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RESEARCH CENTER
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THEME
Embedded and Real Time Systems

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Project-Team TRIO

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2. Overall Objectives

2.1. Objectives of the team

The goal of the TRIO team is to provide a set of techniques and methods that can be applied to design, validate and dimension real time distributed applications. In order to tackle this problem as a whole, our work is structured along two complementary points of view:

- specification of real-time on-line mechanisms (protocols, schedulers, middleware) offering services to the application with a quality of service that ensures the satisfaction of real time constraints; this includes fault detection, fault recovery and fault tolerance,
- modeling, analysis and evaluation of real time distributed systems for the verification of temporal properties and the optimisation of distributed deployment.

Furthermore, we will continue to study the modeling process of real time distributed applications that allows the description of both functional and non-functional aspects of these applications and therefore a formal use of these models for quantitative evaluation and optimal scaling.

The problems to solve are mainly due to three particularities of the targeted applications:

- They are discrete event systems with temporal characteristics (temporal performances of hardware support, temporal properties); this increases the complexity of their modeling and of their analysis. Hence a part of our research objectives is to master this complexity while achieving a satisfactory trade-off between the accuracy of a model and its ability to be analyzed.
- A second aspect is the environment of these systems that can be the cause of perturbations. We need to take into account the impact of an uncertain environment (for example, the impact of electromagnetic perturbations on a hardware support) on the required properties. Therefore we have to develop stochastic approaches.
- Finally, the main characteristic of our work is based on the fact that we consider the performances of the hardware support. Consequently, the time that we manipulate is a physical (continuous) time and the studied systems are event driven timed systems.

These above mentioned main directions contribute to cover the full spectrum from formal modeling and evaluation of real time distributed systems up to their use in industrial problems, in particular, in the field of in-vehicle electronic embedded systems or real-time Quality of Service. Furthermore, some of our results yield to software tools and fruitful collaborations with the automotive industry.

2.2. Highlights

+ "PROARTIS: Probabilistically Analyzable Real-Time Systems" was accepted for publication in "ACM Transactions in Embedded Computing Systems". This paper, co-authored by Liliana Cucu-Grosjean, Luca Santinelli and Codé Lo from the team, is a position paper that results from the work undertaken within the Proartis European project.
+ Nicolas Navet is co-head of the High Performance Embedded Systems (HPES) cluster of GDR CNRS ASR and co-animator of Actriss group (real-time services and infrastructure) of HPES cluster.
+ Startup Alphability has been created to provide risk management solutions and is laureate of the 13th national contest for the creation of innovative technology companies organized by the Ministry of Higher Education and Research (“Création/Développement” category).
+ Three patents in the field of automotive communication systems have been filled in together with PSA Peugeot-Citroën.
+ The Open-PEOPLE software platform, a federative platform aiming at providing energy measurement, modelling and optimization capabilities for software systems, saw the first release of its module giving access and control to the distant hardware platform for actual experimentations.

3. Scientific Foundations

3.1. Fondation 1

In order to check for the timing behavior and the reliability of distributed systems, the TRIO team developed several techniques based on deterministic approaches ; in particular, we apply and extend analytical evaluation of worst case response times and when necessary, e.g. for large-scale communication systems as Internet based applications, we use techniques based on network calculus.

When the environment might lead to hazards (e.g. electromagnetic interferences causing transmission errors and bit-flips in memory), or when some characteristics of the system are not perfectly known or foreseeable beforehand, we model and analyze the uncertainties using stochastic models, for instance, models of the frame transmission patterns or models of the transmission errors. In the context of real time computing, we are in general much more interested by worst-case results over a given time window than by average and asymptotic results, and dedicated analyses in that area have been developed in our team over the last 10 years. An illustration is our contribution to the extension of "consecutive-k-out-of-n:F" analyses, applied to the reliability evaluation of X-by-Wire systems. As far as the design of discrete event systems is concerned, we mainly use scheduling techniques for real time systems.
In the design of discrete event systems with hard real time constraints, the scheduling of the system's activities is of crucial importance. This means that we have to devise scheduling policies that ensure the respect of time constraints on line and / or optimize the behavior of the system according to some other application-dependent performance criteria.

Many current systems can adapt dynamically to the environment. This is why we focus on "weakly hard" real time constraints such as (m, k)-firm constraints and study their applicability in two main application fields. The first one is concerned by application under weakly hard constraints, as real time multimedia application that are deployed for example on internet; in this case, the main problem is to adapt the (m, k)-pattern to the current requirements in terms of real time Quality of Service. The second domain where these techniques are investigated is the co-design of networked control systems. It has to be noted that in this domain several approaches are developed by the community; some of them focus on the automatic control problem and try to solve it by delayed systems while other ones are concerned only by the scheduling techniques to implement in order to guarantee the timing properties required by the closed loops. In this context, we propose to specify how to scale both control law parameters and scheduling strategies for tasks and messages and, for this purpose, we integrate control theory (linear systems, multi-variables), optimisation and schedulability analysis in order to develop off-line and on-line techniques

4. Application Domains

4.1. Application Domains

Four main application domains can be underlined.

- **In-vehicle embedded systems.** A lot of work developed in TRIO is oriented towards transportation systems (cars, autonomous vehicles, etc.). They mainly cover two points. The first one is the specification of what must be modeled in such a system and how to reach a good accuracy of a model; this leads to investigate topics like Architecture Description Languages and automatic generation of models. The second point concerns the verification of dependability properties and temporal properties required by these applications and, consequently, the development of new fault tolerant on-line mechanisms to include in an application or the automatic generation of a standard middleware.

