Network of Excellence

IST-004527 ARTIST2:
Embedded Systems Design

Activity Progress Report for Year 1

JPRA-Cluster Integration:

Adaptive Resource Management for Consumer Electronics

2nd revised version after review

Activity Leader:

Gerhard Fohler (Mälardalen University)

Resource management for consumer electronics faces the challenges of highly variable resource demand, e.g., from MPEG encoded video streams, highly variable resource availability, e.g., wireless networks, shared CPUs, and strong requirements for resource efficiency due to cost considerations in mass markets. Violations of timeliness requirements both on a single resource as well as in the end-to-end chains lead to unacceptable quality impairments. Matching varying demands with varying resources could be addressed by massive over dimensioning, which is not acceptable in this domain. Rather, methods to analyse resource demands and managet resources in an adaptive manner are necessary.

This requires attention to a number of issues in diverse areas of research. The activity addresses these issues by leveraging on the critical mass provided by ARTIST2 and in the ART cluster, with expertise ranging from flexible scheduling and infrastructure to wireless networks and media processing. Expertise outside the team is made accessible via industrial contacts to provide for realistic application requirements.

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1. Introduction

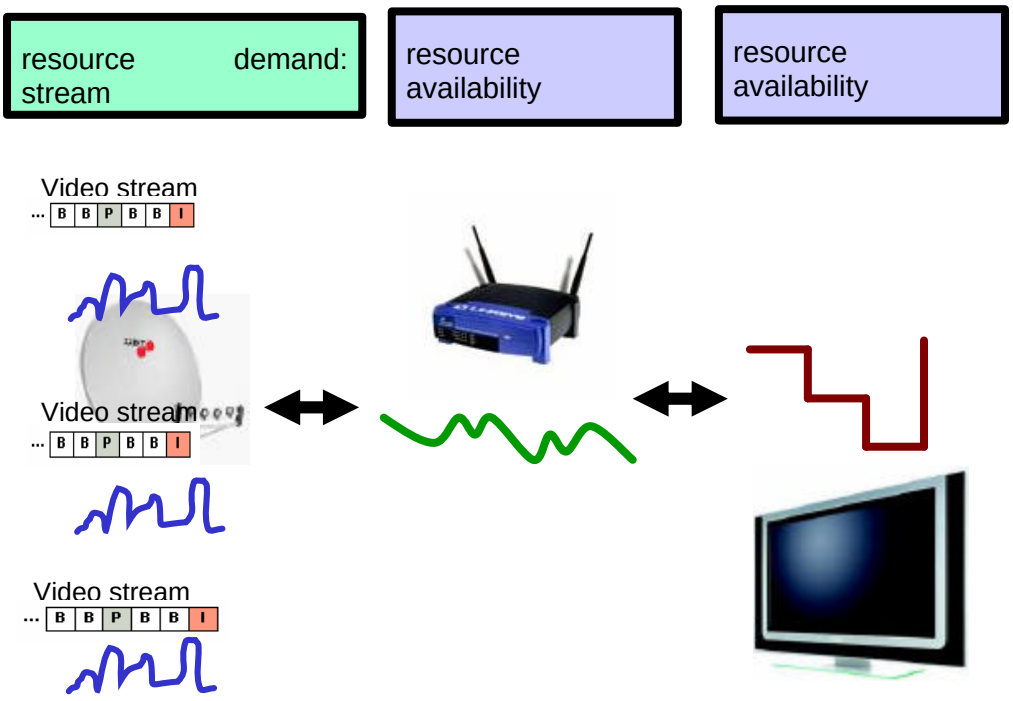
1.1 Activity Leader

Activity Leader: Gerhard Fohler (Mälardalen University)
Area of team expertise: resource management framework, video streaming, wireless networks

1.2 Policy Objective

Resource management for consumer electronics faces the challenges of highly variable resource demand, e.g., from MPEG encoded video streams, highly variable resource availability, e.g., wireless networks, shared CPUs, and strong requirements for resource efficiency due to cost considerations in mass markets. Violations of timeliness requirements both on a single resource as well as in the end-to-end chains lead to unacceptable quality impairments. Matching varying demands with varying resources could be addressed by massive over dimensioning, which is not acceptable in this domain. Rather, methods to analyse resource demands and manage resources in an adaptive manner are necessary.

