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

Activity Progress Report for Year 4

Scheduling and Resource Management

Cluster:

Operating Systems and Networks

Activity Leader:

Professor Alan Burns (University of York, UK)

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Policy Objective (abstract)

The management and scheduling of system resources is one of the main development challenges in any embedded system. This activity is concerned with multi-resource policies and analysis techniques that allow safe and timely, but also effective, resource utilisation. Many resource types are considered: processing units, communication units, storage units, application-specific units and generic resources such as power.

Versions

number	comment	date
0.1	Initial draft which requires input from all partners	19th Oct 2011
0.2 to 0.8	Internal drafts used by the editors	
0.9	Draft for internal review	19th Dec 2011
1.0	Final Draft for external review	11th Jan 2012
1.1	Final Version for delivery	17th Jan 2012

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1. Overview of the Activity

1.1 ArtistDesign Participants and Roles

Professor Alan Burns (University of York - UK)
The Real-Time Systems Research Group at the University of York contributes research on advanced scheduling and resource management policies.

Professor Giorgio Buttazzo (Scuola Superiore Sant'Anna -Italy)
The Scuola Superiore Sant'Anna (SSSA) of Pisa investigates advanced scheduling methodologies for increasing the predictability of real-time systems characterized by a highly variable workload and execution requirements.

Professor Luis Almeida (University of Porto - Portugal)
The team at the University of Porto (UnivPorto) is involved in the design and analysis of tools and mechanisms for supporting dynamic QoS management, mainly for distributed multimedia systems, flexible scheduling, dynamic reconfiguration, graceful degradation and survivability for distributed embedded control systems, particularly robots and vehicles.

Professor Michael Gonzalez Harbour (University of Cantabria – Spain)
University of Cantabria focuses on the integration of the resource management techniques developed by the other partners in the integrated framework for flexible resource management (FRESCOR). The group also participates in the development of the Real-time POSIX operating systems standards and the OMG standard for Modelling and Analysis of Real-Time Embedded Systems (MARTE).

Professor Gerhard Fohler (University of Kaiserslautern - Germany)
The Technical University of Kaiserslautern (TUKL) works on the integration of offline and online scheduling for combining time triggered and event triggered methodologies in the same system and provide resource management methods for media processing.

Professor Karl-Erik Årzén (University of Lund - Sweden)
The team at Lund University (ULUND) works on scheduling of embedded controllers, in particular co-scheduling approaches, and the use of feedback approaches in resource scheduling.

Professor Eduardo Tovar (Polytechnic Institute of Porto – Portugal)
The team at the Polytechnical Institute of Porto (Porto) is involved in Scheduling on Multicores, QoS-Aware in Distributed and Collaborative Computing, Resource Management in Sensor Networks and general purpose abstract models and dynamic run-time adaptability with anytime approaches.

Professor Maja D'Hondt (IMEC)
The runtime resource management team at the Digital Components division in IMEC is focusing on task scheduling, data storage and access methodologies to improve the performance and energy consumption of dynamic software applications, running on MPSoC platforms.

-- Changes w.r.t. Y3 deliverable --

None

1.2 Affiliated participants and their role within the Activity

Professor Alfons Crespo (Technical University of Valencia – Spain, Affiliated to Cantabria)
The team at the Technical University of Valencia is involved in providing real-time memory management OS support, and real-time kernel virtualization.

Professor Marisol García Valls (Universidad Carlos III de Madrid - Spain, Affiliated to Cantabria). *The team at the Universidad Carlos III de Madrid (UC3M) works on building real-time support into middleware for embedded systems, dynamic QoS-based resource management and scheduling, and its implications in Real-time Java.*

Professor Alejandro Alonso (Technical University of Madrid – Spain, Affiliated to Cantabria)
The team at the Technical University of Madrid investigates on integrated resource management policies with emphasis on adaptability.

Professor Lucia Lo Bello (Technical University of Catania - Affiliated to Pisa)
The team at the University of Catania works on QoS-oriented scheduling and management of communication and processing elements in embedded platforms, including energy-aware solutions.

Professor Pau Martí (Technical University of Catalonia – Affiliated to Lund)
The team at the Technical University of Catalonia works on the integration of feedback control and resource management techniques to provide adaptability to changing conditions on both resource and applications demands.

Professor Tullio Facchinetti (University of Pavia - Affiliated to the Scuola Superiore Sant'Anna)
The University of Pavia studies the application of real-time scheduling techniques to the management of energy systems.

Professor Hermann Härtig (University of Dresden – Affiliated to Kaiserslautern)
The team at the University of Dresden are involved in building micro-kernel- and hypervisor-based systems as experimentation platforms.

Professor Paulo Pedreiras (University of Aveiro – Affiliated to UnivPorto)
The team at University of Aveiro, previously a core participant, focuses on the development of scheduling and QoS management policies to cope with dynamic networked embedded systems.

-- Changes w.r.t. Y3 deliverable --

Change to scope of work by University of Pavia.

Change to scope of work by Universidad Carlos III de Madrid

1.3 Starting Date, and Expected Ending Date

This activity started at the commencement of ArtistDesign and continues work undertaken in the previous ARTIST NoE. Although a number of milestones are expected to be achieved and reported on during the duration of this NoE, scheduling and resource management will always

be a research focus as the nature of the resources change and the needs of applications expand. The research topic will therefore extend beyond the lifetime of ArtistDesign.

-- Changes wrt Y3 deliverable --

No changes with respect to Year 3.

1.4 Policy Objective

The main objective of this activity is the provision of models of embedded platform resources and policies, and the necessary analysis for undertaking the run-time scheduling of these resources and policies. A key scientific challenge is to link this resource-centred analysis with models of the application (and their resource usage policies) and the performance profiles of the hardware platform itself. Issues of temporality, safety, reliability and security can only be effectively addressed by an integration of these various abstract views of the overall system.

Seven promising approaches for providing this integration are:

- the use of search techniques to investigate architectural tradeoffs,
- the definition and use of virtual (unshared) resources,
- the use of reservations and contracts to allocate virtual resources,
- the use of coordination languages to integrate the use of different resource types,
- taking advantage of parallel processing platforms, such as multicores and FPGAs, in order to satisfy timing requirements,
- the application of self-adapting (feedback) resource allocation algorithms, and
- the recognition of the various time scales over which resource management must occur.

The nature of the scientific challenge should not be underestimated. Although very effective results for single resource (e.g. the processor) scheduling are available (and are used in industrial practice), for multiple resources there are no current applicable theories that have wide acceptability. Even for multi-processor SMP systems there is no consensus on the appropriate means of managing this resource.

The impact on operating systems will be taken into account via interactions with Activity 1 of this cluster. In addition the management of the network resource(s) will be addressed via joint work with Activity 3.

The industrial domains that will directly benefit from the results of this research include consumer electronics (in particular the games industry and multimedia applications), the automotive and aerospace industries, and environmental electronics such as smart spaces.

-- Changes wrt Y3 deliverable --

No changes with respect to Year 3.

1.5 Background

The platforms on which the next generation of embedded systems will be implemented will be radically different from those used in the current generation. The scale, performance, scope and applicability are all subject to significant enhancement. This presents the application developer and systems engineer with a number of fundamental challenges. At the centre of these challenges is the (effective) management of the platform's resources. Such platforms are likely to be multi-core (64 soon and 200+ within a few years); involve buses and networks of various capabilities and speeds (both off-chip and on-chip, i.e. NoCs); memories of various speeds; include specialised components such as MEMS, ASICs, DSPs, and ASIPs; are linked to a wide variety of sensors and actuators; are embedded in systems powered by batteries (for mobile applications); include areas of FPGA (which are capable of dynamic reprogramming); and may have input/output links to global web-based information systems (for cyber-physical systems). Applications will be multi-resource and configurable. They will want to make dynamic modifications to their behaviour to support adaptability and environmental change. For example, the level of parallelism may alter at run-time and lead to re-evaluation of how this parallelism is delivered, e.g. by a subset of the cores, by application specific processing elements or by reprogramming an area of FPGA.

The main objective of this activity is to investigate how this wide variety of platform resources can be abstracted, modelled and managed, and application-specific resource allocation policies defined. At run-time, near optimal resource usage is desirable, but so are levels of protection for high integrity applications and those that have security constraints. Effective run-time scheduling of multi-resource platforms is not currently achievable; new methods will need to be developed.

-- Changes wrt Y3 deliverable --

No changes with respect to Year 3.

1.6 Technical Description: Joint Research

The technical achievements expected range from specific scheduling algorithms that cater for particular groups of resources, to a general purpose framework for addressing the broad problem of managing multiple resources for multiple applications on multiple time scales with multiple policies. It is expected that a means of abstracting, via a parameterised definition, the capability of each resource will be developed. A greater understanding of the distinctive roles of both static architectural tradeoffs and dynamic run-time adaptability will be obtained by both theoretical study and where possible the analysis of industrially relevant case studies.

The activity will focus on the techniques needed elsewhere in the NoE for predictability and adaptability. It will directly address the run-time techniques and analysis that will need to be supported by the OS and any network protocols.

The first 18 months will focus on producing an outline taxonomy on scheduling system resources and the analysis techniques available to manage their use. One aspect of this taxonomy will be to survey the various forms of parallelism becoming available on current platforms; other topics will be the use of hierarchical scheduling, "anytime" approaches and specialised hardware. For mobile platforms, energy is a key resource that is the subject of much research that will be surveyed. The final class of resources to be considered is that containing specialized components and external devices (and information sources).

It is expected that within 4 years, real-time scheduling algorithms for multicores with a utilization bound greater than 50% will be developed for sporadically arriving tasks. These results will be extended for arbitrary deadlines and for dealing with shared data structures.

Re-configurability is a key issue for some applications. It is essential to not only ensure that the new mode is safe but also to ensure that the transition to the new mode does not violate timing requirements; this is often referred to as the mode change problem, and it is currently unsolved for multicores. Considering the current state-of-art in real-time scheduling in multicores, we expect this result on multicores to be available through the progress of ArtistDesign.

Dynamic memory management has been systematically avoided in real-time systems. One of the main reasons for this is the absence of deterministic allocators. Recently a new algorithm for dynamic memory allocation (TLSF) that solves this problem of the worst case bound whilst maintaining the efficiency of the allocation and de-allocation operations has become available. This allows the reasonable use of dynamic memory management in real-time applications and permits consideration of dynamic memory as a first-class resource which can be used jointly with other resources in the schedulability of embedded systems. This integration of memory management and other resources is likely to become increasingly significant in the coming period.