- **Compilation, memory management and low-power issues for real time embedded systems.** It becomes mandatory to design embedded systems that respect performances and reliability constraints while minimizing the energy consumption. Hence, TRIO is involved, on the one hand, in the definition of ad-hoc memory management at compilation time and on the other hand, in joint study of memory management strategies and tasks scheduling for real time critical systems.
- **Code analyses and software visualization for embedded systems.** Despite important advances, it is still impossible to develop and optimize automatically all the programs with all their variety, especially when deployment constraints are considered. Software design and implementation thus remain highly ad-hoc, poorly automated activities, with a human being in the loop. TRIO is thus involved in the design of better tools for software engineering focusing on helping the human developer understand and develop the system, thanks to powerful automated program analyses and advanced visualizations techniques.
- **Quality of services (QoS) of protocols and telecommunications.** In many application domains, the evaluation and, when required, the improvement of the quality of services provided by the used communication protocols is a way to ensure the respect of real time and dependability properties. In this context, we model and analyze some protocols for Internet and Cyber Physical Systems (CPS) and aim to define the optimal configuration of their characteristics (protocols for the QoS guarantee for multimedia applications or ambient assisted living applications). Although WSN (Wireless Sensors Network) technology is economically a very interesting solution for building CPS, unfortunately its current QoS is not sufficient for supporting such applications. Adaptive QoS seems to be an interesting approach to this problem. This could be achieved in two coordinated directions: one is to develop the on-line adaptive QoS management in network to cope with the time varying performance requirement of an application; another is to make applications to adapt to the network working condition changes if they go beyond the network QoS control range. We follow a pragmatic approach by assuming the use of the COTS components (e.g. IEEE802.15.4/Zigbee) at the lower levels. The adaptive QoS are mainly studied at the routing level with cross-layer optimization and by defining and developing a QoS middleware allowing the necessary on-line interaction between the network and the application.

5. Software

5.1. MPIGate: Multi-Protocols Interface and Gateway for telehomecare and environment monitoring and control

Participants: Shahram Nourizadeh, Hugo Cruz Sanchez, Ye-Qiong Song.

For developing AAL (Ambient Assisted Living) or more generally the environment monitoring and control systems, heterogeneous wireless and wired networks will be used. To solve firstly the interoperability problems, and then to ensure the application required QoS, we developed a software prototype called MPIGate. MPIGate includes two important components: a user interface for telehomecare and home automation, and a gateway for ensuring the interworking of the different networks. In 2010, MPIGate has been laureate of the 12th national contest for the creation of innovative technology companies by the ministry of higher education and research (“Emergence” category). During 2011, MPIGate has been implemented on an embedded linux board and integrated into LORIA smart room platform within CPER IS project (http://infositu.loria.fr) [25], [45]. In its current version, the gateway ensures the communication between IP (Ethernet and Wifi), home automation network (KNX), Bluetooth and Zigbee. Heterogeneous sensors can be now easily used through MPIGate interface for further building the activity monitoring of the elderly person living along at home or other application scenarios.

5.2. SAMOVAR

Participants: Adrien Guénard, Lionel Havet, Françoise Simonot-Lion.

Wireless Sensor and Actuator Networks (WSANs) combine sensors and actuators interconnected by wireless networks in order to perform distributed sensing and acting tasks. Closed-loop controllers can therefore be deployed on WSANs. Such systems have to meet specific requirements in terms of performance, dependability, energy and cost which raises great challenges due to the unreliability of wireless communications. A way to ensure that a system meets the required properties is to model it and go through its analysis. Building a model requires both deep knowledge on the system as well as on the used framework. Therefore there is a need for frameworks well-suited to the targeted systems and to the properties to verify. We proposed an approach meeting these conditions and a simulation framework, Samovar, based on Matlab / Simulink, allowing the modeling of the network protocols (Mac and routing services) and the resources sharing policy thanks to the TrueTime toolbox. Several classes of components (application, nodes, networks and middleware) and a clear semantics for their composition are identified. Furthermore, the design of Samovar was also driven by the need to easily transfer software component model between the concrete systems and its simulated model. The modeling and simulation method as well as the Samovar framework were assessed on several case studies: cooperating robots, intelligent living environment, embedded controllers on UAV robots... The simulation framework is available from http://samovar.loria.fr/. This work is supported by INRIA through the ADT SAMOVAR.

5.3. ANR Open-PEOPLE platform

Participants: Sophie Alexandre, Jonathan Ponroy, Kévin Roussel, Olivier Zendra.

The aim of Open-PEOPLE is to provide a platform for estimating and optimizing the power and energy consumption of systems. The Open-PEOPLE project formally started in April 2009. Two systems administrator and software developers had been hired initially: Sophie Alexandre and Kévin Roussel. Another system administrator and software developer, Jonathan Ponroy, joined them in 2010 when he finished his work on the ANR MORE project where he worked previously. Sophie Alexandre contract ended in February 2011.

Since the beginning of the Open-PEOPLE project, we had made significant progress in setting up the infrastructure for the software part of the platform, for which INRIA Nancy Grand Est is responsible. We had included new features to be able to fully integrate and test software developed as Eclipse plugins, relying on the Buckminster tool. We had also created a specific extension set for SVN and Hudson, called OPCIM (Open-PEOPLE Continuous Integration Mechanism). OPCIM had been registered at APP on 13/04/2010 with number IDDN.FR.001.150008.000.S.P.2010.000.10000.

Concerning the Open-PEOPLE platform itself, we had first tackled the high-level work, working with our partners on the definition of the requirements of the platform according to the needs of industry. We had then realized the specification work to define the global perimeter of our platform, according to the previous requirements. As part of this work had also been designed exchanges formats between the various tools. We had also designed at INRIA Nancy Grand Est a Tools integration Protocol, which specified requirements for external tools to be integrated in our platform. All this design work had been materialized in several reports which were deliveries provided to ANR.

We had also designed and developed an authentication component (Eclipse plugin) for the platform, so as to be able to provide a unique, secured access gate to the platform to all the tools that are or shall be integrated into it.

We had also started and almost finished developing an Internet portal giving access and control to the Open-PEOPLE Hardware Platform, located at our partner's UBS in Lorient. Our portal features included user account management facilities, on the admin side, and on the user side, the ability to create, save, edit, reuse and of course submit jobs, make reservations for the hardware platform resources and get back tests results.

Finally, we had started working on two important parts of the software platform.

First, a way to unify the user experience despite the fact the platform federates several tools which were not developed to interact together. This implied an important and in-depth study of the wanted ergonomy for the platform, which involved taking into account both user needs and habits and the features of the available software tools.

The second work which had begun in 2011 was the design (then implementation) of the communications of between the various tools of the platform. This skeleton will be a key part of our platform, and the quality of its design will have a tremendous impact on its maintainability and its extensibility.

Note that the Open-PEOPLE project had been successfully evaluated on 14/09/2010 by ANR. Developments done during the first two years in the project are detailed in the 2009 and 2010 activity reports. In 2011, these developments went on.