This requires attention to a number of issues in diverse areas of research. The activity addresses these issues by leveraging on the critical mass provided by ARTIST2 and in the ART cluster, with expertise ranging from flexible scheduling and infrastructure to wireless networks and media processing. Expertise outside the team is made accessible via industrial contacts to provide for realistic application requirements



1.3 Industrial Sectors

Consumer electronics (multimedia, telecommunication), transportation industry (automotive), industrial automation (robots, machine tools). The referred research will impact on the design of embedded systems, from a typically static approach to a dynamic approach that will allow adding more SW functionality without extra computing or communications HW, by improving resource utilization.

2. Overview of the Activity

2.1 Artist Participants and roles

Team Leader: Gerhard Fohler (Mälardalen University)
Area of team expertise: resource management framework, video streaming, wireless networks

Team Leader: Giorgio Buttazzo (University of Pavia)
Area of team expertise scheduling mechanisms for temporal isolation

Team Leader: Michael Gonzalez Harbour (University of Cantabria)
Areas of his team's expertise: end-to-end timing analysis of distributed systems

Team Leader: Luis Almeida (University of Aveiro)
Area of team expertise: Bandwidth adaptation in wireless networks

Team Leader: Eduardo Tovar (Polytechnic Institute of Porto)
Area of team expertise: communication protocols for wireless networks

Team Leader Alejandro Alonso (UP Madrid)
Area of team expertise: adaptive techniques for QoS

2.2 Affiliated partners and Roles

Team Leader: Giuseppe Lipari (Scuola Superiore S. Anna)
Affiliated with Pavia
Areas of team expertise: bandwidth reservation techniques, RTOS.

Team Leader: Marisol García-Valls (U. Carlos III, Madrid)
Area of team expertise: QoS management
Affiliated with UPM

Team Leader: Pau Marti (Universitat Politècnica de Catalunya)
Area of team expertise: real-time and control,
Affiliated with Malardalen

Team Leader: Paolo Gai (Evidence, SME)
Area of team expertise: tools for resource management
Affiliated with Pavia

Team Leader: Liesbeth Steffens (Philips Research)
(informally) affiliated with Malardalen
Area of team expertise: consumer electronics, video streaming

2.3 Starting date, and expected ending date

It started in October 2004 and will be complete when research topics of industrial relevance and example solutions have been identified and developed.

Expected ending date: March 2007

2.4 Baseline

In some application domains, such as multimedia, applications are very expensive in terms of resource consumption. In other applications domains, such as automotive or mobile telephony, 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.

2.5 Technical Description

Collecting a meaningful set of requirements of dynamic application domains (media processing) that allow the creation of global mechanisms for resource management, in particular with input from affiliated industrial partners in the area.

Integrate the effort of the partners to create adaptive scheduling and control algorithms for the various resources considered (network, CPU, memory) that can be integrated into a holistic framework for QoS aiming at systems that are highly dynamic.

Integration of the application adaptation processes into a general QoS resource management structure.

3. Activity Progress Report

Approach

The topics of the activity span a wide range, from operating system, scheduling, (wireless) networks, video streaming, architectures, to consumer electronics, each major research areas in themselves. Consequently, the activities within the NoE cannot address the issues themselves, but rely on the expertise represented in the cluster, and the activities and projects of partners. Partners are involved in a number of European or national projects in the area. Meetings within the cluster aim to integrate the expertise of partners.

In addition, the activities exploit industrial contacts of partners, in particular with respect to obtaining real-time requirements and acceptance testing of example solutions. In this phase, the activity focuses on media processing, due to the opportunities arising from the interest of a major consumer electronic company and the necessary setting of focus. The goal here is to make an effort to go as far as possible to reach the actual engineers of the products for realistic information. In a first step, contacts to industrial researchers were asserted, which will enable contact to the actual engineers. Major obstacles to overcome are IPR and availability of relevant engineers.

The steps of achieve the goals of the activity follow a three-tier approach combining input from (i) expertise of partners (ii) international experts (iii) from industrial engineers. First, ongoing activities of partners will be analysed for relevant requirements and selected topics studied in more detail. In parallel, contacts to industrial engineers in the area of media processing (via support of industrial researchers), relevant topics and solutions of interest will be established. This will be the basis of a specific workshop for an encounter of engineers and scientists. International experts from outside the cluster will be invited. Then the procedure in the area of telecommunications will be carried out. At regular intervals, e.g., yearly, a cluster workshop will be held to readjust scope and focus activities. In the end, results of all tiers will be consolidated and presented in an open workshop. The intention is to obtain as realistic results as possible with efforts to overcome IPR issues.

