IST-004527 ARTIST2
Network of Excellence
on Embedded Systems Design

Activity Progress Report for Year 4

JPRA-Network Integration

Adaptive Real-Time, HRT and Control

Clusters:

Control for Embedded Systems

Adaptive Real-Time

Real-Time Components

Activity Leader:

Professor Karl-Erik Årzén, Lund University

http://www.control.lth.se/user/karlerik/

Policy Objective (abstract)

*The objective of the Artist2 network integration activity **Adaptive Real-time, HRT and Control** is to integrate the research performed within the clusters on Adaptive Real-Time System, RT-Components, and Control for Embedded systems on different computational models for embedded control systems and on the use of control techniques to provide adaptivity an flexibility in embedded systems.*

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1. Overview of the Activity

1.1 ARTIST Participants and Roles

Professor Karl-Henrik Johansson – KTH (Sweden)
Role: Provides expertise in applying control techniques to communication networks, including sensor networks.

Associate Professor Anders Robertsson – LUND (Sweden)
Role: Provides expertise in performance control of server systems.

Professor Karl-Erik Årzén – LUND (Sweden)
Role: Provides expertise on embedded control systems and feedback-based scheduling of control systems.

Professor Alfons Crespo – UPVLC (Spain)
Role: Provides expertise on embedded computing.

Professor Pedro Albertos – UPVLC (Spain)
Role: Provides expertise on embedded control.

Professor Martin Törngren – KTH (Sweden)
Role: Provides expertise in architectural design and automotive embedded system applications involving dynamic configuration.

Professor: Giorgio Buttazzo – (SSSA, Pisa)
Role: Provides expertise on adaptive RT techniques

Professor Albert Benveniste – (INRIA)
Role : Provides expertise on embedded real-time systems and components.

Professor Gerhard Fohler – (Univ Kaiserslautern)
Role: Provides expertise on flexible scheduling.

Professor Werner Damm – (OFFIS)
Role: Provides expertise on embedded systems.

Prof. Vladimir Kucera – (CTU)
Role: Provides expertise in real-time control

Dr Zdenek Hanzalek – (CTU)
Role: Provides expertise in real-time embedded control and scheduling.

Professor Hermann Kopetz (TU Vienna)
Role: Provides expertise on time-triggered formalisms.

Professor Luis Almeida - (University of Aveiro)
Role: Provides expertise on communication platforms.

Professor Eduardo Tovar - (Polytechnic Institute of Porto)
Role: Provides expertise on distributed systems and middleware.

1.2 Affiliated Participants and Roles

Dr Johan Eker – Ericsson (Sweden)
Role: Provides expertise on reservation-based scheduling in mobile terminals.

Professor Lui Sha - University of Illinois (US)
Role: Provides expertise on error control of software systems.

Professor Tarek Abdelzaher - University of Illinois (US)
Role: Provides expertise on feedback scheduling.

Dr Pau Marti – (UPC)
Role: Provides expertise on embedded control.

Professor Juan Antonio de la Puente - (UP Madrid)
Role: Provides expertise on target application platform and scheduling.

1.3 Starting Date, and Expected Ending Date

Starting date = 1 Sept 2004. Since the overall status of the activity is to enhance the state of the art in applying control techniques to real-time control and computing systems the activity will run over the entire life-time of the network. Most of the work performed and the collaborations will also continue after the termination of Artist2 within the new NoE ArtistDesign. The majority of the partners in this activity are also either core partners or affiliated partners in ArtistDesign. The work on the use of control techniques to provide adaptivity and flexibility in embedded systems will be continued within the ArtistDesign network activity “Design for Adaptivity”, led by Karl-Erik Årzén. A difference from now is that partners from all the thematic clusters in ArtistDesign will participate in this new activity. Another difference is that also other, non control-based, approaches to adaptivity will be investigated, including, e.g., hardware-based approaches. The work on computational models and implementation techniques for embedded control systems will not continue as a separate activity. However, control will continue to be an important application class for embedded systems also in ArtistDesign. This will in particular be the case in the new thematic cluster “Operating Systems and Networks” led by Giorgio Buttazzo. Here, all the partners in this activity from the Control cluster and the ART cluster are either core or affiliated partners. However, control will also play an important role in the new ArtistDesign thematic cluster “Modelling & Validation” led by Kim Larsen. For example, there the number one objective is to “establish a coherent family of modelling formalisms spanning the areas of computer science, control, hardware and networks covering all aspects of embedded systems”.

1.4 Baseline

The situation at the beginning of this activity, i.e., at the start of ARTIST2 was the following. A number of projects already allowed some structuring and interaction, e.g., FLEXCON (Swedish national project) *Flexible Embedded Control Systems* involving Lund and Mälardalen), OCERA (European project) *Open Components for Embedded Real-Time Applications*, involving Pavia, UPVLC and CTU, RECSYS (European project) *Real-Time Embedded Control of Mobile Systems with Distributed Sensing* involving KTH, ARTIST (European Accompanying Measure) *Advanced Real-Time Systems* involving a majority of the partners, and FIRST (European project) *Flexible Integrated Real-Time Systems Technology* involving Pavia (Pisa) and Mälardalen.