We continued the work to solidify our development platform supporting our work and that of our partners. We produced a finer grained definition of the software platform functionalities, and a more precise definition of the tools integration protocol. We worked towards the corresponding implementation documents, adding two new delivrables about the architecture of the software platform and the âergonomics of the software platform. For the latter, we extensively interviewed user about ergonomics and designed several GUI mockups. We progressed on the implementation of the software platform, especially with respect to the internet portal to remote-control the hardware platform. We participated to the definition of the hardware platform and its functionalities, and participated actively to the work on the Specification document for HW / SW interfacing. We provided the first concrete design and implementation of the HW/SW platform interfacing, with our implementation of the remote control portal for the HW platform. This remote control module was completed in Fall 2011.

We also participated to the work pertaining to basic components model homogenization, by reviewing this in the context of the software platform architecture and implementation, which resulted in several incremental improvements of the underlying models. Finally, progressing towards the first release of the software part of the Open-PEOPLE platform, we realized an ergonomic study for the consumption laws editors, with mockups and user interviews and validation. We worked on the implementation of the editors for the consumption laws, which required learning new environments and development tools (related to the EMF framework and the AADL, QUDV and MathML models). As a consequence, we completed the implementation of the GUI and engine to create units and quantities. We finalized the architecture needed to integrate external modules in the platform.

With this progress, the first release of the whole Open-PEOPE software platform platform is expected early 2012.

5.4. VITRAIL

Participants: Damien Bodenes, Pierre Caserta, Olivier Zendra.

The aim of the VITRAIL operation is to provide tools for the advanced and immersive visualization of programs. It partners with the University of Montréal, University of Montpellier and Pareo team of INRIA Nancy Grand Est.

Last years, in VITRAIL, we had developed software to instrument and trace Java programs at the bytecode level. We then had developed an analysis tool able to exploit these traces to compute relevant software metrics. We had hired Damien Bodenes as software developer, and had begun the work on a prototype able to render a 3D world, symbolizing software, onto various visualization hardware, with the possibility to change the display metaphor. The main part of our development work had been in 2009 the choice and validation of the technology, and a first architecture. In 2010, the development had go on at a good pace, building on chosen technologies and architecture. This had brought new experience, and with the first actual runs of our platform, we had realized that with the Irrlicht platform we had chosen, we could reach unforeseeable problem when scaling up. We had thus decided to reverse our choice to the Ogre3D 3D engine at the beginning of 2010. Our development had then progressed steadily.

We had released in 2010 a first prototype of our platform, with all the underlying architecture, able to provide navigation features and interaction capacities limited to the driving of the navigation, as per our plans. This had included dual screen management.

Our first prototype, using 2 large 2D screens, with a city metaphor, had been demonstrated during the "Fête de la Science" in November 2010 and had received a lot of attention and enthusiasm from the general public. About 55 persons per day had visited our booth and got demonstrations.

We had also progressed significantly in our Java bytecode tracer, by improving its granularity, the completeness of the traced information, and its performance as well. We have a unique tool which is able to trace both program classes and JDK classes, at basic block level. In addition, it does so with a dynamic instrumentation of classes, which means there is no need to have an instrumented version of the class files on disk. This is very convenient, especially when changing machine of JVM, or when upgrading either the JDK or the program itself. In addition, the performance is good enough that the instrumented programs are still fully usable in an interactive way, without bothering the user. To the best of our knowledge, this is the only Java bytecode tracer that offers these features nowadays.

Our software development had lead to several registrations with APP:

- VITRAIL - Visualizer had been first registered on 29/12/2009 under number IDDN.FR.001.530021.000.S.P.2009.000.10000.
- VITRAIL - Tracer, was registered at APP on 20/09/2010 with number IDDN.FR.001.380001.000.S.P. 2010.000.10000.

In 2011, we acquired a workstation and three 30 inches computer screens, to be able to set up a "boxed 3D workstation", that would provide display in front and on both sides of the operator. This would constitute the next step in our experiments, by improving immersion with a larger field of vision (on the sides). The software developments to do this are ongoing. We also integrated a WiiMote interaction device to our system, but our experiments found that its spacial resolution was too poor for our needs.

We finally improved significantly our VITRAIL prototype in 2011, especially by designing and implementing a new representation for the relations between software (hence visual) elements, with limited clutter and the possibility to regroup links and see their direction.

6. New Results

6.1. Real-time services and protocols

In this area, we developed, on the one hand, policies for managing the quality of service of operating support (mainly, networks and protocols) in order to meet the properties required by real time applications (hard real time, weakly hard real time) and, on the other hand, strategies for scheduling activities and memory management.

6.1.1. Network-MAC cross-layer framework for differentiated QoS in wireless sensor networks

Participants: Bilel Nefzi, Ye-Qiong Song.

Self-adaptive QoS mechanism is preferable in large-scale wireless sensor networks because of frequent network condition changes and the difficulty to statically configure the network parameters. A network-MAC cross-layer framework has been developed for facilitating packet scheduling, congestion control and energy consumption minimization. The work is based on a very simple idea of “collecting-and-transmitting burst” scheme, called CoSenS (Collecting and Sending burst Scheme). The underlying MAC protocol is the widely adopted and deployed unslotted CSMA/CA of IEEE802.15.4. An algorithm is designed making the network self-adapts to the dynamic traffic changes. CoSenS provides a simple but efficient improvement of the MAC layer of IEEE 802.15.4 in terms of reliability, delay and throughput. Two extensions have been made: P-CoSenS for integrating priority management and S-CoSenS which adds dynamic sleeping period management [15], [8].

6.1.2. QoS in UWB-based sensor networks

Participants: Jamila Ben Sliman, Mounir Frikha [INIT, SupCom, Tunisia], Anis Koubaa [ISEP-IPP-Politechnic Institute of Porto, Portugal], Ye-Qiong Song.

IEEE802.15.4a provides higher data rates with smaller energy consumption thanks to the UWB (Ultra Wide Band) technology. However there exist few solutions on how to optimally exploit the great potential of this new standard. Similar to the industrial wireless network initiatives (e.g. WirelessHART, ISA SP100, IEEE802.15.4e), we developed PMCMTP, a multi-channel multi-time slot MAC protocol, which dynamically assigns channels and time slots for dense and large-scale WSNs with QoS support. The most challenging issue is providing a tradeoff between the resource efficiency and the multi-constrained QoS support. For this purpose, we propose a cross-layer algorithm JSAR (Joint duty-cycle Scheduling, resource Allocation and multi-constrained QoS Routing algorithm), based on multi-channel multi-time slot PMCMTP MAC. JSAR simultaneously combines a duty-cycle scheduling scheme for energy saving, a resource allocation scheme for efficient use of frequency channels and time slots, and an heuristic for multi-constrained routing protocol. The performance of JSAR has been evaluated, showing that it is suitable for on-line implementation [20].

