Center of Excellence for Research DEWS

Research Activity Report

Years 2012-2014

"Design methodologies for Embedded controllers, Wireless interconnect and Systems-on-chip"

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Summary

Activity Overview

DEWS started its operations in 2001 after the Ministry of Scientific Research and University awarded grants for the formation of centers of excellence on a competitive basis. DEWS was among the very first organizations that proposed research on the use of networks of sensors, controllers and actuators to solve societal scale problems such as health, disaster recovery, transportation systems, and education. Since its inception, DEWS has addressed a cross-section of information and communication technology domains by activating research activities that anticipated the themes at the core of the Horizon 2020 vision:

"The potential and capabilities of modern ICT systems are still growing exponentially fuelled by the progress in electronics, microsystems, networking, the ability to master increasingly complex cyber-physical systems and robots, and progress in data processing and human machine interfaces. These developments provide major opportunities for Europe to develop the next generation of open platforms on top of which a multiplicity of innovative devices, systems and applications can be implemented."

DEWS promotes interdisciplinary cooperation among researchers to achieve its research objectives. In particular, DEWS researchers are active in networked embedded systems, automatic control, analog and digital electronics, computer science and telecommunications.

Research Strategy

DEWS research organization continues to be structured into the same six research areas as in the past three years, where applications are vertical lines and methodologies, tools and models are horizontal lines (see Fig. 1).

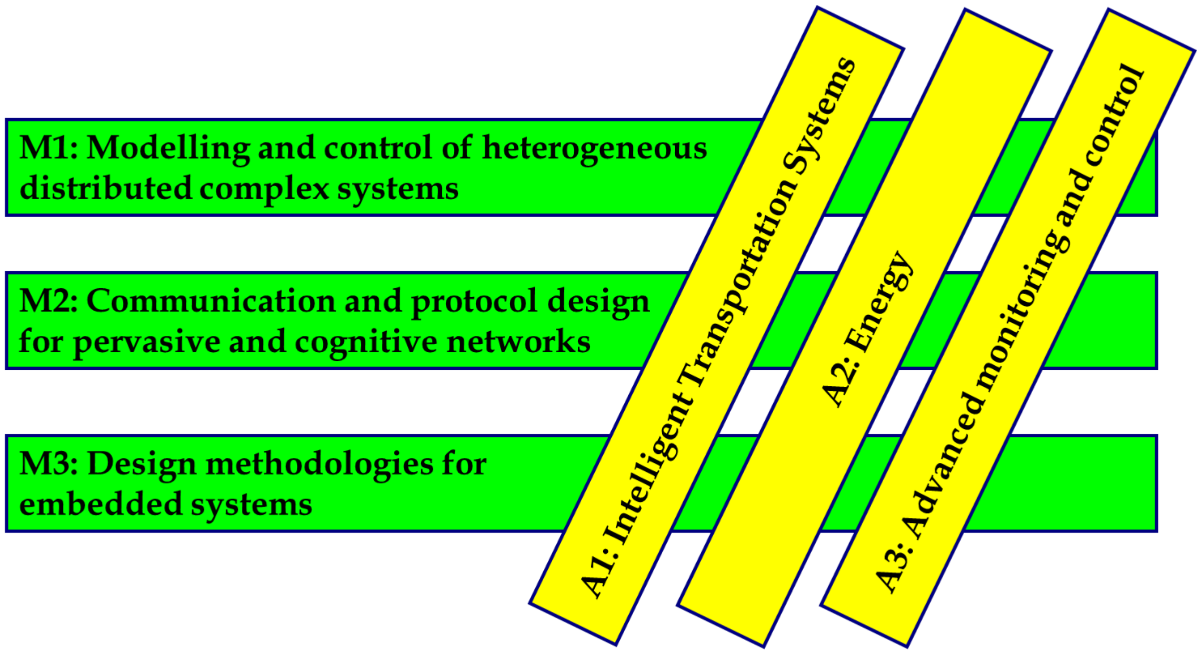


Figure 1: DEWS methodological and applicative research areas.

Methodologies and Technologies:

- M1: Modelling and control of heterogeneous distributed complex systems
- M2: Communication and protocol design for pervasive and cognitive networks
- M3: Design methodologies for embedded systems

Research Areas M1, M2 and M3 are foundational, they are aimed at developing new methodologies for the design of complex embedded systems and communication paradigms for their mutual interaction. In particular, M1 provides the mathematical methodologies and tools for control, design and formal verification of networked embedded control systems; M2 provides fundamental methodologies for networked systems architectures and design; M3 provides the fundamental background on models, metrics and tools for embedded systems development.

Applications:

- A1: Intelligent Transportation Systems
- A2: Energy
- A3: Advanced monitoring and control

Research Areas A1, A2 and A3 are orthogonal to the Foundational Areas M1, M2 and M3, each covering an application specific research domain.

DEWS created the DEWSLab from the start, a laboratory for the design and implementation of wireless sensor networks using products developed by Memsic (ex Crossbow) and Texas Instruments. The lab has been configured as a "testbed" for innovative solutions related to routing and coding algorithms and it is used as a web service to allow remote access to interested parties. Since 2005, DEWS has been chosen by the FP7 Network of Excellence HYCON as the node of the European Embedded Control Institute (http://www.eeci-institute.eu) for the realization of the European Networked Control Systems Laboratory (NCSlab).

Education

DEWS has been awarded a grant to set up an Advanced ICT School on pervasive computation, communication and control systems. This initiative gained enthusiastic support from industry because of its goal of connecting the ICT research and industry communities. This award had a number of important outcomes: i) the ICT School was considered as a founding pillar of the recently approved Innovation District (Polo di Innovazione) "ICT Abruzzo", ii) it was supported by OCSE as an enabling initiative to reinforce/innovate the local economic context after the 2009 earthquake, iii) it created the framework for joint research initiatives and laboratories funded by industry in recognition of the School's potential economic impact. DEWS is now in the process of establishing the School with a target of 20-30 students enrolled from the international community.

As member of the European Embedded Control Institute (EECI), DEWS offers each year PhD courses in L'Aquila, in the context of the EECI Graduate School on Control. In particular, the following modules have been given in the period 2012-2014:

- EECI GSC, 2012: Specification, Design and Verification of Distributed Control Systems, Prof. R. Murray;
- EECI-GSC, 2013: Optimality, Stabilization, and Feedback in Nonlinear Control, Prof. F. Clarke;
- EECI-GSC, 2013: Modeling and estimation for control, Prof. E. Witrant;
- EECI-GSC, 2014: Convergence theory for observers: Necessary, and Sufficient conditions, Prof. L. Praly.

Further, DEWS signed a Joint Doctoral Degree agreement with the *Royal Institute of Technology* (KTH, Stockholm, Sweden) and with the *Centro de Investigación y Estudios Avanzados* (CINVESTAV, Instituto Politécnico National, Campus Guadalajara, Mexico). The doctoral candidates carry out their activities under the responsibility and the guidance of thesis advisors from each of the two universities. The two advisors act in all respects as academic mentors for the doctoral candidate. The joint doctoral degree allows candidates to obtain a PhD degree from each of the co-advising universities.

DEWS is partner of the International Curriculum Option (http://www.eeci-institute.eu/ICO-NEH) of Doctoral Studies in Hybrid Control for Complex, Distributed and Heterogeneous Embedded Systems. ICO-NEH started in January 2006 to provide a common cultural and academic platform by establishing a network of institutions that have a set of common supplementary criteria for the participating PhD students in addition to those of their already-existing doctoral programs.

We signed an international agreement with EECI for the establishment of a Path-to-Excellence master Program (PEP) . The PEP has the objective of increasing the value of the education of Master students, who deserve and are interested in deepening knowledge activities and cultural integration. The mission of PEP is to provide high-profile scholars combining in-depth disciplinary knowledge from their MSc program in Automatic Control, Computer Engineering, Telecommunication and Electronics with interdisciplinary skills that are needed in advances in Cyber Physical Systems. The PEP curriculum consists of educational activities that are added to the normal student curriculum. PEP is supervised by a Scientific Committee composed of three members, two members of the University of L'Aquila and one member nominated by the EECI. The Scientific Committee selects the students that are admitted to the PEP in each academic year among the applicants to the Master of Science Program in Automatic Control and Computer Engineering, the Master of Science Program in Telecommunications and the Master of Science Program in Electronics at University of L'Aquila. Students enrolled in the PEP are required to perform specific activities, agreed upon by the Scientific Committee, including internships at foreign participating Institutions and participation in recommended international activities and courses.

The PEP will facilitate the participation of the students in joint research projects, in particular in coordination with other joint initiatives such as ICO-NEH within the NoE HYCON2.

The Scientific Committee certifies the successful completion of the requirements for the PEP upon analysis of the activities of each student every year. At the end of the program, the EECI will deliver a certification of accomplishment.

Academic Collaborations

As a consequence of the participation to high-level EU funded research projects and of exchanges of researchers/PhD students, DEWS has established strong research collaborations with some of the most prestigious universities and research centers in the world such as the University of California at Berkeley, the University of California at Los Angeles, the University of California at Santa Barbara, the University of Pennsylvania, the Ohio State University, the Royal Institute of Technology (KTH, Stockholm), the Technical Universities of Delft and Eindhoven, Supélec (Paris), the Berkeley Center for Hybrid and Embedded Software Systems (CHESS), the Center for Automotive Research (CAR, Ohio State University), the National Aerospace Laboratory (NLR, Netherlands). The worldwide academic and industrial collaboration network of DEWS is depicted in Figure 2.

In particular, DEWS signed formal cooperation agreements with the University of California at Berkeley (UCB, US) at the beginning of its operation and with the "Antonio Ruberti Institute on Systems Analysis and Computer Science" (IASI-CNR, Italy) recently, which involve the mutual exchange of researchers and students working on joint projects.

DEWS is coordinator of the Committee of the Centres of Excellence established during the period 2001-2003 by the Ministry of Education, University and Scientific Research (http://www.centrieccellenza.it).

Industrial collaborations and SPIN-OFF activities

DEWS has ongoing collaborations with multinational companies such as Selex Communications and Selex Elsag (Chieti, Florence, Genoa, Pomezia - Italy), Intecs (L'Aquila - Italy), Power Control (Pisa - Italy), Thales Communications (Chieti - Italy), Thales Alenia Space (L'Aquila and Rome - Italy), LFoundry Marsica (Avezzano - Italy), Terna (Roma – Italy), ITACO (Roma - Italy), SEKO (Terni – Italy), Telecom Italia (Rome – Italy), ICT Abruzzo Innovation District and the partners of EU and national research and industrial projects. In this context DEWS has been planning and managing projects of significant complexity as well as to spin-off an engineering company (WEST AQUILA, http://www.westaquila.com).

