Research Centre in
Real-Time Computing Systems
FCT Research Unit 608

Annual Report
2010

CONTENTS

EXECUTIVE SUMMARY

The CISTER Research Unit is based upon the IPP-HURRAY Research Group (HUgging Real-time and Reliable Architectures for computing sYstems), which was created in 1997, and has since grown to become the most prominent research group of the School of Engineering (ISEP) of the Polytechnic Institute of Porto (IPP), and one of the leading International research groups in the area of real-time computing systems.

In both the 2003 and 2007 evaluations, the Unit was granted the classification of 'Excellent' from an international panel of experts. We firmly believe that ever since then, and particularly during 2009, we have been exceeding the expectations placed on us. The strategy set down by the Unit has been definitely towards top-quality research, able to compete with the best international groups in our research areas.

The strategy set down by CISTER has been definitely towards top-quality research, able to compete with the best international groups in our research areas. The goal of the unit is to continue (and reinforce) to be one the International leaders of research in real-time embedded systems. This objective is aligned with the growing strategic importance of embedded systems in Europe, and the role that needs to be played in the international research landscape of the area.

MANAGEMENT STRUCTURE

The unit has a Director, the Unit leader, and two Vice Directors. Together these form the Board of Directors (BoD).

The main responsibilities of the Director are: to represent externally the Unit; to manage and co-ordinate the activities of the Unit; to co-ordinate the definition of the plan of activities and budget; and to present the plan of activities, budget and yearly report (scientific and financial) to the Unit's Steering Committee and Executive Boards. The main responsibilities of the Vice Directors are to assist and replace the Director when necessary.

The BoD is assisted in governance by an Executive Board (ExecB), to manage day-to-day activities. The ExecB is structured by areas of responsibilities: (i) Finances, Quality & Procedures; (ii) Human Resources; (iii) Research Projects; (iv) Industry Contracts, IP-issues (v) Presentation & Image; (vi) Infrastructures & Facilities; (vii) IT Infrastructure and (viii) Administrative Support. These responsibilities are associated with individuals in the ExecB.

The Steering Committee (SC) supports the BoD in contributing to the medium to long term strategic planning of the CISTER Research Unit. This includes providing direct input to the half yearly budget planning process, as well as reviewing the resulting overall budget. It is also involved in planning the opening or closure of research areas. Additionally, the SC supports the BoD in the selection process and management of research staff and students. The SC includes the ExecB members and the research leaders.

The activities of the Unit are periodically reviewed by international top-ranked researchers. Annually, a number of on-site visits are performed by these researchers to discuss the Unit's activities and plans. Current members of the External Advisory Board are: Alan Burns (University of York, UK); Tarek Abdelzaher (UIUC, USA); Sanjoy Baruah (UNC, USA) and Raj Rajkumar (CMU, USA). The Unit has also been actively endorsing and driving bilateral research workshops with top research centres. These have been extremely useful as well in providing inputs for research plans and strategy.

CISTER IN NUMBERS

In the year of 2010, the CISTER research team was composed by:

- Number of Researchers holding a PhD: 16
- Number of Researchers holding a MSc: 17

In 2010 the unit had around 575K EUR of competitive funding. During 2010 CISTER had 7 international and industrial driven projects, and 5 fundamental research projects (FCT supported) running.

In 2010 CISTER got approved a set of new projects, accounting for a budget of 228K EUR in the year, with a total budget of 682K EUR.

GENERAL OBJECTIVES

The CISTER Research Unit focuses its activity in the analysis, design and implementation of real-time computing systems (RTS). In RTS, correctness depends not only on the logical result of computation, but also on the time at which the results are produced. Thus correctness and performance are very tightly interrelated. In recent years an increased pervasiveness of embedded systems in general and large-scale distributed systems in particular has emerged. This has introduced real-time concerns into mainstream enterprises, with clients in a wide variety of industries and academic disciplines.

The strategy adopted by the Unit is the pursuit of excellence in research which is benchmarked against the best international groups in our research areas. These include the most prestigious research groups in Europe (e.g. York, UK; SSSUP, Italy; MdH, Sweden; TUW, Austria), the U.S. (e.g. UNC-CH; UIUC; UVa; WUStL; CMU), and Asia (e.g. KAIST, South Korea). This is just a sample of prestigious institutions with whom we collaborate, but also with whom we compete in the advancement of the state-of-the-art in real-time computing systems. Despite our relatively small dimension, we have produced cutting-edge and seminal research. The results have been recognised by our peers as world class.

There are four key strategic options that have been driving the research agenda of the Unit: (i) sustained growing and research focus; (ii) selective and demanding publication efforts; as a consequence of the two previous, (iii) selective, demanding and consistent participation of key Unit's researchers in scientific service; and finally, as a consequence of the three previous, (iv) a strong participation in international reputed academic/industrial research partnerships with focus both on fundamental and applied research.

The continued focus and excellence of CISTER's research is supported through the Unit's definition of a few, but strategic research areas: Wireless Sensor Networks; Multicore Systems; Cyber-Physical Systems; Adaptive Real-Time Systems; and Real-Time Software.

In line with the strategy of research excellence, CISTER researchers aim and succeed to publish in highly reputed, peer-reviewed, international journals, as well as top conferences in the respective fields, many of which have higher impact than top journals.

Aligned with its development plan, the CISTER started in 2009 to actively collaborate in the ECE PhD program at FEUP, where CISTER leads and coordinates a course stream on embedded and real-time computing systems. Also related to PhD studies, the research unit launched 2 calls. In these more than 150 students applied, with more than a third of applicants having marks equivalent of 15 or better in the bachelor / master degrees. A rigorous selection process has led to the selection of 10 promising new PhD students coming from Russia, Mexico, India, Cuba, Iran, Pakistan and Portugal.

