Distributed Object Computing for Real-Time Embedded Systems, Washington, DC, USA, July, 2008.

[UC5] Michael González Harbour, Daniel Sangorrín, Miguel Tellería, "Sporadic Server Scheduling in Real-Time Operating Systems and Networks". Technical report.

[UC6] Michael González Harbour, Daniel Sangorrín, Miguel Tellería, "Mode Change Protocol for Budget Changes in Contract-Based Scheduling". Technical report.

### **University of York**

[YORK1] A. Zuhily and A. Burns. "Exact Scheduling Analysis of Accumulatively Monotonic Multiframe Tasks Subjected to Release Jitter and Arbitrary Deadlines". 13<sup>th</sup> IEEE International Conference on Emerging Technologies and Factory Automation (ETFA), pages 600-608, 2008

[YORK2] Ameet Patil and Neil Audsley. "Adaptive Framework for Efficient Resource Management in RTOS". Proc. APRES, 2008, pages 12-15

[YORK3] M. Bartlett and I. Bate and D. Kazakov. "Challenges in Relational Learning for Real-Time Systems Applications". Proceedings of the 18<sup>th</sup> International Conference on Inductive Logic Programming, volume 5194, Lecture Notes in Computer Science, Springer, pages 42-58, sep 2008.

[YORK4] R.I. Davis, A. Zalos, and A. Burns. "Efficient Exact Schedulability Tests for Fixed Priority Real-Time Systems". IEEE Transactions on Computers, 2008

[YORK5] A. Zuhily and A. Burns. "Exact Response Time Scheduling Analysis of Accumulatively Monotonic Multiframe Real Time Tasks". 5<sup>th</sup> International Colloquium on Theoretical Aspects of Computing (ICTAC), pages 410-424, 2008

[YORK6] N. Lay and I. Bate. "Improving the reliability of real-time embedded systems using innate immune techniques" Evolutionary Intel., 2008, volume 1, number 2, pages 113-132

[YORK7] Zheng. Shi and Alan. Burns. "Real-time communication analysis for on-chip networks with wormhole switching". Proceeding of the IEEE International Symposium on Networks-on-Chip(NoCS), 2008

[YORK8] A. Burns and S. Baruah. "Sustainability in Real-time Scheduling", Journal of Computing Science and Engineering, 2008, volume 2, number 1, pages 74-97

[YORK9] Iain Bate. "Systematic Approaches to Understanding and Evaluating Design Trade-Offs". The Journal of Systems & Software, 2008, volume 1, number 8, pages 1253-1271

[YORK10] Iain Bate. "Utilising Application Flexibility in Energy Aware Computing". 14th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications, 2008, pages 285-290

[YORK11] Fengxiang Zhang, Alan Burns. "Analysis of Hierarchical EDF Pre-emptive Scheduling". Proceedings of IEEE Real-Time Systems Symposium, 2007, pages 423-434

[YORK12] R.I. Davis and A. Burns. "Robust Priority Assignment for Fixed Priority Real-Time Systems". Proceedings of IEEE Real-Time Systems Symposium, 2007, pages 3-14

### **University of Aveiro**

[AV1] J. Silvestre, L. Almeida, R. Marau, P. Pedreiras. Dynamic QoS Management for Multimedia Real-Time Transmission in Industrial Environments. ETFA 2007, 12th IEEE International Conference on Emerging Technologies and Factory Automation. Patras, Greece, September 2007.

### **Polytechnic Institute of Porto**

[Por1] Nogueira, L., Pinho, L., "Shared Resources and Precedence Constraints with Capacity Sharing and Stealing", Published in Proceedings of the 22nd IEEE International Parallel and Distributed Processing Symposium, April 14-18, 2008, Miami, Florida, USA

[Por2] Nogueira, L., Pinho, L., "Handling QoS Dependencies in Distributed Cooperative Real-Time Systems", Published in Proceedings of the 6th IFIP Working Conference on Distributed and Parallel Embedded Systems, Milan, Italy, September 2008

[Por3] Nogueira, L., Pinho, L., "Dynamic QoS Adaptation of Inter-Dependent Task Sets in Cooperative Embedded Systems", Published in Proceedings of the 2nd ACM International Conference on Autonomic Computing and Communication Systems, Turin, Italy, September 2008

### **University of Catania**

[CT1] S. Vittorio, E. Toscano, L. Lo Bello, "CWFC: A Contention Window Fuzzy Controller for QoS support on IEEE 802.11e EDCA". In Proceedings of the 13th IEEE International Conference on Emerging Technologies and Factory Automation, ETFA'08 accepted.