After a competitive call issued by the local government (Regione Abruzzo) in agreement with the EU policy for stimulating the creation of Innovation Districts (Poli di innovazione) in the globalized economy, the Center of Excellence DEWS has been very active in preparing a successful proposal for the foundation of "ICT Abruzzo". ICT Abruzzo includes about 50 companies (among those Micron Technology and LFoundry, Selex-Elsag, Telespazio, Fastweb, several SMEs), University of L'Aquila and other research centers (e.g. Radiolabs and CNIT). In this context, the ICT School has been included as a founding pillar for promoting and implementing innovation through advanced training at the doctoral level: the School is intended also as a fundamental environment for improving cooperation among companies and between companies and universities/research centers as well. The School is supported by ICT Abruzzo as an integral part of its program.

As enabling and complementary efforts for promoting innovation and technology transfer, the Center of Excellence DEWS has joined new initiatives targeted to support the creation of high-tech start-ups (see RICOSTRUIRE http://ricostruire.org and SMILING http://dews.univaq.it/smiling projects).

Figure 2: DEWS worldwide collaboration network.

Projects

The activities of DEWS are supported by the participation in several research and industrial international projects, in particular:

Sensor networks and distributed architectures for control and wireless communications (2013-2015, MIUR): A research project funded by MIUR and led by Thales Italia; it also involves the DISIM department and the spin-off companies WEST Aquila and Beep Innovation of the University of L'Aquila. It is a large R&D project that aims at supporting the development of novel technological assets at Thales Italia in the field of heterogeneous wireless networks and advanced platforms for computation and communications in support of various applications. The activities are concerned with a hierarchical wireless communications network that include RFiD, WSNs, MANETS and wireless backbone segments. The project also includes a smart middleware that embeds advanced algorithms for supporting distributed coding at source and network level, positioning and security. Advanced HW/SW architectures represent the main target on the implementation side.

Total cost of the project: about 14 M€, whose 50% is funded by MiUR

Funding for DEWS: 350.000,00 €

The GRETA (2013-2016, MIUR) *GREen TAgs and sensors with utrawideband identification and localization capabilities:* this project is concerned with innovative solutions and disruptive technologies aimed at the realization of a distributed system for identification, localization, tracking and monitoring in indoor scenarios, based on ecofriendly materials, where the tags must be: i) localizable with sub-meter precision even in indoor scenarios and in the presence of obstacles, ii) small-sized (flat, with an area in the order of a few square centimeters) and working without cumbersome batteries, iii) made with recyclable materials, to be integrated in goods, clothes and packings. Ultra-wideband (UWB) localization techniques are fundamental enablers and rely on environmental energy gathering, together with passive transmission techniques based on backscattering modulation and tag circuitry based on "green electronics".

Total cost of the project: 1.652.824 €

DEWS cost: 211.740,00 € - National contribution (MIUR) to DEWS: 148.217,00 €

COST Action IC0806 IntelliCIS (2009-2013) *Intelligent Monitoring, Control and Security of Critical Infrastructure Systems:* The main objective of the Action is to develop innovative intelligent monitoring, control and safety methodologies for critical infrastructure systems, such as electric power systems, telecommunication networks, and water distribution systems. The work done by DEWS is concerned with architecture and development of an Intrusion Detection System (IDS) in wireless sensor networks (WSN). The logic design is based on a WPM (Weak Process Model) based approach to model system behavior and a lightweight modified Viterbi algorithm to detect all possible behavioral patterns; alarms are generated according to scores associated to each pattern. The architecture design is agent-based, where the dynamic portion of IDS logic (i.e., the part specific to cluster heads in a dynamical WSN topology) is implemented through mobile agents, while the static part (i.e., the part shared by all nodes) resides directly on nodes and is implemented through SW modules embedded into a middleware platform. SW development was based on the Agilla middleware, wherein several improvements were made, e.g., porting of the platform on TinyOS 2.x.

DAHMS (2010-2014) *Distributed Architecture Home Modular Multifunctional Systems*: DEWS participates to the project through the Associated Lab of Radiolabs Consortium, that is in part hosted by DEWS Lab. The project aims at developing a modular architecture and related services for Home Automation and Remote Healthcare delivery. The project will provide tools for appropriate resources allocation (infrastructure, services, data processing etc.). DEWS is mainly involved in defining and developing protocol architectures for WSNs in home environment, their exploitation for indoor localizazione and their integration with typical electrical power bus.

DEWS cost: 150.000 €

EMC² (2014-2017, WIP website) *Embedded multi-core systems for mixed criticality applications in dynamic and changeable real-time environments*. EMC² project, funded by Artemis-JU AIPP, has just started (April 2014). It focuses on the industrialization of European research outcomes and builds on the results of several previous ARTEMIS, European and National projects. It provides the paradigm shift to a new and sustainable system architecture which is suitable to handle open dynamic systems. EMC² is part of the European Embedded Systems industry strategy to maintain its leading edge position by providing solutions for: dynamic adaptability in open systems, utilization of expensive system features only as service-on-demand in order to reduce the overall system cost, handling of mixed criticality applications under real-time conditions, scalability and utmost flexibility, full scale deployment and management of integrated tool chains, through the entire lifecycle. The main contributions of DEWS will be related the development of a MW for service interoperability support, to provide contribution to the definition and the integration of innovative design space exploration approaches and, in collaboration with Thales Alenia Space Italy, to perform the evaluation of different multi-core architectures on FPGA platforms and related development methodologies and tool chains (including RTOS and/or Hypervisor) in order to assess their suitability for space (i.e. satellite) mixed-criticality applications, opening new application domains to the use of multi-cores.

Total cost of the project: about 100.000.000 €

DEWS cost: 93.750 € - Contribution from ARTEMIS JU: 15656 € - National contribution (MIUR): 45.281 €

KHE-STO (2012-2015) *Know-How Enhancement for Sustainable transportation organization***.** KHE-STO has been financed by IPA Program which is focused on the cooperation in the Adriatic area. A good transportation system is the fundamental basis for the attractiveness of a territory for investments and competitiveness. Moreover, the improvement of accessibility between and towards peripheral areas will surely reduce the depopulation of these areas. KHE-STO intends to contribute to Priority 3, measure 3.2, "Sustainable mobility systems" since its main goal is the improvement of the links among the Adriatic territories by promoting a better use of travelling time of commuters and students stimulating the use of public lines and reducing traffic jam and pollution. KHE-STO, by the installation of innovative ICT tools on buses and trains used by commuters, will experiment a new type of e-work, with the following main features: 1) worker delocalization; 2) availability of suitable tools; 3) direct connection with company/school. KHE-STO aims to consider the travelling in the computation of the daily working/studying hours, providing the traveller more free time for the social life.

Total cost of the project: about 1.000.000 € - DEWS cost: 300.000 €

CRAFTERS (2012-2015, http://www.crafters-project.org): *ConstRaint and Application driven Framework for Tailoring Embedded Real-time Systems.* Call ARTEMIS JU 2011, 2012-2015 (36 months). This project brings to bear an holistically designed ecosystem, from application to silicon, for real-time, heterogeneous, networked, embedded many-core systems. The ecosystem is realized as a tightly integrated multi-vendor solution and tool chain complementing existing standards.

Total cost of the project: 17.861.802 €

DEWS cost: 518.400 € - Contribution from ARTEMIS JU: 86.573 € - National contribution (MIUR): 172.627 €

RICOSTRUIRE (2012-2014): *Trasferimento tecnologico e creazione di nuove imprese nell'ambito delle tecnologie ICT avanzate applicate allo sviluppo economico e territoriale post-sisma*. Bando RIDITT 2009, 21 months. The focus of the project is on promoting technology transfer in the ICT domain through development and consolidation of university laboratory, improvement of policies in technology transfer from university to industry and direct support to novel start-ups. DEWS is mainly involved in developing facilities of two laboratories, namely i) Smart and heterogeneous networks laboratory, and ii) Laboratory for structural monitoring of buildings. The first lab encompasses facilities for simulation and emulation of wireless ad-hoc networks and their integration with fixed network segments, deployment of large patches of wireless sensor nodes, design methodologies that rely on advanced HW/SW platforms. The second lab is concerned with a specific deployment of wireless sensor nodes provided with low cost inertial sensors and other specific sensors, along with specific processing for supporting real time monitoring building dynamics.

Total cost of the project: 2.000.000,0 €

UNIVAQ cost: 1.675.000 € - National contribution (MISE): 837.500 €

SMILING (2012-2015): *SMart In home LIviNG: Tecnologie innovative per la sensoristica e l'automazione dedicate alla Domotica*. Bando RIDITT 2009, 33 months. The project aims at realizing a laboratory for knowledge and technology transfer from the research to the world of industries focusing on advanced automation and sensing technologies for the home automation domain.

Total cost of the project: 1.999.687,5 €

DEWS cost: 501.250 € - National contribution (MISE): 250.625 €

PRESTO (2011-2014, http://www.presto-embedded.eu): *ImProvements of industrial Real Time Embedded SysTems development process.* Call ARTEMIS JU 2010, 2011-2014 (38 months). PRESTO aims at improving test-based embedded systems development and validation, while considering the constraints of industrial development processes.

Total cost of the project: 8.662.934 €

DEWS cost: 518.400 € - Contribution from ARTEMIS JU: 86.573 € - National contribution (MIUR): 172.627 €

HYCON2 (2010-2014, http://www.hycon2.eu/): *Highly-complex and networked control systems*. EU FP7 NoE, 2010-2014. HYCON2 started in September 2010, is a four-year project coordinated by CNRS. It aims at stimulating and establishing a long-term integration in the strategic field of control of complex, large-scale, and networked dynamical systems. It focuses in particular on the domains of ground and aerospace transportation, electrical power networks, process industries, and biological and medical systems. The FP7 NoE HYCON2 provided its vision on the challenges of future for systems and control science technology in the Position Paper on Systems and Control in FP8.

Total cost of the project: 4.905.855 €

DEWS cost: 332.926 € - EU contribution: 273.000 €

VISION (2010-2015, http://www.vision-ercproject.eu): *Video-oriented UWB based Intelligent Ubiquitous Sensing*. FP7 "Ideas" Specific programme ERC Staring Grant 2009, 2010-2015 (50 months): VISION will develop an innovative infrastructure aiming at strengthening future wireless sensor networks (WSN) with the capability of supporting intelligent services for ubiquitous sensing, with particular emphasis on real-time 3D video sensing.

Total cost of the project: 1.173.680 €

DEWS cost: 120.342 € - EU contribution: 120.342 €

MAREA (2011-2013): *Mathematical approach towards resilience engineering in ATM*. SESAR WP-E: the aim of MAREA project tis to provide the formal methodology to address the new SESAR 2020 concepts of operation, at present under study by the air traffic management systems' experts at EUROCONTROL.