MAIN ACHIEVEMENTS

In the emerging Cyber-Physical Systems (CPS) area, we have been keeping a prominent role. Researchers of the group have further advanced the state-of-the-art in distributed algorithms that exploit dominance-based MAC protocols [O6, T3], which provide unprecedented advantages for WSNs, as aggregate computations (data aggregation, interpolation) can be performed with time complexity independent of the number of nodes, greatly leveraging scalability. This is a key feature, core on a project proposal, SmartSkin, led by the group, with partners Embraer and Critical Materials, for reducing fuel consumption in aircrafts by reducing drag. Also in the area of CPS, we are now leading a project with Portugal Telecom and CMU to use CPS technologies for energy-optimized data centres, typically voracious of energy and cooling. The CPS research line leader gave a keynote lecture on "Densely Instrumented Physical Infrastructures" within the 2010 CONET Network of Excellence Summer School, which took place in Dagstuhl, Germany, August 2010, and has been organizing the CPS Special issue in the IEEE Transactions on Industrial Informatics. We hosted in June the General Meeting of the FP7 European Network of Excellence in Cooperating Objects (CONET).

In the Wireless Sensor Networks (WSN) area, the group has been leading R&D in IEEE 802.15.4 and ZigBee technologies (http://www.open-ZB.net) and provided methodologies to analyze, dimension and engineer WSNs with improved QoS [J6, J7, O15, O16, O22, T2, T4,]. We, in collaboration with researchers at T.U. Berlin and U. Pisa, have finalized the implementation of the IEEE 802.15.4 protocol in TinyOS, within the TinyOS 15.4 Working Group and in the context of our leadership of the COTS4QoS research cluster (http://www.cooperating-objects.eu) under the CONET NoE. During 2010, we have consolidated our critical mass on radio link quality estimation in WSNs by designing an innovative estimator [O2] and an open-source benchmarking test-bed (T1, http://www.open-LQE.net). Importantly, we have designed, implemented and demonstrated the largest WSN test-bed in Europe to date (303 nodes) under the EMMON project (http://www.artemis-emmon.eu). A CISTER researcher participated in a panel of worldwide renowned researchers in the area of sensor networks, in the SenSys 2010 Doctoral Colloquium.

The current use of software as the key component of any real-time embedded system is increasing the, often contradictory, demands for attributes such as flexibility, adaptation, isolation, reliability or availability. In the Real-Time Software area, group researchers have continued the work on middleware for cooperative and autonomic embedded systems [O19, O20, O25], and analysed the support for developing multicore applications, both at the language level [O3], and at the operating system level (software transactional memory [O23] and parallel tasks [O24]). Furthermore, area members have actively participated in a joint effort (project RESCUE with UBI, FCUP and UMinho) to integrate concurrency models with software verification approaches in embedded systems.

In the Adaptive Real-Time Systems area, group researchers have further developed work in the area of open real-time systems [J1] and with application in the widely used Android operating system [O13]. Group researchers have also continued the successful cooperation with the University of Pennsylvania addressing temporal isolation in hierarchical real-time systems [O1]. Our researchers have also investigated the issue of contention for implicitly shared resources, which are a major obstacle in ensuring temporal isolation in multicore systems [J4]. In a similar direction the group has developed an approach to the increased execution time due to the loss of working set in the caches [O4] and investigating the contention issues in a real-time environment using transactional memory [O23]. The achievements also included work in Quality of Service guarantees in distributed real-time systems [O18].

During 2010, researchers in the multicore area of CISTER have achieved two important results: (i) researchers created the first provably good resource sharing scheme for real-time tasks on multiprocessors and (ii) researchers created a new algorithm for scheduling a set of tasks on a specific type of heterogeneous multiprocessor and this algorithm was shown produce schedules that were as

good as the previous state of art (actually better) but with the additional advantage that the algorithm runs much faster (both in terms of time-complexity and in terms of running times in experiments). The former is relevant because the trend in multicore processors is towards a large core count and for system systems, sequential bottlenecks (such as sharing of non-cpu resources) becomes of greater importance. The latter is relevant because the trend among chipmakers is towards multicore chips with different types of processor cores (heterogeneous multicore). Intel Sandybridge and AMD Fusion exemplify this trend.

CISTER initiated a new project titled "Reduced Certification Costs for Trusted Multi-core Platforms" (RECOMP) on 1st of April 2010. RECOMP is an ARTEMIS project jointly funded by the Member States and the European Commission (ARTEMIS-JU). RECOMP has an overall budget of close to 26 Million Euros, with approximately half million Euros being allocated to ISEP. RECOMP is being executed by a consortium comprised of 41 industrial/academic partners from Czech Republic, Denmark, Finland, France, Germany, Ireland, Portugal, Spain, and United Kingdom. Some of the prominent partners in the project include Kone Oyj, Finland; Infineon Technologies UK Limited, United Kingdom; Thales, France; PSA Peugeot Citroen, France; and EADS, Germany.

CISTER researchers organised several international events, such as the CONET General Meeting (June), the EMMON Audit Meeting (December), various Distinguished Keynote Talks (e.g. by Tarek Abdelzager, UIUC, USA). CISTER Researchers were PC Co-Chairs and Keynote Speakers at the 16th IEEE RTCSA 2010. CISTER Researchers were also PC Co-Chair of OSPERT 2010.

For the second consecutive year, CISTER got accepted 50% of the project proposals submitted to the annual FCT call of project proposals. This is an excellent performance that compares with the 10% of overall acceptance rate nationwide. The three projects approved in 2010 are: MASQOTS, VIPCORE and REPOMUC.

ACTIVITIES

INTEGRATIVE/MULTIDISCIPLINARY ACTIVITIES

As the Unit is relatively small, its areas of research are by their nature multidisciplinary. The unit has strategically fostered the integration of researchers from different background areas with the goal of setting up a team with focused and complementary competencies.

This policy was continued during 2010, particularly by the strategic hiring of researchers in the area of multicore systems. CISTER includes researchers with diverse academic backgrounds, such as Electrical and Computer Engineering, Informatics Engineering, Computer Science and Applied Physics/Mathematics.