-- Changes wrt Y3 deliverable --

No changes with respect to Year 3.

2. Work Achieved in the NoE

2.1 Synthesis View of the Main Overall Achievements

During the 4 years of activity within the NoE, significant results have been achieved in a number of areas (the main ones being listed below), but in terms of an overview the international resource management/scheduling community has been primarily concerned with the topic of multi-core architectures and multiprocessor allocation and scheduling issues. Considerable and significant work has been published by ArtistDesign partners (and of course by others internationally). Five years ago there were a large number of open issues; some of which still remain, but the research landscape is now much clearer. For example, it is now known that for the Sporadic task model (the more general of the usually employed task models) an optimal allocation of tasks or jobs to processors is intractable. For partitioned systems effective priority assignment schemes now exist that make them almost as effective as dynamic placement schemes. Empirical studies have confirmed this view (as partitioned schemes are much more efficient to implement). For systems with significant number of large tasks (that themselves require over 50% of a processor) semi-partitioned approaches now seem to be the most appropriate schemes to use in industrial engineering practice. As well as the task/job allocation and scheduling issues, multi-core platforms have also lead to increased attention been given to on-chip networking (reported elsewhere) and shared-bus traffic control. The latter issue is leading to a merging of the previously separate research areas of scheduling analysis and worst-case execution time analysis.

The following is a more focused list of highlights from the work achieved during the existence of the ArtistDesign NoE:

- Multiprocessor scheduling: A comprehensive survey has been published on research in this area in ACM Computing Surveys. Optimal priority assignment policies have been introduced for global fixed priority scheduling. Efficient and effective scheduling approaches have been developed based on semi-partitioned and minimally dynamic scheduling algorithms. For example, one semi-partitioned approach abstracts from the tasks and introduces notional processors of different speed which migrate among physical processors instead of migrating individual tasks. This has shown to have moderate numbers of preemptions and migrations. The approach has been demonstrated through a working implementation of the scheduler for Linux, which has stressed the capability to move from solid theoretical work to practical relevance.
- Uniprocessor scheduling: Techniques have been developed for limited pre-emption scheduling reducing pre-emption delays, improving both real-time performance and predictability. Fundamental results have been derived comparing the effectiveness of fixed priority pre-emptive and EDF scheduling. Sensitivity analysis and exact schedulability tests for EDF have been derived that are tractable for practical systems. Mode change models continue to be evaluated and refined.
- Green scheduling: the foundation has been established to use real-time modelling, analysis and scheduling methods to balance the energy usage in electric power systems. Several novel theoretical results have been discovered on the subject. In particular, the relationship has been investigated between the parameters describing the physical process under control and timing parameters used for the scheduling.
- A new task model for target sensitive applications, gravitational task model, was developed based on work within the FRESCOR and ACTORS projects. Instead of the classic view that feasibility, i.e., executing between earliest start-time and deadline suffices, it provides for applications which have a preferred point in time, but can

execute around this if needed and justified. A pendulum analogy serves as intuitive way to express relations between competing tasks.

- Mixed criticality systems have emerged as a topic with industrial and theoretical importance. A table driven approach to scheduling, as used by the time triggered paradigm, has been introduced as suitable for such systems. The different criticality levels are expressed as modes with scheduling tables, which are switched upon tasks indicating changed criticality demands. Analysis has also been produced for multi-critically systems implemented using fixed priority scheduling (this work also addressing the optimal assignment of priorities).
- Real-time garbage collection continues to be the focus of much research. Methods now exist that make this feasible for soft real-time systems. Even for hard real-time systems schemes are currently being evaluated. The impact of this, and related work on memory management, continues to be applied to the real-time specification for Java, and related technologies for other languages such as Ada.
- The application of scheduling results to distributed systems has continued throughout the period of the NoE. Although network scheduling is reported elsewhere, the holistic problem of scheduling a complete system continues to be studied with important empirical results being made available.
- For mobile devices working from batteries the topic of energy efficiency is crucial; many of the classical results from scheduling theory have been revisited to allow them to deliver deadline satisfaction with minimum rates of execution. One of the advances that have been made over the period is the move to more realistic models of system-wide energy consumption. This has highlighted the drawback of some of the earlier results (not from ArtistDesign partners) in this area.
- Another main achievement has been the development of new theory for co-design and scheduling of embedded control system. A new jitter margin result has been developed that allows tradeoffs between sampling and actuation jitter for control system. This has been applied to co-design of networked control loops. Special attention has been given to event-based control where computations and/or communication is performed only when needed. For these systems there are no known general closed form solutions. Work has also considered stationary event-based control problems with mixed continuous/discrete time dynamics and stochastic disturbances. By modeling the system by a set of path constraints, upper and lower bounds on the control objectives are derived using sum-of-squares techniques and convex programming. The problem of jointly deriving the optimal controller parameters and the bounds has also been investigated. A Matlab toolbox for packaging the methodology is under development.
- Network scheduling - a number of network bandwidth management mechanisms have been developed for distributed systems with the main purpose of improving the efficiency of bandwidth usage while enforcing timeliness and mutual temporal isolation of the communications, covering both wireless and wired technologies. In wireless sensor networks several advances were made concerning the joint energy and QoS management. In switched networks a reconfigurable hierarchical scheduling framework allowed setting up a layer of virtual channels that provide guaranteed latency and throughput.
- As an increasing number of users run both real-time and traditional desktop applications in the same system, the issue of how to provide an efficient resource utilisation in this highly dynamic, open, and shared environment becomes very important. Based upon a careful study of the ways in which unused reserved capacities can be more efficiently used to meet deadlines of tasks whose resource usage exceeds their reservations, researchers proposed the coexistence of the traditional isolated

servers with a novel non-isolated type of servers, combining an efficient reclamation of residual capacities with a controlled isolation loss. The work undertaken unified the sharing and stealing strategy with reservations exchange within bandwidth inheritance, in order to mitigate the cost of blocking on soft real-time tasks whose actual execution behaviour is only known by executing tasks until completion.

- In embedded systems there is an ongoing paradigm shift towards relatively higher static power consumption via leakage currents when compared to the dynamic power consumption caused by the switching of transistors. As such the returns for the use of DVFS are diminishing and the use of sleep states emerges as the superior energy saving strategy. Researchers have developed an approach which makes extremely efficient use of spare capacities in the system to initiate sleep states. This improvement comes in several dimensions: (i) reducing drastically the complexity of the decision process when compared to that of the state of the art; (ii) it does not require hardware changes proposed in other works; (iii) substantial energy consumption reduction of up to 10%.

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

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

As indicated in the Description of Work the first milestone set for this activity during 2009 was to produce, in the second year, the outline of a **taxonomy** of resource management and usage. This taxonomy is aimed at being as broad as possible in the sense that:

- It covers all forms of processing devices from single processors to multicores, FPGAs etc.
- It covers all forms of communications including NoCs – although networking itself is covered by another activity within this cluster.
- It covers all specialised components; ASIC etc – although platform issues are covered more in another cluster.
- It covers system-wide resources such as energy.
- It covers all forms of (offline) verification including simulations, analysis (scheduling analysis), and various forms of model checking – although this later topic is covered more in another cluster.
- It covers online resource management (including control issues) to achieve openness, adaptability and fault tolerance.

Ongoing research on scheduling focuses on resource specific analysis, various resources have been considered including single processor with fixed priority or EDF scheduling, multiprocessor platforms of various types (including virtualised execution environments, multicore systems, and caching issues), communications media (but see Network activity report), memory and energy. Work has been done to extend the Contract Model (developed in the FRESCOR project) to include a wider range of resources and multiprocessor systems.

A focus on control applications has addressed period selection (sampling periods), low cost implementations and event-based control. Improvements to control effectiveness have been addressed by applying sensitivity analysis. Also the use of predictable CAN for control applications has been studied.

Another key problem addressed is the Adaptive Management of Multiple Resources. The resources typically used in end-to-end delivery of data 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.

The first year deliverable described technical achievement under the following headings:

- **Towards a taxonomy of resource usage**
- **Flexible scheduling framework**
- **Multi-resource scheduling on multicore platforms**
- **Memory arbitration on heterogeneous multicore platforms**
- **Flexible control on low cost microcontrollers**
- **Schedulability analysis for CAN-based control applications with dynamic bandwidth management**
- **Profiling and analysis**
- **Sensitivity analysis**
- **Optimal period selection and scheduling for embedded controllers**
- **Sporadic event-based Control**
- **Real-Time scheduling on multicores**
- **Dynamic run-time adaptability**
- **Integrated memory and communications management based on RTSJ**
- **Assessment of the IEEE 802.15.4 GTS scheduling and allocation mechanism for real-time WSNs**
- **Combined Energy and QoS management in WSNs**

-- No changes wrt Y3 deliverable --

This section was already presented in the Y2 deliverable, in section 1.7 and 3.1.

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

The problems tackled during Year 2 focused on the milestones defined in the Year 1 deliverable. Here a brief description is provided; further details are to be found in the Year 2 deliverable.

Extend the taxonomy of resource usage

The main cluster-wide problem tackled was the establishment of a wiki-based taxonomy of resource usage that was started during the first year. This wiki is open for external read-only access. Within this taxonomy resources have been categorised and characterised. Approaches to structuring multi-resource platforms are being considered including the use of banded notions of time, hierarchical structures and a resource usage model.

Extend the use of hierarchical and contract-based scheduling to multi-resource systems

Hierarchical scheduling gained increased attention in particular in virtualised environments. The virtualisation may be chosen for composability reasons like the 653-2 standard or may be driven by considerations of security (i.e. separation of data in different partitions), robustness (e.g. avoidance of life style applications threatening the basic communication infrastructure in mobile phones) or data privacy reasons (e.g. preventing identity theft in banking applications).

Produce effective scheduling and placement algorithms for multiprocessor systems

Multiprocessor scheduling (including multicore) continued to be a topic that was actively pursued in many centres world-wide, including a number in the ArtistDesign consortium. A significant number of publications were produced in this area and a number of approaches were developed, including the use of resource reservation techniques. The scheduling of communications that are necessary with multiprocessor systems was also considered.

Extend sensitivity analysis to EDF and multiprocessor systems.