There also existed strong links between the core partners and the affiliated partners, e.g., between Lund and Ericsson, between Lund, Virginia and Illinois, and between UPC and Mälardalen.

1.5 Problem Tackled in Year 4

The objective of the Artist2 network integration activity **Adaptive Real-time, HRT and Control** is to integrate the research performed within the clusters on Adaptive Real-Time System, RT-Components, and Control for Embedded systems on different computational models for embedded control systems and on the use of control techniques to provide adaptivity and flexibility in embedded systems. Each of the clusters have matching internal cluster activities, e.g., in the Control for Embedded Systems the corresponding cluster activities are Real-time techniques in control system implementations and Control in real-time computing.

The research problems involves both the use of control-techniques in resource scheduling for embedded systems and scheduling techniques and computational models for embedded control applications. These two lines are also combined in the form of feedback-based scheduling of embedded control systems.

During Year 4 the interaction among all the three clusters has been larger than previous years. Established collaborations have been strengthened and new collaborations have been established, e.g., between KTH (Control) and PARADES (RT-Components), between Lund (Control) and Linköping University (RT Components), and between UPVLC (Control) and University of York (ART). The number of joint publications is also considerable.

1.6 Comments From Year 3 Review

1.6.1 Reviewers' Comments

"The document is well written. It clearly describes the achievements in year 3, the dissemination activities and the integration activities. The list of publications indicates significant technical progress and interaction among the cluster members. The future work plans are appropriate and consistent with the roadmap."

1.6.2 How These Have Been Addressed

Since the reviewer's were very positive we have tried to continue along the same lines as previous year.

2. Summary of Activity Progress

2.1 Previous Work in Year 1

2.1.1 Work achieved in the first 6 months of Y1

- Kick-off meeting held
- UPVLC (Crespo) has evaluated the performance of the scheduling policies related to offer constant bandwidth behaviour. In conjunction with SSSA (Lipari), a new version of the CBS called IRIS was developed. This new algorithm was implemented and evaluated in a real-time environment providing both hard and soft real-time constraints. The IRIS algorithm was implemented in RTLinux and included in the distribution of the OCERA project.
- Collaboration between Mälardalen (Fohler) and LUND (Cervin) about the combination of the jitter margin index and flexible scheduling methods.
- CTU studied holistic scheduling methods and analyzed a case study using the MAST tool (Cantabria).
- Karl-Erik Årzén contributed to the Artist2 workshop on diagnosis in Vienna, Dec 20-21, organized by the HRT cluster

2.1.2 Work achieved in months 6-12 of Y1

- The Lund Workshop was held. The interaction between the control cluster, the participants from the ART cluster and the US affiliated partners was very valuable
- In order to add flexibility to the real-time applications UPVLC has developed a nanokernel called Xtratum. Xtratum is a thin layer of software that provides a simple and convenient API to access interrupt mechanism and timer devices. Xtratum permits the execution of environments/applications spatial and temporal isolated. Xtratum has been developed under the OCERA project.
- Collaboration between LUND (Cervin) and Pavia (Buttazzo) about the use of the Shark real-time kernel as a shared platform for implementing control applications.
- Collaboration between LUND (Cervin) and Ericsson (Eker) on distributed versions of the control server model
- A collaboration between UPC (Marti), Mälardalen (Fohler) and LUND on feedback scheduling of control system has been initiated
- CTU has built up several demonstrators for communication components based on the OCERA architecture (UPVLC, SSSA, CTU) including fish breeding control and supervision system (process control application), remote programming of mobile robot (robotics and supervision), human machine interface for autogiro (data acquisition and visualization), robotic arm demonstrator (servo control).
- Interaction between CTU and Aveiro (Almeida) on deadline constrained scheduling on FPGAs and multicast traffic optimization.

2.2 Previous Work in Year 2

Achievement: Organization of Workshop

The workshop **Interaction between control and embedded electronics in automotive industry** was jointly organized by the RT Components and the Control clusters in Innsbruck, March 23. It was co-located with the Beyond AUTOSAR meeting organized by the network activity "Forums with Specific Industrial Sectors". Three invited presentations were given by Stefan Kowalevski (RWTH Aachen), Karl-Erik Årzén (Lund University), and Carlos Canudas de Wit (LAG Grenoble) followed by a panel discussion. A more detailed description of the content and focus of the presentations is given in the activity report of the "Forums with Specific Industrial Sectors" activity. Several conclusions can be drawn:

- There is a permanent misunderstanding between control & software engineers in the automotive industry
- Regarding the relative merits of ET/TT, control design aspects provide complementary views, not considered in the embedded design community. For example, in general a long but constant controller input-output latency is worse from a control performance point of view than a shorter but time-varying latency, also if the former constant latency is taken into account in the control design.
- The control systems in automotive systems are often structured in a multi-layer or multi-cascade fashion. This further increases the need to minimize the input output latency and puts special requirements on component-based architectures. For example, it is important to organize the computations in such a way that first only the parts of the controller components that are needed for the generation of the component outputs are calculated and then, afterwards, the parts of the components that are responsible for updating the state of the controller components are calculated. This is something that is well-known within the field of process automation, but for some reason has not yet spread to, e.g., the automotive systems area
- In an automotive system there is only a limited amount of sensors and actuators. Both the sensors and actuators are typically used by several control systems or control functions. In an integrated system it is important to make it possible for several functions to use the same physical sensors and actuators, rather than, e.g., use several sensors to measure the same physical entity, something which is not uncommon in federated architectures. Hence sensor and actuator component should have a special role in a component-based automotive system.
- Today, the structure of the control systems in an automotive system is to a large degree derived from the constraints of the federated system architecture. In an integrated system new possibilities for structuring the control systems open up. Hence, it would be worthwhile to take a completely new look upon how the overall control system for a car ought to be structured, including powertrain control, chassis control, safety systems, etc.

Achievement: Joint Research Activities Involving the ART and the Control Cluster

The joint research initiatives that were started during Y1 have continued. These include

- Anton Cervin (Lund) and Giorgio Buttazzo (Pisa) have worked on a comparison of jitter reduction techniques for control tasks. When implementing a controller in a multitasking operating system, there is a risk that the control loop will experience delay and jitter due to pre-emption from other tasks. Several jitter control methods have been proposed in the literature, and they all have different strengths and weaknesses with respect to timing and control performance. In this work, they have compared and evaluated four

different task models: the Standard Task Model (STM), Reducing Jitter by Task Splitting (RJTS), Reducing Jitter by Advancing Deadlines (RJAD), and Reducing Jitter by Non Preemptive Execution (RJNP). It is found that RJTS is good for jitter reduction, but introduces a long delay which gives sluggish control performance. RJAD works well for reducing both jitter and delay, and gives good control performance in most cases. RJNP reduces input-output jitter to a minimum but may cause some tasks to miss their deadlines. A conference publication describing this joint work is under preparation and a technical report is available.

- Lund (Cervin) and Pisa (Bini) have worked on optimal period selection for multiple controllers under fixed-priority scheduling. Traditionally, when scheduling controllers, it has been assumed that the deadline of each control task is less than or equal to its period. Under fixed-priority (FP) scheduling, this typically implies that the processor cannot be fully utilized. In this work, they have explored what control performance is possible to gain by moving outside the FP schedulability bound. Utilizing a simple upper bound on the response time of a task, the input-output delay can be bounded. Combining this bound with an approximate expression for the control performance (as a function of the rate and the delay of the controller), the optimal task periods can be found by solving a constrained optimization problem. For certain simple cases, exact analytical solutions can be found. A publication describing this joint work is under preparation.
- UPC (Marti, Selga) and Lund (Henriksson, Cervin) have worked on feedback-based scheduling of linear controllers with varying disturbance intensities. In previous work from Lund on feedback scheduling of linear controller tasks, it has been assumed that the amount of disturbances entering the control loops is constant over time. In [1] the initial states of the controlled plants are taken into account by the feedback scheduler by including the initial state in the cost function. The motivation for this is that a plant with a large error should receive more resources in order to better cope with the disturbance. However, in all but extreme cases it is the expected future disturbances that completely dominate the cost function. In this work, they have explored how one can obtain a more reactive feedback scheduler by estimating the amount of noise in the various control loops. They have also extended the cost functions to take a constant delay (obtained using Control Servers) into account. The project has included a PhD student visit from UPC to Lund: Rosa Castañe spent 5 months (from August 2005 to December 2005) in Lund. In addition, several working meetings have taken place during 2006, in Pisa, March 2006 and Dresden, June 2006.
- Lund (Cervin) and Mälardalen/Univ Kaiserslautern (Moris, Isovic, Fohler) have continued the work on flexible scheduling of controllers based on the jitter margin. The work combines two previously developed tools and techniques for flexible real-time systems: the jitter margin and the slot-shifting algorithm. Using the jitter margin, it is possible to guarantee a level of a performance of a controller, given bound on the worst-case input-output jitter. On the other hand, the slot-shifting technique can be used to allow sporadic tasks to execute at the cost of more jitter for the periodic tasks. In this work, an off-line design method based on simulated annealing has been developed that tries to find an optimal schedule such that all control tasks meet their performance specifications, while at the same time allowing as many sporadic tasks as possible to execute. The work has resulted in a Master Thesis which recently received the price for the best Swedish Master Thesis in the field of Real-tIme and Embedded systems during 2005-2006.
- Several of the groups have focused their activities on the SHARK kernel and the TrueTime tools as common platforms for feedback-based scheduling work. In Lund a project has started in which the suitability of using SHARK in control laboratories will be

investigated. UPC has modified the Truetime simulator to better study new feedback scheduling theoretical results. UPC has also added new features to Shark to allow easy implementation of feedback scheduling.