These complementary backgrounds allowed increasing the capabilities of the Unit, through research initiatives that encompassed hardware and software integration, vertical frameworks, ranging from lower level issues such as hardware platforms for sensor network communication to higher level design, such as applications and test-beds. Utilising this, the Unit leads international research in embedded real-time systems, attacking emerging challenges in a focused manner through its research areas.

Wireless Sensor Networks experience the transition from research to industrial deployment. During this transition new challenges appear in link quality management and general communication paradigms to scale small deployments to 1000s of nodes in a reliable and energy efficient manner. In Cyber-Physical Systems, the computer systems do not only compute quantities, but are also tightly integrated and interacting with their physical environment, by taking sensor readings and acting on it. Such systems require a rethinking in the usual computing and networking concepts, while the importance of timeliness is increasing steadily.

Another trend is towards massively networked embedded computing devices. Such extreme networking poses considerable technical challenges in terms of the distributed programming paradigms not reflected in current languages. Real-Time Software is concerned with languages, management of software concurrency, as well as decentralised middleware and operating system adaptation, which form fundamental building blocks of autonomic distributed systems.

Adaptive Real-Time Systems address the emergence of embedded devices exposed to different levels of criticality, reconfigurable and mobile systems. This is reflected in the work on server-based scheduling, adaptive service management, hierarchical systems, as well power management of energy constrained embedded systems. A final trend addressed by the group is the increased deployment of Multicore Systems and the inherent challenges in providing solutions, which are able to support real-time guarantees, considering both identical and heterogeneous multicores.

The research unit is involved in a number of national and international projects that are multi-site and multi-disciplinary; e.g. SENODs, RESCUE, EMMON and RECOMP, or the ArtistDesign and CONET networks of excellence.

OUTREACH ACTIVITIES

The CISTER Research Unit has been devoting a special attention to outreach activities, trying to leverage synergies between our scientific achievements and society, both in a broader sense (public in general) as well as in more specific niches (e.g. Portuguese industrial community and secondary school students). Visits from secondary schools or universities to our applied research labs are very frequent. The Unit also regularly participates in workshops organised by its hosting institutions ISEP and IPP, which aim at

disseminating ongoing education and research to all ISEP/IPP but also the general public, namely to potential candidates to our engineering degrees.

Most of our fundamental research activities are supported by applied research vertices, which facilitates that CISTER scientific results are accessible to the general public through practical demonstrations with state-of-the-art technology and appealing application scenarios. Notable examples are the RFieldbus manufacturing automation field-trial, the ART-WiSe search&rescue testbed or the developments being carried out in the scope of the EMMON project.

Also, during 2010 CISTER organized a series of seminar talks and distinguished lectures. The talks involved several senior researchers and PhD students from CISTER, and were well attended by not only students and faculty members of Instituto Superior de Engenharia do Porto, but also by members of the Faculdade de Engenharia of University do Porto (FEUP). During the year we organized distinguished lectures by highly reputed academics and industrial researchers like Professor Tarek Abdelzaher (University of Illinois at Urbana –Champaign, USA), CISTER researchers have also participated in similar initiatives of other institutions, with the invited talk "Real-time scheduling on multicores" within the "Back-to-Basics" distinguished invited researcher´s seminar of FEUP.

CISTER strategy was also to reinforce collaborations with industry. This is achieved through projects within ARTEMIS, where we have been successful in the EMMON project in 2008 (started in 2009), the RECOMP project (approved in 2009, started 2010) as well as more recent projects just to start with ISA, EnergyNoord, ENEL, NOKIA, ST-Ericsson, etc.

CISTER researchers have been consistently enrolled in supervising undergraduate, MSc and PhD students in collaboration with several national and international universities, namely in Brazil (e.g. UFSC), India (IIT Roorkee), Czech Republic (CTU, Prague), Tunisia (ENIS, Sfax) and Korea (KAIST, Daejeon), either funder by CISTER or by these institutions or specific funding programs. Importantly, CISTER continued to consolidate its enrollment in the Doctoral Program in Electrical and Computer Engineering(PDEEC) at the University of Porto (FEUP). CISTER is responsible for the "Real-Time and Embedded Systems" stream, involving 4 courses (2 mandatories and 2 elective).

CISTER participated in a joint undertaking by IPP together with the Municipality of Paços de Ferreira for the creation of a Technological City; CISTER was among the research units invited for a road show on the municipality's state of the art industry for fostering collaborations between academia and industry. Companies visited included Sweedwood (IKEA), Petratex and Ibermetais.

ORGANIZATION OF CONFERENCES

By integrating the top-ranked scientific community in the real-time and embedded systems area, the Unit regularly organizes scientific events related to those scientific topics.

Particularly noteworthy were the participation as PC Chairs in ARTISTDesign (FP7-NoE) supported workshops:

- Workshop on Operating Systems Platforms for Embedded Real-Time Applications (http://www.artist-embedded.org/artist/Organisation,1912.html), co-located with ECRTS 2010

- CISTER Researchers were PC Co-Chairs at the 16th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA 2010)

Senior researchers of the group were also called upon to serve on program committees of reputed conferences, in some cases several researchers at the same time: IEEE RTSS, IEEE RTAS, ECRTS, IEEE RTCSA,

IEEE EFTA, IEEE ICDCS, ACM SAC, OPODIS, IFIP DIPES, Ada-Europe, among others. One researcher is since 2007 editor for Real-Time and Embedded Systems for the Journal of Systems Architecture: Embedded Software Design (JSA) and another researcher is since June 2007 Editor-in-Chief of the Ada User Journal. One researcher is since 2010 Associate Editor of the Springer Real-Time Systems Journal.

In national events, the group participates in the steering committee of the INFORUM, the Portuguese Symposium in Informatics, and has co-organized the Real-Time and Embedded Workshop of the symposium (http://inforum.org.pt/INForum2010).