6.1.3. Wireless Networked control systems (WNCS)

Participants: Najet Boughanmi, Eric Rondeau [CRAN UMR 7039, Nancy], Ye-Qiong Song.

With recent technology progress, it is becoming attractive to use wireless solutions for industrial process monitoring and control. Our approach for developing wireless networked control systems (WNCS) is based on the application and network co-design principle. The idea is to adjust on-line the network parameters (QoS) according to the needs of the control loops or Quality of Control (QoC). For achieving this on a WSN (Wireless Sensor Network) which is based on CSMA/CA MAC protocol, several enhancements have been done. In the PhD work of N. Boughanmi [7] , we proposed several QoS management mechanisms with priority (based on blackburst scheme) for both the beacon enabled mode and the non-beacon enabled mode of the IEEE 802.15.4 protocol. QoS online adaptation protocols have also been designed which take as parameter the QoC of the system. These proposals are validated through simulations (using TrueTime) and partially with fixed priority scheduling analysis approach.

6.1.4. Wireless networks and middleware for ambient assisted living systems

Participants: Claude Deroussent [MEDeTIC], Shahram Nourizadeh, Ye-Qiong Song, Jean-Pierre Thomesse.

Wireless sensor networks have a great potential for contributing to build the ambient assisted living environment for elderly people at home (PhD work of S. Nourizadeh under LORIA-MEDETIC contract). However several problems have to be addressed for the integration of WSN into the existing home automation networks. The PhD thesis of Shahram Nourizadeh addresses the problem of QoS in context-aware heterogeneous healthcare systems [9]. For providing real-time data collecting in a telehealthcare system composed of wireless sensor network and home automation network, a middleware called CodaQ is designed. It provides context data and takes into account QoS requirements of the applications. In [30], we showed how the data are modeled for including context information and how the QoS requirements are handled within a middleware. First measurements on a test bed have been carried out, showing the good performance of our design.

6.2. Evaluation and optimal dimensioning of real-time systems

6.2.1. Code analyses and advanced visualization of software in real-time

Participants: Damien Bodenes, Pierre Caserta, Olivier Zendra.

Last years, strong developments for our instrumentation, tracer and analyzer, had been performed, allowing us to really enter the experimental phase and getting first interesting results. A thorough state of the art had also been written.

This year, in 2011, this state of the art paper was finally published in TVCG, a leading journal in computer visualization [10]. Thanks to the experimental setup efforts of previous years, we were in 2011 able to conduct good experiments. We designed and implemented a new way to visualize relations between software elements These relations include static relations (is-a, direct heir, caller, callee, etc.) and dynamic ones (runtime caller, runtime callee). Our new relation visualization comprises a new way of placing way points so as to significantly decrease spatial and visual clutter when visualizing software systems with large numbers (thousands up to millions) of relations. This lead to a publication in VISSOFT, one of the most recognized conferences in the software visualization domain [23], as well as a Best Poster in ECOOP, one of the most recognized conferences in the object-oriented domain [46] The important design and implementation work realized on the tracing and analysis software also lead to the publication of our method in ICOOOLPS 2011 [24]

Work is going onto analyze polymorphism in Java programs, answering an apparently simple yet so far unanswered question: how much polymorphism is there actually in Java programs. This is of paramount importance, since a lot of work occur around polymorphism, which is an important concept, but no one is currently able to tell how much it impact programs in real life. We have begun writing this paper in cooperation with the LIRMM lab in Montpellier. In addition, we are in the process of finishing work pertaining to analyzing program evolutions, looking at differences between versions, and analyzing how dynamic metrics and static metrics correlate to evolution rate.

6.2.2. Open Power and Energy Optimization PLatform and Estimator

Participants: Sophie Alexandre, Jonathan Ponroy, Kévin Roussel, Olivier Zendra.

Work in this domain was performed in the context of the ANR Open-PEOPLE (Open Power and Energy Optimization PLatform and Estimator) project, financed since the very end of 2008. INRIA Nancy Grand Est is responsible for the software part of the platform and is involved in memory management for low-power issues. Work in this project begun in April 2009 (kick-off meeting). We have finished setting up the very important infrastructure for the software part of the Open-PEOPLE platform. We have finished expressing the requirements for the platform, in order to start the actual developments and the actual integration of tools provided by the different partners. In 2011, we have finished expressing the platform architecture and user interface (GUI). We have also finished implementing the part of the software platform that is the remote control to the hardware platform. We finally have finished implementing the core of the software platform and canonical models handling. Several technical reports were written in relation to this work [38], [39], [40], [42], [43], [44].

We are now in the process of finishing the design and implementation of the PCMD (Power Consumption Model Development) and the PCAO (Power Consumption Analysis and Optimization) parts of the software platform, as well as the external tools integration work. The very first release of the whole Open-PEOPE platform is expected early 2012. This lead to the several presentations and posters in conferences [51], [47], [52].

6.2.3. Robustness evaluation for a critical distributed system

Participants: Adrien Guénard, Lionel Havet, Françoise Simonot-Lion.

Wireless Sensor and Actuator Networks (WSANs) combine sensors and actuators interconnected by wireless networks in order to perform distributed sensing and acting tasks. Closed-loop controllers can therefore be deployed on WSANs; such systems have to meet specific requirements in terms of performance, dependability, energy and cost which raises great challenges due to the unreliability of wireless communications. A way to ensure that a system meets the required properties is to model it and go through its analysis. Building a model requires both deep knowledge on the system as well as on the used framework. Therefore there is a need for frameworks well-suited to the targeted systems and to the properties to verify. We proposed an approach meeting these conditions and a simulation framework, Samovar, based on Matlab / Simulink, allowing the modeling of the network protocols (Mac and routing services) and the resources sharing policy thanks to the TrueTime toolbox. Several classes of components (application, nodes, networks and middleware) and a clear semantics for their composition are identified. Furthermore, the design of Samovar was also driven by

the need to transfer easily software components model between the concrete systems and its simulated model. The modeling and simulation method as well as the Samovar framework were assessed on several case studies. This work is supported by INRIA through the ADT SAMOVAR.