- A strong research connection is currently being established between CTU and UPCLC in the Control cluster and UCantabria, Pisa, and UYork in the ART cluster. This is funded through the FRESCOR project. Here several activities are currently being initiated, e.g., the implementation of contract-based kernels for embedded systems. Both CTU and UPVLC also participated in the ARTIST2 requirements workshop (Paris June 16 2006).

Achievement: Joint Summer School

The summer school First European Laboratory on Real-Time and Control for Embedded Systems was organized in Pisa, Italy, July 10-14, 2006. The number of participants was 40. http://www.artist-embedded.org/FP6/ARTIST2Events/Events/RT-Control/

2.3 Previous Work in Year 3

Achievement: Organization of 2nd International Artist2 Workshop on Control for Embedded Systems

The 2nd International Artist2 Workshop on Control for Embedded Systems was successfully organized in Urbana-Champaigne at Univ of Illinois with Tarek Abdelzaher as the local host. The topics of the workshop were Real-Time and Control in Sensor/Actuator Networks, Control in Cyber-Physical Systems, Event-Based Control and Computing, and Control of Software Errors. The workshop activity was intended and planned as a network activity. However, due to two unfortunate late cancellations from participants from the ART cluster, we ended up with Artist2 participants representing only the control cluster (Lund, KTH, UPVLC, and the international associated partner UIUC). However in spite of this the workshop was very valuable.

The number of participants was 20, excluding PhD students. Out of these six were form Europe. The US control community was represented by Bruce Krogh, Geir Dullerud and Michael Lemmon. The US real-time systems community was represented by Lui Sha, Tarek Abdelzaher, Marco Caccamo, P.R. Kumar, and Chenyang Lu. Industry was represented through Microsoft and PARC. The conclusions from the workshop are available as a separate document available through

http://www.artist-embedded.org/artist/-Control-for-Embedded-Systems,810-.html

Achievement: Joint Research Activities Involving the ART and the Control Cluster

The joint research initiatives that were started during Y1 have continued also into Y3. These include:

- The joint work between Lund and SSSA/Pisa on jitter reduction methods for control system applications has continued and has been extended to also include Halmstad University.
- TUKL and Lund have recently started working on a control-based evaluation infrastructure for combined offline and online scheduling. The Truetime tool of Lund is used as an initial basis for this work.

- Aveiro and UPC are working together on dynamic rate and control adaptation in networked control system. The TrueTime tool from Lund is used as the simulation platform for this work. In particular they study dynamic rate adaptation in simple microcontroller-based computer control systems, maximizing the admitted load in such systems while minimizing the control performance degradation. They also work on minimizing the resources (computing and communicating) consumed by a feedback control loop using a dual-rate (dual-controller) approach, i.e., one nominal controller and a low bandwidth one, for periods of near stationarity.
- CTU and Porto have worked together on simulation of wireless radio protocols. The IEEE 802.15.4 protocol has the ability to support time-sensitive Wireless Sensor Network (WSN) applications due to the Guaranteed Time Slot (GTS) Medium Access Control mechanism. Recently, several analytical and simulation models of the IEEE 802.15.4 protocol have been proposed. Nevertheless, currently available simulation models for this protocol are both inaccurate and incomplete, and in particular they do not support the GTS mechanism. An accurate OPNET simulation model, with focus on the implementation of the GTS mechanism has been proposed. The motivation that has driven this work is the validation of the Network Calculus based analytical model of the GTS mechanism that has been previously proposed and to compare the performance evaluation of the protocol as given by the two alternative approaches. Additionally, and probably more important, based on the simulation model they proposed a novel methodology to tune the protocol parameters such that a better performance of the protocol can be guaranteed, both concerning maximizing the throughput of the allocated GTS as well as concerning minimizing frame delay.
- UPC and Lund are working jointly on feedback scheduling of real-time control tasks. A theoretical framework for feedback scheduling of real-time control tasks was reported in last year's deliverable. This year the work has focused on implementing a case study at UPC to show the validity of the theoretical approach. The experimental implementation corroborates the simulated results reported last year.
- A strong research connection is currently being established between Ericsson, Lund, SSSA/Pisa, TU Kaiserslautern, and Evidence though the new FP7 STREP project ACTORS (Adaptivity and Control of Resources in Embedded Systems) that recently has been approved. The project also contains two non-ARTIST2 partners and has Xilinx US as an associated partner. The goal of the project is to combine reservation-based scheduling, data-flow actors-based programming models, and feedback control for control and media processing applications on Linux-based multicore platforms and FPGA platforms. The project will formally start 1 Dec 2007, but the preparations for the project started already in February 2007.
- During the HSCC conference in Pisa in April 2007 a special meeting was held involving several partners in this activity, on the topic Future trends on Networked and Embedded Control Systems. The participants were Michael Lemmon (University of Notre Dame, Indiana, USA), Paulo Tabuada (University of California at Los Angeles, California, USA), Giorgio Buttazzo (University of Pisa, Italy), Enrico Bini (University of Pisa), Anton Cervin (University of Lund), Manel Velasco (Technical University of Catalonia) and Pau Martí (Technical University of Catalonia). After reviewing the state-of-the-art on Networked and Embedded Control Systems, several topics were discussed. One of the clear conclusions was that event-based scheduling, or alternatively event-based control, is a major trend that should be further studied because it has the ability of dramatically saving computing resources while guaranteeing acceptable control performance.