Total cost of the project: 649.658 €

DEWS cost: 182.000 € - EU contribution: 163.800 €

CASA+ (2010-2012): *Integrated domotic platform for enabling autonomy of disabled people*. The project started in 2010 and it is funded by AIPD (No profit association for disabilities) and Vodafone Foundation. The research is focused on developing smart and non-intrusive solutions for networking, tracking and user interfaces to help people with disabilities to carry out basic daily life operations. A test bed has been developed in cooperation with WEST Aquila srl.

DEWS cost: 82.000 € - National contribution (AIPD): 82.000 €

ESSOR (2008-2012): *European Secure SOftware Radio programme*. (MP-IST-083-04). ESSOR is a major European research program in SDR, supported by several european countries and led by major industrial manufacturers, whose main objectives are to strengthen European autonomy on a crucial technological area, federate European industries activities to support production equipment and support development of open standards. The focus is on developing mobile ad-hoc networks (MANETs) with a large number of nodes (hundreds) that are able to operate in harsh environments. Activities of this project have been carried out in the frame of the Radiolabs Consortium. DEWS cost: 120.000 € - EU contribution: 120.000 € (managed through Radiolabs Consortium)

Former projects

iFly: *Safety, Complexity and Responsibility based design and validation of highly automated Air Traffic Management*. EU FP6 STREP, 2007-2011: In the last years the ATM community research trend is to direct large airborne self-separation research projects to situations of less dense airspace. iFly aims at fostering this transition through a systematic exploitation and further development of the advanced mathematical techniques that have emerged within the HYBRIDGE project of EC's 5th Framework Programme. iFly research intent is to establish an upper bound on traffic levels for which airborne self-separation is safe. For en-route traffic, iFly has the objective to develop an advanced control design for airborne self-separation within the SESAR framework. The goal is to accommodate a three- to six-fold increase in current en-route traffic levels. The approach is to develop an overall validation plan which incorporates safety analysis, complexity assessment and pilot/controller responsibilities together with an assessment of ground and airborne system requirements.

Total cost of the project: 3.309.000 €

DEWS cost: 330.000 € - EU contribution: 166.500 €

PAR2010 (2010-2011): *Analisi dei Sistemi di Supervisione, Controllo e Protezione per Reattori Nucleari di Nuova Generazione*. MISE. The Italian Ministry of Economic Development (Ministero dello Sviluppo Economico, MISE) and the Italian Agency for new technologies, energy and sustainable economy (Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, ENEA) established an agreement to grant financial assistance for the execution of the three-year plan of research and development of general interest to the “National Electric System”. In particular, ENEA has signed a research contract on the theme "Analysis of core instrumentation and simulation" under the area "Nuclear Fission: Methodologies for analysis and verification of nuclear projects fueled by pressurized water". The themes developed under this collaboration agreement between ENEA and DEWS, focus on the supervision, control and protection for pressurized water nuclear reactors of new generation.

DEWS cost: 130.000 € - National contribution (MISE): 130.000 €**DISTRETTO ABRUZZO:** *Wireless Networks and Advanced Platform for Smart Agriculture*. Funded by Ministry of Research (MIUR, 2007-2011) and Selex Communications. The aim of this project is to define and develop a platform relying on wireless sensor networks for constant and energy efficient environment monitoring oriented to support advanced practices in the food chain. The project has led to a test-bed development.

Total cost of the project: 1.500.000,0 €

DEWS cost: 54.500+80.000 € - National contribution (MIUR): 35.560 € + 80.000 €

IRMA: *Impulse Radio for Multimedia Applications*. Research Contract with Thales Communications in the frame of a project funded by the Italian Ministry of Defense (MD). The project was concerned during the first two phases (2006-2010) with definition and validation of an UWB physical layer for integrated communications, positioning and multi-static radar scanning. The third phase was concerned with the development of a demonstrator (HUMANET) that involves our startup WEST Aquila srl.

DEWS cost: 105.000 € - National contribution (MD): 105.000 €

PRIN 05: *Forecast and control systems for landslides: local sensor distributed networks integration, monitoring techniques and hydro-geological models*. MIUR, 2006-2007. The research project aims at combining locally deployed sensors and remote sensing for acquisition of a multitude of physical parameters that are directly or indirectly related to those phenomena that may determine landslides events in unstable slopes. If compared to currently employed techniques, the proposed method is characterized by the use of advanced technologies such as remote sensing e dense wireless sensor networks: thus, a large set of measurements can be performed and collected, and then used to feed advanced models and algorithms, with the ultimate goal of performing more reliable and economic forecast tools.

Total cost of the project: 84.000 €

DEWS cost: 52.000 € - National contribution (MIUR): 36.000 €

HYCON: *Hybrid Control: Taming Heterogeneity and Complexity of Networked Embedded Systems*. EU FP6 NoE, 2004-2008: The objective of the NoE HYCON is establishing a durable community of leading researchers and practitioners who develop and apply the hybrid systems approach to the design of networked embedded control systems that are found, for example, in industrial production, transportation systems, generation and distribution of energy, communication systems. Hybrid systems provide a scientific paradigm to systematically address the analysis, modelling, simulation, synthesis, and optimisation of digital controllers for physical plants that communicate directly or via networks with other computerized systems and with human users and supervisors. HYCON aimed at a major advancement of the methodology for the design of such systems and their application in power management, industrial controls, automotive control and communication networks.

The long-lasting result was the establishment of a European Embedded Control Institute (EECI) that is a worldwide focal point for hybrid and embedded systems research. The network contributed significantly to bridge the gap between traditional control engineering and embedded system design.

Total cost of the project: 5.608.166 €

DEWS cost: 236.000 € - EU contribution: 236.000 €

HYBRIDGE: *Distributed Control and Stochastic Analysis of Hybrid Systems Supporting Safety Critical Real-Time Systems Design*. EU FP5 STREP, 2002-2005: HYBRIDGE was a project within the 5th Framework Programme IST-2001-IV.2.1 (iii) (Distributed Control), funded by the European Commission under contract number IST-2001-32460. The 21st century finds Europe facing a number of remarkable changes, many of which involve large complex real-time systems the management and control of which undergoes a natural trend of becoming more and more distributed while at the same time the safety criticality of these systems for human society tends to increase. However good the control design for these systems will be, humans are the only ones carrying responsibility for the operational safety. This implies that control system designs for safety critical operations have to be embedded within sound safety management systems such that the level of safety stays under control of humans. The objective of HYBRIDGE was to develop the methodologies to accomplish this, and to demonstrate their use in support of advanced air traffic management design. In addition to direct application to air traffic management, these contributions formed the nucleus for further research and development into a complex, uncertain system theory, and into application of this theory to distributed control of other real time complex systems such as communication, computer and power networks.

Total cost of the project: 3.991.156 €

DEWS cost: 453.697 € - EU contribution: 226.848 €

PRIN02: *Methods for the design of embedded controllers for hybrid systems. MIUR, 2003-2004*. The aim of this project is about bridging the dichotomy between functional design and implementation. To achieve this goal, we drew on the theory of hybrid system control with safety specifications and the principles of platform-based design. In this method, the design process is decomposed into a sequence of steps that involve different levels of abstraction (platforms) related by a refinement relation. The choice of the layers of abstraction and of the corresponding parameters is essential for the quality of the final solution of the design problem. Platforms for the embedded control design problem were defined in terms of their parameters and appropriate cost functionals introduced. The design of the engine control unit for automotive applications was considered for illustrating the advantages of the proposed method.

Total cost of the project: 171.000 €

DEWS cost: 96.900 € - EU contribution: 67.800 €

COLUMBUS: *Design of Embedded Controllers for Safety Critical Systems*. EU FP5 STREP, 2002-2004: The design of embedded systems deals with the implementation of a set of functionalities satisfying a number of constraints ranging from performance to cost, emissions, power consumption and weight. The choice of implementation architecture implies which functionality will be implemented as a hardware component and which as software running on a programmable component. The design of embedded hardware and software poses a number of problems that cannot be addressed by traditional methods.

These include hard constraints on reaction speed, memory footprint, power consumption, and, most importantly, the need to verify design correctness. The latter is a critical aspect of embedded systems since several application domains, such as transportation and environment monitoring, are characterized by safety considerations that do not arise in traditional, PC-like software applications. In this project we developed design methods and tools for embedded systems in safety critical applications.

Total cost of the project: 1.919.154 €

DEWS cost: 600.141 € - EU contribution: 300.070 €

M1: Modeling and control of heterogeneous distributed complex systems

M1 research activities provide the basic mathematical methods and tools for analysis and control of complex heterogeneous Networked Embedded Control Systems. The growing relevance of Networked Embedded Control Systems is sustained by the evolution of enabling technologies such as embedded systems and networks. Embedded systems are computing systems designed to perform one or more dedicated functions often with real-time constraints. Embedded systems are present in all aspects of everyday life, from automotive to avionics systems, from white goods to consumer electronics.

The research lines pursued in M1 include hybrid and non-linear systems theory, decentralized control/observability/diagnosis, and networked embedded control. In this report we emphasize the following activities, the first two being characterized by an interdisciplinary approach: i) the development of correct-by-design methods to address controller synthesis for Networked Embedded Systems, taking into account non-idealities at the implementation layers.; ii) the analysis and controller/network co-design challenges for networked control systems, taking into account the dynamics and non-idealities of the communication media and protocols; iii) event- and self- triggered control, with the aim of minimizing the usage of network resources by triggering sensing and actuation only when needed in order to keep a control-loop stable.

Symbolic Control of Networked Embedded Systems

Discrete abstractions of continuous and hybrid systems have been the topic of intensive study in the last twenty years from both the control systems and the computer science communities. While physical world processes are often described by differential equations, digital controllers and software and hardware are usually modeled through discrete/symbolic processes. During the years, the heterogeneity of these mathematical models has posed interesting and challenging theoretical problems that must be addressed to ensure the formal correctness of control algorithms in the presence of non-idealities at the implementation layers. From the synergistic collaboration of researchers in the control systems and computer science communities, a novel and sound approach has recently emerged, which is termed "Correct-by-Design Embedded Control Software". This research line can be roughly described as a three-step process, as shown in Figure M1.1, and detailed hereafter:

1. A finite state machine (or symbolic model) is firstly constructed, which is equivalent or approximates the continuous control system.

2. The original control design problem is solved at the discrete abstraction layer on the symbolic model obtained.

3. The symbolic controller synthesized at the discrete layer is appropriately refined so that it can be successfully applied to the original continuous control system.