6.3. Real-time scheduling

6.3.1. Scheduling of tasks in automotive multicore ECUs

Participants: Aurélien Monot, Nicolas Navet, Françoise Simonot-Lion.

As the demand for computing power is quickly increasing in the automotive domain, car manufacturers and tier-one suppliers are gradually introducing multicore ECUs in their electronic architectures. Additionally, these multicore ECUs offer new features such as higher levels of parallelism which ease the respect of safety requirements such as the ISO 26262 and the implementation of other automotive use-cases. These new features involve also more complexity in the design, development and verification of the software applications. Hence, car manufacturers and suppliers will require new tools and methodologies for deployment and validation. We address the problem of sequencing numerous elementary software components, called runnables, on a limited set of identical cores. We show how this problem can be addressed as two sub-problems, partitioning the set of runnables and building the sequencing of the runnables on each core, which problems cannot be solved optimally due to their algorithmic complexity. We then present low complexity heuristics to partition and build sequencer tasks that execute the runnable set on each core, and derive lower bounds on their efficiency (i.e., competitive ratio). Finally, we address the scheduling problem globally, at the ECU level, by discussing how to extend this approach in the case where other OS tasks are scheduled on the same cores as the sequencer tasks. An article providing a summary of this line of work will appear in IEEE TII [14].

6.3.2. Fine-grained hardware modeling in response time analyses

Participants: Dawood Khan, Nicolas Navet.

Early in the design cycle, the two main approaches for verifying timing constraints and dimensioning the networks are worst-case schedulability analysis and simulation. In [29], we advocate that both provide complementary results and that, most often, none of them alone is sufficient. In particular, it is shown on automotive case-studies that response time distributions that can be derived from simulations cannot replace worst-case analysis. On the other hand, it is shown on examples that the analytical models, as used in worst-case analyses, are error-prone and often much simplified abstractions of the real system, which might lead to optimistic (i.e., unsafe) results.

As an illustration of the latter point, the classical WCRT analysis of Controller Area Network (CAN) implicitly assumes an infinite number of transmission buffers which is not the case in practice. This might lead high priority messages to suffer from priority inversion if the buffers are already occupied by low priority messages. This gives rise to an additional delay for high priority messages, which, if not considered, may result in a deadline violation. In an earlier work, we explained the cause of this additional delay and have extended the existing CAN schedulability analysis to integrate it. We have then studied the case where low-priority transmissions cannot be aborted because the communication controller or the driver does not allow it. We show on two case studies that the impact on response times is important and cannot be neglected in most real-time systems. This work was published in [26].

6.3.3. Probabilistically analysable real-time system

Participants: Liliana Cucu-Grosjean, Codé Lo, Luca Santinelli, Dorin Maxim.

The adoption of more complex hardware to respond to the increasing demand for computing power in next-generation systems exacerbates some of the limitations of static timing analysis for the estimation of the worst-case execution time (WCET) estimation. In particular, the effort of acquiring (1) detail information on the hardware to develop an accurate model of its execution latency as well as (2) knowledge of the timing behaviour of the program in the presence of varying hardware conditions, such as those dependent on the history of previously executed instructions. These problems are also known as the timing analysis walls. The probabilistic timing analysis, a novel approach to the analysis of the timing behaviour of next-generation real-time embedded systems, provides answers to timing analysis walls. In [11] we have showed how the probabilistic timing analysis attacks the timing analysis walls. We have also presented experimental evidence that shows how probabilistic timing analysis reduces the extent of knowledge about the execution platform required to produce probabilistically-safe and tight WCET estimations.

6.3.4. Optimal scheduling policies for real-time systems with probabilistic execution times

Participants: Liliana Cucu-Grosjean, Luca Santinelli, Dorin Maxim, Olivier Buffet, Rob Davis [University of York].

We have investigated the problem of optimal priority assignment in fixed priority preemptive single processor systems where tasks have probabilistic execution times. We have identified three sub-problems which optimise different metrics related to the probability of deadline failures. For each sub-problem we have proposed an algorithm that is proved optimal. The first two algorithms are inspired by Audsley's algorithm which is a greedy (lowest priority first) approach that is optimal in the case of tasks with deterministic execution times. Since we prove that such a greedy approach is not optimal for the third sub-problem, we have proposed a tree search algorithm in this case. These results were published in [27].

6.3.5. Statistical analysis of real-time systems

Participants: Liliana Cucu-Grosjean, Lu Yue, Thomas Nolte [Malardelan University], Ian Bate [University of York].

The response time analysis of real-time systems usually needs the knowledge of WCET estimation and this knowledge is not always available, e.g., because of intelectual property issues. This problem may be avoided by estimating statistically either the WCET of a task [18] or the response time of each task [37].

6.3.6. Multiprocessor scheduling of real-time systems with probabilistic execution times

Participants: Liliana Cucu-Grosjean, Joel Goossens [Université Libre de Bruxelles].

After providing exact feasibility tests for the case of arbitrary tasks on unrelated processor in [12], we have proposed feasibility tests for tasks wih probabilistic execution times [34]. These tests are based on intervals that are proved to contain the highest probability of having tasks with deadline missed.

6.3.7. Probabilistic Component-based Approaches

Participants: Luca Santinelli, Patrick Meumeu Yomsi, Dorin Maxim, Liliana Cucu-Grosjean.

We have proposed a probabilistic component-based model which abstracts in the interfaces both the functional and non-functional requirements of such systems. This approach allows designers to unify in the same framework probabilistic scheduling techniques and compositional guarantees that go from soft to hard real-time. We have provided sufficient schedulability tests for task systems using such framework when the scheduler is either preemptive fixed-priority or earliest deadline first. These results were published in [35].

6.3.8. Mixed-criticality problems for probabilistic real-time systems

Participants: Bader Alahmad, Luca Santinelli, Liliana Cucu-Grosjean, Sathish Gopalakrishnan [University of British Columbia].

Critical embedded systems (CESs) face the need of new functionalities imposed by the end users. These new functionalities of CESs impose the utilization of complex architectures. The complex architectures increase the time variability of programs and this coupled with worst-case reasoning implies over-provisioned systems. Avoiding such over-provision became an important problem within CESs. One model answering such problem in the mixed-criticality problem. It is natural then to combine mixed-criticality with probabilistic approaches known to decrease the over-provision by taking into account the information that worst-case situations have low probability of occurrence. We have proposed and contrasted in [19] two probabilistic execution-behavior models for mixed-criticality independent job systems as they execute on a single machine. The models differ in both the system assumptions and the amount of job information they offer and exploit. While one model is compliant with the current standard practice of fixing jobs' criticalities, the other is a proposal to treat job criticalities as random entities with predetermined probabilities of jobs being of certain criticalities throughout the lifetime of the system.