3.1 Work achieved in the first 6 months

In the first 6 months, the ART cluster investigated the following topics:

1. Video stream demand analysis. Analysis of the demands of realistic MPEG-2 encoded video streams with respect to timing and bandwidth. Identification of scheduling algorithms and adaptation strategies. Analysis and test of kernel mechanisms and communication for stream adaptations based on integrated, flexible scheduling. (Malardalen, Philips, Pavia, Pisa, Cantabria)
2. Resource management framework, middleware support for QoS management. Identification of strategies for both active end-to-end negotiations and global resource control. Infrastructure for providing resource management facilities in remote method invocations, particularly Java RMI. (UPM, UC3M, Cantabria)

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 gave 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.

3.2 Work achieved in months 6-12

In months 6-12, the ART cluster investigated the following topics:

1. Identification of functional units with impact on the end-to-end timing of video streams including processing and transport in (wirelessly) network systems. (Philips, Malardalen)
2. Adaptive methods for network bandwidth management. Development of methods to analyse bandwidth availability, provide methods for adaptation both on the network protocol side as well as on the sender side via the operating system. Identification of control theoretic aspects of adaptation, e.g., to prevent instability. (Aveiro, Porto, UPC, Malardalen)
3. Start of work on multi resource management, in particular with respect to cache aware scheduling. Analysis of level 2 caches and the impact of scheduling. (Philips, Malardalen)
4. Scheduling mechanisms for temporal isolation. Ensuring via scheduling that activities with unpredictable timing behaviour, such as video decoding, can be restrained within predefined temporal scopes, while other activities are protected from overruns. Providing for coexistence of scheduling schemes. (Pavia, Evidence, Pisa, Malardalen, Cantabria)

A focused Workshop at ECRTS was held by partners understand realistic industrial demands. Further specification of research topics of relevance to industrial engineers and researchers, identification of stakeholders in companies and academia. A meeting with industrial engineer has been agreed on, but delayed due to scheduling difficulties.

3.3 Difficulties Encountered

IPR

The main difficulties encountered were of non technical nature. Before the start of the NoE, Philips had expressed strong interest in the ART activities of ARTIST and had committed to participate in proposal preparation and as core partner during the NoE duration. These commitments, however, had to be withdrawn due to legal concerns regarding IPR within the NoE.

IPR issues became an issue in the course of the NoE activities as well in particular, as more realistic scenarios are studied, and contacts to engineer closer to actual production were established. Some information cannot be disclosed of the engineers to outsiders and some of the knowledge gained, such as preliminary insights into actual requirements, falls under NDA, and thus, while obtained by partners, cannot be published. Work on resolving these issues, e.g., via sanitized data, has started.

Scheduling

Due to the support of researchers at Philips and the involvement of partners at Philips event, contacts to product engineers have been established and a basic agreement on an “engineer – scientist” workshop has been achieved. The mundane difficulty delaying this event, apart from IPR issues, however, is the difficulty of finding appropriate dates of availability of the product engineers. The workshop had been planned for September, but had to be postponed.

An easier way to handle such issues, e.g., requirements would be to work on a higher level or use more synthetic results. To this point, partners believe that the potential insights gained justify the difficult efforts.

Focus

The wide ranges of areas of expertise and ongoing work in the cluster are instrumental for progress in this activity of the NoE. The first phase appears to indicate that the initial scope of activities needs to be narrowed

One technical issue has been the wide range of areas involved, including differences in terminology between partners, selection of representative resources for analysis out of a very wide range in the area. It appears necessary to adjust the scope of activities to stay within reasonable scope for the resourced provided by the NoE, e.g., by focusing activities. This can also counter a "positive" difficulty can be the potentially large follow-up work arising, which has the potential to go far beyond the scope and resources of ARTIST.

3.4 Recommendations

Based on the difficulties mentioned above, key recommendations include the awareness and resolution of IPR issues to ensure understanding of the real issues at hand. The planned workshop between engineers and scientists has to be carefully planned to ensure differences in terminology ("language") will be avoided and both understanding of practical issues and scientific solutions can be achieved.