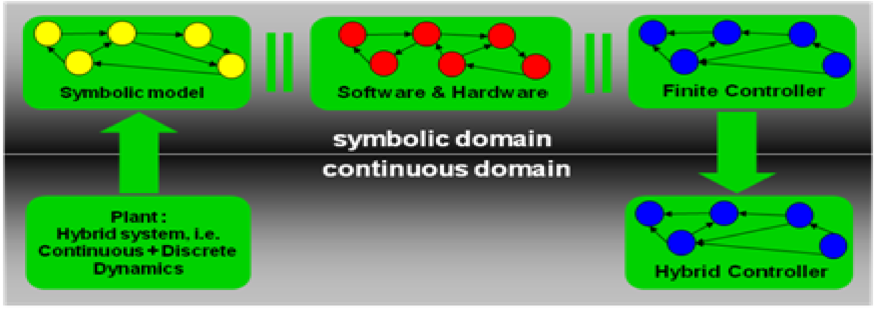


Figure M1.1: Correct-by-Design Embedded Control Software.

The correct-by-design approach guarantees that controllers synthesized at the symbolic layer enforce the desired specification on the continuous layer with guaranteed approximation bounds. Moreover, this approach provides the designer with a systematic method to address a wide spectrum of novel logic specifications that are difficult to enforce by means of conventional control design paradigms. The kernel of this approach resides in the definition and construction of symbolic models that are equivalent or approximate continuous and hybrid systems (Step 1 in the aforementioned methodology).

DEWS researchers have been active in this research topic and their collaboration with researchers from the University of California at Los Angeles (USA) and the Université Joseph Fourier (France) was fruitful.

The first contribution concerned symbolic models for nonlinear control systems. We identified two key ingredients to accomplish this ambitious goal: the notion of approximate bisimulation, introduced by Antoine Girard and George Pappas in 2007 and the notion of incremental stability introduced by David Angeli in 2002. We showed that these two key ingredients can be combined so that for any incrementally input-to-state stable nonlinear control system with compact state space it is possible to construct a symbolic model that approximates the original system in the sense of approximate bisimulation with arbitrarily good accuracy. This result was then generalized to the case of control systems affected by disturbances, time-delay systems and switched systems. The generalization to control systems affected by disturbances required the introduction of a novel notion of approximation that is termed alternating approximate bisimulation; this notion guarantees that control strategies synthesized on symbolic models, based on alternating approximate bisimulations, can be readily transferred to the original model, independently of the particular evolution of the disturbance inputs. The generalization to time-delay systems and switched systems required also the introduction and characterization of novel notions of incremental stability for these classes of systems.

In the reporting period 2012-2014, we extended the above results along several directions.

Previous results concerning symbolic models for control systems affected by disturbances were of existential nature: indeed the proposed construction of symbolic models was based on the computation of the set of reachable states which is a hard task in general. For this reason we proposed in [BPDB12b], alternative symbolic models which can be effectively computed; the key idea was to leverage results from spline analysis for approximating the disturbance inputs functional space.

All these results were based on a notion of incremental stability. In [ZPMT12] we relaxed this assumption and showed that any incremental forward complete nonlinear control system admits symbolic models that approximate the original system in the sense of alternating approximate simulation. Incremental forward complete assumption is a rather mild assumption which is fulfilled for example by unstable linear control systems.

We also considered the class of discrete-time piecewise affine control systems in [PDB14]. IWe proposed a sequence of symbolic models that can be effectively constructed and that converge, without stability assumptions, to the original control system in the sense of the so-called simulation metric. Symbolic control design was then addressed with specifications expressed in terms of non-deterministic finite automata. A sequence of symbolic control strategies was derived which converges, in the sense of simulation metric, to the maximal controller solving the given specification on the control system.

We then used symbolic models for control design purposes. In particular, we faced the problem of designing symbolic controllers that enforce a control system to satisfy a specification expressed in terms of automata on infinite strings and so that the interactions between the control system and the symbolic controller is non-blocking. An explicit solution to this problem was explicitly derived, resulting in the non-blocking part of the approximate parallel composition between the specification automaton and the symbolic model of the continuous system. While being powerful, this approach often encounters some limitations in concrete applications, because of the large size of the symbolic models needed to be constructed in the implementation. Inspired by on–the–fly techniques for verification and control of finite state machines, we proposed in [BPDB12a] efficient algorithms that integrate the construction of the symbolic model of the continuous system with the design of the symbolic controller.

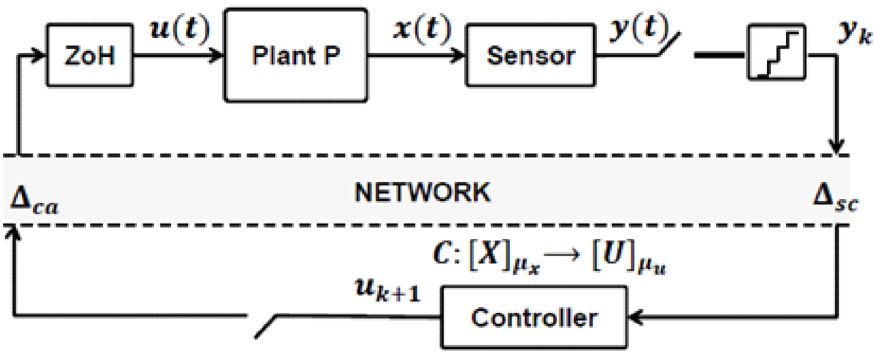


Figure M1.2: Networked control system architecture.

The above results do not consider imperfect communication infrastructures conveying information between the plant and the controller. For this reason we considered symbolic control design of Networked Control Systems (NCSs). In particular, we considered a fairly general framework of NCSs which comprises most relevant non-idealities in the communication channel as quantization errors, saturations in the control action, bounded time-varying network access times, bounded time-varying communication delays induced by the network, bounded time-varying computation time of computing units, limited bandwidth in the communication channel and bounded packet losses. The NCS scheme we considered is depicted in Figure M1.2. In [BPDB12a] we showed that NCSs with incrementally input-to-state stable nonlinear control systems admit symbolic models that are an alternating approximate bisimulation of the original NCS. The proposed symbolic models were then used to solve symbolic control design problems for NCS where specifications are expressed in terms of automata on infinite strings. The results of [BPDB12a] were generalized in [BPDB12c] to the case where control systems are incrementally forward complete, hence, possibly unstable. On-the-fly type algorithms studied in [PBDB12] were extended to the symbolic control design of nonlinear NCS.

The above frameworks consider only one plant and one controller. In order to tame complexity or realistic large-scale NCS we considered in [PPDB14] the case where several plants interact with one another in order to accomplish a given task. More specifically, we considered networks of discrete–time nonlinear control systems and we showed that under some small gain theorem–type conditions, a network of symbolic models can be constructed which approximates a network of incrementally stable control systems in the sense of approximate bisimulation with any desired accuracy. Compositional design of quantization parameters of the symbolic models was also derived and based on the topological properties of the network. Along this line, the work in [BDJ+13] addressed decentralized symbolic control design of a network of continuous-time nonlinear control systems in serial configuration; an application to the vehicle platooning system with collision avoidance specifications was also investigated.

Modelling, Analysis and Co-Design of Wireless Control Networks

The growing relevance of Cyber-Physical Systems (CPS) is due in part to the development of technologies that are essential for their effective deployment, namely: embedded systems and wireless communication networks. In particular, Wireless Sensor and actuator Networks (WSN) have greatly facilitated and enhanced the automated, remote and intelligent monitoring and control of a large variety of physical systems. These networks consist of many tiny, inexpensive and low-power devices, each incorporating sensing, actuation, processing, and wireless communication capabilities. These devices are now used in a number of application domains from industrial and building automation, to environmental, wildlife, and health monitoring, and disaster relief management. Sensing, computation and communication are at the basis of any WSN physical architecture. While monitoring physical systems was one of the first applications of WSN, the most advanced WSN applications today available involve control in one form or another. Wireless Control Networks (WCN) are WSN applied to control.

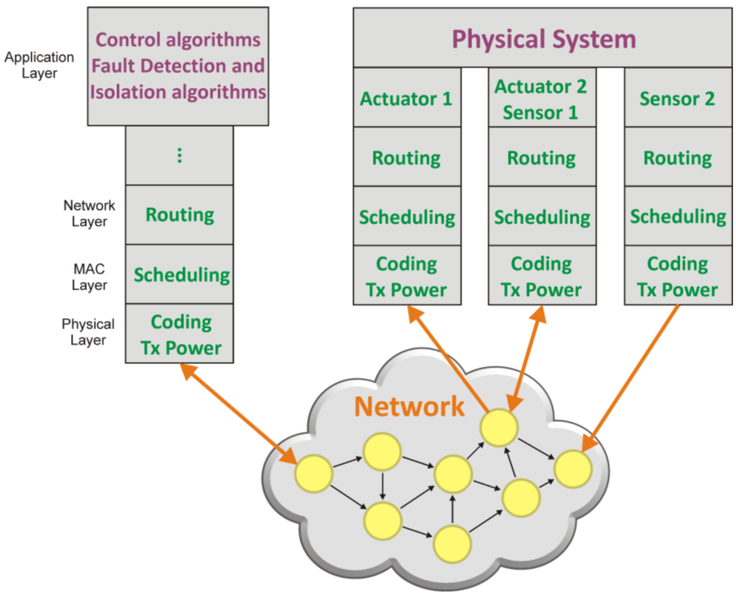


Figure M1.3: Control loop over wireless networking protocols.

The opportunities offered by WCN, and the increasing computing power of control nodes, are accompanied by some tough challenges. To advance the state-of-the-art in modelling, analysis and design of WCNs, classical control problems have to take into account the joint effect of Control, Computation and wireless Communication, evidencing the need to solve new theoretical and implementation problems. Despite some initial fundamental scientific achievements, the convergence of the "3Cs" has not yet had a significant impact on society and industry. In some cases, methodologies have been derived for general models, but their computational complexity is intractable, i.e. they require the solution of NP-hard or even undecidable problems. In other cases, methodologies have been developed with an affordable computational complexity, but for simplified models that neglect the most relevant issues arising in real implementations - e.g., critical non-idealities, communication protocol dynamics and constraints, limited resources - rendering them practically useless. In general, scientific research on WCNs models the network non-idealities as aggregated network performance variables or disturbances, neglecting the dynamics introduced by the communication protocols.

In the context of the EU FP7 NoE HYCON2, we followed an interdisciplinary approach by developing a unifying mathematical framework that takes into account the joint dynamics of physical systems and communication protocols. By formally quantifying the interactions within the heterogeneous environment typical of WCN, we expect that powerful formal methods and tools, developed over decades by different (and often disconnected) scientific communities, can now be combined to solve problems arising in a WCN.