2.4 Final Results

2.4.1 Technical Achievements

Achievement: Optimal period selection for multiple controllers under fixed-priority scheduling (LUND, SSSA/Pisa)

When several digital controllers should execute on the same platform, a key question is how to distribute the computing resources among the control loops. For controllers based on periodic sampling, this boils down to selecting sampling periods for the set of controllers. In this work, they are interested in a static design problem, where the objective is to assign sampling periods in order to minimize the aggregate cost (performance index) of the controllers [5]. For controllers, the delay between sampling and actuation has a great impact on the performance. For this reason, it is important to include a model of the delay in the design problem. They have developed an approximate response-time analysis that allows them to estimate the delay for a controller under fixed-priority scheduling. Assuming cost functions that are linear in period and delay, the approximate analysis allows giving analytical expressions for the optimal sampling periods. A case study with random second- and third-order plants are used to evaluate the improvements compared to methods that do not take the delay into account.

Achievement: Optimal period selection and scheduling for multiple distributed controllers (LUND, Linköping Univ)

Similar to the previous topic, this work also considers the implementation of multiple controllers on a shared implementation platform. The model used here is however more general: the system consists of a number of nodes, connected by a communication bus. The nodes and the bus may be scheduled statically or dynamically (using priorities). Again, 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. The Jitterbug toolbox from Lund] is used to evaluate the control performance, taking the delay and jitter into account. A case study with several benchmark plants is used to evaluate the performance compared to previous, heuristic design methods [6].

Achievement: Dynamic memory management (UPCLC, York)

Here UPVLC and University of York collaborate on dynamic memory management. Dynamic memory management can be considered in the proper way in real time applications due to the availability of dynamic memory allocators with constant allocation and deallocation. This work proposes a framework for handling dynamic memory in real-time systems [16]. The framework provides both a flexible contract negotiation model to adapt the memory allocated to a set of task as closed as the required during the execution.

Achievement: Event-Driven Control, Embedded Control, and Feedback Scheduling (UPC, SSSA/Pisa, Aveiro)

The group led by Pau Martí at UPC has been doing research on event-driven control, embedded control systems and feedback scheduling with strong, but informal connections to LUND. In event-based control they focuses on studying whether it is possible to derive sampling intervals for certain types of event-driven controllers. It is interesting to solve the problem because this will permit to obtain their resource demands, and ultimately, it will facilitate their schedulability analysis [2]. Here UPC collaborates with SSSA/Pisa. In embedded control the focus is on implementation of research results on low-cost microcontrollers with small real-time kernels. Here UPC collaborates with Aveiro [7]. UPC also studies practical solutions to the jitter problem. In particular, a task model including an asynchronous observer and a synchronized output operation is shown to be very effective when sampling intervals are not constant [3]. Finally, UPC studies feedback scheduling (or optimal sampling period

selection) for real-time control tasks: this research has evaluated in simulation diverse existing results on feedback scheduling. The study concludes that on-line period assignment as a function of the controlled plant dynamics is the best approach [4]. However, it is also noted that jitter may be a problem for these approaches.

Achievement: A Simulation Model for the IEEE 802.15.4 protocol (CTU, Porto)

The joint work on simulation models for the IEEE 802.15.4 protocol by CTU and Porto has resulted in the two joint publications [8, 9].

Achievement: Loosely Time-Triggered Architectures (PARADES, INRIA, Trento, VERIMAG)

In joint work between INRIA, PARADES, and VERIMAG, the LTTA architecture (Loosely Time-Triggered has been proposed in the form of a middleware with associated mathematical MoCC and services. This distributed architecture, used in particular by some aircraft manufacturers, is compliant with the ARINC-653/AFDX architecture for Integrated Modular Avionics.

Summary

Kopetz' TTA has shown the way to develop embedded systems based on a comprehensive architecture formal model; being very strict, TTA has a cost in terms of resource and development time. Loosely Time-Triggered Architectures (LTTA) aim at coping with these difficulties, by relaxing the strict synchrony constraint of TTA. In a LTTA, the system is composed of Computing Units (ECU) and Communication Units where each unit has its own clock, clocks are not synchronized, and communication is by Sampling (CbS) meaning that it behaves like a shared memory with asynchronous writes and reads, see figure below.