On the technical side, regular revisiting of the goals, e.g., on a yearly basis, to ensure that take-up of insights gained stay realistically focused for the scope of the NoE are recommended and partners activities are not spread to thin. As a concrete measure, a meeting in Spring 2006 is planned for revisiting scope.

As for areas, media processing will receive continued attention. The next focus will be on telecommunications. Milestones

3.5 Main Funding

Major funding comes from a number of projects on European and national level.

3.6 Indicators for Integration

The goal of this activity is to provide a uniform view on the requirements of some highly adaptive application environments, based on specific industrial needs.

Expected results and visible impact are: influence on the operating system design, network, and middleware; joint papers, joint projects, joint PhD students, deployment of integrated frameworks involving the work of several groups.

3.7 Evolution

This activity is planned to last at least four years but it may be extended if interest on the topic continues to grow. By then we expect to reach understanding of requirements, a common middleware, based on adequate operating system and networking mechanisms.

The 18 months objective is to 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. This will also result in the specification of the desired middleware.

4. Detailed Technical View

4.1 Brief State of the Art

In the past, models and methods to design systems that fulfil hard deadlines in time have been the target of investigations in the embedded system domain. For streaming data in the consumer electronic domain, there are not so many hard deadlines in time as there are trade-offs between resource use, power consumption and meeting timing deadlines to reach a certain quality level. Consequences of deadline misses, while undesired, result in reduce quality of experience, e.g., lower quality video, but do not have severe consequences, such as loss of human live

The recent past has shown increasing emphasis on system aspects other than timeliness, such as power or energy, partly because of limited power supplies, partly also due to increasing power densities of integrated circuits and heat dissipation. Furthermore the methods currently existing for efficient resource management are mostly for one single criterion, for example only time, energy, CPU or network load. The strong mutual impact and interdependencies among these demand an integrated approach for practical use. This does not exist today.

Furthermore, the static view of a system's operation condition is highly inadequate, as video streams in consumer electronic exhibit both large variations in resource demands as well as availability. Demands vary, e.g., due to encoding techniques, frame sizes, video content, or different complexity of decoding algorithms; availability of resources varies, e.g., due to wireless network links or changes in CPU speed for energy management.

Due to the large number of parameters and the strong inter-dependencies, it is not possible to explicitly calculate or simulate different compromises so the architect or designer can make an educated choice on what is most important in the overall system optimisation. Currently the compromise between "timeliness", "saving energy" and "utilising resources" is made at the design stage, and is at best optimised at device level. In a future where almost all devices will be networked, this will not lead to optimal system performance at minimal cost for the end-user. Keeping the power consumption low in the hand-held device increases the user's experience. Also at this point in time it is not possible for the manufacturer and end-user to make educated choices in this area. End-users might well be willing to spend more money on a hand-held device which uses much less battery power for a certain perceived quality level, so the experience can last longer without having to recharge the batteries.

Wireless networks have certain peculiarities that need to be taken care of during application design. One of the most critical ones is the large Bit Error Rate (BER), which can be up to 10^{-5}, whilst wire-bound networks like 100BaseT usually have about 10^{-8}. Such a large BER in fact means that the probability is very high that almost every second one third of the video frames and error occurs during transmission. Due to the audio/video compression, such transmission errors can be fatal in a non-scalable/non-embedded bit stream format wart. the perceived quality of the transmitted video. It is therefore mandatory to develop good error recovery schemes.

4.2 Industrial Needs and Experience

The increasing use of digital technology and digital media not only for audio but also for video distribution, with the convergence of technologies between the CE (consumer electronics) and IT (information technology) domains have, in the past decade, opened huge market

opportunities. On the other hand, the use of standardized algorithms (MPEG 2), mass volume chip sets (DVD players) and regulatory trends (ending of terrestrial analogue broadcasting) have opened not only markets for the established players, but also reduced the entry barriers for low-price, high-volume newcomers from Asia. So, the landscape has been fundamentally altered to the point where true innovators investing heavily in R&D have less and less time to enjoy the fruits of their efforts before “me too” producers arrive. The reducing lengths of the innovation-to-commodity product cycles challenges the whole CE industry, so only the leading brands can get genuine innovation through large investment in R&D. In the last decade, many medium-sized CE manufacturers vanished or were merged with larger companies

Thus the industrial needs for adaptive resource management are obvious for consumer electronics, in particular for video processing and streaming, such as TV, DVD, DVB, as well as telecommunications, with sophisticated phones and the introduction of video conferencing.