[CT2] E. Toscano, L. Lo Bello, "On the Use of IEEE 802.15.4 for Real-Time Wireless Sensor Networks", In Proceedings of the 7th International Workshop on Real-Time Networks, RTN'08, Prague, Czech Republic, July 2008, pages 47-52.

[CT3] E. Toscano, L. Lo Bello, "Cross-Channel Interference in IEEE 802.15.4 Networks". In Proceedings of the 7th IEEE International Workshop on Factory Communication Systems, WFCS'08, Dresden, Germany, May 2008, pp. 139-148, IEEE 2008, ISBN 978-1-4244-2349-1.

[CT4] L. Lo Bello, K.H. Kim, "Overrun handling approaches for overload-prone soft real-time systems", *Advances in Engineering Software*, Vol. 38, pp. 780-794 ISSN: 0965-9978, Elsevier Science Ltd., Oxford, UK, Nov-Dec. 2007.

[CT5] G.A. Kaczynski, L. Lo Bello, T. Nolte, “Deriving Exact Stochastic Response Times of Periodic Tasks in Hybrid Priority-driven Soft Real-time Systems”. In Proceedings of the 12th IEEE International Conference on Emerging Technologies and Factory Automation, ETFA’07, Sept. 25-28, 2007, Patras, Greece.

[CT6] E. Toscano, L. Lo Bello, “A Topology Management Protocol with Bounded Delay for Wireless Sensor Networks”, In Proceedings of the 13th IEEE International Conference on Emerging Technologies and Factory Automation, ETFA’08, accepted.

### UC3M

[UC3M1] P. Basanta-Val, M. García-Valls, and I. Estévez-Ayres. *Simplifying the Dualized Threading Model of RTSJ* Proc. of the 11th IEEE International Symposium on Object/component/service-oriented Real-time distributed Computing, ISORC 2008. May 5 - May 7, 2008. Orlando, Florida, USA.

[UC3M2] P. Basanta-Val, M. García-Valls, I. Estévez-Ayres y J. Fernández-González. *Integración de capacidades de multiplexación en el conjunto de subprotocolos JRMP*. Pendiente de publicación en *IEEE América Latina*, ISSN 1548-0992. 2008. In Spanish

### UPM

[UPM1] Juan A. de la Puente, Juan Zamorano, José A. Pulido, Santiago Urueña. *The ASSERT Virtual Machine: A Predictable Platform for Real-Time Systems*. In Myung Jin Chung, Pradeep Misra (eds.), Proceedings of the 17th IFAC World Congress. IFAC-PapersOnLine, ISBN 978-3-902661-00-5, 2008.

[UPM2] Juan Zamorano, Juan A. de la Puente, José A. Pulido, Santiago Urueña. *The ASSERT Virtual Machine Kernel: Support for preservation of temporal properties*. Data Systems in Aerospace — DASIA 2008. Palma de Mallorca, Spain, 2008.

[UPM3] David Embid, Alejandro Alonso. *Resource manager BACC: upgrade and porting to new platforms*. Master Thesis, Universidad Politécnica de Madrid, 2008

### 2.4.3 Interaction and Building Excellence between Partners

TUKL and NXP (formerly as partner Philips) work together on integrated resource management via a joint PhD student. Resulting publications have been submitted.

In the scope of the collaboration between Aveiro and Cantabria, work on the integration of the FRESCOR framework and the FTT-SE protocol has continued, resulting in a joint publication [R2]. In this work the contract-based reservation framework defined in the FRESCOR project has been implemented using the FTT-SE protocol developed in Aveiro, showing that the framework is adaptable to a centralized scheduling architecture.

Cantabria, Valencia and Pisa have collaborated towards editing a special issue of the EURASIP Journal on Embedded Systems on “Operating System Support for Embedded Real-Time Applications” [R1]. The special issue had six papers accepted, some of which are closely related to adaptive resource management in real-time systems.

The Computer Engineering and Networks Laboratory at ETH Zurich, Switzerland, the Institute of Computer and Communication Network Engineering at TU Braunschweig, Germany, and the University of Cantabria have collaborated in a study of different real-time analysis methods for distributed systems evaluating their influence on the results of the analysis [R3] [R4].

#### *2.4.4 Joint Publications Resulting from these Achievements*

[J1] C. Otero-Perez, J v. Elndhoven, G. Fohler: "Execution-aware cache reservations for media applications", submitted

[J2] C. Otero-Perez, G. Fohler Memory access impact on scheduling of media streaming applications on shared memory multiprocessor SoC submitted

[J1] Alfons Crespo, Ismael Ripoll, Michael González-Harbour, and Giuseppe Lipari, "Operating System Support for Embedded Real-Time Applications". EURASIP Journal on Embedded Systems, Volume 2008 (2008), Article ID 502768,, February, 2008, pp. 1,2.