In collaboration with Prof. George J. Pappas, University of Pennsylvania, USA, and Prof. Karl H. Johansson, Royal Institute of Technology, Sweden, we proposed in [Alur et Al., TAC2011] to model as a Switching Linear System the joint dynamics of a physical system, an embedded controller and of the MAC (scheduling) and Network (routing) ISO/OSI layers of a time-triggered communication protocol over a shared multi-hop communication network. In particular, our framework makes it possible to model recently developed wireless industrial control protocols such as WirelessHART and ISA-100.

On the basis of this mathematical framework, we considered [SDID+12b, DIDB+13b, DIDB+13a, DBDI+14] WCNs subject to failures and/or malicious attacks in the communication nodes: we addressed and solved the problem of designing a set of controllers and communication protocol parameters, making it possible to detect and isolate failures on-the-fly and consequently apply an appropriate controller to stabilize the closed-loop system. We leveraged both algebraic and graph theoretic methods to derive necessary and sufficient conditions both on the physical system (i.e., its dynamics) and on the communication protocol (i.e., on topology, scheduling, routing and network coding) that guarantee stabilizability and allow failures to be detected and isolated.

We addressed in [SDID+12a] the problem of co-designing a digital controller and the network parameters (scheduling and routing) in order to guarantee stability and maximize a performance metric on the transient response to a step input, with constraints on the control effort, on the output overshoot and on the bandwidth of the communication channel. We show that the above optimization problem is a polynomial optimization problem, which is in general NP-hard. We provide sufficient conditions on the network topology, scheduling and routing such that it is computationally feasible, namely such that it reduces to a convex optimization problem.

In collaboration with Prof. Raphaël Jungers, Université Catholique de Louvain, Belgium, we recently derived [JDID+12, JDID+14b, JDID+14a] necessary and sufficient conditions for stabilizability for a WCN switching linear model. Our goal has been to leverage the particular algebraic structure induced by the networking communication protocol in order to improve theoretical understanding of the dynamics at stake in these systems. This has enabled us to design tailored controllers whose performances are better than for classical switching systems. We have also tried to distinguish situations where exact algebraic methods are still applicable from situations where the time-varying delays make the system hard to control with exact methods, obliging the system to resort to conservative Lyapunov-like methods.

Future activities involve the extension of our unifying mathematical framework to accurately model all the ISO/OSI layers of the communication protocols for WCNs, as well as the development of novel control methodologies and algorithms for this framework.

Event- and self- triggered Control

In modern control system it is common to use digital technology, where the control task consists of sampling the outputs of the plant then computing and implementing new actuator signals. The classic way to proceed is to sample in a periodic fashion the output, thus allowing the closed–loop system to be analyzed on the basis of sampled–data systems. Recent years have seen the development of a different paradigm where, instead of sampling periodically, i.e. with a time triggered policy, the system is triggered when needed, i.e. using an event triggered policy. In the line of the works on this subject, the research developed at DEWS investigated the impact of the event triggered paradigm on observer–based (i.e. dynamical feedback) control systems [EDBZ14]. More precisely, the observer–based control problem was considered for linear systems in the presence of model uncertainties. Different kinds of event triggered policies allow practical or asymptotic stability. Some studies are available on observer–based controller and on practical stability in the presence of disturbances and perturbations on the plant (Donkers, 2010 and 2012, Lehmann 2011, Tallapragada 2013, Garcia 2013). The studies at DEWS brought to some global results (in the sense that the stability does not depend on initial condition and initial observation error) for the case shown in Figure M1.4.

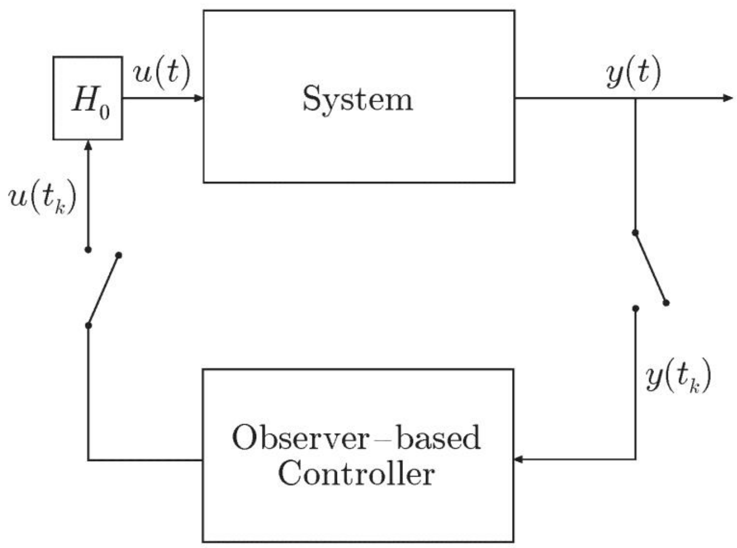


Figure M1.4: Control system architecture.

Figure M1.4 shows a system controlled by a dynamic controller. Due to communication constraints, there is no continuous communication between the sensor and the controller, nor between the controller and the plant. The sampled value of the system output $y(t_k)$ is available for the controller to implement the control, and the value $u(t_k)$ is applied to the system, through a classic zero order holder H_0. This means that the output y and the input u are sampled synchronously, but the results can be generalized to the case of asynchronous sampling.

The obtained results can obviously also be applied in the case of full state feedback. We investigated the robustness issues of the event triggered observation and control with respect to modeling uncertainties, and showed that if the continuous closed loop system is robust, then the perturbed system is stabilizable with the event triggered policy. Moreover, asymptotic stabilization of an uncertain system using an adapted event triggered policy is obtained. Finally, ultimate boundedness of the closed loop system is obtained in the presence of perturbations on the plant, noise on the output, as well as model uncertainties.

The application of self triggered strategies was investigated. The implementation of controllers with digital devices presents many advantages, but some important issues arise. In particular, one important aspect is the design of the digital controller so that the control system recovers, at least in first approximation, the same behavior of a system controlled with a continuous time controller. Many authors propose nonlinear digital controllers reproducing the performances of a certain continuous controller, viz. emulating the behavior of the continuous controller (Nesic 2005 and 2006, Yamamoto 2002). This very popular technique relies on the simple idea that when the (fixed) sampling period is short enough, the continuous behavior is recovered. Other authors aim at designing the digital controller directly in the digital setting, although nonlinear systems cannot be discretized exactly in closed form, in general. In both cases, a relevant problem arises: the determination of the sampling period. From a theoretical point of view, the sampling period is usually considered constant, namely the new control value is computed periodically at each sampling time. This simplifies the analysis of the sampled nonlinear system from a mathematical point of view, and gives some mathematical tools to solve the design problem. However, in practice, the control law is calculated when the hardware on which the digital algorithm is implemented, is not busy with processes with higher priority. In other cases, e.g. when a wireless sensor network is used, it would be better to calculate the control value only "when necessary". This clearly complicates the problem from an analytical point of view. But there are also other practical aspects that push to deal with variable sampling. A first one is that a constant sampling is quite inefficient (in terms of hardware usage, communication bandwidth, energy, etc.),. In fact, since the system dynamics are nonlinear, one has to ensure good performances for all the operating points.. A further aspect is that, usually, digital microcontrollers perform various tasks at the same time. This is quite typical, especially in the case of embedded systems. An example is the electronic central unit in an automobile, which has to deal with different tasks, with different priority. Their scheduling is clearly of critical importance to prevent negative coupling effects of lower priority tasks when computing high level tasks, such as attitude control laws. Another important example is given by networked systems, where not only the processor time is a resource to be optimized, but also the available communication bandwidth is limited. In wireless sensor networks, an important issue is the minimization of the power consumption, in order to augment the life span of the network. In all these applications, the energy consumption is related to the frequency of measurements and transmission over the network. Clearly, in these cases measurement/computation/ actuation data transmission should be minimized and should occur only "when necessary".

Among the various techniques proposed to face this problem, the event triggered technique seems to be promising (Arzen 1999, Otanez 2002, Tabuada 2007, Heemels 2008). This technique formalizes the statement "when necessary": the measurement/computation/ actuation data transmission event occurs when the state of the system assumes certain values. Clearly, this technique requires the continuous measurement of the state. To circumvent this drawback, self–triggered techniques have been proposed. In this case the controller determines its next execution time, and does not require continuous measurements of the state. For example, when the stabilization of the system origin is considered, this event is triggered only when the asymptotic stability property, as formalized by the Lyapunov approach, can be lost. This approach can be also generalized to a weaker property such as safety.

Our research at DEWS allowed generalizing the self–triggered stabilization and safety problems to a specific class of stochastic systems, where the state equations are described by an Itô differential equation driven by a Wiener noise. Self triggered control was also investigated in the case of multi–agent systems (MAS) [DDD13b],where the main interest relies on the fact that multiple agents may perform a mission more efficiently than a single one, increase tolerance to possible agent fault and provide flexibility during the task execution. During the two last decades, cooperative control of MAS has attracted a great deal of attention due to its broad range of applications in many areas, e.g. flocking (Olfati 2006), rendezvous (Su 2010), distributed estimation (Cao 2010), formation control (Fax 2004, Defoort 2008), consensus (Ren 2005), etc. Consensus of multi–agent systems means to design control policies that enable a group of agents to reach an agreement regarding a certain quantity of interest (attitude, position, velocity, etc.) by negotiating with their neighbors. A crucial part in the deployment of consensus strategies is the communication and controller execution condition. Although each agent may naturally be described by continuous–time dynamics, the control law is only updated at discrete time instants: these can either be pre–specified, usually separated by a fixed period (time–scheduled control), or be determined by certain events that are triggered depending on the system behavior. In MASs, the small embedded microprocessors form the computational core of the network. They are required to execute a variety of tasks including the relay of information packets, monitoring physical quantities from neighboring nodes and computation of feedback control laws. Since in practice, the embedded microprocessors have limited energy and computation ability, it is very important to increase the functionality of these devices through novel scheduling algorithms. A fixed sampling period is quite inefficient since the worst–case scenario has to be considered. Relaxing the usual fixed sample rate assumption allows scheduling control, where the control values are updated when necessary. Among the various techniques proposed to dynamically adapt the sampling, to reduce the microprocessors and network loads while ensuring the desired control performances, event and self–triggered control are interesting approaches. This latter emulates event–triggered control without dedicated hardware, and uses the current sampled state to specify the next sampling time, through a scheduling procedure. At each sampling instant, a lower–bound of the next admissible sampling interval is computed such that the control system maintains some desirable properties, first of all (but not only) the asymptotic stability at the origin or at a neighborhood of the origin. From a theoretical point of view, [DDD13b] is a first attempt to study a self–triggered strategy to solve the consensus problem for first order MASs, affected by unknown nonlinear inherent dynamics (considered as uncertainties) under fixed and switching communication topologies. The design of a self–triggered control law for uncertain systems is not an easy task, due to the effect of the sampling, and one has to ensure the stability property also in the inter–sampling. A methodology for the computation of the feedback gains and the next execution times were derived based on multiple quadratic Lyapunov function and Lipschitz condition on the uncertainties. While in the event–triggered control framework there exist methods for the decentralized determination of the sampling instants (Seyboth 2013), such a result was not available in the self–triggered setting.