In particular, the cluster has focused on Consumer Electronics in this phase. Media processing and –delivery has been identified as real-time problem with clear need for adaptively, as worst case provisions are extremely expensive, but timely delivery and display are crucial for perceived quality. A number of European manufacturers are leading in this field. Philips in particular has expressed strong interest. In the next phase, the cluster will look to telecommunications, where media delivery on handset is arising as a key issue. Partners of the cluster have established contacts with Ericsson Mobile Platforms and Nokia as preparation.

Two quotes can underline the industrial need for adaptive resource management:

“Delivering a frame too late is a competitive disadvantage; so is the cost over provisioning of resources.”

“Competition on the handsets is via features; efficient resource usage provides enables more features.”

4.3 Ongoing Work in the Partner Institutions

Mälardalen University is working with Philips Research on video streaming in wireless home entertainment networks. The work concentrates on temporal issues and resource management framework, demand with respect to time and resources of video stream, and adaptive methods for network bandwidth management. On the operating system side, attention has been given to the issues of multiresource management, in particular with respect to cache aware scheduling.

The team at the University of Pave is being working on scheduling mechanisms for temporal isolation. On consumer electronics applications, in fact, most of the computational activities have highly variable computation times, which are also very difficult to estimate and bound. As a consequence, a temporal isolation mechanism is essential to control tasks interference and enable a more flexible QoS management **.**

The team at the Scuola Superiore Sant’Anna of Pisa (affiliated to Pavia) is being working on bandwidth reservation techniques. In combination with temporal isolation mechanisms, bandwidth reservation schemes allow to virtualize the processor partitioning the processing power among the different application tasks. In this way, each task behaves as it were executing alone on a slower processor, and the feasibility analysis of the application can be significantly simplified **.**

Evidence is providing software support and tools for resource management. In particular, efforts are focusing on the development of a graphical tool for the feasibility analysis of the application. The most interesting and innovative feature of the tool is that it is based on

powerful analysis techniques that can provide sensitivity analysis to help the user in changing task set parameters when the application is not feasible.

The University of Cantabria has been working in the integration of flexible scheduling techniques with the network protocols to support the requirements of consumer electronic systems. Work consisted on the development of the API for resource management in the network, and a design of a real-time network protocol, based on modifications to existing protocols. Further work consisted of the implementation of these resource management techniques in the network protocols, and their evaluation for a system with requirements for adaptive multimedia streaming on a real-time network that was shared with control applications. The evaluation was positive in showing that the same real-time network could be adapted to scheduling both kinds of traffic, multimedia and control, with full control of network resources.

Universitat Politècnica de Catalunya (affiliated to Malardalen) is working on feedback mechanisms for resource management. Consumer electronic applications demand constant bandwidth to meet QoS requirements. However, in-home processor and network bandwidth availability may change dramatically. Feedback based mechanisms are applied to detect bandwidth changes and to adapt applications to the bandwidth variability.

The team at Universidade de Aveiro has focused on the network support to provide dynamic QoS management of streams. The team has studied three different application domains namely distributed computer control systems (based on FTT-CAN), distributed video monitoring systems (based on FTT- Ethernet) and multi-agent cooperative systems (based on a new wireless adaptive TDMA protocol). The first one included a new step-wise rate-adaptation mechanism together with a controller, the second one included on-going work on the deployment of the (m,k)-firm model for video adaptation and the third allowed to cope with varying channel load while synchronizing the nodes without a clock synchronization service.

UPM (in collaboration with UC3M) has continued with development on resource and QoS management. The CPU accounting and enforcing facilities has been improved and ported to the 2.6.9 Linux kernel. Another work has been devoted to develop infrastructure for providing resource management facilities in the execution of remote method invocations. In particular, Java RMI has been extended for supporting QoS in the execution of the invocations. This implies the integration of the negotiation functions within this communication model and the management of the network. One of the networks target of this study is AFDX. This is a network used in avionics applications and that can be used for hard and soft real-time systems.

The Polytechnic Institute of Porto is addressing the problem of resource consumption feedback, by developing mechanisms for online monitoring of the behaviour of the operating system, and the real resource consumption per task. Also, work is being done on collaborative QoS-aware coalitions of services, in order to support devices with limited resources in hybrid wired/wireless environments.