This topic has been pursued at York (with Professor Sanjoy Baruah of North Carolina). A set of techniques were produced that allow sensitivity analysis to be undertaken via a single pass of a schedulability test. An internal report is available.

Produce mode change algorithms suitable for multiprocessor systems.

Global and pre-emptive scheduling problem of multi-mode real-time systems upon identical multiprocessor platforms has been tackled by the Polytechnic Institute of Porto.

Determine an effective way of undertaking (static) architectural tradeoffs.

Work started on this via the INDEXYS project.

Determine an effective way of undertaking (dynamic) adaptive resource management (making use of feedback techniques from the control environment).

Issues concerning control and scheduling (and resource management) were considered. Period selection was addressed, and event based control problems. This work was undertaken by Carlos III University of Madrid. Issues concerned with education were also covered in this topic.

Define a framework that can accommodate multiple time-frames within a single system and facilitate hierarchical scheduling, cascade control and other means of separating temporal concerns.

Work on the timeband notion continued at York and contributing to the taxonomy work.

The second year deliverable provided more detail on the technical achievement (TAs) under the following headings:

- **Development of the taxonomy as a wiki**
- **Hierarchical scheduling**
- **Language support for programming schedulable systems**
- **Memory resource management**
- **Deadline-period analysis in embedded control systems**
- **Resource management for control tasks**
- **Extending resource reservation to multicore systems**
- **Limited pre-emptive scheduling**
- **Produce effective scheduling and placement algorithms for multiprocessor systems**

- **Effective way of undertaking (dynamic) adaptive resource management**
- **Mode change algorithms suitable for multiprocessor systems**
- **Virtual educational laboratory of distributed process control**
- **Optimal period selection and scheduling for embedded controllers**
- **Sporadic event-based control**
- **Task concurrency management and access scheduling for dynamic systems**
- **Techniques to avoid beacon collisions in IEEE 802.15.4 cluster-tree networks**
- **Multi-resource contract-based scheduling framework**
- **Dataflow scheduling using constraint programming**
- **Low-level adaptation mechanisms in contract-based systems**

-- No changes wrt Y3 deliverable --

This section was already presented in the Y2 deliverable, in sections 1.8 and 3.1.

2.4 Work achieved in Year 3 *(Jan-Dec 2010)*

The problems tackled during Year 3 focused on the milestones defined in the Year 2 deliverable. Here a brief description is provided; further details are to be found in the Year 3 deliverable.

Extend the taxonomy of resource usage.

A major activity this year was the resource wiki which is open for external read-only access: http://www.cs.york.ac.uk/ArtistResourceManagement. Within this taxonomy resources have been categorised and characterised. Approaches to structuring multi-resource platforms are considered including the use of banded notions of time, hierarchical structures and a resource usage model.

Extend the use of hierarchical and contract-based scheduling to multi-resource systems.

A number of projects and research activities continued to look at means of supporting multiple applications (or components) on the same platform. These techniques need to support composition and isolation. Two important schemes that enable this to happen are hierarchical scheduling and the use of contracts.

Produce effective scheduling and placement algorithms for multiprocessor systems.

Multiprocessor scheduling (including multicore) continued to be a topic that is actively pursued in many centres world-wide, including a number in the ArtistDesign consortium. A significant number of publications were produced in this area and a number of approaches developed, including the use of resource reservation techniques. Issues concerned with scheduling communications that are necessary with multiprocessor systems were also considered. Multiprocessor systems that are also distributed have also been considered.

Determine an effective way of undertaking (static) architectural tradeoffs.

Work here focused on the emerging topic of Cyber-Physical systems and the trade-offs that must be made when energy usage has to be considered. Also considered is the way static analysis can be used to define the slack that can be used at run-time to enhance the quality of the system's outputs.

Determine an effective way of undertaking (dynamic) adaptive resource management (making use of feedback techniques from the control environment).

Issues concerning control and scheduling (and resource management) were considered.

Extend sensitivity analysis to EDF and multiprocessor systems

The work undertaken in previous years was consolidated into a number of publications and resulted in the development of a C=D algorithm for semi-partitioned multiprocessor scheduling.

Support resource management software construction in programming languages

The need to be able to program systems that make use of the resource management notions developed by researchers means that support at the programming language and operating system level is required. The latter is discussed in the OS cluster deliverable. Language issues and their standardisation were progressed.

The third year deliverable provided more detail on the technical achievement (TAs) under the following headings:

- **Development of the Taxonomy as a wiki**
- **Development of component-based real-time systems using reactive behaviour models**
- **Real-time scheduling**
- **Optimal period selection and scheduling for embedded controllers**
- **Sporadic Event-Based Control**
- **Dataflow Scheduling using Constraint Programming**
- **Scheduling real-time multimedia with dynamic priorities over contract-based budgets**
- **Non-functional information models for distributed real-time Java**
- **New time-deterministic reconfiguration algorithms for service-based real-time applications**
- **Sub-optimality of Scheduling results**
- **Effective hard real-time multiprocessor scheduling algorithms with low Overheads)**
- **Slack management for control tasks in monoprocessor systems**
- **A reconfigurable hierarchical scheduling framework**
- **Utilisation-based Schedulability tests**
- **Investigation on a new class of Real-Time Systems: Real-Time Physical Systems**
- **Power-constrained embedded system design**
- **Design space exploration framework for run-time resource management on multi-core systems**
- **Software Transactional Memory for Real-Time Systems**
- **Parallelism in Server-based Multiprocessors**
- **Effective Energy Management in Real-Time Systems**
- **Scheduling algorithms for real-time and reliable communication in IEEE 802.11 networks**

- **Load management in flexible industrial networks characterized by a hybrid wired/wireless architecture and mobile wireless nodes**
- **Frequency hopping management mechanism for Bluetooth networks used in industrial environments**
- **Dynamic resource management**
- **Language support for Programming Schedulable Systems**
- **Sensitivity analysis and task splitting**
- **Resource management**
- **Scheduling algorithms for adaptive and flexible real-time systems**
- **Hierarchical scheduling in hypervisored systems**

-- No changes wrt Y3 deliverable --

This section was already presented in the Y3 deliverable, in sections 1.11 and 2.1.

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

The problems tackled during Year 4 have focused on the milestones defined in the Year 3 deliverable. Here a brief description is provided; further details are to be found in the following Technical Achievements (TA) section, which are numbered for convenience.

Produce effective scheduling and placement algorithms for multiprocessor systems, *including dynamic priority schemes for efficient, low-cost scheduling on multiprocessors*

Multiprocessor scheduling and allocation algorithms are topics that are being actively pursued in many centres world-wide, including a number in the ArtistDesign consortium. Research under this topic includes: Semi-partitioned and minimally dynamic scheduling algorithms (TA1 and TA2). How to optimally schedule a set of distributed control algorithms (TA12 and TA13). A framework for analyzing and allocating parallel real-time applications on multiprocessor platforms (TA18). Parallel task models where multiple threads of a single job can execute concurrently (TA22). The use of Software Transactional Memory (STM) as an alternative to lock-based approaches to synchronisation (TA23). Analysis bounding the bus traffic generated by a single CPU in a multicore system (TA25).

Development of new theoretical results in the field of energy and power systems.

New results have been derived for Real-Time Physical Systems (RTPS) with applications including minimising the overall peak load for a distributed schedule of battery charging for electric vehicles (TA4). In terms of processor time and energy management, Dynamic Voltage and Frequency Scaling (DVFS) has been the dominant approach in the past; however, race-to-halt based approaches which utilise processor sleep states have recently taken on a more prominent role (TA24). Further work has extended Real-time Calculus to account for dynamic power management in hard real-time systems (TA20).

Extend the use of hierarchical and contract-based scheduling to multi-resource systems. Modelling and design under contract-based scheduling.

Research has continued on means of supporting multiple applications (or components) on the same platform, with projects focusing on the modelling of components for building applications that run on open platforms with contracts that are negotiated under the resource-reservation paradigm (TA5 and TA6).

Resource management in distributed contexts.

Schedulability analysis and optimisation techniques have been developed for heterogeneous distributed hard real-time systems that use event-triggered fixed priority and EDF scheduling policies (TA7). Under the Flexible Time-Triggered (FTT) paradigm, work has been done to integrate processor and network resources and provide consistent reservations that are enforced throughout the distributed system (TA28). A reconfigurable hierarchical scheduling framework for switched Ethernet communications has also been developed (TA26).

Extend the taxonomy of resource usage.

The resource wiki was opened up to external evaluation in year 4. Although there is some evidence of usage, the wiki has not been as successful as hoped. There are a number of public wikis available for related topics (TA8).

Determine an effective way of undertaking (dynamic) adaptive resource management.

Work in this area includes algorithms for dynamic assignment of priorities in multimedia systems. These algorithms allow exhausted-budget tasks to continue execution if enough processor capacity is available, thus improving quality of service (TA9). Other research in this area includes probabilistic admission control for cloud computing systems (TA21).

Integration of support for bounded-time reconfiguration in networked embedded systems.

Bounded-time reconfiguration algorithms for service-based real-time applications have been developed (TA10). Other research has looked at the design of appropriate architectures and building blocks for bounded-time reconfiguration (TA28), as well as methods of performing elastic resource management that reduce the time needed to find the new bandwidth distribution upon a reconfiguration (TA27).

Evaluation and possible enhancement of the expressive power of certain languages to integrate the support for QoS aware scheduling (e.g. real-time Java).

Enhancement of the expressive power of programming languages to support multiprocessor and distributed scheduling has focused on Real-Time Java and Ada (TA11, TA15, and TA23).

Building resource-awareness into communication middleware.

Development of resource managers for middleware that provides and enforces reservations extending across processors and networks has been explored within the scope of the iLAND ARTEMIS project (TA28).

Produce mode change algorithms suitable for multiprocessor systems.

This topic spans two clusters. It is reported in the Deliverable for the Design for Adaptivity Cluster.

Uniprocessor scheduling

Research has continued into uniprocessor scheduling in areas including: multi-criticality (TA17 and TA30), limited pre-emption (TA19), cache related pre-emption delays (TA31), and the sub-optimality of fixed priority scheduling (TA3).