INDUSTRY CONTRACT RESEARCH

CISTER engaged with Portugal Telecom (along with CMU and MIT) in a project called SENODS for monitoring of the future PT's Data Centres and solve some of the major challenges currently posed to data centres. Related to CISTER's leadership in the SENODs (Cyber-Physical Systems Technologies for Energy-Optimized Data Centers) project, a number of other efforts have been driven by CISTER aiming at promoting an European-wide effort that builds on current synergies within SENODs partners (CISTER-ISEP, Portugal Telecom and CMU) and expands on it by addressing, in an holistic perspective, issues such as virtualization, dynamic load balancing and dense sensor deployments, with the purpose of attaining energy-efficient data centers. In this context, various meetings have already taken place with key technology providers such as Schneider-Electric (France), Honeywell (Czech Republic) or Critical Software, end users such as Portugal Telecom and Ericsson (Sweden) and other academics such as the University of Lund (Sweden) or the Czech Technical University of Prague (Czech Republic).

CISTER was also key player together with Critical software and Trinity College Dublin in the success of the EMMON demonstrator for large scale embedded monitoring (http://www.criticalsoftware.com/media/press_releases/2011/2/emmon/). This demonstrator – the largest in Europe up to date – acknowledges the capability of CISTER and Critical to develop such complex and large systems that can be further commercially exploited. In fact, within the scope of technology exploration of EMMON, CISTER prepared an offer for a pre-competitive research on the applicability of wireless sensing and monitoring technologies to the area of edgeband & drill at Swedwood (IKEA) Portugal.

INTERNATIONALIZATION

While collaborations with Portuguese academic, research and industrial parties were not neglected, the group mostly plays at the international arena, collaborating with the most prestigious research groups in Europe and the U.S., and being regularly active in international events, standardization committees and organizations (e.g. the Euromicro Real-Time Systems Technical Committee, the IEEE Technical Committee of Real-Time Systems, the IFIP WG10.2 on Embedded Systems, the Ada-Europe Board and the TinyOS 15.4 and ZigBee WGs).

We have published results together with international institutions, e.g. University of Pennsylvania, Korea Advanced Institute of Science and Technology, Czech Technical University of Prague, Federal University of Santa Catarina, National school of Engineers in Sfax, and University of Sousse [J4,J5 J7,O2,O9,O15,O17,O18,O22].

During 2010 we participated in several successful consortia in the context of ARTEMIS. All the proposals we participated in were graded above the threshold enabling in principle funding. While the COSYWORKS proposal led by the University of Tampere was ranked 17th on the list of projects and not selected for funding, Symbeose and Encourage were retained into the negotiations phase. In Symbeose which was

initially coordinated by Symbian Foundation), CISTER researchers played a central role leading one of the work packages and several tasks within work packages.

We will start yet another Artemis project, ENCOURAGE (Embedded iNtelligent COntrols for bUildings with Renewable generAtion and storage), dealing with ICT support to energy-efficient buildings. The new consortium is led by Intel Labs Europe (Ireland), and includes other companies such as ENEL (Italy), EnergiNord (Denmark), ISA - Intelligent Sensing Anywhere (Portugal), and research organizations such as the University of Alborg (Denmark), University College Dublin (Ireland), and Atos Research (Spain).

We have been active in the ArtistDesign and CONET NoEs. In particular, in ArtistDesign we are actively (and increasingly) contributing to the "Design for Adaptivity" Inter Cluster activity, while in CONET we lead the COTS4QoS and SDP research clusters.

In the reporting period we also added 6 PhD students from Mexico, Pakistan, Russia, Serbia, Ukraine and Egypt to our Research centre, extending our capabilities and bringing further internationalization to the team. We have also started a program of granting 6 month internships to future potential PhD students.

RESEARCH PROJECTS

EUROPEAN NETWORKS OF EXCELLENCE

ARTIST2

Network of Excellence on Embedded System Design

Project IST-004527, EU-funded
CISTER funding: 150 KEUR

4 YEARS (OCT 2004 TO SEP 2008)

The objective of ARTIST2 is to strengthen European research in Embedded Systems Design, and promote the emergence of this new multi-disciplinary area. We gather together the best European teams from the composing disciplines, and will work to forge a scientific community.

CONET

Cooperating Objects Network of Excellence

Project FP7-ICT-224053, EU-funded
CISTER funding: 250 KEUR

4 YEARS (JUN 2008 TO MAY 2012)

A number of different system concepts have gained a lot of relevance in the area of embedded systems over the past couple of years: Embedded systems, pervasive computing and wireless sensor networks. These three types of quite diverse systems share a lot of commonalities but also have some complementary aspects in common that make a combination into a coherent system vision promising.

The term "Cooperating Objects" was coined explicitly for the purpose of describing such systems by the Embedded WiSeNts Consortium, a Coordination Action funded by the EC in FP6. One of the main results was the publishing of the Embedded WiSeNts Research Roadmap that defines the concept of Cooperating Objects. The vision of Cooperating Objects is, therefore, quite new and needs to be understood in more detail and probably extended with inputs from the relevant individual communities that compose it. This will enable us to better understand the impact on the research landscape and to steer the available resources in a meaningful way.

The main goal of CONET is to build a strong community in the area of Cooperating Objects capable of conducting the needed research to achieve, in the long run, the vision of Mark Weiser.

RESEARCH PROJECTS

EMMON

EMBEDDED MONITORING
Project Artemis 100036
CISTER Funding: 250 KEUR

3 YEARS (SEP 2007 TO SEP 2010)

EMMON goal is to allow monitoring huge geographical extensions in real time, obtaining information from the field of observation as variations occur, using Wireless Sensor Network (WSN) devices – small communicating & cooperative nodes with sensors.

PT-CMU

CMU PORTUGAL

CISTER Funding: 350 KEUR

6 YEARS (JAN 2007 TO DEC 2012)

The CMU-Portugal Program is a partnership between the Carnegie Mellon University (CMU, Pittsburgh, USA) and the Portuguese Government, aiming at creating top level and internationally recognized education and research programs in Information and Communication Technologies (ICT).