M2: Communication and protocol design for pervasive and cognitive networks

The objective of the research in M2 is the overall development of communication and networking technologies for supporting advanced applications. Since the early stage of DEWS activities in 2001, M2 has pursued theoretical research in close cooperation with M1; recently, it has leveraged embedded SW methodologies and tools that are investigated in M3. In this reporting period the research organization of M2 has been further expanded: while still focusing on major items described in the latest report 2009-2012 (algorithms, techniques and models for signal processing, transmission systems and protocols for secure and efficient networking), the set of activities has been extended according to both specific internal interests and to novel projects also proposed by industrial partners. Moreover, the activities often include experimental validation and are in many cases connected to methodologies addressed in M3 for implementation issues; a close connection with the applications depicted in the Research Line A3 is pursued. Although mainly focused on the wireless domain, our concept of networking has been actually spanning across a set of heterogeneous components that are integrated not only on the traffic side but also in terms of management and control. In the following we provide a short description of recent achievements and work in progress, according to our major topics:

- signal design and physical layer techniques for novel communication paradigms, that include cooperative and cognitive wireless systems, network coding, distributed MIMO and spatial modulations;
- characterization of interference as a prominent and limiting feature of many wireless environments, along with evaluation of achievable performance and development of novel paradigms for radio resource management;
- analysis, modelling and specification of cross-layer protocol stacks that are able to meet specific application requirements in distributed wireless systems;
- network management and traffic modelling in broadband infrastructures for the future Internet;
- distributed algorithms and platforms for localization, sensing and security in networked embedded systems.

Cooperative wireless techniques towards green communications

An unprecedented surge of mobile data traffic in the cellular industry has already motivated telecom operators and researchers to develop new transmission technologies, protocols, and network infrastructures to maximize achievable throughput and spectral efficiency. However, little or no attention has been paid to energy consumption and signal processing complexity. Furthermore, with the current design methodology at hand, wireless systems can achieve energy savings only at the cost of performance and Quality of Service (QoS) degradation. Therefore, the key stakeholders in the mobile industry and current standards are already promoting a network delivery platform that is: i) heterogeneous and characterized by a small cell infrastructure through the use of small, inexpensive, and low-power base stations to achieve high data rates in a capillary fashion; ii) green, by evolving from throughput optimized networks towards energy optimized networks; and iii) characterized by a high level of cooperation among base stations and mobile terminals, by achieving better coverage and reduced energy consumption through network-coded relay-aided transmission, as well as better reliability and reduced energy consumption through distributed diversity.

The path followed by DEWS researchers towards the development of green communications was originated by analysis on cooperative diversity. As a matter of fact, cooperative systems take advantage of relayed and spatial diversity technologies to boost channel capacity, and to reduce the error probability due to multipath fading. In the latest report 2009-2012 we have already reported our comprehensive frameworks for performance analysis of a generic cooperative system, up to a multi–hop multi–branch network. However, the efficient exploitation of cooperative/multi–hop networking is faced by the following challenges: i) due to practical considerations, such as the half–duplex constraint or to avoid interference caused by simultaneous transmissions, distributed cooperation needs extra bandwidth resources (e.g., time slots or frequencies), which might result in a loss of system throughput; ii) relay nodes are forced to use their own resources to forward the packets of other nodes, usually without receiving any rewards; and iii) in classical cooperative protocols, the relay nodes that perform a retransmission on behalf of other nodes must delay their own frames, which has an impact on the latency of the network. At the technical level, the drawbacks of cooperative communications can be effectively balanced by synergic exploitation of two breakthrough access paradigms such as Network Coding (NC) and Multiple–Input–Multiple–Output (MIMO) Spatial Modulation (SM). These three main research domains interact and work together to provide ubiquitous high quality services (high data rates with low energy requirements). NC can be broadly defined as an advanced routing or encoding mechanism at the network layer, which allows network nodes not only to forward but also to process incoming data packets. It can be considered a potential and effective enabler to recover the throughput loss experienced by cooperative/multi–hop networking.

Moving from previous research already exposed in the latest report, the challenge faced more recently by DEWS researchers consists in the analysis of the multiplexing gain introduced by NC and the achievable diversity/coding gain introduced by cooperation when practical communication constraints (erroneous decoding and fading) are taken into account. As a matter of fact, the typical approach considered in literature has mainly relied on information-theoretic assumptions, according to which data packets are processed by the network layer only if they are without errors. While this prevents possible performance loss, this might be highly spectral inefficient as, even though a single bit in the packet is in error, the packet is dropped. In order to avoid this sub-optimal operation mode and to consider more realistic communication-theoretic assumptions, we have considered the MIMO-NC approach, which can be considered as a sort of network-coded aware Chase combiner.

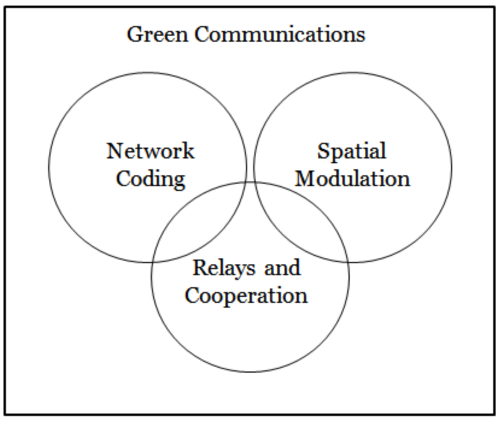


Figure M2.1: Main research domain.

The main idea is that all received packets are kept at the destination and processed at the network layer even though some bits of the packet are not received correctly, [IDRG12b] . Our research activity has two research lines: i) how to develop the optimal Chase combiner in the presence of NC; and ii) to study the achievable diversity gain as a function of the adopted network code.

Some recent results, obtained by collaboration with Laboratoire des Signaux et Systèmes (L2S), Supélec (France), have highlighted, for some network topologies and encoding schemes, the potential benefits of NC to recover the throughput loss of cooperative/multi–hop networking. The additional research goal was to investigate the scenario when the relays do not act as dedicated network elements with no data to transmit but have their own data packets to be transmitted to a common destination, and exploit NC to transmit them along with the packets that have to be relayed on behalf of the sources. This way, the relays can help the sources without the need to: i) delay the transmission of their own data packets; and ii) use specific resources (energy and processing) to forward the packets of the sources [IDRG12a]. Furthermore, we proposed a network code design based on Unequal Error Protection (UEP) codes. To the best of our knowledge, this is the first time that UEP coding theory is exploited for the design of distributed network codes for diversity purposes [DRIG12].

A different and alternative technology for green communications is SM, which is able to outperform, with low implementation and computational complexity, many traditional transmission schemes, such as multiple-antenna in Multiple-Input-Multiple-Output (MIMO) systems, which can be exploited in different ways to achieve multiplexing, diversity, or antenna gains. However, regardless of the use as spatial multiplexing, diversity, or smart antenna system, the main drawback of any MIMO scheme is an increase in complexity and cost. Spatial Modulation (SM) has been proposed as a new modulation concept for MIMO systems, which aims at reducing the complexity and cost of multiple-antenna schemes without deteriorating the end-to-end system performance and still guaranteeing good data rates. In particular, Space Shift Keying (SSK) modulation exploits only the spatial–constellation diagram for data modulation, which results in a very low–complexity modulation concept for MIMO systems. In other words SSK exploits the location–specific property of the wireless channel for data modulation: the messages sent by the transmitter can be decoded at the destination since the receiver sees a different Channel Impulse Response (CIR) on any transmit–to–receive wireless link. Due to its inherent working principle, the major criticism about the adoption of SSK modulation in realistic propagation environments is its robustness to the imperfect knowledge of the wireless channel at the receiver. The main contribution given by DEWS researchers is to shed light on this matter and to develop a very general analytical framework to assess the performance of space modulation with coherent detection and practical channel estimates [DRDL+12]. In particular, DEWS researchers focused their attention on two transmission technologies, which are the building blocks of space modulation: Space Shift Keying modulation and Time–Orthogonal–Signal–Design (TOSD) SSK modulation, which is an improved version of SSK modulation providing transmit–diversity. Our theoretical and numerical results highlight three important outcomes: i) SSK modulation is as robust as single–antenna systems to imperfect channel knowledge; ii) TOSD–SSK modulation is more robust to channel estimation errors than the Alamouti scheme; and iii) only few training pilots are needed to get reliable enough channel estimates for data detection.

The bridge between cooperative communications and spatial modulation principle, which is the third investigated research domain, allows to propose innovative and advanced solutions to reduce energy consumption and complexity for relay-aided cooperative cellular networks. More specifically, DEWS researchers focused on the design, the analysis, and the optimization of both the uplink and the downlink of cellular networks. Specifically, we considered the scenario where fixed relay nodes or other mobile terminals, which are in close-proximity of a single or multi-antenna terminal, are willing to help forwarding data to the intended BS and to transmit their own data, without any drawback in terms of throughput. In addition to exploiting relay-aided and cooperative wireless communications to take advantage of the SM-MIMO approach for the uplink, the effort aimed at exploiting the multiplexing gain introduced by the (virtual) spatial-constellation diagram to develop innovative relaying protocols that allow us to recover the throughput loss experienced by multi-hop networking and caused by the half-duplex constraint, while keeping the energy gain introduced by multi-hop transmission. The developed protocol provides that data symbols transmitted from the source are univocally encoded into the channel impulse responses of different relay–to–destination links. Thus, source's data is implicitly relayed to the destination through a relay activation process, rather than using conventional amplitude/phase modulation, as already seen in literature. As a consequence, this latter degree of freedom can be used by the relays to transmit their own data without any reductions of the aggregate throughput, and by still guaranteeing the protection (i.e., distributed diversity) of the source's data. The specific research contributions have been obtained in GREENET and thanks to the fruitful collaboration with Laboratoire des signaux et systèmes (L2S), Supélec (France).

Interference modelling and radio resource management in heterogeneous wireless networks

Cellular networks are undergoing a major shift in their deployment and optimization. New infrastructural elements, such as femto/pico base stations, fixed/mobile relays, cognitive radios, and distributed antennas are being massively deployed, thus making future cellular systems more heterogeneous. As a consequence, new cellular deployments are characterized by a more unplanned, irregular, and random location of many infrastructure elements, whose positions may vary widely over a very large area. The interference scenario is becoming more complex, thus making evaluation and design of different communication technologies and protocols more challenging. As a matter of fact, network interference might be mitigated in systems with a centralized control, where the coordinator is able to assign different channelization and power levels to the network nodes. However, this is not possible in systems such as cognitive radio networks (CRNs), where a centralized control is often not feasible, and there is the need for a distributed resource allocation.