-- The above is new material, not present in the Y3deliverable --

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

3.1 Technical Achievements

1. Effective hard real-time multiprocessor scheduling algorithms with low overheads: minimally dynamic algorithms (York)

Minimally dynamic algorithms are based on global scheduling policies such as global EDF and global FP, but with a single additional change in job priority when a job reaches zero laxity. Such –ZL algorithms dominate the underlying algorithm in terms of scheduling performance at the cost of one additional pre-emption per job release.

Fixed Priority until Zero Laxity (FPZL) scheduling is similar to global fixed priority pre-emptive scheduling; however, whenever a task reaches a state of zero laxity it is given the highest priority. FPZL is a minimally dynamic algorithm, in that the priority of a job can change at most once during its execution, tightly bounding the number of pre-emptions. We developed polynomial time and pseudo-polynomial time sufficient schedulability tests for FPZL. These tests were subsequently improved by computing upper bounds on the amount of execution that each task can perform in the zero laxity state. Empirical evaluation showed that FPZL is highly effective, with a significantly larger number of tasksets deemed schedulable by the tests for this algorithm, than by state-of-the-art schedulability tests for global EDF or Earliest Deadline until Zero Laxity (EDZL) scheduling.

This work was extended with the introduction of the Fixed Priority until Critical Laxity (FPCL) algorithm. FPCL reduces the number of context switches with respect to FPZL, by only evaluating the laxity of tasks at job release and completion. At those times, it promotes the priority of any task that could potentially reach zero laxity prior to the next scheduling point. FPCL is theoretically inferior to FPZL (in the sense that the schedulability tests developed for FPCL are dominated by those for FPZL); however, an experimental investigation showed that this potential reduction in performance is negated by the reduced overheads. The work on FPCL was done in collaboration with Shinpei Kato at the University of California.

2. Effective hard real-time multiprocessor scheduling algorithms with low overheads: task splitting (York)

Semi-partitioned algorithms allocate most tasks to a single processor, splitting just a few tasks which are the only ones able to migrate from one processor to another at run time. Semi-partitioned algorithms are another promising approach to achieving effective multiprocessor scheduling with low overheads.

The previous work on task splitting has continued. In this scheme the first part of a split task has the constraint that its computation time must be equal to its deadline (hence the name of the algorithm C=D), while the second part has a normal behaviour, and must execute the remaining execution time in the remaining deadline. Effective methods of selecting which tasks to split have been developed, with experimental results showing the approach to be highly effective.

3. Sub-optimality of fixed priority scheduling (York, INRIA)

In previous years, we have collaborated with Thomas Rothvoss (EPFL), Sanjoy Baruah (North Carolina), and Laurent George and Pierre Courbin (INRIA) on research determining the sub-optimality of fixed priority scheduling (compared to an optimal algorithm). This year, we extended this thread of research, via an experimental investigation into speedup factors for tasksets with arbitrary deadlines. In this case, previous theoretical results gave a low bound of $1/\Omega \approx 1.76322$ and an upper bound of 2 for the speedup factor. We used a genetic algorithm combined with simulated annealing to search for tasksets with high speedup factors. This

approach found tasksets with speedup factors close to the lower bound, but none that exceeded it. Experiments for tasksets of cardinality two exhibited the same behaviour with respect to the theoretical lower bound for that case. These experimental results lead to the conjecture that the relaxation from constrained to arbitrary deadlines does not increase the speedup factor. Proof of this conjecture is a topic on ongoing research.

4. Derivation of new results on Real-Time Physical Systems (Pavia)

New theoretical results have been derived for Real-Time Physical Systems (RTPS). Their relationship with Switched Hybrid Systems has been identified and studied. The applicability of RTPS to energy systems based on compressed air has been investigated. Ongoing experimentation was started in collaboration with the Department of Electrical Engineering at the University of Pavia, section on energy management, regarding the control of multiple air compressors to optimize their energy usage. Moreover, collaboration was started with the Department of Energy of the "Politecnico di Milano" (Italy) to study the application of RTPS to the distributed schedule of battery charging for electric vehicles. The goal is to limit the overall peak load of power usage under electric distribution topology constraints.

5 Design of real-time component-based applications on open platforms (Cantabria)

Combining component-based development and resource reservation techniques a methodology has been developed that allows hard real-time component-based applications to be designed that can be installed in open platforms, in which the rest of the workload supported by the platform is unknown. RT-CCM is the component-based technology used: With the proposed methodology, the application is designed on top of a virtual platform, formulated as a set of virtual resources that model the capacity that the application requires from the platform to execute and meet its timing requirements. The internal management of the virtual resources was introduced at the container level.

Resource reservation techniques: When the application is going to be installed in a real platform, the virtual platform is negotiated through the resource reservation service, and if the workload can be supported by the platform, then the new application is installed. The approach has been tested in a single processor environment although the technology is prepared for applications that can be executed on distributed platforms. We have used two platforms that implement the resource reservation paradigm. The FRESH platform, which is oriented to embedded systems and has been developed in the FRESCOR project, over a distributed platform built by means of PC nodes with MaRTE OS and a Ethernet network based on the RT-EP protocol. And an experimental platform, which is oriented to general-purpose systems, based on PC nodes with Ubuntu Linux 10.04 and the Linux-rt patch 2.6.31.11 with a heuristic algorithm applied to the resource reservation service to negotiate the contracts with the platform.

6 Modelling real-time applications based on resource reservations (Cantabria)

The MAST 2 metamodel has recently been proposed for modelling real-time systems. Specifically, this work focuses on the introduction of two new classes named Virtual_Schedulable_Resource and Virtual_Communication_Channel used for modelling the schedulable entities in real-time applications that are designed and executed relying on a resource reservation paradigm.

Due to its recent proposal, updating the previous tools (MAST) that form the complete modelling and analysis suite will take some time. However, the capacity of the models conforming to MAST 2 to support in a uniform way the different phases of development of a real-time application based on a resource reservation paradigm has been demonstrated. With this approach, a single application model supports the whole resource reservation-based development cycle for real-time applications. However, in each stage, temporary models suitable for the currently available MAST tools are generated by lightweight model-to-model (M2M) tools implemented with the ATL language. This contribution is a starting point towards

updating the MAST tools in order to support the new advanced design paradigms for real-time systems covered by MAST 2.

7 Schedulability Analysis and Optimization in Heterogeneous Distributed Real-Time Systems (Cantabria)

The increasing acceptance of the Earliest Deadline First (EDF) scheduling algorithm in industrial environments, together with the continued usage of Fixed Priority (FP) scheduling is leading to heterogeneous systems with different scheduling policies in the same distributed system. Schedulability analysis techniques usually consider the entire system as a whole (holistic approach), with only one pre-established scheduling policy in all the resources. Composition mechanisms have been developed to enable us to combine different FP and EDF response-time analysis techniques for checking the schedulability of heterogeneous systems. Additionally, priority and scheduling deadline assignment techniques were combined into a new algorithm called HOSPA (Heuristic Optimized Scheduling Parameters Assignment), for optimizing the assignment of priorities and scheduling deadlines to tasks and messages in heterogeneous distributed hard real-time systems. Finally, all these techniques and methodologies were implemented into the MAST set of tools. This enabled us to perform a preliminary evaluation over a range of examples. This showed that these techniques are capable of performing worst case response time analysis and assigning scheduling parameters for heterogeneous systems. http://mast.unican.es

8 Development of the Taxonomy as a wiki (all partners lead by York)

An initial definition of the taxonomy was produced in Year 2. Year 3 produced a plan for the wiki and to populate it with relevant material. This has taken time as it involved a new way of working for many people (in a very wide community). In Year 4, it was opened up to external evaluation. Although there is some evidence of usage, the wiki has not been as successful as hoped, possibly due to their being public wikis available for related topics.

9. Scheduling real-time multimedia with dynamic priorities over contract-based budgets (UC3M)

Algorithms have been introduced for dynamic assignment of priorities in multimedia systems that utilize contract-based scheduling and guaranteed budget assignment. An efficient, light-weight mechanism has been developed that enables to combine budget scheduling with a fixed dual-band priority scheduling mechanism to allow exhausted-budget tasks to continue execution if enough processor capacity is available. This mechanism allows safe overruns of the processor whereby guaranteeing execution isolation. A framework for real-time execution in multimedia systems has been extended based on HOLA-QoS that allows the integration of remote multimedia processing.

10. New time-deterministic reconfiguration algorithms for service-based real-time applications (UC3M)

Time-bounded reconfiguration algorithms have been developed for service-based real-time applications that take into account the real-time characteristics of the whole system. UC3M has developed a real-time reconfiguration scheduling framework that is being used in the iLAND middleware. An analysis of the difficulties and implications of real-time reconfiguration in different distributed environments was made. Primarily the work has focused on resource management and scheduling policies that are integrated in middleware architectures. An architecture has been defined and implemented for a middleware that supports real-time reconfiguration carried out in the context of the iLAND project (ARTEMIS-Call1-100026). Efforts have continued in defining new algorithms for predictable service composition. As a result of this research, a novel hybrid approach for service composition was evaluated and compared against other available techniques. A service-oriented video surveillance system has

been developed for Android. In this system smart-phones participate in a video surveillance process.

11. Non-functional information models for distributed real-time Java (UC3M)

UC3M revised the programming abstraction of distributed real-time Java, which now considers a dual programming abstraction: one based on remote invocations and another on messages and queues. The programming model of real-time Java, has also been improved avoiding priority inversion introduced by the garbage collector Moreover, the non-functional transmission patterns for distributed real-time Java have been revised, evaluating the impact of different approaches on the end-to-end path of Java communications. Moreover, the communication protocol used by the RMI middleware has been extended with special tags for multiplexing and de-multiplexing, improving the end-to-end predictability of OSGi.

12. Optimal period selection and scheduling for embedded controllers (ULUND, Linköping Univ)

The work on how to optimally schedule a set of distributed control algorithms studied by ULUND and Linköping University and introduced in the Y1-Y3 deliverables has continued further, leading to one joint publication, one journal publication under submission and one PhD thesis at Linköping University. The objective is to minimize the combined cost of the controllers in the application. The design problem is solved using a genetic algorithm that decides the execution pattern of the control tasks. In the dynamic scheduling case, simulation is used to estimate the average delay and jitter of the control tasks. Similar to before the Jitterbug toolbox from ULUND is used to evaluate the control performance, taking the delay and jitter into account.