Within the CMU-Portugal Program, CISTER/IPP-HURRAY is involved in a collaborative scientific program that integrates the capabilities of the Carnegie Mellon University, in particular the Electrical and Computer Engineering Department and CenSCIR, and the following Portuguese research institutions: ISR-Lisbon and INESC-ID (affiliated with IST/UTL), CISTER/IPP-HURRAY (affiliated with ISEP/IPP) and the ISQ Group.

This collaborative scientific program includes a dual doctoral program in the area of Electrical and Computer Engineering. The main focus of this doctoral program is on Sensing Technologies and Networks for Risk Minimization Systems, with an additional emphasis on their application to Cyber-Physical Systems such as critical infrastructures. This wide area of research includes communication infrastructures (e.g., wireless sensor and ad-hoc networks), hardware/software platforms (embedded real-time and distributed computing systems), sensing and decision systems (signal/video processing, surveillance, robotics and distributed decision systems) and risk assessment.

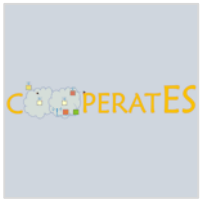
Students will be supervised by two faculty advisors, one from Carnegie Mellon and the other from one of the Portuguese partners. The dual doctoral program is structured so that students spend part of their time at CMU and at one of the Portuguese partner Institutions.

This PhD is to be offered by the Department of Electrical and Computer Engineering at the Carnegie Mellon University (CMU), Pittsburgh, USA and by the Department of Electrical and Computer Engineering at Instituto Superior Técnico (IST), Universidade Técnica de Lisboa (UTL), Lisbon, Portugal.

This research partnership has been launched in Portugal between CISTER/IPP-HURRAY, ISR-Lisbon, INESC-ID and ISQ, but it is expected to

bring together other leading Portuguese institutions. The following CMU Units are involved: Center for Sensed Critical Infrastructure Research (CenSCIR), Electrical and Computer Engineering (ECE) Department, Computer Science (CS) Department, Engineering and Public Policy (EPP) Department, and Tepper, the CMU Business School.

CooperatES



QoS-Aware Cooperative Embedded Systems

PTDC/EIA/71624/2006
CISTER Funding: 80 KEUR

3 years (Sep 2007 to Sep 2010)

Quality of Service (QoS) is considered an important user demand, receiving wide attention in real-time research. However, in most systems, users do not have any real influence over the QoS they can obtain, since service characteristics are fixed when the systems are initiated.

Furthermore, applications (and their users) can differ enormously in their service requirements as well as in the resources which need to be available to them. These applications present increasingly complex demands on quality of service, reflected in multiple attributes over multiple quality dimensions.

At the same time, the use of embedded devices with wireless network interfaces is growing rapidly. The increasing pervasiveness of these devices in the everyday life is changing the way computing systems are used and interact, creating a new, highly dynamic and decentralized environment.

MASQOTS

Mobility mAnagement in wireless Sensor networks under QoS constraints using standard and Off-The-Shelf technologies

FCOMP-01-0124-FEDER-014922 PTDC/EEA-TEL/112220/2009
CISTER Funding: 94.8 KEUR

42 months (Feb 2011 to Jul 2014)

MASQOTS aims at real-time and reliable communications in IEEE 802.15.4/ZigBee (15.4/ZigBee, for short) Wireless Sensor Networks (WSNs) supporting physical mobility. Physical mobility concerns mobile sensor/actuator nodes and node groups (e.g. body sensor networks (BSNs), robots), and also mobile sinks (e.g. gateways, user-interface equipment).

The main objective of this project is to design a real-time and reliable mobility management mechanism for IEEE 802.15.4/ZigBee-based WSNs.

We will build upon the most widespread WSN technologies – the 15.4 and ZigBee protocols and the TinyOS operating system (OS) – for which the research team in this proposal is international leader. OnWorld predicts that in 2012, 88.3% of the WSN units will be standards-based. Freescale reports over 7 million 15.4/ZigBee units sold in 2008 and In-Stat forecasts 292 million units in 2012. TinyOS is the most used OS for WSNs.

MASQOTS will also address some fundamental (not yet solved) problems, such as the ones related to reliable Radio Link Quality Estimation (LQE), efficient and dynamic resource management, reliable and time-bounded handoff and re-association mechanisms and the provision of (simulation, analytical) models/tools for WSN analysis and dimensioning.

RECOMP

REDUCED CERTIFICATION COSTS FOR TRUSTED MULTI-CORE PLATFORMS

Artemis 100202
CISTER Funding: 456 KEUR

3 YEARS (APR 2010 TO MAR 2013)

RECOMP recognizes the fact that the increasing processing power of embedded systems is mainly provided by increasing the number of processing cores. The increased numbers of cores is commonly regarded as a design challenge in the safety-critical area, as there are no established approaches to achieve certification. At the same time there is an increased need for flexibility in the products in the safety-critical market. This need for flexibility puts new requirements on the customization and the upgradability of both the non-safety and safety-critical critical part. The difficulty with this is the large cost in both effort and money of the re-certification of the modified software, which means that companies cannot fully leverage the advantages of modular software system. RECOMP will provide reference designs and platform architectures together with the required design methods and tools for achieving cost-effective certification and re-certification of mixed-criticality, component based, multi-core systems. The aim of RECOMP is to define a European standard reference technology for mixed-criticality multi-core systems supported by the European tool vendors participating in RECOMP.