Accurately modeling network interference, understanding its impact on the end-to-end performance, and developing efficient techniques to mitigate or exploit it are three important and fundamental research assets. An accurate performance prediction of these emerging heterogeneous wireless communication systems is instrumental to circumvent time-consuming computer simulations, to avoid expensive field test campaigns, as well as to facilitate system optimization via a suitable design choice for some given practical implementation constraints, and, ultimately, to inspire optimal and innovative algorithms and designs. System performance depends critically on the spatial configurations of the nodes, and the computation of new "average" performance metrics, are instrumental for the system designer and the network planner. The analysis of such systems requires extensive, complex, and time-consuming system-level simulations to average over the spatial distributions of the network nodes. Thus, new and advanced mathematical and statistical tools are required to explicitly and accurately model the random distribution of these nodes, as well as to avoid lengthy and seldom insightful numerical simulations.

Motivated from all the above, the aim of DEWS researchers, in collaboration with the University of Bologna and the Laboratory of Signals and Systems at Paris-Sud University, has been the development of a simple but accurate framework for the analysis and design of heterogeneous networks and cooperative spectrum sensing methods by taking into account realistic channel conditions and system operations. In [DRMG+13], an analytical framework for performance analysis and design of Single-Input-Multiple-Output (SIMO) wireless systems is introduced, by considering the presence of noise, fading, and radio frequency interference produced by randomly distributed active interferers surrounding an intended probe receiver. The framework leverages recent application of stochastic geometry and Poisson Point Processes (PPPs) theory to network interference modeling. To assess the impact of spatial dependence across multiple receive-antennas, different models of network interference were studied. Depending on the fading distribution of the interferers, the Nakagami-m fading parameter of the probe link, and the number of receive-antennas, either exact or upper-bound formulas of the error probability averaged over noise, fading, and spatial interference were given. The analysis showed that, depending on the interference model, performance can either improve or get worse with multiple antennas at the receiver. The proposed analytical methodology is applicable to single- and multi-PPPs interference environments. Moreover, the PPP framework has been successfully applied to the study of the outage Probability and the Average Symbol Error Probability (ASEP) of dual–hop Amplify–and–Forward (AF) relaying systems, in the presence of noise, fading, and network interference [GBDR+13]. Numerical results showed that the intended communication performance worsen significantly in the presence of interferers with constant/varying transmit energy. However, accurate system behavior predictions are provided with the proposed approach, so that a proper end-to-end optimization can be exploited.

Finally, in collaboration with the Royal Institute of Technology (KTH, Stockholm), a new approach for the handover optimization in cellular networks was proposed in [FAS14]. First, a new modeling of the handover process by a hybrid system that takes as input the handover parameters was established. Then, this hybrid system was used to pose some dynamical optimization approaches where the probability of outage and the probability of handover are considered. Simple approximations of adequate accuracy were developed. Based on these approximations, a new approach to the solution of the handover optimizations was proposed by the use of a trellis diagram. A distributed optimization algorithm was then developed to maximize handover performance. From an extensive set of results obtained by numerical computations and simulations, it was shown that the proposed algorithm allows for a performance improvement of the handover considerably when compared to more traditional approaches.

Analysis, modelling and specification of cross-layer protocol stacks

Energy conservation is important for the sustainable development of new communication technologies. A potential infrastructure for developing energy-aware applications is represented by low power wireless networks. They include any network of devices with limited power, memory, and processing resources that are interconnected by a communication protocol such as IEEE 802.15.4, Bluetooth, or low power WiFi. Mobile ad-hoc networks (MANETs) and wireless sensor networks (WSNs) are examples of low power infrastructure interconnected by heterogeneous protocols. Wireless sensor networks (WSNs) are often used in areas where it is difficult to recharge or replace power units. In smartphones, recharge is possible and not expensive but a short battery lifetime limits the usability. The presence of many wireless devices causes interference, which imposes a constraint to the transmitted energy. Applications often share the same communication infrastructure, so the wireless protocol needs to adapt dynamically to requirements ranging from monitoring to safety critical applications.

However, most proposed protocols are designed and optimized for specific implementation platforms and system requirements and they may not be scalable or interoperable with existing standards. Current standards often guarantee a certain performance as stand-alone solutions, but may not be efficient when patched together. Understanding the basic interactions between communication technologies and control applications is essential to obtain efficient overall operations. The design of wireless protocols for networked control systems can benefit from analysis, optimization, and appropriatecomposition of protocol mechanisms.

The underlying aspect that motivates this work is the relevance of analytical modeling in design, protocol selection, and optimization of energy efficient communication. For a vendor, it is often the key to profitability to have an efficient engineering process for modeling. In the design of communication systems for transmitting information through physical channels, it is convenient to use an analytical model that reproduces the most important characteristics of the transmission medium. One of the advantages is that, by distinguishing the different components of the networked system, the designer can study the interaction between design parameters and the effects of these parameters on the applications running on top of the network. Same approach is applied in the design of applications on top of the communication stack. By abstracting key network features in simple models, the design can be optimized according to the specified requirements. A drawback is that the abstraction needed for the sake of simplicity in the model may be inefficient to capture the behavior and the performance of a certain application over the communication stack.

The problem is formulated as follows. Given a set of system requirements, communication and control strategies are chosen by a proper composition of protocol components. The essence of the problem can be visualized by the block diagram below, in which we synthesize the main components and the mutual interaction between the layers of interest.

First, in collaboration with Prof. Carlo Fischione and Prof. Karl Henrik Johansson at the Royal Institute of Technology, the design loop interaction between routing and MAC protocols has been investigated. The mutual influence between routing decisions and MAC performance was investigated in terms of reliability, delay, and load balancing, by considering the ROLL routing specifications over unslotted IEEE 802.15.4 MAC. To do so, an analytical model that includes the important features of multi-hop networks, such as heterogeneous distribution of the traffic and hidden terminal nodes was presented [DMPF+12], [DMFA+13]. It was shown that the distribution of traffic load in the network influences the performance in terms of reliability, delay, and energy consumption of the links. This effect depends strongly on the carrier sensing range of nodes in the network. There are conditions in which routing decisions based on packet loss probability or delay may lead to an unbalanced distribution of the traffic load across paths with potential dangerous effects on the energy consumption. Based on this, MAC aware routing metrics that take into account the cross layer interaction between MAC and routing were proposed. Furthermore, it was established to what extent channel fading conditions can be beneficial for the overall performance of a network using IEEE 802.15.4 MAC [DMFS+13], [DMFS+14].

The modeling framework based on Markov chain analysis was also applied to anti-collision protocols in RFID systems in [DMFS14], by considering explicit effects of multi-path shadowed fading channels and the presence of interferers. Based on the analytical results, a protocol for fast identification was presented in [ACS+14] and [DMAS+14]. The proposed solution exploits the benefit of a hybrid ultra-high frequency (UHF) and ultra-wideband (UWB) architecture.

Finally, cross-layer protocol design has been carried out in the frame of ESSOR project for advanced mobile ad hoc networks (MANETs) contexts with large number of nodes and large mobility. In this frame DEWS researchers have been developing component-based design methodologies [CFRS12], [CFRS12a] that are based on formal models for specifications, advanced tools for modelling, and automatic code generation for high fidelity simulators and subsequent implementation on target platform (DSP, programmable HW). This is particularly suited for the Software Defined Radio and emerging Cognitive Radio contexts

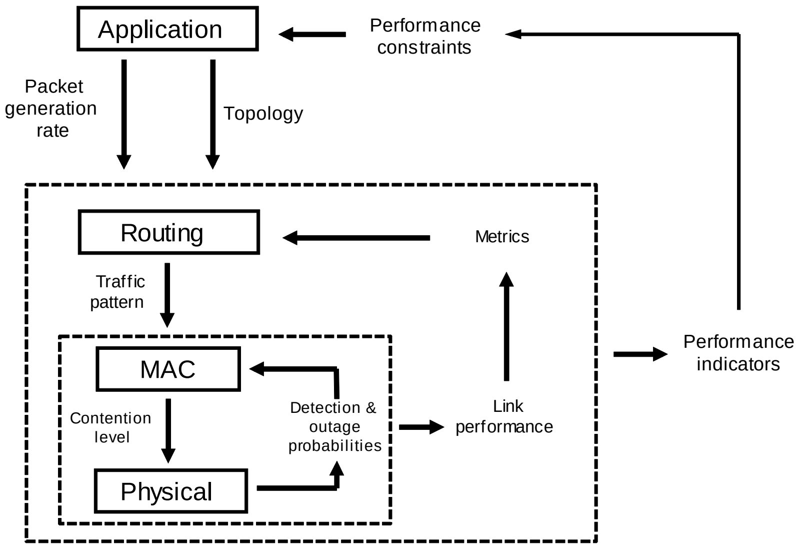


Figure M2.2: Networking layers interaction for protocol modeling and design

Network management and traffic modelling in broadband infrastructures for the future Internet

This activity started in 2013 under a research contract funded by the research department of Telecom Italia (TiLab, Roma). It consists of two related research lines that are fully supported by a strict cooperation between M1 and M2.

Network management: Moving from the need of identifying methods and tools for effective management of malfunctions and faults of ISP networks, it was found that troubleshooting a network that uses the Internet Protocol version 6 may be more complex than it is today with the IP version 4. The main problem is the lack of features for the new protocol version tools; such behavior is due to the fact that IPv4 is still the dominant protocol in networks and there are no plans of an imminent migration to IPv6. IPv6, on the other hand, provides new features that may lead to development of useful troubleshooting tools before the total migration of networks to the new version.Recently, researchers in the networking area worldwide have been investigating ways to solve the major problems that exist in the current Internet. This design activity is referred to the ''Future Internet'', which has become a very hot topic, especially in the US, Europe, Japan and Korea. Network management is a very important area; however, it was not one of the original design goals of the current Internet. Rather, it emerged as a "necessary means" to enable functionality provided by the Internet to grow. As a result, managing the current Internet is still very cumbersome and difficult.

Taking into account the upcoming large-scale migration to IPv6, the DEWS Center of Excellence has started the research carried out in collaboration with Telecom Italia, which aims to evaluate the impact of the new protocol both on TroubleShooting and on Performance Management methodologies.The management of failures and malfunctions in large ISP (Internet Service Provider) networks requires huge efforts by network technicians. Interventions are quite critical in the case of sub-optimal operation of the network, as it is difficult to identify the link or device to be investigated. The analysis of a network path between a source and a destination using traditional networking tools like ping and traceroute, does not provide information about the return path. Due to the availability of multiple tools to retrieve information from individual nodes of the network, we give special emphasis on the identification of which devices need to be analyzed.