4.4 Interaction, Building Excellence Between Partners

The topics of the activity span a wide range, from operating system, scheduling, (wireless) networks, video streaming, architectures, consumer electronic demands, each major research areas in themselves. Consequently, issues can only be addressed by the combined expertise represented in the cluster. Some of the partners have been working together previously, however, in sub groups on isolated topics, e.g., scheduling, networking, or QoS middleware.

The activities in the first phase already indicate progress for more general integration, including:

Philips and Malardalen set up a regular meeting framework and now have a joint PhD student. The possibility to meet regularly provides close supervision and intensive technical exchange. A joint tutorial on real-time issues for media processing can be developed.

A summer school, organized by UPC, brought together UPC, Philips, and Malardalen. In addition, it provided for the start of cooperation on control theoretical issues in video transmissions and processing.

A student from UPC spent 6 month at the University of Lund of the control cluster. The project dealt with a resource management strategy for control tasks that maximize control performance within the available resources by readjusting tasks periods at run-time. A feedback scheduling framework is used to determine online the optimal task periods considering the response over an infinite time horizon of the plants controlled by arbitrary control laws, accounting for stationary and non-stationary noise processes.

A workshop for real-time and control, organized by Lund, provided partners of ART to start interacting with the control cluster.

UPM, UM, and Cantabria started the work for porting HOLA-QoS on top of the resource management facilities provided by MARTE.

The interaction among the partners has led to the definition of the requirements for a project proposal that was presented in September 2005. Among the objectives of the project is the exploration of adaptive real-time techniques for media processing systems.

A number of staff exchanges from previously not cooperating partners is planned for the next phase.

4.5 Spreading Excellence

The results will be disseminated to the scientific community in the standard ways of publications, but also by specific workshops to be organized with appropriate conferences.

The industrial impact is expected from the pickup of solutions to the specific identified application requirements and the interaction in the planned workshop meeting between industrial engineers and academic researchers.

Partners are actively involved in the real-time research community, contributing to the organization of conferences and events, as well as being involved in the executive boards of the Technical Committee on Real-time Systems of IEEE and Euromicro, responsible, for the development of major conferences, such as RTSS and ECRTS.

In addition, public activities included:

ARTIST Summer school on Adaptive Real-time Systems, with emphasis on Real-Time Control Systems

Automatic Control Dept., Technical University of Catalonia (UPC), Barcelona, Spain, June 2005, Lecturers: Gerhard Fohler (Malardalen), Peter van der Stok (Philips), Pau Marti, Manel Velasco (UPC)

Objective: Provide an overview of scheduling and resource allocation techniques for developing predictable and adaptive real-time systems. A short introduction to control theory with practical exercise in a lab, with strong emphasis on the interaction and integration of control systems and real-time systems. Introduction to issues in in-home network middleware and video streaming.

Participation: 25 students from Universities in Spain, Portugal, and Germany, one representative from a Spanish company.

Real Time Systems tutorial at Philips Software Conference

Within the annual Philips Software Conference, a tutorial on real-time systems was held. Partners from the activities gave presentations: Introduction to Real-time Systems (Gerhard Fohler), Tools for the RT Engineer (Clara Otero Perez), Resource Reservations (Liesbeth Steffens). The tutorial provided an excellent opportunity for dissemination, learning about real-time issues, and to establish contacts to engineers within Philips working with RT.

OSPERT 2005

Workshop on Operating Systems Platforms for Embedded Real-Time applications, in conjunction with ECRTS 05, Palma de Mallorca, Spain, July 2005

This workshop was a forum for researchers and practitioners of RTOS to discuss the recent advances in RTOS technology and the challenges that lie ahead. The workshop consisted of invited presentations about academic state-of-the-art and industrial state-of-practice within the area, as well as submitted papers with 30+ participants. Partners from the activity organized and gave presentations on related topics. The workshop was shared with other activities in the cluster.

Tutorial at RTAS 06

Partners of the clusters were invited to give a tutorial on activity related issues for the IEEE Real-time and Embedded Technology and Applications Symposium - RTAS 06, April 2006, San Jose, California, USA. The event will be collocated with the Embedded Systems Conference Silicon Valley 2006, featuring 194 sessions, and an expected 200+ industrial exhibitors.