Partners of the RECOMP consortium include, among others:

REHEAT

REAL-TIME SCHEDULING ON HETEROGENEOUS MULTICORE ARCHITECTURES

FCOMP-01-0124-FEDER-010045 PTDC/EIA-CCO/105716/2008
CISTER Funding: 130 KEUR

3 YEARS (FEB 2010 TO JAN 2013)

Parallel processing platforms are spreading at an unprecedented rate. Traditionally, parallel processing platforms were used to reduce the execution time of a large computational job such as predicting the weather but now they are also used in low-end systems and embedded real-time systems thanks to the availability of multicore processors. And those systems are often comprised of a large number of independent tasks. Designers are well-aware that processing units specialized for a specific function can offer a significant performance boost. Consequently, heterogeneous multicores now enjoy a period of widespread use. Virtually all major semiconductor companies are offering

or have declared plans to offer heterogeneous multicores.

This project aims to create provable good real-time scheduling algorithms for heterogeneous multicores.

REJOIN

REAL-TIME SCHEDULING ON MULTICORE PROCESSORS: ADDRESSING TWO OPEN PROBLEMS JOINTLY

FLAD/NSF 91-02/10
CISTER Funding: 7 KEUR

11 MONTHS (JUN 2010 TO MAY 2011)

The objectives of this project is to study the following two problems:

P1. Multiprocessor Global Feasibility Analysis - Arbitrary-Deadline Tasks;
P2. Resource sharing on Multiprocessor Systems.

The main challenge with respect to P1 is that optimal scheduling for the problem P1 requires knowledge of future job arrivals. It has recently been shown [1] that no optimal solution exists for problem P1 even for the slightly more restricted model of sporadic tasks. Creating non-optimal algorithms is worthwhile though.

Problem P2 is non-trivial because normal uniprocessor solutions, Priority-Inheritance Protocol (PIP) and Priority Ceiling Protocol (PCP, perform poorly. The former (PIP) allows a large degree of parallel execution but there are many situations when a lower priority task inherits a much higher priority and this can happen multiple times and this cause delays to a medium priority task. The latter (PCP) severely limits parallel execution. Because of the poor performance PIP and PCP, new solutions to P2 must be devised.

REPOMUC

REAL-TIME POWER MANAGEMENT ON PARTITIONED MULTICORES

FCOMP-01-0124-FEDER-015050 PTDC/EIA-EIA/112599/2009
CISTER Funding: 106 KEUR

3 YEARS (FEB 2011 TO JAN 2014)

The fundamental objective of the RePoMuC project to provide a methodology for real-time power-management in Multicores, considering: 1. the non-linear behaviour of dynamic frequency and voltage scaling (DVFS) on execution-time and energy, 2. pre-emption delays, and 3. memory bus contention Particular focus will be given to demonstrate with a real-world implementation the practicality and limitations of the proposed methodology.

The approach we intend to take is to build on successful experience of the group in the areas of DVFS power management, real-time multiprocessor scheduling and temporal isolation. The issues of DVFS behaviour, pre-emption delays, and memory bus contention have a fundamental communality in the sense that they are all tightly coupled to the amount of memory traffic.

RESCORE

REAL-TIME SCHEDULING ON MULTICORES

PTDC/EIA/78141/2006
CISTER Funding: 156 KEUR

3 YEARS (SEP 2007 TO SEP 2010)

Multiprocessors have already made the transition from high-end computing to desktops and laptops. This was possible because of the miniaturization of integrated electronics system which allowed the implementation of multiprocessors on a single chip, called multicores.

Now, the next step is about to begin. These multicores are targeting embedded real-time systems as witnessed by (i) the commercial availability of multicore PowerPC and ARM processors and (ii) Intel's and AMD's recent marketing of the use of multicores in embedded systems. Today, more than 99% of all computers are embedded systems. These computers operate within products to improve their functionality.

Often human beings are not aware of the existence of these computers - as long as they are working as intended. Pace makers, cars, electronic pianos, vacuum cleaners and walking robots, all represent examples of embedded computers. In fact, virtually every product developed in the future will host an embedded computer. For this reason, they constitute an enabling technology for most goals in our life, our society and the economy.

RESCUE

RELIABLE AND SAFE CODE EXECUTION FOR EMBEDDED SYSTEMS

PTDC/EIA/65862/2006
CISTER Funding: 80 KEUR

3 YEARS (SEP 2007 TO SEP 2010)

This project looks at an important requirement in safety critical systems -- that of supporting verifiability of software components. The project partners focus on embedded systems, thereby making the approach more manageable. This also provides a more significant challenge, in that the device in which the verification is being undertaken is resource constrained. The approach is clearly applicable to a variety of different contexts and scenarios.

The use of certificates in Proof Carrying Codes provides a useful basis to support such verifiability provides a useful first step for the research being proposed here. The authors advocate the use of: (i) Type-based; (ii) Language-based; and (iii) Logic-based security enforcement mechanisms.

REWIN

Real-Time Guarantees in Wireless Sensor Networks

FCOMP-01-0124-FEDER-010050 PTDC/EIA-CCO/109027/2008
CISTER Funding: 68 KEUR

3 years (Feb 2010 to Jan 2013)

A class of WSN applications require timely response to events. For example, in a smart nursing home WSN scenario, it is necessary to guarantee that life-threatening events such as heart-attacks are communicated to doctors within a bounded time. The ability to support real-time applications is fundamental to the advancement of capabilities of WSN, and is the motivation for this proposed research. Since communication is an integral part of WSN, the performance of WSN is mainly determined by the quality and capacity of the wireless channel. The limited previous research that exists is insufficient to guarantee (with mathematical proofs) a low delay for disseminating the occurrence of rare but critical events, such as the heart-attack mentioned above. This project, we will develop methods to offer hard real-time guarantees to individual real-time flows over multi-hop WSN of arbitrary node deployments and arbitrary traffic pattern. These methods will guarantee a small delay for disseminating the occurrence of critical events.

SENODs

Sustainable ENergy-Optimized Datacenters

FCOMP-01-0124-FEDER-012988 CMU-PT/SIA/0045/2009
CISTER Funding: 219KEUR

39 months (Oct 2010 to Dec 2013)

Data centres increasingly constitute a critical backbone of the worldwide information technology (IT) infrastructure, forming the server infrastructure for search engines, mail servers, e-commerce, data warehousing and other cloud computing functions.