During the reporting period we have developed two variants of LTTA:

a) By borrowing ideas from *elastic circuits* by Cortadella et al. and *latency insensitive design with back-pressure* by Carloni et al., both from circuit design area. Here the aim is to preserve the Kahn Process Network semantics of the specification. In this approach, logical time dominates over physical time and no assumption is needed regarding the local clocks of the subsystems.

b) By developing a physical time based approach, where bounded relative drift is assumed between local clocks, an original protocol guarantees preservation of specification semantics. This protocol does not use back-pressure nor any token based mechanism.

a) Activities on approach (a), by all participants

PARADES, INRIA, and Verimag, jointly with UC-Berkeley and Cadence Berkeley, have developed approach (a), resulting in publications [10] and [11]. The approach assumes a single-clocked synchronous specification – single-clocked is not really a restriction in this context as it can be relaxed by using the extra symbol *nil* meaning the absence of a certain data at a given reaction. It is known that such specifications can be seen as a Kahn Process Network with bounded buffers. This observation has been the basis for the development of so-called *elastic circuits* by Cortadella et al. and *latency insensitive designs with back-pressure* by Carloni and Sangiovanni-Vincentelli in the area of circuit design. These are circuits with token based mechanisms. Controlling buffer overflow is achieved by implementing backward tokens controlling the permission to write in buffers – hence the term of *back-pressure.* This idea has been adapted to our case where neither writing nor reading can be blocking, see the figure above. The idea is to replace blocking by skipping. Performance of such architectures is classically studied by means of Marked Graphs, a simple form of Petri nets where Max-Plus algebra applies. Pros and Cons of this approach are:

- Pros: no assumption on local clocks; very adaptive, scales up easily to complex systems; easy upgrade.
- Cons: need for back-pressure, which results in additional links, resulting in additional requests for fault tolerance mechanisms.

b) Activities on approach (b), by Verimag and INRIA

Verimag and INRIA have further developed initial work by Verimag on the study of Airbus system architecture for low level flight control. They have come up with the systematic idea of replacing token based mechanisms by the use of purely local counters with no additional link. Each unit maintains a local counter based on its own independent clock. This local counter controls the right to acquire new input data from the communication media, perform computation steps, and write output data to the communication media. This approach is entirely local. Pros and Cons of this approach are:

- Pros: no back-pressure, no additional communication link, no blocking communication; this simplifies the design of fault-tolerance and degraded modes.
- Cons: uses boundedness assumptions on the relative drift between local clocks (the management of the local counters depends on these bounds). This means a higher cost compared to approach (a) when re-design is needed.

Control over loosely time-triggered networks has been studied in [1].

Achievement: Feedback Reservation Mechanisms in Multimedia Streaming (ART and Control cluster partners)

A number of partners from the Control and the ART cluster (Ericsson, LUND, TUKL, SSSA/Pisa, Evidence) collaborate within the FP7 STREP project ACTORS on Adaptivity and Control of Resources in Embedded Systems (http://www.actors-project.eu) that started in February 2008. In the project three key technologies are combined; reservation-based resource management, feedback scheduling and dataflow modeling of embedded media applications. The target platform is an ARM 11 multi-core platform. In the project, which is coordinated by Ericsson, three demonstrators will be developed: a cellular phone demonstrator, a control system demonstrator, and a high-performance video demonstrator. The collaboration among the partners initiated through Artist was very important for the successful outcome of the ACTORS proposal.

A coordination meeting between ACTORS and Artist2 was held in Lausanne in January 2008. Also, ACTORS and Artist2 co-organized a one day workshop on dataflow modeling for embedded systems in Pisa, May 5, 2008 (http://www.artist-embedded.org/artist/DataFlow-Modeling-for-Embedded.html).

Collaboration between the ART and the Control cluster also takes place within the ongoing previously reported FP6 project FRESCOR involving CTU, UPVLC in the Control cluster and UCantabria, Pisa, and UYork in the ART cluster. There are also strong links between FRESCOR and ACTORS.

Achievement: Wireless protocols for automation and control (KTH and PARADES)

KTH and PARADES have done joint work on minimum coding in CDMA networks and on Breath, a self-adapting protocol for wireless sensor networks in control and automation [12,13,14,15]

2.4.2 Individual Publications Resulting from these Achievements

The individual publications from the core partners of the control cluster and from most partners in the ART and the RT-Components clusters are reported in the cluster activity reports from the respective cluster.

INRIA

[1] P. Caspi and A. Benveniste. Time-Robust discrete control over networked Loosely Time-Triggered Architectures. In Proc. of 2008 IEEE Control and Decision Conference. Cancun, Dec. 9-11, 2008.

UPC

[2] Manel Velasco, Pau Martí and Camilo Lozoya, “On the Timing of Discrete Events in Event-Driven Control Systems. In 11th International Conference on Hybrid Systems: Computation and Control (HSCC08), St. Louis, MO, USA, April 2008.

[3] Camilo Lozoya, Manel Velasco, and Pau Martí, “The One-Shot Task Model for Robust Real-Time Embedded Control Systems”, In IEEE Transactions on Industrial Informatics, Vol. 4, No. 3, August, 2008

[4] Camilo Lozoya, Pau Martí, Manel Velasco and Josep M. Fuertes, “Control Performance Evaluation of Selected Methods of Feedback Scheduling of Real-time Control Tasks”, In 17th IFAC World Congress, Seoul, Korea, July, 2008.

2.4.3 Interaction and Building Excellence between Partners

There are interactions between several of the core partners in the activity and with several of the associated partners. These are of several types, including participation in the same European project, joint participation in national projects, and participation in meetings organized by this cluster. Most of the interactions are bilateral or trilateral.