[J3] R. Marau, L. Almeida, P. Pedreiras, M. González Harbour, D. Sangorrín, and Julio Medina. "Integration of a flexible time triggered network in the FRESCOR resource contracting framework". 12th IEEE Conference on Emerging Technologies and Factory Automation, ETFA, Patras, Greece, September, 2007.

[J4] S.Perathoner, E.Wandeler, L.Thiele, A.Hamann, S.Schliecker, R.Henia, R.Eacu, R.Ernst, and M. González Harbour. "Influence of different system abstractions on the performance analysis of distributed realtime systems". Proceedings of the 7th ACM&IEEE international Conference on Embedded Software, EMSOFT 2007, October, 2007, ISBN:978-1-59593-825-1, pp. 193,202.

[J5] S.Perathoner, E. Wandeler, L.Thiele, A.Hamann, S.Schliecker, R.Henia, R.Racu, R.Ernst, M. G. Harbour, "Influence of different abstractions on the performance analysis of distributed hard real-time systems". Journal on Design Automation for Embedded Systems, Springer, April, 2008, ISSN: 0929-5585.

[J6] C. Otero-Perez, J v. Elndhoven, G. Fohler: "Execution-aware cache reservations for media applications", submitted

[J7] C. Otero-Perez, G. Fohler Memory access impact on scheduling of media streaming applications on shared memory multiprocessor SoC submitted

[J8] M. Masmano and I. Ripoll and J. Real and A. Crespo and A. J. Wellings. "Implementation of a constant-time dynamic storage allocator", Software: Practice and Experience, volume 38, number 10, pages 995-1026, 2008.

[J9] Ricardo Marau, Luis Almeida, Paulo Pedreiras, Thomas Nolte. Towards Server-based Switched Ethernet for Real-Time Communications. Proceedings of Work-In-Progress Session of ECRTS 2008, 20th EUROMICRO Conference on Real-Time Systems, Prague, Czech Republic, 2-4 July 2008.

[J10] L. Almeida, Sebastian Fischmeister, Madhukar Anand, Insup Lee. A Dynamic Scheduling Approach to Designing Flexible Safety-Critical Systems. EMSOFT 2007, 7th ACM Conference on Embedded Software. Salzburg, Austria. Sept 2007.



[J11] I. Estévez-Ayres, M. García-Valls, L. Almeida, and P. Basanta-Val. *Solutions for Supporting Composition of Service-Based Real-Time Applications* Proc. of the 11th IEEE International Symposium on Object/component/service-oriented Real-time distributed Computing, ISORC 2008. May 5 - May 7, 2008. Orlando, Florida, USA

### 2.4.5 Keynotes, Workshops, Tutorials

#### **Workshop: RTN 2008: Real-Time Networks**

*Prague, Czech Republic, July 1, 2008, with ECRTS 08*

**Organizers:** Anis Koubâa IPP-HURRAY Research Group, ISEP-IPP, (Portugal)

**Objectives:** RTN focuses on the current technological challenges of developing communication infrastructures that are real-time, reliable, pervasive and interoperable.

**Topics:** Distributed systems, communication protocols, wireless sensor networks, mobile ad-hoc networks.

**Results:** The workshop attracted 25 participants from different European countries and technical papers have been published in proceedings.

URL <http://www.hurray.isep.ipp.pt/rtn08/index.php>

#### **Workshop: OSPERT 2008: Operating Systems Platforms for Embedded Real-Time Applications**

*Prague, Czech Republic, July 1, 2008, with ECRTS 08*

**Organizers:** Jim Andersson, University of North Carolina, USA.

**Objectives:** This workshop is intended as a forum for researchers and practitioners of RTOS to discuss the recent advances in RTOS technology and the challenges that lie ahead.

**Topics:** Support for component based development; Scalability, from very small scale embedded systems to full-fledged OSES; Real-Time on Linux; Interaction with reconfigurable hardware; Support for embedded multi-processor architectures; Security and fault tolerance for embedded real-time systems; Power-aware operating systems..

**Results:** The workshop attracted 30 participants from different European countries and technical papers have been published in proceedings.