Thousands of data centres operate across the world occupying various millions of square meters. While such data centres generally target large-scale virtual IT services, the design, construction and operation of data centres (i) depend on cyber-physical infrastructure with major power and cooling requirements, (ii) incur significant energy costs, and (iii) can lead to significant economic and societal impact from the failures of physical subsystems. In fact, power and cooling in a data centre cost more than the IT equipment supported. As a result, data centres face an emerging crisis.

The SENODs (Sustainable ENergy-Optimized Datacenters) project will rectify that by:

(i) using ultimate distributed sensing technologies to provide fine-grained monitoring of power consumption, cooling and data centre environmental variables to identify, model, analyse and optimize energy costs;
(ii) developing intelligent layout optimization algorithms that offer recommendations regarding placement of new servers so as to minimize local hotspots and improve energy efficiency;
(iii) providing support for alerts and notifications of actual or pending failures in cooling and other infrastructure equipment to gracefully shut down some or all of centre operations;
(iv) online capacity and workload management that allows dynamic reallocation of

computing loads driven by energy and cost minimization.

Partners of the SENODs consortium include:

SMARTSKIN

Densely Instrumented Physical Infrastructures

FCOMP-01-0124-FEDER-020312 PTDC/EEA-ELC/121753/2010
CISTER Funding: 141KEUR

3 YEARS (MAR 2012 TO FEB 2015)

Although the information technology transformation of the 20th century appeared revolutionary, a bigger change is on the horizon. The term Cyber-Physical Systems (CPS) has come to describe the research and technological effort that will ultimately allow the interlinking of the real-world physical objects and the cyberspace efficiently. The integration of physical processes and computing is not new.

Embedded systems have been in place for a long time and these systems often combine physical processes with computing. The revolution will come from massively networked embedded computing devices, which will allow instrumenting the physical world with pervasive networks of sensor-rich embedded computation.

In this project we intend to develop techniques and technologies that allow performing scalable and efficient data processing in large-scale dense cyber-physical systems. This is yet an unsolved problem. The major novelty of this proposal is effectively in the co-design of distributed algorithms for sensor data processing and underlying networked distributed computing systems with corresponding resource management schemes such that the utilization of resources is low.

VIPCORE

Virtual Processor-based Multicore Scheduling

FCOMP-01-0124-FEDER-015006 PTDC/EIA-CCO/111799/2009
CISTER Funding: 111KEUR

40 MONTHS (FEB 2011 TO JUN 2014)

Scheduling on multicores is a much harder problem than those studied under single processor scheduling theories, largely because of the inherent non-parallelism in workload tasks. Although a multicore platform may execute different tasks from a workload at the same time, it is typically not allowed to execute the same task on more than one core simultaneously. This project plans to research multiprocessor frameworks and platforms to tackle these issues. One important concept is the notion of virtual processors, which allow to use a three-step scheduling strategy: partitioning of workload tasks and assigning virtual processors to each partition, scheduling of tasks on virtual processors within each cluster, and scheduling of virtual processors on the physical cores. Another important concept is the notion of pJobs, which allow tasks to be executed in parallel in the physical cores,

increasing the potential parallelism of applications. The project will also research into architectures and platforms for supporting these concepts, and the underlying resource sharing paradigms.

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[T4] Jurcik, P., Real-time Communication over Cluster-tree Wireless Sensor Networks, PhD Thesis, Faculty of Electrical Engineering Czech Technical University, Prague, Czech Republic, October 2010.

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[J2] Andersson, B., Easwaran, A., “Provably Good Multiprocessor Scheduling with Resource Sharing”, Real-Time Systems Journal, Vol. 46, Issue 2, September 2010, pp 153-156.

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PATENTS/PROTOTYPES

The patent “Using a Prioritized Medium Access Control for Incrementally Obtaining an Interpolation of Sensor Readings”. was submitted to the US patent office in May 6, 2010. The inventors where CISTER researchers Björn Andersson, Nuno Pereira, Eduardo Tovar and Ricardo Gomes. The invention was related to communication and processing techniques for efficient data processing in wireless sensor networks.

CISTER is leading worldwide research on IEEE 802.15.4 and ZigBee technologies, the most widespread technologies for Wireless Sensor Networks (WSNs). Within this line, CISTER has been developing cutting edge methodologies and tools (e.g. [J6, J7, O15, O22, T2, T4] that are available to the international community, and with an outstanding recognition. The toolset site (http://www.open-zb.net) already witnessed over 125 000 visits (effective visits, not just mouse clicks), with more than 7000 downloads of the toolset from all around the world (including top universities and companies). Notably, there are 4-5 downloads in average per day, almost 4 years after the first release (November 2006). The synergies created by CISTER's open-ZB research team have triggered the creation of the TinyOS15.4 and ZigBee Working Groups, in which CISTER researchers have been actively involved since their foundation (early 2009). In this line, CISTER has been working towards "official" implementations of the standard 15.4 and ZigBee protocols, as well as of Quality of Service add-ons (e.g. traffic differentiation [T2, O15], energy-efficient clusters scheduling [J6, O22]). This work has been mainly performed within the COTS4QoS research cluster (http://www.cooperating-objects.eu/research-clusters/cots4qos/), under the CONET NoE.

In 2010, we continued our collaboration with the ISISE(http://www.isise.net) Research Unit on structural health monitoring based on WSNs (http://www.cister.isep.ipp.pt/activities/MSM/). A prototype system has been designed, implemented and validated, based on standard/COTS technologies integrated with a customized signal acquisition board [O16].

During 2010, we consolidated our critical mass on radio link quality estimation (LQE) in WSNs, a basic building block for supporting higher level protocols and mechanisms such as routing, mobility management ([O14]), fault-tolerance, deployment, topology control. We have devised RadiaLE - a benchmarking test-bed for the performance evaluation of LQEs [T1], available as an open-source (http://www.open-LQE.net) and innovative link quality estimators based on Fuzzy Logic that show significant benefits over existing ones [O2].