6.3.9. Energy optimization for real-time systems

Participants: Cristian Maxim, Liliana Cucu-Grosjean, Olivier Zendra.

Many embedded real-time systems integrate battery operated microprocessor systems with limited battery autonomy. Minimizing energy consumption is thus crucial. We have proposed in [28] an algorithm that improves energy consumption in real-time systems by combining Dynamic Voltage Scaling and a decrease in the number of preemptions. Our overall purpose is to focus on a specific part of the problem, namely selectively increasing frequency to lower the number of preemptions of a task to try and decrease the total energy consumption.

6.4. National Initiatives

6.4.1. ANR Project "QUAlity of ServIce for wireless sensor networks and Mobile Objects – parameter aDaptatiOn (QUASIMODO)

Participants: Bilel Nefzi, François Despaux, Abdelkader Lahmadi, Adrien Guenard, Françoise Simonot-Lion, Ye-Qiong Song.

Quasimodo project (http://quasimodo.loria.fr/) is a joint "ANR Programme blanc international" project (March 2011 - February 2014) between LORIA laboratory- Nancy University and SKLICT - Zhejiang University, funded by ANR (n°ANR 2010 INTB 0206 01) and NSFC (n°NSFC 61061130563). The objective of the project is to provide an adaptive real-time quality of service (QoS) in wireless sensor and actuator networks (WSAN). The main QoS parameters are bounded delay and packet transmission success rate under stringent energy constraint and node mobility. The typical application scenario consists of a multi-robots tracking, coordination and cooperation through the WSAN. This first project year has been focused on the application scenario development, MAC layer design. A first scenario is the single mobile target tracking using mobile sensor nodes. Theoretic tracking algorithm has been developed based on Kalman filter estimation (an ellipse) and optimal sensor coverage. Its extension to including both communication delay and mobile node speed are under simulation using SAMOVAR simulator (http://samovar.loria.fr/). The MAC protocol will be based on the CoSenS framework with one enhancement for avoiding collisions during the waiting period of CoSenS.

6.4.2. PRST MISN / SSS Theme: Eco-Sûr2

Participants: Hugo Cruz Sanchez, Jamila Ben Sliman, Najet Boughanmi, Bilel Nefzi, Françoise Simonot-Lion, Ye-Qiong Song.

EcoSur2 aims at controlling and managing the energy production and consumption within a smart space. An important part of the system is the wireless sensor and actuator network (WSAN) which is used to sense devices and to activate actuators. The activities of TRIO team are focused on the design of wireless sensor network architectures that guarantee communication by optimizing the available resources of the WSAN, and the development of the interoperability solution aimed at linking the heterogeneous technologies used in the system. This activities include: 1) Implementation of a modified version of the Collection Tree Protocol (CTP)

by using energy resources for routing decisions; 2) Implementation of asynchronous and periodical sensing applications on nodes; 3) The analysis of different platforms allowing to communicate with the available WSN equipment of previous projects and to facilitate the implementation of optimal communication mechanisms over different routing protocols (eg. Zigbee, RPL); 4) The implementation of the WSN system in the MPIGate to allow interoperability with other technologies (eg. building automation networks, WiFi, Ethernet); 5) The design of an energy oriented messaging system in a WSN; 6) The adaptation and the development of the QoC and QoS co-design approaches based on our previous results in networked control system co-design. This year we have focused on the network architecture design and the technical implementation. Contiki based sensor nodes have been chosen. Part of code of S-CoSenS protocol has been developed in Cooja simulator before the actual deployment on the sensor nodes.

6.4.3. PRST MISN / Thème IS: Smartroom for personal assisted living

Participants: Hugo Cruz Sanchez, Adrien Guenard, Lionel Havet, Bilel Nefzi, Shahram Nourizadeh, Ye-Qiong Song.

The aim of the smartroom project is to provide an open platform for developing and testing innovative solutions for personal assisted living. The main task of TRIO team is the definition of the communication architecture with interoperability and QoS support. MPIGate is the starting point for this project. The first phase is focused on the platform implementation. MPIGate has been extended to run on Web service platform [25], [45]. Further development will be around the auto-adaptive application-network middleware and the design of extra low-power and low duty-cycle protocols.

6.4.4. INRIA AEN PAL (Personal Assisted Living)

Participants: Hugo Cruz Sanchez, Shahram Nourizadeh, Ye-Qiong Song.

TRIO team has participated to the Large-scale initiative action AEN PAL project (http://pal.inria.fr/) which aims to provide technologies and services for improving the autonomy and quality of life for elderly and fragile persons. Communication is one of the key components for ensuring real-time data gathering and exchange between heterogeneous sensors and actuators (robots). TRIO team's participation aims to design the most suitable communication architectures with guaranteed QoS. For this purpose the interface part of MPIGate has been revised in order to shift from a web server based gateway to a web service oriented architecture [36]. This part of work will mainly be supported via the upcoming ADT APL-PERCEE project which will start at the end of 2011.

6.5. European Initiatives

6.5.1. NOE High Performance Embedded Architectures and Compilation (HiPEAC)

Participant: Olivier Zendra.

The TRIO team is involved in the HiPEAC (High Performance Embedded Architecture and Compilation) European Network of Excellence (NoE). Olivier Zendra was initiator and leader in this context of a cluster of European Researchers "Architecture-aware compiler solutions for energy issues in embedded systems" from mid-2007 to mid-2009. A STREP proposal tentatively titled "Integrated and generic energy-aware adaptation for extreme computing systems" is currently being written, mostly in the context of this network of excellence, for submission in Call ICT 2011.9.8 FET Proactive: Minimising Energy Consumption of Computing to the Limit (MINECC).

6.5.2. PROARTIS - Probabilistically Analysable Real-Time Systems

Participants: Liliana Cucu-Grosjean, Luca Santinelli, Codé Lo, Dorin Maxim.