13. Sporadic Event-Based Control (ULUND)

The work on event-based control carried out by ULUND continues. This year the focus has been on the development of a Matlab-based software toolbox. A PhD thesis on the topic will be presented during Spring 2012.

14. Dataflow Scheduling using Constraint Programming (ULUND, Ericsson)

ULUND and Ericsson continued work on constraint programming for static uniprocessor scheduling of synchronous data-flow (SDF) networks and cyclo-static data flow (CSDF) networks. The model compiler described in earlier deliverables has been further refined.

15 Programming language support for multiprocessor resource management and scheduling (York)

Traditionally, real-time programming languages have provided limited explicit support for the programming of multiprocessor real-time systems. However, multiprocessor implementations are increasingly being required for all classes of real-time systems. Main stream languages like Ada and the RTSJ have responded by introducing support for different scheduling policies (global, fully-partitioned and semi-partitioned) via the introduction of thread affinities. Similarly, those languages that rely on Operating System support in this area (e.g. C) can use affinities, although these have yet to be standardized by POSIX. Unfortunately, the lack of standardization in the area of resource control protocols has resulted in simple priority inheritance being adopted as the main monitor control policy. This policy is not optimal (or even efficient) in all application scenarios. Recent research in the area indicates that the various protocols have their pros and cons. It is unlikely that in the near future agreement will be reached on which policies should be universally supported. York has been investigating the facilities that could be introduced into languages and operating systems that allow the programmer to provide their own protocols. A generic framework has been created and instantiated for Ada and the RTSJ.

16. Resource management (TUKL, UNIBO)

TUKL had a workshop to discuss the extension of the resource management framework on the CPU and network level to the system on chip level, e.g., by looking at the core and bus level. Collaborative work has started towards a trial implementation with the goal of using adaptive video streaming as a case study.

17. Mixed criticality scheduling (TUKL, York)

York has collaborated with Professor Sanjoy Baruah of University of North Carolina at Chapel Hill on response time analysis for mixed criticality scheduling in fixed priority systems. This analysis bounds the worst-case response times of tasks via a simple sufficient schedulability test. TUKL has also collaborated with Professor Baruah on extending these result for fixed priority mixed criticality scheduling to the Time-Triggered paradigm. This has resulted in proven analysis that has been compared with a purely fixed priority approach. In the future, efficient Time-Triggered mixed criticality methods will be studied.

18. Software framework for analyzing and allocating parallel real-time applications on multiprocessor platforms (PISA, TUKL, LUND)

A software framework for analyzing and allocating parallel real-time applications on multiprocessor platforms has been developed by the Pisa group, in collaboration with the University of Lund, and the University of Kaiserslautern. The framework uses resource reservation for achieving a virtual multiprocessor layer that isolates the temporal behaviour of concurrent applications running on the same platforms. Schedulability analysis is performed in isolation for each application to guarantee real-time requirements. Optimization techniques have been also provided to perform resource allocation to minimize the bandwidth used while meeting timing constraints.

19. Limited preemption scheduling (PISA, USAAR, UIUC)

Limited pre-emption scheduling has been investigated, in collaboration with University of Saarland and University of Illinois at Urbana Champaign, for increasing both predictability and efficiency in real-time embedded systems. Results have shown that limited pre-emption algorithms are quite effective in increasing the schedulability of fixed priority systems, while reducing worst-case execution times (WCETs), their variability, and the runtime overhead.

20. Energy aware scheduling (PISA, ETHZ, KIT (Karlsruhe))

The Pisa group continued work on energy-aware scheduling, extending the investigation to distributed systems with timing, bandwidth, and battery lifetime requirements. Together with ETH in Zurich and the University of Karlsruhe, real-time calculus has been extended to account for dynamic power management in hard real-time systems.

21. Scheduling framework for service-oriented architectures (PISA, Athens)

Pisa and the University of Athens collaborated to develop a scheduling framework for service-oriented architectures and apply probabilistic admission control methods in cloud computing systems.

22. Parallelism support in Multiprocessors (Porto)

There has been significant effort to extend real-time scheduling theory to make it applicable to multiprocessor systems; nevertheless the majority of those works consider task models where tasks use at most a single core at each time instant. Most of the works that consider parallel task models consider that parallel jobs have the same number of parallel threads, and the number of parallel threads per job must be no greater than the total number of processor cores. Such restrictions make the solutions unsuitable for many real-time applications that often employ different numbers of threads in different segments of computation.

This year development continued on a general parallel task model that allows jobs to generate an arbitrary number of parallel threads in different stages of their computations. We are

approaching the problem with two different approaches. The constant-bandwidth server abstraction has proved useful in designing, implementing, and reasoning about single core open real-time systems. The preliminary work of the previous year has been extended; a new policy for scheduling parallel jobs is being finalized. In parallel, a similar approach has been used to combine Real-time Java with Fork/Join on top of a real-time Java virtual machine with fixed priority scheduling. Two important aspects are being taken into account: the specification of a scheduling algorithm based on work stealing where parallel jobs inherit the timing properties of the parent job and the definition and specification of the memory model for handling and sharing parallel jobs among the work-stealing double-ended queues.

23. Software Transactional Memory for Real-Time Systems (Porto, York)

The evolution of chip architectures to higher numbers of heterogeneous cores brings renewed attention to the use of Software Transactional Memory (STM) as an alternative to lock-based synchronisation. STM relies on the possibility of aborting conflicting transactions to maintain data consistency, which impacts on the responsiveness and timing guarantees required by real-time systems. Contention delays must be (efficiently) limited so that the response times of tasks executing transactions are upper bounded and task sets can be feasibly scheduled.

Continuing the work of the previous year, we are assessing the use of STM in the development of embedded real-time software, analysing methods that introduce predictability to the STM conflict management. The use of multi-version STM in real-time systems is able to execute read-only transactions in a wait-free manner and reduces the amount of data access conflicts in a STM-based system; a method to predetermine off-line the necessary maximum memory overhead to store multiple versions of shared data, profiting the timing characteristics of hard real-time systems was developed. Research on predictable distributed conflict management algorithms preventing transaction starvation, and permitting response-time analysis was carried out, and is currently being tested.

The concept of transactions executing concurrently in isolation with an underlying mechanism maintaining a consistent system state was already explored in fault-tolerant and distributed systems, and is already supported by programming languages oriented for reliable and concurrent systems, such as Ada. Preliminary work on how to integrate STM transactions in Ada semantics and syntax resulted on a draft of a general programming interface to transactional memory, supporting future implementations of STM oriented to real-time systems. This proposal was discussed at the IRTAW 15 (http://www.artist-embedded.org/artist/IRTAW-15,2204.html).

24. Energy Management via Sleep Modes (Porto)

Energy dissipation in embedded platforms is driven by two components: Static and dynamic power. Dynamic power consumption may be decreased using DVFS, while static power consumption can be decreased using sleep states of the processors. Since the balance between static and dynamic power consumption is shifting towards relative lower dynamic power consumption, the exploitation of dynamic power delivers diminishing returns and sleep states emerge as the more favourable approach. Porto has combined in the ERTH approach the use of sleep states with a server based scheduling framework, which has been demonstrated to have on the one hand superior energy savings on the other hand substantially lower complexity than the state of the art. This is a continuation of the Year 3 work. Of particular concern is the investigation of the impact of sleep modes on pre-emptions and the reduction in complexity.

25. Bus/Network Contention in Multicore and Many-core Processors (Porto)

The individual CPUs of multicore and many-core processors are connected via network-on-chips or buses, which provide the facility of communication between cores, and more importantly the interconnect to the main memory. This connection to memory is the source of

contention when several CPUs attempt to access the main memory at the same time. Partitioning this access does not work, as the presence of caches imply that the accesses may be fairly infrequent and not predictable, leading to a substantial loss of performance. Porto has developed an approach to analyse and bound the bus traffic generated by a single CPU. The approach takes into account the distribution of memory accesses during program execution and in doing so outperforms related work.

26. A reconfigurable hierarchical scheduling framework for switched communications (Aveiro, UnivPorto, Malardalen and Mallorca)

Aveiro, UnivPorto, Malardalen and Mallorca continued the collaboration towards the implementation and analysis of a reconfigurable hierarchical scheduling framework within an enhanced Ethernet switch. This framework allows the dynamic creation, removal and adaptation of virtual channels with minimum guaranteed bandwidth and upper bounded latency. This enhanced switch is an enabling building block for large networks with bandwidth/latency guarantees as generally needed for Cyber-Physical Systems, including remote interaction, smart grid, collaborative robotics, etc. The implementation has been essentially carried out at Aveiro on top of an FTT-enabled switch that was developed within the HaRTES Portuguese FCT project and led to the conclusion of a successful PhD thesis. The timing analysis was carried out in collaboration with UnivPorto and Malardalen and an initial dependability analysis was triggered by Mallorca. An experimental prototype was demonstrated at several events, and a timing analysis was presented at EMSOFT. This thread of work will continue, focusing on dependability and composability issues within the CPSserv Portuguese FCT project starting in 2012.

27. Efficient implementation of the elastic resource management (UnivPorto, CMU and Aveiro)

This thread of work focused on the implementation of elastic resource management in dynamic embedded systems for low computational overhead as required for prompt adaptation. In particular, this work analysed different ways of performing elastic resource management on CPUs and networks and proposed a specific sorting of tasks/messages that substantially reduces the time needed to find the new bandwidth distribution upon a reconfiguration.

28. Implementing resource managers for distributed systems (UnivPorto, Aveiro, Bilbao)

UnivPorto, Aveiro and Bilbao (UPV-EHU) have been collaborating towards the development of multi-resource managers for distributed systems that can be integrated in distribution middlewares. Two directions have been followed, one to support the deterministic service-oriented middleware developed within the iLAND ARTEMIS project and the other one for prompt reconfiguration in RT-CORBA systems. The former direction has exploited two approaches, both starting from the network and extending to processor management, one uses the FTT-SE protocol and the other uses Linux-TC (Traffic Control) [UnivPorto]. The latter uses the FTT paradigm on top of CORBA to control the methods invocations and thus manage the processors, and it can be extended to include the management of the network resource. These threads of work are still active and will continue in the near future.