The following is a list of the major collaborations between partners in Control, ART, and RT-Components cluster within this activity as well as with partners outside the activity which has contributed to creation of excellence between partners.

Activities within the activity:

- Lund and SSSA/Pisa collaborate on optimal period selection for multiple controllers.
- Lund and Linköping collaborate on optimal period selection and scheduling for multiple distributed controllers.
- UPVLC and York collaborate on dynamic memory management.
- UPC, SSSA/Pisa, and Aveiro collaborate on embedded control.
- CTU and Porto collaborate on simulation models for wireless protocols.
- PARADES, INRIA, and VERIMAG collaborate on loosely time-triggered architectures.
- KTH and PARADES collaborate on wireless sensor network protocols.
- CTU, UPVLC, UCantabria, UYork, SSSA/Pisa, Evidence, Enea, and TUKL collaborate in the FRESCOR project on contract-based resource reservation.

- Ericsson, Lund, TUKL, SSSA/Pisa, and Evidence collaborate in the ACTORS project on feedback-based reservation mechanisms.
- Lund and Ericsson collaborate in a national project on resource management for multimedia.
- INRIA (Benveniste) and Lund (Årzén) have organized an invited session on networked control at CDC, Cancun, Mexico, December 2008.
- Several of the previous ART, RT-Components and Control collaborate in the new ArtitDesign NoE. Of particular interest to this activity is the transversal activity Design for Adaptivity led by Lund.

In addition to this all of the partners have collaboration outside the scope of this activity, both with partners in Artist2 and partners outside Artist2.

2.4.4 Joint Publications Resulting from these Achievements

[5] Enrico Bini, Anton Cervin: "Delay-Aware Period Assignment in Control Systems." In Proc. 29th IEEE Real-Time Systems Symposium, Barcelona, Spain, December 2008. To appear.

[6] Soheil Samii, Anton Cervin, Petru Eles, Zebo Peng: "Integrated Scheduling and Synthesis of Control Applications in Distributed Embedded Systems." In submission to DATE'09, Nice, France, April 2009.

[7] Ricardo Marau, Pedro Leite, Manel Velasco, Pau Martí, Luis Almeida, Paulo Pedreiras and Josep M. Fuertes, “Performing Flexible Control on Low-Cost Microcontrollers Using a Minimal Real-Time Kernel”, In IEEE Transactions on Industrial Informatics, vol. 4, n.2, May 2008.

[8] Petr Jurcik, Anis Koubaa, Mário Alves, Eduardo Tovar, Z. Hanzalek: A Simulation Model for the IEEE 802.15.4 protocol: Delay/Throughput Evaluation of the GTS Mechanism, In the 15th IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS´07), Istanbul, Turkey, October 2007.

[9] Petr Jurčík, Ricardo Severino, Anis Koubâa, Mário Alves, Eduardo Tovar. Real-Time Communications over Cluster-Tree Sensor Networks with Mobile Sink Behaviour In proceedings of the 14th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA 2008), Kaohsiung, Taiwan, 25-27/AUG/2008. In preparation for ACM Transactions on Sensor Networks (ISSN: 1550-4859).

[10] A. Benveniste, P. Caspi, M. Di Natale, C. Pinello, A. Sangiovanni Vincentelli, and S. Tripakis. Loosely Time-Triggered Architectures based on Communication-by-Sampling. Proc. of EMSOFT'07, Oct. 1-3, 2007.

[11] S. Tripakis, C. Pinello, A. Benveniste, A. Sangiovanni Vincentelli, P. Caspi, and M. Di Natale. Implementing Synchronous models on Loosely Time-Triggered architectures. IEEE Transactions on Computers, 57(10), 2008.

[12] P. Park, C. Fischione, A. Bonivento, K. H. Johansson, A. Sangiovanni-Vincentelli, Breath: a Self-Adapting Protocol for Timely and Reliable Data Transmission in Wireless Sensor Network. In journal submission.

[13] C. Fischione, A. Speranzon, K. H. Johansson, and A. Sangiovanni-Vincentelli, Distributed estimation over wireless networks. In journal submission.

[14] C. Fischione, K. H. Johansson, A. Sangiovanni-Vincentelli, and B. Zurita Ares, Minimum energy coding in CDMA wireless sensor networks. IEEE Transactions on Wireless Communications, 2008. To appear.

[15] P. G. Park, C. Fischione, A. Bonivento, K. H. Johansson, A. Sangiovanni-Vincentelli, Breath: a self-Adapting protocol for wireless sensor networks in control and automation, IEEE SECON, San Francisco, CA, USA, 2008.

[16] Miguel Masmano, Ismael Ripoll, A. Crespo, J. Real, A. Wellings. “Implementation of a constant-time dynamic storage allocator”, Software: Practice and Experience. Published Online: Oct 2007.

2.4.5 Keynotes, Workshops, Tutorials

Most of the keynotes, workshops and tutorials related to this activity have been reported as parts of the three involved cluster’s internal cluster activity reports.