URL: <http://www.cs.unc.edu/~anderson/meetings/ospert08/OSPert.html>

#### **Workshop: Workshop ARTIST - NXP**

*Eindhoven, The Netherlands, Nov 15,16, 2008*

**Organizers:** Liesbeth Steffens, NXP, Gerhard Fohler, TUKL.

**Objectives:** The workshop is intended to bring together researchers from ARTIST with engineers and researchers from NXP on application requirements for media processing and QoS management.

**Topics:** Application requirements for media processing and QoS management, specific questions/discussions, on actual engineering problems

**Results:** The workshop attracted 25 participants, copies of presentations and additional material have been made available to the participants within IPR limits.

URL: no public page due to IPR issues

#### **Workshop: Workshop on Adaptive and Reconfigurable Embedded Systems APRES 2008 .**

*St. Louis, USA, 21st April 2008, satellite of the 14th IEEE Conference on Real-Time and Embedded Technology and Applications - RTAS 2008*

**Organizers:** S. Fishmeister, L. Almeida, J. Proenza, I.

**Objectives:** Discuss new and on-going research that is centred on the idea of adaptability as first class citizen and consider the involved.



**Topics:** Capturing and modelling of flexible application and reconfiguration requirements, Tradeoff analysis and modelling, support and models for adaptability, Policies and algorithms for single and multi-resource reconfiguration.

**Results:** The workshop attracted 16 presentations and had a keynote on adaptivity in embedded systems. Technical papers have been published in proceedings.

URL: <http://www.artist-embedded.org/artist/APRES08.html>

### 3. Milestones, and Future Evolution Beyond the NoE

#### 3.1 Milestones

- Year1: Identify case studies, perform preliminary assessment . Preliminary work on the integration of diverse scheduling schemes.

*Achieved for the case of CPU and energy, and CPU and networks.*

- Year2: 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.

*Achieved 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.*

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.

*Achieved both in theoretical developments for server-based hierarchical scheduling, and in practice through the FIRST scheduling framework.*

- Year3: Expend the requirements into a meaningful set of requirements of adaptive application domains that allow the creation of global mechanisms for resource management. Define a set of requirements and an architectural model for the framework for flexible scheduling that integrates multiple resources, including CPUs and networks, multiple processors, shared resources with time protection, memory protection, and energy/power-aware scheduling.

*Achieved*

- **Year4: Integration of the application adaptation processes into a general QoS resource management structure. 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.**

**Achieved**, although work on the framework will continue in the future to extend it with additional capabilities.

#### 3.2 Indicators for Integration

Expected results and visible impact are: influence on integrating the operating system design, network, and middleware, joint results on scheduling algorithms, analysis tools, and kernel and network support for the integration and coexistence of diverse system-wide scheduling schemes.

### **3.3 Main Funding**

The FRESCOR EU IST project, in which the following ARTIST2 partners are involved: University of Cantabria, University of York, Scuola Superiore Santa Anna, Technical University of Kaiserslautern, Technical University of Valencia and the Czech Technical University in Prague

– [www.frescor.org](http://www.frescor.org)

The ACTORS EU IST project, starting early 2008, in which the following ARTIST2 partners are involved: Scuola Superiore Santa Anna, Technical University of Kaiserslautern, Lund University

THREAD Spanish project, in which the following ARTIST2 partners are involved: Technical University of Madrid, University of Cantabria, Technical University of Valencia

The CooperatES Project, started July 2007, a Portuguese funded FCT project involving the Polytechnic Institute of Porto.

### **3.4 Future Evolution Beyond the Artist2 NoE**

The work in the activity has strengthen the collaboration between partners and opened new possibilities to investigate new related areas with input from related projects and workshops with a wider audience, notably from industrial engineers and researches. These can be seen as strong indicators that the area of resource management will continue to be of central importance to the embedded system community.

The work in ARTIST2 has also underlined the use of real-time methods in areas which are not perceived as real-time per se, such as media processing, where real-time resource management has been seen to be effective in handling activities without stringent temporal constraints. This has already formed a basis for expanding research into new areas.

Furthermore, work within the activity has both highlighted the need and developed methods for the integration of resources, formerly handled mostly individually, e.g., CPU, cache, and busses, or CPU and networks, and the modularization of methods. Parts of the frameworks within the activity have been integrated by (previously diverse) implementations by different partners from different systems. Further integration of resources, with particular emphasis on energy will be needed. The achieved results lead the way for further joint and integration work.

A number of activities have been picked up for continuation in the NoE ARTISTDesign, or have formed the basis for granted projects and proposals.

## **4. Internal Reviewers for this Deliverable**

Giorgio Buttazzo, SSSA

Michael Gonzalez, UC