29. High integrity systems (UPM)

The work of UPM has centred on the development of high integrity systems. During the last year, the main achievements have been related to virtualization, distributed systems, and hardware/software co-design. In the context of the virtualization, UPM has ported ORK on top of the Xtratum hypervisor. ORK+ (Open Ravenscar Kernel) is a small and reliable real-time kernel supporting Ada Ravenscar. The aim of the work is to allow for a concurrent design and implementation of the software and hardware components of a real-time embedded system. The ASSERT process has been extended to support such a development paradigm. In the context of distributed systems, UPM has participated in the development of an approach based

on Model-Driven Engineering to ease the automatic generation of such applications from high-level system models. In addition to a toolset for MDE, it has provided a response analysis tool for assessing the response time of a system, during the development phases.

30. Accounting for Cache Related Pre-emption Delays (CRPD) in fixed priority systems (York)

In embedded real-time systems that utilise cache memory, the pre-emption costs occurring due to Cache Related Pre-emption Delays (CRPD) can be significant. York has collaborated with Sebastian Altmeyer of Universität des Saarlandes, Saarbrucken and Claire Maiza of Grenoble INP / Verimag, on techniques for analysing, bounding and integrating cache related pre-emption delays into response time analysis for fixed priority pre-emptive systems. Ongoing work in this area is focussing on comparisons with the use of scratchpad memory, and task layouts that minimise the CRPD.

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

3.2 Individual Publications Resulting from these Achievements

University of York

S. Altmeyer, R.I. Davis, C. Maiza “Pre-emption cost aware response time analysis for fixed priority pre-emptive systems”. In proceedings 32nd IEEE Real-Time Systems Symposium (RTSS'11), Nov 29th - Dec 2nd, 2011.

A. Burns, R.I. Davis, P. Wang, F. Zhang “Partitioned EDF Scheduling for Multiprocessors using a C=D Scheme”. Real-Time Systems, published online 7th May 2011, full publication Vol 48, No 1, pp 3-33, 2012.

R.I. Davis, A. Burns "A Survey of Hard Real-Time Scheduling for Multiprocessor Systems." ACM Computing Surveys, 43, 4, Article 35 (October 2011), 44 pages. DOI=10.1145/1978802.1978814.

R.I. Davis, A. Burns, “Improved priority assignment for global fixed priority pre-emptive scheduling in multiprocessor real-time systems”, Real-Time Systems, Vol 40, pp1-40, 2011.

R.I. Davis, A. Burns “FPZL Schedulability Analysis”. In proceedings 17th IEEE Real-Time and embedded technology and Applications Symposium (RTAS'11) , pages 245-256, April 11-14th, 2011.

S. Lin, A. J. Wellings, A. Burns “Ada 2012: Resource Sharing and Multiprocessors”, Proceedings of the 15th International Real-Time Ada Workshop (IRTAW-15).

D. Maxim, O. Buffet, L. Santinelli, L. Cucu-Grosjean, R. I. Davis “Optimal Priority Assignment Algorithms for Probabilistic Real-Time Systems”. In proceedings 19th International Conference on Real-Time and Network Systems (RTNS'11), Sept 29-30th, 2011.

M. Paolieri, E. Quinones, F. J. Cazorla, R. I. Davis, M. Valero “IA3: An Interference Aware Allocation Algorithm for Multicore Hard Real-Time Systems”. In proceedings 17th IEEE Real-Time and embedded technology and Applications Symposium (RTAS'11), pages 280-290, April 11-14th, 2011.

A. J. Wellings , S. Lin , A. Burns , “Resource sharing in RTSJ and SCJ systems” Proceedings of the 9th International Workshop on Java Technologies for Real-Time and Embedded Systems (JTRES '11) ACM New York, NY, USA ©2011 ISBN: 978-1-4503-0731-4 doi>10.1145/2043910.2043913.

A. Burns and S.K. Barugh, “Timing Faults and Mixed Criticality Systems”, Dependable and Historic Computing, Springer, editors Jones and Lloyd, LNCS 6875, 2011.

Scuola Superiore Sant’Anna, Pisa

M. Bambagini, M. Marinoni, F. Prosperi, G. Buttazzo, "Energy Management for Tiny Real-Time Kernels", Proceedings of the 2nd International Conference on Energy-Aware Computing (ICEAC 2011), Istanbul, Turkey, Nov. 30 – Dec. 2, 2011.

M. Bertogna, G. Buttazzo, G. Yao, "Improving Feasibility of Fixed Priority Tasks using Non-Preemptive Regions", Proceedings of the 32nd IEEE Real-Time Systems Symposium (RTSS 2011), Vienna, Austria, Nov. 30 - Dec. 2, 2011.

M. Bertogna, O. Xhani, M. Marinoni, F. Esposito, G. Buttazzo, "Optimal Selection of Preemption Points to Minimize Preemption Overhead", Proceedings of the 23rd Euromicro Conference on Real-Time Systems (ECRTS 2011), Porto, Portugal, July 6-8, 2011.

E. Bini, “Mapping real-time applications over multiprocessors”, 10th Workshop on Models and Algorithms for Planning and Scheduling Problems, Nymburk, Czech Republic, June 2011.

G. Buttazzo, "Handling Overload Conditions in Real-Time Systems", in Real-Time System, Seyed Morteza Babamir (Ed.), IN-TECH, ISBN 979-953-307-584-5.

G. Buttazzo, M. Marinoni, G. Franchino, "Real-Time and Energy Issues in Mobile Health Monitoring Systems" Proceedings of AICA 2011, Torino, November 15-17, 2011.

G. Buttazzo, "HARD REAL-TIME COMPUTING SYSTEMS: Predictable Scheduling Algorithms and Applications", Third Edition, Springer, 2011.

G. Buttazzo, E. Bini, and Y. Wu, "Partitioning Parallel Applications on Multiprocessor Reservations", IEEE Transactions on Industrial Informatics, Vol. 7, No. 2, pp. 302-315, May 2011.

T. Cucinotta, G. Anastasi. "A Heuristic for Optimum Allocation of Real-Time Service Workflows," In Proceedings of the IEEE International Conference on Service-Oriented Computing and Applications (SOCA 2011), Irvine, CA, December 2011.

G. Lipari, E. Bini, “On the Problem of Allocating Multicore Resources to Real-Time Task Pipelines”, 4th Workshop on Compositional Theory and Technology for RealTime Embedded Systems, Vienna, Austria, November 2011.

M. Marinoni, M. Bambagini, F. Prosperi, F. Esposito, G. Franchino, L. Santinelli, G. Buttazzo, "Platform-aware Bandwidth-oriented Energy Management Algorithm for Real-Time Embedded Systems", Proceedings of the 16th IEEE International Conference on Emerging Technology and Factory Automation (ETFA 2011), Toulouse, France, September 5-9, 2011.

L. Santinelli, G. Buttazzo, E. Bini, “Multi-Moded Resource Reservations”, Proceedings of the 17th IEEE Real-Time and Embedded Technology and Applications Symposium, Chicago, IL, USA, April, 2011.

G. Yao, G. Buttazzo, M. Bertogna, "Feasibility Analysis under Fixed Priority Scheduling with Limited Preemptions", Real-Time Systems, Vol. 47, No. 3, pp. 198-223, May 2011.

Universidad de Cantabria

L. Barros, P.L. Martínez, J.M. Drake “Design of real-time component-based applications on open platforms”. 37th Euromicro Conference on Software Engineering and Advanced Applications (SEAA), Oulu (Finland), pp. 65-72, August 2011.

L. Barros, C. Cuevas, P.L. Martínez, J.M. Drake, M. González Harbour. “Modelling real-time applications based on resource reservations”. 2nd International Workshop on Analysis Tools

and Methodologies for Embedded and Real-time Systems (WATERS 2011), Porto (Portugal), July 2011.

J.M. Rivas, J.J. Gutiérrez, J.C. Palencia, M. González Harbour. “Schedulability Analysis and Optimization of Heterogeneous EDF and FP Distributed Real-Time Systems”. 23th Euromicro Conference on Real-Time Systems, Porto (Portugal), July 2011.

University of Porto / Aveiro

A. Noguero, I. Calvo, L. Almeida, “The design of an Orchestrator for a middleware architecture based on FTT-CORBA”. 6th Iberian Conference on Information Systems and Technologies, Chaves, Portugal, 15-18 June, 2011.

R. Santos, “Enhanced Ethernet Switching Technology for Adaptive Hard Real-Time Applications”, Universidade de Aveiro, Portugal, PhD Thesis defended 12 July 2011.

M. Sousa, L. Silva, R. Marau, L. Almeida, “A Real-Time Resource Manager for Linux-based Distributed Systems”. Work-in-Progress session of RTSS 2011, Vienna, Austria, November 30, 2011.

TUKL

G. Fohler, “What is the Difference Between Offline and Online Scheduling?”, RTSOPS 2011: 2nd International Real-Time Scheduling Open Problems Seminar, ECRTS, July 2011.

R. Guerra, G. Fohler, “Gravitational task model based bandwidth compression algorithm for adaptive resource management”, Proceedings of the 13th Brazilian Workshop on Real-Time and Embedded Systems, Florianopolis, Brazil, November 2011.

R. Guerra, G. Fohler, “What is the meaning of preemption in utility-based real-time scheduling?” Proceedings of 2nd International Real-Time Scheduling Open Problems Seminar, July 2011.

R. Guerra, G. Fohler, “Handling overload of target sensitive real-time applications for increased system utility and improved resource usage”, SAC'11: Proceedings of 26th ACM Symposium on Applied Computing, ACM Publisher, Taiwan, March 2011.

Polytechnic Institute of Porto

M.A. Awan, S.M. Petters , “Enhanced Race-To-Halt: A Leakage-Aware Energy Management Approach for Dynamic Priority Systems” In Proceedings of the 23rd Euromicro Conference on Real-Time Systems (ECRTS 2011), Porto, Portugal.

A. Barros, L.M. Pinho. "Software transactional memory as a building block for parallel embedded real-time systems". In Proceedings of the 37th EUROMICRO Conference on Software Engineering and Advanced Applications (SEAA 2011). Oulu, Finland. September 2011.

A. Barros, L.M. Pinho. "Revisiting Transactions in Ada". In Proceedings of the 15th International Real-Time Ada Workshop (IRTAW-15), Liébana, Spain. September 2011.