Workshop: Beyond Software and Control (in honour of Paul Caspi)

Location: Grenoble, Sep 28, 2007. Presentations of several of the members of the RT-Components cluster + from Årzén of the Control cluster.

Workshop: “Dataflow Modelling for Embedded Systems”

Location: Pisa, 5 May, 2008 Organized jointly by members of the ART cluster and the Control cluster. Co-organized with the ACTORS project.

3. Milestones, and Future Evolution Beyond the NoE

3.1 Milestones

The milestones for year 4 as defined in the previous activity report were as follows.

- The organization of a new industrial workshop along the lines of the workshop organized jointly with the Beyond AUTOSAR activity. *Achieved: The workshop Dataflow Modelling for Embedded Systems was organized on May 5 in Pisa.*
- Disseminate the total amount of work done within this activity at Artist organized events. *Achieved.*
- Continued joint and individual research along the lines of the roadmaps developed during Year 1-2. This includes research on control of server systems, control-based resource management, and interactions between control, scheduling and networking, including feedback scheduling-based approaches. *Achieved.*
- Coordinate and help to disseminate the results generated by the EC projects FRESCOR and ACTORS which both can be seen as continuations of the work done within this network activity. *Achieved.*

3.2 Indicators for Integration

Since this activity will finish when Artist2 finishes and that all the three clusters also will cease to exist, at least in their current form, within ArtistDesign, it is not realistic to define any detailed milestones. It is, however, clear that Artist2 has created closer connections between the involved clusters and that this also will continue within ArtistDesign, although in different forms. For example, part of what this activity has focused on will continue within the Design for Adaptivity activity and part of it will continue within the Operating Systems and Networks cluster. A kick-off meeting for the Design for Adaptivity activity was held in Lund, 13-14 May 2008 with several members from the different communities.

The work within the activity will also continue within the currently ongoing STREP projects involving the partners, including ACTORS, FRESCOR, PREDATOR and COMBEST.

The indicator for successful integration for the future is:

- Continued joint work (publications, project proposals, etc) on control, scheduling and component technology within ArtistDesign and the STREP projects mentioned.

3.3 Main Funding

The partners have a good funding situation for the coming years. The main sources are:

- Nationally funded projects. Here only the projects for the control cluster partners are listed. The national projects for the partners from the ART and the RT-Components cluster are found in their internal activity reports.
    - Lund: The large 10 year VR Linneaus center “LCCC – Controlling Complex Engineering Systems”. The VINNOVA project “Feedback Based Resource Management and Code Generation for Soft Real-Time Systems”. The VR projects “Control of Server Systems” and “Periodic and Event-Based Control over Networks”.
    - KTH: The large 10 year VR Linneaus center ACCESS. The VINNOVA projects reSENSE, WISA II, NECS and SERAN. The VR projects Wireless Control and

CoopNets, The Rembrant project together with Scania and Chalmers. The SSF projects NEC and IDIOM. KTH has also created ICES – Innovative Centre for Embedded Systems where among others ABB, Ericsson, Scania, and Enea participate.

- UPVLC: SIDIRELI: Sistemas distribuidos con recursos limitados. Núcleo de control y coordinación funded by the Ministerio de Ciencia y Tecnología. RT-Model: Plataformas de tiempo real para diseño de sistemas empotrados basado en modelos funded by the Ministerio de Ciencia y Tecnología.
- CTU: Centre for Applied Cybernetics (CAK) funded by the Ministry of Education of the Czech Republic. Modular FLY-BY-WIRE Control System for Light Aircraft (Aero) funded by the Ministry of Industry and Trade of the Czech Republic.

- European projects. The European projects where the partners participate are the following: ArtistDesign (Many Control, ART, and RT-Components partners), SOCRADES (KTH, ABB), WIDE (KTH, Honeywell, Eindhoven, UPC), FeedNetBack (KTH, INRIA, ETH), ACTORS (Lund, Ericsson, SSSA/Pisa, TUKL, Evidence), FRESCOR (Cantabria, SSSA/Pisa, TUKL, York, CTU, UPVLC, Enea, Evidence), CHAT (Lund, Trento, Siemens, Univ Pisa), AEOLUS (Lund), ATESST II (KTH, CEA, Volvo Cars, Volvo Technology), DySCAS (KTH, Enea, Volvo Technology), ROSETTA (Lund, ABB), Euro-NF (KTH) , VIKING (KTH), PREDATOR(SSSA/Pisa), COMBEST (Verimag, INRIA, OFFIS, PARADES), TECOM/ITEA-2 (UPVLC) and MEDEIA (TU Wien). Part of these projects as are projects that have been accepted but not yet started.

3.4 Future Evolution Beyond the Artist2 NoE

Control will continue to play an important role in embedded systems both as an application area and as an implementation technique. Most of the work on adaptive scheduling and resource management is feedback-based. The special requirements of control application puts special requirement on component technologies and frameworks related to, e.g., input-output latencies. Hence, the collaboration between the different communities will be necessary also in the future.

4. Internal Reviewers for this Deliverable

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