CISTER played a key role on putting together the first integrated system prototype (coined "DEMMON1"), a monitoring application encompassing all system components, ranging from hardware, communication architecture, middleware and command and control GUI. This was demonstrated live during the second review meeting of the EMMON European Project. In DEMMON1, the EMMON WSN architecture has been validated through extensive simulation and experimental evaluation, namely through a 300+ node test-bed (in ISEP premises), which is, to the best of our knowledge, the largest single-site WSN test-bed in Europe to date. The specification of the EMMON WSN system architecture and consequent implementation and integration work were mainly carried out by CISTER-ISEP, Critical Software (Portugal), Trinity College Dublin (Ireland) and SESM (Italy). DEMMON1 dissemination video and can be found at http://www.artemis-emmon.eu.

Further, in collaboration with the University of Pennsylvania (USA), one of our researchers has further advanced the development of a new tool called Compositional Analysis of Real-Time Systems (CARTS), available on the public forum as an open-source entity (http://rtg.cis.upenn.edu/carts/).

Future Research

Objectives

The research group is one of the leading European research groups in the area, contributing with seminal research works. We will continue to pursue research excellence in the coming years, by structuring our strategic research plans around our five research areas:

Highly Scalable Aggregate Computations in Cyber-Physical Systems (CPS)

One of our main continuing efforts is tackling the problem of scalable and efficient information processing in large-scale and dense systems. As discussed in the group objectives we will continue work on (PD)2 and advocate its use in industry. One initiative that we have been driving together with Portuguese Critical Materials and Brazilian Aircraft manufacturer Embraer aims at exploiting these results (the SmartSkin project). It relates to the environmental concerns in the industry by developing technologies to allow sustained air travel growth while minimizing carbon footprint. Local modulation of aircraft surfaces is a form of active flow control, which will be explored in term of its potential to offer significant reduction of fuel consumption and emissions. Implementing such a flow control system requires thousands of sensor/controller/actuator systems to be embedded across the aircraft wings and fuselage to create an active aircraft. New challenges will come from the recently started projects SENODs and ENCOURAGE.

Multicore Systems

During 2011, researchers in the multicore area of CISTER will continue the successful ongoing research. We expect to create even better algorithms for assigning tasks on heterogeneous multiprocessors and we expect to allow resource sharing with provably good performance (resource sharing with provably good performance has already been achieved for identical multiprocessors but not for a heterogeneous multiprocessor).

Researchers will also explore practical aspects (i) implementation of scheduling algorithms in real operating systems and (ii) analysis of shared low-level hardware resources.

Adaptive Real-Time Systems

We will develop a novel technique, which allows temporal isolation in multicore systems by developing metrics to estimate memory-bus and cache contention. Furthermore, we will explore power and thermal management in densely packed multicore systems.

We will continue the successful work in hierarchical systems scheduling, tackling hierarchical slack time management, as well as the development of component interfaces exploiting results obtained for flat uniprocessors and furthermore drive it into a multicore context, exploiting current research on cache and bus contention mentioned before.

Further efforts will explore mode changes in multicore systems, to ensure system stability in the face of environmental changes.

The efforts described are supported by a number of project proposals under evaluation (FCT SMARTS and MoMu), in negotiation (ARTEMIS SYMBEOSE), starting (FCT RePoMuC and ViPCore) and active (ARTEMIS RECOMP). Additionally, all of the above work aims to be implemented on commercial grade operating systems.

REAL-TIME SOFTWARE

In this area work will continue in the current efforts of the cooperative embedded system middleware and the use of software verification tools with concurrent embedded programming models. The cooperative embedded platform will also be explored for mobile middleware, targeting commercial operating systems such as Android or Symbian.

We will continue the work on the autonomic behaviour of interdependent nodes in dynamic distributed environments with QoS constraints, partly supported by the ARES project proposal, with issues such as the non-linear nature of nodes' interactions and mechanisms to control their autonomic adaptation.

We will also continue to work on the specification of advanced concurrency models and mechanism within languages and operating systems, to support the raised abstraction level required by the more complex modern systems. In particular work will be developed in software transactional memory and parallel support of real-time tasks at the operating system and virtual machines levels.

Continuing the active participation in the standardization activities of the Ada language, we will foster the introduction of native support in the Ada language for multicore and multiprocessor architectures.

WIRELESS SENSOR NETWORKS (WSNS)

We will continue our strategy for excellence in collaborative R&D sustained by analytical, simulation and experimental models, as well as validating and consolidating of our findings through real-world applications.

Continuing our work in the area of QoS in WSNs, we will focus on real-time/timeliness, reliability/robustness, mobility support and energy-efficiency aspects within the scope of both national (e.g. REWIN, MASQOTS) and international (e.g. EMMON, CONET) projects. This will be based both on off-the-shelf technologies, as well as on novel solutions designed from scratch (e.g. hexagonal WSNs or BANMAC).

We will continue to contribute to the TinyOS 15.4 and ZigBee WGs, aiming developing platform-independent, standard-compliant, IEEE 802.15.4 Medium Access Control and ZigBee Network Layer protocols. We are also looking into emerging technologies and standards such as the IETF 6loWPAN for pervasive Internet and IEEE 802.15.6 for body sensor network applications.

We will consolidate the EMMON WSN architecture for large-scale and dense real-time monitoring with several QoS add-ons such as in what concerns reliability and data aggregation, as well as completing the supporting set of tools for system planning, worst-case dimensioning and simulation. The EMMON project will be complemented by the design of real-time and reliable mobility support in WSNs, through hand-off heuristics, radio diversity, interference modelling and link quality estimation.

Within the context of the ARTEMIS ENCOURAGE project (about to start), we will design a WSN architecture to enable more energy-efficient buildings.