D. Dasari, B. Andersson, V. Nelis, S.M. Petters, Arvind Easwaran, Jinkyu Lee, “Response Time Analysis of COTS-Based Multicores Considering The Contention On The Shared Memory Bus”, In Proceedings of the 8th IEEE International Conference on Embedded Software and Systems (IEEE ICESS-11), Changsha, China, November 16-18, 2011

D. Dasari, V. Nelis, B. Andersson, “WCET Analysis Considering Contention on Memory Bus in COTS-Based Multicores”, In Proceedings of the Work in Progress Session of 6th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2011)

C. Maia, L. Nogueira, L.M. Pinho “Combining RTSJ with Fork/Join: A Priority-based Model”. 9th International Workshop on Java Technologies for Real-Time and Embedded Systems, York, UK, September 2011. pp. 82-86.

Universidad Politécnica de Madrid

F. Ferrero, E. Alaña, A.I. Rodríguez, J.A. de la Puente, J. Zamorano, E. Conquet. “Extending ASSERT for HW/SW Co-design”. Data Systems in Aerospace — DASIA 2011. Malta, 2011.

Universidad Carlos III de Madrid

P. Basanta-Val, M. García-Valls and I. Estévez-Ayres. “Extending the Concurrency Model of the Real-Time Specification for Java”. Concurrency and Computation: Practice and Experience, 23(14): 1623-1645, 2011.

P. Basanta-Val, M. García-Valls, I. Estévez-Ayres. “A dual programing model for distributed real-time Java”. IEEE Transactions on Industrial Informatics, Nov. 2011.

P. Basanta-Val, M. García-Valls, I. Estévez-Ayres. “Non-Functional Information Transmission Patterns for Distributed Real-Time Java”. Software Practice and Experience. 41(12): 1409–1435, 2011.

P. Basanta-Val, M. García-Valls, I. Estévez-Ayres. “Fine tuning of the multiplexing facilities of Java’s Remote Method Invocation”. Concurrency and Computation Practice and Experience. 23(11): 236-1260, August 2011.

I. Estévez-Ayres, M. García-Valls, P. Basanta-Val, J. Díez-Sánchez. “A hybrid approach for selecting service-based real-time composition algorithms in heterogeneous environments”. Concurrency and Computation: Practice and Experience 23(15): 1816-1851 (2011).

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

M. García-Valls, F. Gómez Molinero. “Real-Time Reconfiguration in Complex Embedded Systems: A Vision and its Reality”. IEEE International Conference on Industrial Informatics (IEEE INDIN 2011). Caparica, Portugal. July 26 - 29, 2011.

M. García-Valls, P. Basanta-Val , I. Estevez-Ayres. “Supporting service composition and real-time execution through characterization of QoS properties”. ACM/IEEE International Symposium on Software Engineering for Adaptive and Self-Managing Systems, Honolulu, Hawaii, May 2011.

M. García-Valls, P. Basanta-Val, I. Estévez-Ayres. “Real-Time Software Framework for Supporting Reconfiguration in Consumer Electronics”. 11th IEEE Conference on Consumer Electronics, pp.865-866. 9-12 Jan. 2011

University of Pavia

T. Facchinetti, M.D. Vedova, "Real-Time Modeling for Direct Load Control in Cyber-Physical Power Systems", in IEEE Transactions on Industrial Informatics, special issue on Information Technology in Automation, IEEE, 2011.

G. Quartarone, N. Anglani, T. Facchinetti, "Improving energy management of electrically driven air compressors through real-time scheduling techniques", in Proceedings of the 37th Annual Conference of the IEEE Industrial Electronics Society (IECON), Melbourne, Australia, November, 2011.

M.D. Vedova, E. Di Palma, T. Facchinetti, "Electric Loads as Real-Time tasks: an application of Real-Time Physical Systems", in Proceedings of the First IEEE Workshop on Design, Modeling and Evaluation of Cyber Physical Systems (CyPhy), Istanbul, Turkey, July, 2011.

ULUND

S. Samii, P. Eles, Z. Peng, A. Cervin: “Design Optimization and Synthesis of FlexRay Parameters for Embedded Control Applications”, In Proc. International Symposium on Electronic Design, Test and Applications (DELTA), Queenstown, New Zealand, January 2011.

Toivo Henningsson, "Sporadic Event-Based Control using Path Constraints and Moments", In 50th IEEE Conference on Decision and Control and European Control Conference, Orlando, Florida, USA, December 2011.

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

3.3 Interaction and Building Excellence between Partners

The partners involved in this activity are part of an international community that meets regularly at the main conferences for the disciplines covering scheduling and resource management. These conferences include the IEEE International symposia RTSS and RTAS, and the European conference on real-time issues, ECRTS.

Interactions also take place as part of other funded EU projects such as ACTORS. Finally ArtistDesign specific meetings have taken place, for example a meeting in Porto and in Vienna. Other interactions include:

- UC3M and Pisa have started collaboration in two areas: QoS-based resource management for embedded multimedia platforms, and service oriented architectures. Currently, UC3M hosted a PhD student from Pisa for a one -year stay to collaborate on these topics. They have produced a joint publication in RTSOAA 2011.
- UC3M and UPM are collaborating to enhance the dynamic priority assignment protocol initially to be validated for multimedia systems and to study its validation on hard real-time platforms. They have produced a joint publication lead by UC3M and accepted in the index journal Future Generation Computer Systems, Elsevier, that will appear in 2012.
- The ACTORS project where ULUND, SSSA, TUKL, EPFL, Ericsson, and Evidence collaborated on feedback-based resource scheduling for multimedia terminals finished in February 2011.
- ULUND and TUKL have continued the development on the adaptive resource management developed within ACTORS during year 4. For 2012-2015 ULUND has received a Swedish VR grant to further continue the development.
- ULUND and Linkoping University collaborate on integrated scheduling and synthesis of distributed and embedded control applications within the Swedish ELLIIT project.
- TUKL had a workshop with UNIBO on resource management on the chip level and flexible scheduling.
- A post-doc from Malardalen stayed for 6 months at UnivPorto to work on the analysis of the hierarchical scheduling framework that was implemented in a specialized Ethernet switch as well as on other collaborations reported in the Real-Time Networks deliverable.
- UPV and UPM have collaborated on the integration, validation, and analysis of the porting of the kernel of ORK+ on top of the Xtratum hypervisor. This will allow Ada applications compliant with the Ada Ravenscar profile to run on a virtual machine in a safe and predictable way.

- UC and UPM have developed tool support for the development of distributed hard-real time systems using Model-Driven Engineering principles. The toolset is intended to facilitate code generation from high-level models.

-- Changes wrt Y3 deliverable

The above are all Year 4 specific activities

3.4 Joint Publications Resulting from these Achievements

Univ. Carlos III de Madrid & Univ. Politécnica de Madrid:

M. García-Valls, A. Alonso, J. A. de la Puente. "A dual-band priority assignment algorithm for dynamic QoS resource management". Future Generation Computer Systems, Elsevier. doi:10.1016/j.future.2011.10.005 To appear in 2012.

Univ. Pisa & Univ. Carlos III de Madrid:

G. Anastasi, T. Cucinotta, G. Lipari, M. García-Valls. "A QoS registry for adaptive real-time service-oriented applications". IEEE International Workshop of Real-Time Service Oriented Architecture and Applications. CA, USA. December 2011.

UnivPorto & Aveiro & Malardalen & CMU

R. Santos, P. Pedreiras, M. Behnam, T. Nolte, L. Almeida, "Demonstrating an Ethernet switch enhanced with hierarchical scheduling". Demo at APRES 2011, 3rd International Workshop on Adaptive and Reconfigurable Embedded Systems. Within the CPS WEEK at Chicago, USA, 11 April, 2011.

R. Santos, P. Pedreiras, M. Behnam, T. Nolte, L. Almeida, "A Demonstration of Hierarchical Scheduling over Ethernet". RTSS@Work session of RTSS 2011, Vienna, Austria, November 29, 2011.

R. Santos, P. Pedreiras, M. Behnam, T. Nolte, L. Almeida, "Multi-level Hierarchical Scheduling in Ethernet Switches". EMSOFT 2011, International Conference on Embedded Software. Taipei, Taiwan, 9-14 October, 2011.

R. Marau, K. Lakshmanan, P. Pedreiras, L. Almeida, R. Rajkumar, "Efficient Elastic Resource Management for Dynamic Embedded Systems". ICESS 2011, The 8th IEEE International Conference on Embedded Software and Systems, Changsha, China, November 16-18, 2011.

ULUND & TUKL

S. Schorr, A. Kotra, G. Fohler, J. Eker, K-E. Arzen, V. Romero, "Adaptive Resource Management in the ACTORS Framework - A live DVB-T/webcam Demo", RTSS@Work Demo Session of the IEEE Real-Time Systems Symposium, November 2011.

K-E. Arzen, V. Romero, S. Schorr, G. Fohler, "Reservation-Based CPU Management for Multicore Platforms", June 2011.

K-E. Arzen, V. Romero, S, Schorr, G. Fohler, "Adaptive Resource Management Made Real", Proceedings of the 3rd Workshop on Adaptive and Reconfigurable Embedded Systems (APRES 2011), Chicago, April 2011.

K-E. Arzen, V. Romero, M. Kralmark, S. Schorr, A. Kotra, G. Fohler, "Demo: Adaptive Resource Management Made Real", Proceedings of the 3rd Workshop on Adaptive and Reconfigurable Embedded Systems (APRES 2011), Chicago, April 2011.

M. Steine, C.V. Ngo, R.S. Oliver, M. Geilen, T. Basten, G. Fohler, J-D. Decotignie, “Proactive Reconfiguration of Wireless Sensor Networks”, 14th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems, ACM Publisher, Miami, FL, USA, October 2011.

J. Theis, G. Fohler, “Transformation of Sporadic Tasks for Off-line Scheduling with Utilization and Response Time Trade-offs”, Proceedings of the 19th International Conference on Real-Time and Network Systems (RTNS'11), pag. 119-128, Proceedings of 19th International Conference on Real-Time and Network Systems (RTNS11), September 2011.

York & UNC (Affiliated International Partner)

S.K. Baruah, A. Burns, R.I. Davis “Response Time Analysis for Mixed Criticality Systems” In proceedings 32nd IEEE Real-Time Systems Symposium (RTSS'11) , Nov 29th - Dec 2nd, 2011.

TUKL & UNC (Affiliated International Partner)

S. Baruah, G. Fohler, “Certification-cognizant time-triggered scheduling of mixed-criticality systems”, Proceedings of IEEE Real-time Systems Symposium 2011, December 2011.