PROARTIS (http://www.proartis-project.eu/) is a STREP project within the FP7 call and it started on February 2010. It has six partners: Barcelona Supercomputing, University of York, University of Padova, INRIA and Airbus. The overarching objective of the PROARTIS project is to facilitate a probabilistic approach to timing analysis. The proposed approach will concentrate on proving that pathological timing cases can only arise with negligible probability, instead of struggling to eradicate them, which is arguably not possible and could severely degrade performance. This will be a major turn from previous approaches that seek analyzability by trying to predict with cycle accuracy the state of hardware and software through analysis.

The PROARTIS project will facilitate the production of analysable CRTE systems on advanced hardware platforms with features such as memory hierarchies and multi core processors. PROARTIS has the following overall strategic industrial goals:

- Increased performance, reliability and reduced costs by enabling critical real-time systems to take full advantage of advanced hardware like deep memory hierarchies and multi core processors. The use of these features will allow designers to schedule more tasks while reducing the weight, power consumption and the size of the whole system and maintaining the desired predictability. It will also reduce the risk of temporal budget overruns. Application-level tasks will have an execution behaviour free (with sufficient low probability) from pathological temporal overruns.
- Increased productivity by enabling software engineers to develop more complex real-time software systems through timing-aware systems that reveal crucial timing details while dramatically simplifying analysis. For example, memory latencies will be predicted with less effort, requiring knowledge only of the total number of memory accesses, rather than the exact memory addresses and memory access patterns.
- Reduced time-to-market by enabling trustworthy WCET and other analyses for large-scale real-time systems that will dramatically reduce testing time.

The work within this project during 2011 lead to the following two publications: [11] and [35].

6.5.3. TIMMO-2-USE - Timing Model - TOols, algorithms, languages, methodology, USE cases

Participants: Nicolas Navet, Françoise Simonot-Lion, Liliana Cucu-Grosjean, Ammar Oulamara, Luca Santinelli.

TIMMO-2-USE (http://timmo-2-use.org/ is an ITEA 2 European project and it started in November 2010.

TIMMO-2-USE will address the specification, transition and exchange of different types of timing information throughout different steps of the development process. The general goal is to evaluate and enhance standards for different applications in the development by different technical use cases covering multiple abstraction levels and tools. For this, TIMMO-2-USE will bring the AUTOSAR standard, TADL and EAST-ADL2 into different applications like WCET analysis and in-the-loop scenarios. This will bring new algorithms and tools for the transition and conversion of timing information between different tools and abstraction level based on a new advanced methodology which, in turn, will be based on a combination of the TIMMO and the ATESST2 methodologies. The main impact of TIMMO-2-USE will be:

- Improved, predictable development cycle: An extended and further developed infrastructure for handling timing constraints, containing additional features, will increase the predictability and effectiveness of the development cycle even more. As a result, both development cost and development time are expected to go down due to fewer costly design iterations, while at the same time the resulting design will moreover be more reliable.
- Reduced time-to-market by massive reuse: Reusing components annotated with timing information for the construction of a new system will enable the derivation of more accurate system timing behaviour at early development stages. Therefore the system can be developed with a reduced number of design iterations.

- More efficient communication and collaboration between different parties involved in development: This will support cooperative development scenarios and reduce the risk of mutual misunderstanding between different parties contributing to the design of the same system, for example OEMs and Tier-1 suppliers, and lead to safer and more accurate systems.
- Reduced development risk: A formal and unambiguous foundation for reasoning about time provides a steady basis and a common ground for better cooperation between tools with respect to timing information based on commonly agreed, industry-wide standards like AUTOSAR. The project will further develop methodologies and languages developed in ATESST2 and TIMMO. TADL (Timing Augmented Description Language) and EAST-ADL2 were introduced as a major leap forward and will be further adapted and extended in TIMMO-2-USE.

7. Dissemination

7.1. Animation of the scientific community

- Françoise Simonot-Lion is director of LORIA (CNRS UMR 7503)
- Françoise Simonot-Lion is elected member of the administration board of Ecole Nationale Supérieure des Mines de Nancy.
- Jean-Pierre Thomesse is DRRT at Region Lorraine.
- Ye-Qiong Song is member the administration board of ENSEM.
- Ye-Qiong Song is head of the doctoral department of Computer Science of Lorraine.
- Liliana Cucu is the Delegate of International Relations for the INRIA Nancy-Grand Est center.
- Françoise Simonot-Lion is elected members of LORIA Laboratory Council.
- Olivier Zendra is an elected member of the Research Center Committee of INRIA Nancy Grand Est.
- Françoise Simonot-Lion chairs with Steve Hung (Clemson University, USA) the subcommittee on Automotive Electronic and Embedded Systems of the IEEE Industrial Electronic Society (IES) - Technical Committee on Factory Automation (TCFA).
- Nicolas Navet chairs with Thomas Nolte (MRTC Mälardalen) of the Sub-Committee on Real-Time Fault Tolerant Systems of the IEEE Industrial Electronic Society (IES) - Technical Committee on Factory Automation (TCFA).
- Françoise Simonot-Lion is an associate editor of IEEE Transactions on Industrial Informatics.
- Nicolas Navet is member of the Editorial Board of the Journal of Embedded Computing (IOS Press).
- Liliana Cucu is an elected member of INRIA Evaluation Commission (CE) since September 2011. This commission advices the INRIA direction on important issues like recruiting new permanent researchers, deciding strategic research directions, evaluate the work of INRIA teams. She is also member of INRIA Working Group on International Relations (GTRI-COST) and member of the Evaluation Commission and the Commission of Technological Development for the INRIA Nancy-Grand Est center.
- Olivier Zendra is head of the Documentation Committee of INRIA Nancy Grand Est, member of the Health and Safety Committee of INRIA Nancy Grand Est - LORIA, member of the Permanent Education Committee of INRIA Nancy Grand Est - LORIA, member of the new Sustainable Development Local and National Committee. He was member in 2011 of the INRIA national workgroup on professional travel.
- Ye-Qiong Song was co-chair of Track 2 of the 16th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA2011), co-chair of the real-time network and QoS session of the ETR 2011 (Summer school on real-time) and seminar of Charles Hermite federation on random graphs and wireless networks.