Pisa & TUKL & ULUND

E. Bini, G. Buttazzo, J. Eker, S. Schorr, R. Guerra, G. Fohler, K-E. Arzen, V. Romero, C. Scordino, "Resource Management on Multicore Systems: The ACTORS Approach," Micro, IEEE , vol.31, no.3, pp.72-81, May-June 2011, doi: 10.1109/MM.2011.1

Pisa & UNC (Affiliated International Partner)

M. Bertogna, S. Baruah, “Tests for global EDF schedulability analysis”, Journal of Systems Architecture, 57(5): 487-497. May 2011.

M. Bertogna, N. Fisher, "The Explicit Preemption Placement Problem for Real-Time Conditional Code" Proceedings of the 2nd International Real-Time Scheduling Open Problems Seminar (RTSOPS 11), Porto, Portugal, July 2011.

Pisa & UC3 Madrid

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

Pisa & Catalonia

M. Velasco, P. Martí, J. Yépez, F.J. Ruiz, J.M. Fuertes, E. Bini, “Qualitative Analysis of a One-step Finite-Horizon Boundary for Event-driven Controllers”, Proceedings of the 50th IEEE Conference on Decision and Control (CDC), Orlando, FL, USA, December 2011.

Universidad de Cantabria and Universidad Politécnica de Madrid

H. Pérez, J.J. Gutiérrez, E. Asensio, J. Zamorano, J.A. de la Puente. “Model-driven development of high-integrity distributed real-time systems using the end-to-end flow model”. 37th Euromicro Conference on Software Engineering and Advanced Applications. September 2011.

Universidad Politécnica de Valencia and Universidad Politécnica de Madrid

A. Esquinas, J. Zamorano, J.A. de la Puente, M. Masmano, I. Ripoll, A. Crespo. “ORK+/XtratuM: An Open Partitioning Platform for Ada”. In A. Romanovsky and T. Vardanega

(eds.), Reliable Software Technologies — Ada-Europe 2011, LNCS 6652, pp.160–173. Springer-Verlag, 2011. June 2011. ISBN 978-3-642-21337-3

Pisa & Design for Predictability and Performance Cluster

C-W Lin, M. Di Natale, H. Zeng, A. Sangiovanni-Vincentelli, “Performance Analysis of Synchronous Models Implementations on Loosely Time-Triggered Architectures”, WiP Proceedings of RTAS 2011.

M. Di Natale, H. Zeng, “Task Implementation and Schedulability Analysis of Synchronous of Finite State Machines”, WiP Proceedings RTAS 2011.

H. Zeng, M. Di Natale, “Efficient Implementation of AUTOSAR Components with Minimal Memory Usage”, Proceedings of the Workshop on Synthesis and Optimization Methods for Real-time Embedded Systems (SOMRES 2011), Vienna, Austria, November 30, 2011.

H. Zeng, M. Di Natale, “Mechanisms for Guaranteeing Data Consistency and Flow Preservation in AUTOSAR Software on Multi-Core Platforms”, Proceedings of the 6th IEEE International Symposium on Industrial Embedded Systems (SIES 2011), Vasteras, Sweden, June 15-17, 2011.

Q. Zhu, H. Zeng, W. Zheng, M. Di Natale A. Sangiovanni-Vincentelli, “Optimization of Task Allocation and Priority Assignment in Hard Real-Time Distributed Systems”, ACM Transactions on Embedded Systems, to appear.

Pisa & Hardware Platforms and MPSoC Design Cluster

K. Huang, L. Santinelli, J.J. Chen, L. Thiele, G. Buttazzo, "Applying Real-Time Interface and Calculus for Dynamic Power Management in Hard Real-Time Systems", Real-Time Systems, Vol. 47, No. 2, pp. 163-193, March 2011.

P. Kumar, J.J. Chen, L. Thiele, A. Schranzhofer, G. Buttazzo, "Real-Time Analysis of Servers for General Job Arrivals", Proceedings of the 17th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA 2011), Toyama, Japan, August 28-31, 2011.

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

3.5 Keynotes, Workshops, Tutorials

Keynotes

Keynote: Integrating Real-Time Analysis into Design Flows
Speaker: Michael González Harbour, Universidad de Cantabria
2nd International Workshop on Analysis Tools and Methodologies for Embedded and Real-time Systems (WATERS) Porto, Portugal, July 2011
http://retis.sssup.it/waters2011/

Workshops

Workshop: 2nd International Real-Time Scheduling Open Problems Seminar.
Program Co-chair: Robert Davis, University of York.
Conference: 23rd Euromicro Conference on Real-Time Systems (ECRTS 2011), Porto,

Portugal, July 5th 2011.
http://www.cs.wayne.edu/~fishern/Meetings/rtsops2011/

Workshop: 2nd International Workshop on Analysis Tools and Methodologies for Embedded and Real-time Systems (WATERS 2011)
Program Co-chairs: Tommaso Cucinotta and Giuseppe Lipari, Pisa.
Conference: 23rd Euromicro Conference on Real-Time Systems (ECRTS 2011), Porto, Portugal, July 5th 2011.
http://retis.sssup.it/waters2011/index.php

Workshop: 4th Workshop on Compositional Theory and Technology for Real-Time of Embedded Systems.
Program Co-chair: Robert Davis, University of York.
Conference: IEEE Real-Time Systems Symposium, Vienna, Austria, December 2011.
http://www.rapitasystems.com/crts2011/

Workshop: RTSS@Work, Real-Time SystemS @ Work, Open Demo Session of Real-Time Techniques and Technologies
Program Chair: Stefan M. Petters, CISTER-IPPorto,
Conference: IEEE Real-Time Systems Symposium, Vienna, Austria, December 2011
http://webpages.cister.isep.ipp.pt/~smp/RTSS@Work/

Workshop: 4th IEEE International Workshop on Real-Time Service-Oriented Architecture and Applications (IEEE RTSOAA 2011) December 12th-14th, 2011, Irvine, USA
Program Co-chair: Tommaso Cucinotta, Pisa.
http://retis.sssup.it/?q=node/115

Workshop : 15th International Real-Time Ada Workshop (IRTAW-15)
Liébana (Cantabria), Spain, September 2011

The 15th International Real-Time Ada Workshop (IRTAW-15) took place on September 14-16 of 2011 in Liébana (Cantabria), Spain. Since the late Eighties the International Real-Time Ada Workshop series has provided a forum for identifying issues with real-time system support in Ada and for exploring possible approaches and solutions, and has attracted participation from key members of the research, user, and implementer communities worldwide. Recent IRTAW meetings have significantly contributed to the Ada 2005 standard and to the proposals for Ada 2012, especially with respect to the tasking features, the real-time and high-integrity systems annexes, and the standardization of the Ravenscar profile. This particular meeting was organized by the University of Cantabria and received 22 participants from different countries in Europe and North America. The discussions were centred around multiprocessor real-time scheduling, multiprocessor resource control protocols, language profiles, application frameworks, and concurrency in Ada 2012. Some of the results of the workshop were submitted to the standardization bodies producing the Ada 2012 standard, and some others were captured in the proceedings to generate new work for future standardization phases. The proceedings will be published as a special issue of the ACM Ada Letters, and will include the papres submitted by the participants and reports on the results of the workshop. A summary of the results of the workshop will also be published in the Ada User Journal.
http://www.artist-embedded.org/artist/IRTAW-15,2204.html

Conferences

Conference: 23rd Euromicro Conference on Real-Time Systems (ECRTS)
General Co-Chairs: Eduardo Tovar, Stefan M. Petters, Porto.
Porto, Portugal, July 2011.

Conference: 15th International Conference on Principles of Distributed Systems (OPODIS 2011)

Program Chair: Giuseppe Lipari, Pisa.
Toulouse, France*, Dec 2011.*

Conference: 8th IEEE International Conference on Embedded Software and Systems (ICESS 2011)
Program Chair: Marco Di Natale, Pisa.
Changsha, China, November 2011.

Tutorials

Tutorial : MAST: Predicting Response Times in Event-Driven Real-Time Systems, by Michael González Harbour, Universidad de Cantabria
The Ada Connection
Edinburgh, UK – June, 2011
This tutorial was focused on modelling the timing behaviour of event-driven real-time systems and on the methods used to guarantee the predictability of their response times. It started by looking at simple single processor systems scheduled with fixed priorities, and then it progressed through dynamic scheduling and distributed systems. The tutorial gave a practical introduction to the use of the MAST modelling and analysis tools for schedulability analysis. It also reviewed new features that are being added to MAST such as hierarchical partitioned scheduling and advanced flexible scheduling techniques that allow protection among different components of a complex application. The tutorial is designed to help real-time system designers in learning about advanced modelling methods and tools, and to provide practical experience with using the MAST toolset. http://conferences.ncl.ac.uk/adaconnection2011/

Tutorial: Real-time middleware – Master course on Airborne Software
Speaker: Marisol García-Valls of Universidad Carlos III de Madrid
UC3M-EADS Master on Aircraft Systems Integration
Leganés, Madrid, Spain - May-June 2011.

Events in 2012

Giuseppe Lipari, Pisa, is **Track Chair** for the track on Real-time, Networked and Dependable Systems, at the ACM Design and Automation Conference (DATE 2012), March 2012, Dresden, Germany.

Marco Di Natale, Pisa, is **Track Co-Chair** for the track on Transportation and Energy, at the ACM Design and Automation Conference (DATE 2012), March 2012, Dresden, Germany.

Marco Di Natale, Pisa, is **Program Chair** of the 18th IEEE Real-Time and Embedded Technology and Applications Symposium (RTAS 2012), Beijing China, April 16-19 2012.

Robert Davis, York, is **Program Chair** of the 24th Euromicro Conference on Real-Time Systems (ECRTS 2012), Pisa Italy, July 13-16 2012. Butazzo, Pisa, is **General Chair**.

Marco Di Natale, Pisa, is **Track Co-Chair** for the track on Real-Time and (Networked) Embedded Systems, at the 17th International Conference on Emerging Technologies and Factory Automation (ETFA 2012), September 17 - 21, 2012, Krakow, Poland.

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

4. Internal Reviewers for this Deliverable

- **Andy Wellings (York)**
- **Michael Gonzalez Harbour (Cantabria)**
- **Gerhard Fohler (TUKL)**
- **Stefan Petters (Porto)**