- Ye-Qiong Song was reviewer for the PhD of Fei YANG (INSA Lyon) and of X-H. NGUYEN (LAAS Toulouse).
- Ye-Qiong Song was program committee member for the IEEE RTSS2011, IFIP NTMS WSN workshop 2011, ICOST2011, RTN2011, EFTA2011, ETR2011, ANT2011, IST-AWSN2011, WiSARN2011, ComNet2011.
- Liliana Cucu was chair of the real-time sessions within EVOLVE 2011 and ROADEF 2011.
- Liliana Cucu was program committee member of the 16th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2011), Toulouse, September 5-9, 2011 (track on Real-Time and Networked) Embedded Systems); the 19th International Conference on Real-Time and Network Systems (RTNS 2011), Nantes, September 29-30, 2011; the 2nd International Real-Time Scheduling Open Problems Seminar (RTSOPS 2011), Porto, July 2011.
- Olivier Zendra is CIR expert for the Ministry of Research for the scientific evaluation of research in companies.
- Nicolas Navet and Françoise Simonot-Lion are steering committee members of the RTNS conference.
- Olivier Zendra is founder and steering committee member of the ICOOOLPS (International Workshop on Implementation, Compilation, Optimization of Object-Oriented Languages, Programs and Systems) workshop, now in its 6th edition. He was co-chair for ICOOOLPS 2011 (The 6th Workshop on Implementation, Compilation, Optimization of Object-Oriented Languages, Programs and Systems), July 26th, Lancaster, UK.
- Olivier Zendra was program committee member of DASIP 2011 (Design and Architectures for Signal and Image Processing), Tampere, Finland, 2-4 november 2011 ; of VMIL 2011 (the 5th workshop on Virtual Machines and Intermediate Languages), 22-27 October, 2011, Portland, OR, USA.
- Nicolas Navet was Publicity Co-Chair of the 6th IEEE International Symposium on Embedded Multicore SoCs (MCSoC-11), Aizu-Wakamatsu, Japan, September 21-23, 2011.
- Nicolas Navet was program Committee member of the 9th International Symposium on Embedded Computing (EmbeddedCom 2011), Dec. 12-14, 2011, Sydney, Australia; of the 17th IEEE International Conference on Parallel and Distributed Systems (ICPDAS 2011), Tainan, Taiwan, December 8-9, 2011; of the 2011 International Conference on Reliable & Autonomous Computational Science (RACS 2011), Miami, USA, November 2-5, 2011; of the first Workshop on Technologies for Next Generation Industrial and Embedded Communication Networks (NexIENet 2011), Taipei, Taiwan, October 9, 2011; of the Workshop on "Domain specific languages for cyber physical systems", Berlin, Germany, October 4-7, 2011; of the 19th International Conference on Real-Time and Network Systems (RTNS 2011), Toulouse, France, September 29-30, 2011 ; of the 16th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2011), Toulouse, France, September, 2011, Track on Industrial Communication Systems, Track on Information Technology in Automation, Track on Real-Time and (Networked) Embedded Systems; of the 6th International Conference on Embedded and Multimedia Computing (EMC 2011), Enshi, China, August 11-13, 2011; of the IEEE Symposium on Industrial Embedded Systems (SIES 2011), Vasteras, Sweden, June 15-17, 2011; of the 22nd IEEE International Symposium on Rapid System Prototyping (RSP), Karlsruhe, Germany, May 24-27, 2011; of the First International Workshop on Cyber-Physical Networking Systems (CPNS'2011), Shangai, China, April 15, 2011.
- Olivier Zendra is Guest Editor for ICOOOLPS-MASPEGHI 2010 Special issue of The Journal of Object Technology (JOT).
- Ye-Qiong Song is one of the guest editors of the special issue on "Sensor Networks for High-Confidence Cyber-Physical Systems" of International Journal of Distributed Sensor Networks (HINDAWI).

- The permanent members of TRIO team are reviewers for numerous international Conferences and Workshops and, in particular for the following journals: IEEE Transactions on Industrial Informatics, Real-Time Systems, IEEE Computer Communications, Journal of Discrete Event Systems, Journal of Systems Architecture, Journal of Embedded Computing, Journal of Scheduling, Theoretical Computer Science, ACM Surveys, ACM Transactions on Embedded Computing Systems, Information Processing Letters.

7.2. Teaching

The permanent members of TRIO are teaching real-time systems, programming languages, safety-critical systems, communication networks at INPL, Université Henri Poincaré-Nancy 1 and Université de Nancy 2 (engineer schools and masters). The following Phds were defended or are in progress:

PhD in progress : Jamila Ben Slimane, "Optimisation inter-couche des réseaux de capteurs basés sur la technologie UWB", co-supervised thesis with INPL Nancy and SupCom Tunis, started in november 2009, supervisors: Ye-Qiong Song and Mounir Frikha.

PhD : Najet Boughanmi, "Conception conjointe des systèmes contrôlés en réseau sans fil", Institut National Polytechnique de Lorraine - INPL, defended in April 2011, supervisors: Ye-Qiong Song and Eric Rondeau.

PhD in progress : Pierre Caserta, "Analyse de code et visualisation immersive pour l'optimisation semi-automatique des programmes", started in October 2008, supervisors: Olivier Zendra and Jean-Pierre Thomesse.

PhD : Maha Idrissi-Aouad, "Conception d'algorithmes hybrides pour l'optimisation de l'énergie mémoire dans les systèmes embarquées", UHP Nancy 1, defended on 04/07/2011, supervisors: Olivier Zendra and René Schott.

PhD : Dawood A. Khan, "Schedulability analyses for the design of reliable and cost-effective automotive embedded systems", INPL, defended on 29/11/2011, supervisors: Nicolas Navet and Françoise Simonot-Lion.

PHD in progress : Dorin Maxim, "Probabilistic analysis of real-time system", INPL, started in September 2010, supervisors: Liliana Cucu-Grosjean and Françoise Simonot-Lion.

PhD in progress : Aurélien Monot, "Vérification des contraintes de temps de bout-en-bout dans le contexte AutoSar", INPL (CIFRE PSA peugeot-Citroën), started in October 2008, supervisors: Nicolas Navet and Françoise Simonot-Lion.

PhD : Bilel Nefzi, "Mécanismes auto-adaptatifs pour la gestion de la Qualité de Service dans les réseaux de capteurs sans fil", Institut National Polytechnique de Lorraine - INPL, defended in September 2011, supervisor: Ye-Qiong Song.

PhD : Shahram Nourizadeh, "Un système de télésanté contextuel avec support de qualité de service pour le maintien à domicile", Institut National Polytechnique de Lorraine - INPL, defended in July 2011, supervisors: Ye-Qiong Song and Jean-Pierre Thomesse.

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