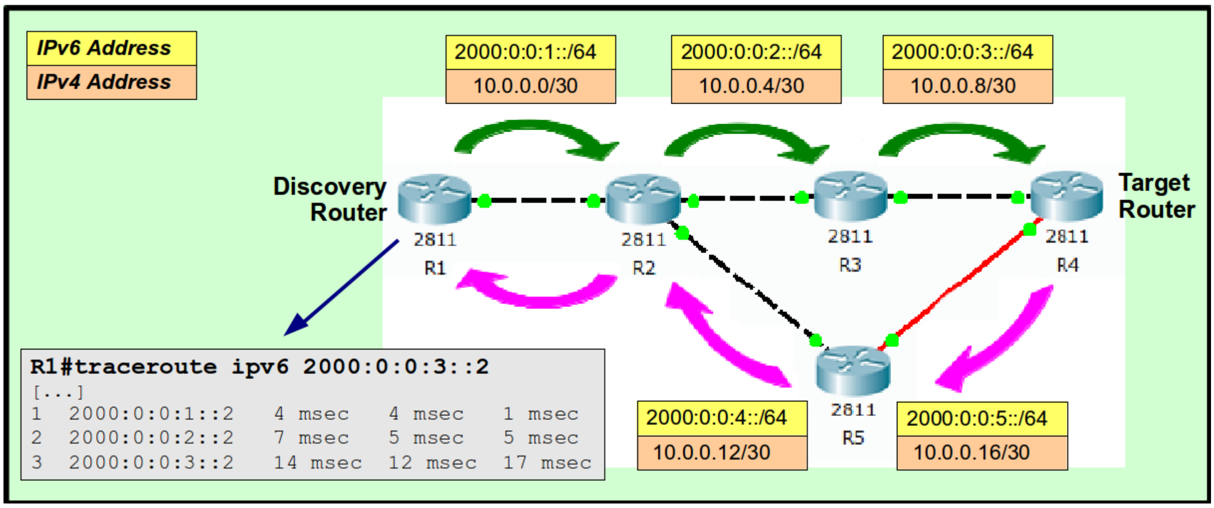


Figure M2.3: Example of asymmetric path with a hidden device (R5) and related traceroute output.

In [VPSI14] we have proposed two solutions to find those nodes on the bidirectional traffic's path that would remain invisible to traditional analysis. They can be implemented with a small effort, through a few configuration changes and without introducing new equipment or protocols. We also strongly focus on the upcoming migration to IPv6: indeed, both solutions are conceived for the new version of the networking protocol, even though the second proposed solution is fully applicable to IPv4, too.

The research can be summarized in the following points:

1. Identification and study of reference scenarios for the analysis of asymmetric paths;
2. Approach with historical and widely used instruments in networks for IPv4 and IPv6;
3. Analysis of strengths points and limitations of IPv6 and its impact both on TroubleShooting Performance Management methodologies;
4. Identification of possible approaches to the Path Discovery taking into consideration the limitations of a production network.

Modeling of traffic congestion and re-routing: This research line deals with the development of a mathematical and simulation environment to formally model the effect of router/link failures on the dynamics of TCP and UDP packet flows belonging to different end-user services (i.e. http, ftp, mailing and video streaming) transiting through a Service Provider backbone network. Our model takes into account network topology, routing (a simplified version of OSPFv2 on Ipv4), TCP (a full model of the TCP-Sack protocol) and different end-user services.In particular, we addressed the modeling problem, in strict connection with M1, leveraging hybrid systems theory, which combines both continuous time dynamics and discrete-time logic. Our approach fills the gap between packet-level and aggregate models by averaging discrete variables over a very short time scale (on the order of a round-trip time). This means that the model is able to capture the dynamics of transient phenomena fairly accurately, as long as their time constants are larger than a couple of round-trip times. This time scale is quite appropriate for the analysis and design of network protocols including congestion control mechanisms. Our model also takes into account the dynamics of packet drops with accuracy up to the duration of round-trip time, which is good enough since the variations on the round-trip time typically occur at a slower time scale. Also note that our model does not assume constant round-trip time. In the paper [DBDL+14] we extended the hybrid modeling framework in [Bohacek et al., SIGMETRICS'03] to take into account re-routing dynamics in the network due to e.g. link failures and a simplified model of different user services, i.e. http, ftp, mailing and video streaming. To make this possible we have proposed a scalable framework that allows such modeling using hybrid systems and automata composition theories.

Our framework makes the further extension of our model to different and new routing algorithms very easy because of its modular and compositional characteristics. In addition to this, our framework has been developed in order to be easily extendable and generalizable to other protocols and to take into account QoS for packets priority in the routers. The final aim of this research line is to provide a framework to analyze quantitatively (using an appropriate QoS metric for each service) and ad-hoc (with respect to different end-user services) the effect of network failures, in order to appropriately design the network redundancy and implement diagnosis of future failures (supporting service and network troubleshooting) and/or prognosis (supporting network trend analysis) of failures by using feedback and feedforward statistical information on the users' behavior.

Distributed algorithms and platforms for localization, sensing and security

Positioning. The Global Positioning System (GPS) can greatly facilitate the task of location estimation by potentially allowing every GPS–equipped receiver to accurately localize itself in any point located on or above the Earth surface. However, GPS–based localization solutions are often considered a non–completely viable and well–suited solution for position estimation in WSNs, as sensor nodes are supposed to operate at low–complexity and low–power consumptionsMoreover, GPS–based solutions have the undesirable side–effect that they cannot provide reliable location estimates in indoor environments. As a consequence of the above, much research has been done in the WSNs community to develop new techniques for localization in those environments where GPS–aided positioning is either unfeasible or does not meet the design requirements and paradigms of networked embedded systems, i.e., the so–called GPS–denied (or GPS–less) environments. Although several optimization algorithms for location estimation have been proposed in the literature to date, each of them exhibits advantages and disadvantages in terms of computational cost, overall accuracy, and suitability to be deployed onto today's available WSNs' devices, taking also into account the need for tracking mobile nodes.

At DEWS several localization algorithms have been recently studied. In the frame of collaborative solutions (i.e., where the mobile entity carries a node participating in the network) the proposed solution is an anchor-based algorithm, which means it runs in a scenario where several fixed anchor nodes, i.e., nodes knowing a-priori their positions based on a common reference system of coordinates, are deployed in the environment and broadcast their positions using either periodic beacons or upon request. A second set of nodes is mobile and called blind since they need to estimate their own positions according to the same reference system of coordinates, by relying on the data they are able to gather from the anchors and the environment. The algorithm is also range-based, since the blinds estimate their positions by first computing the distance with respect to the anchors available. On the other hand, an example of non-collaborative (or, device free) scenario, where the mobile object, e.g., a person, needs to be localized in a network-equipped environment, has been studied. In particular, an experimental setup have been developed where a number of nodes have been deployed along the perimeter of a conference room at around 1 meter above the ground. These nodes were configured to transmit beacon signals in a collision-free and scheduled fashion on a IEEE 802.15.4 compliant channel and each time a node transmits, the other nodes record the received signal strength (RSS) measurement of the link. Through the analysis of the variations of such RSS measurements on each link when a person is steady or moving inside the area covered by the network, it is possible to identify the position of the person with an accuracy ranging from 5 cm to 95 cm. A paper is currently under preparation to better describe our achievements.

In the frame of collaborative solutions, loosely speaking, tracking a person or a mobile object inside an environment means continuously running a localization service and updating the position estimations. Nevertheless, the tracking algorithm assumes that the blind needs to wait to receive enough RSS data from enough anchors. Moreover, since the single RSS measurement intrinsically might suffer from high fluctuations, usually there is the need to average among several successive (e.g., 4 or 8) RSS readings from the same anchor. Thus, a simple consideration is straightforward: there is a limit to the nodes' mobility speed that the algorithm can accept to keep results reliable and enough accurate, unless any complementary mechanism takes place to cope with these gaps of the WSN-aided only position estimations.

Consequently, for tracking purposes, we are also studying the performance of the WSN-aided localization algorithm and evaluating the integration with an Inertial Navigation System (INS) composed by an Inertial Measurements Unit (IMU) such as accelerometer and gyroscope. We have already shown in this regard that the tracking can be accurately achieved through sensor fusion techniques, such as the Simple Convex Combination algorithm, whose output is the optimal combination of WSN-aided and INS-provided position estimations.

Security. Homeland security and monitoring of critical infrastructures, such as buildings, bridges, nuclear power plants, aircrafts, etc., represent challenging application domains for modern networking technologies. In this context wireless sensor networks (WSN) are gaining interest as a fundamental component of an advanced platform that embeds pervasive monitoring, networking and processing. While most literature contributions propose to put intelligence (that is usually more consuming both in computational resources and in memory as well) outside the WSN, our research target is to show experimentally that, under certain limitations, a WSN can operate as a functionally "autonomous entity" not only for sensing operations. Specifically this research program, started in 2008, is focused on the security application to WSN through the introduction of the "Secure Platform" concept. The "Secure Platform" has been designed and being implemented within the framework of the internal project WINSOME (WIreless sensor Network-based Secure system fOr structural integrity Monitoring and AlErting) at DEWS Lab. Specific activities carried out in the reporting period 2012-2014 are as follows:

1. development of a framework to provide security in applications of WSN;
2. proposal / Development of novel cryptographic schemes over WSN;
3. proposal / Development of novel intrusion detection schemes over WSN;
4. proposal of novel monitoring techniques for critical infrastructures over WSN.

1. The underlying idea has been to design a secure cross-layer platform for advanced applications over WSNs that are able to operate in non-standard environment such as monitoring of critical infrastructures, data acquisition in hazardous environments under standard security conditions. This platform has been denoted simply as "Secure Platform", where providing security in a WSN system cannot be restricted to providing a robust cryptographic scheme, also because this kind of schemes are heavy demanding in terms of computational power and memory. Indeed, a smart intrusion detection service should be provided also with ciphering and authentication in order to build up a "security service" package that will enhance the typical middleware services provided by an Application Execution Environment (AEE). Fig. M2.4 sketches the main functional blocks of the proposed Secure Platform: apart from the block providing the typical middleware services (MW Services) and shared memory, other specific services (in this case security-oriented) are implemented as customizations of specific SW component and provided to the AEE via different APIs. It is very important to note that the "secure platform approach" offers a guideline to design and implement "integrated security" over WSNs through an "application-oriented" approach which is aligned to the current SW development paradigms over resource constrained devices.

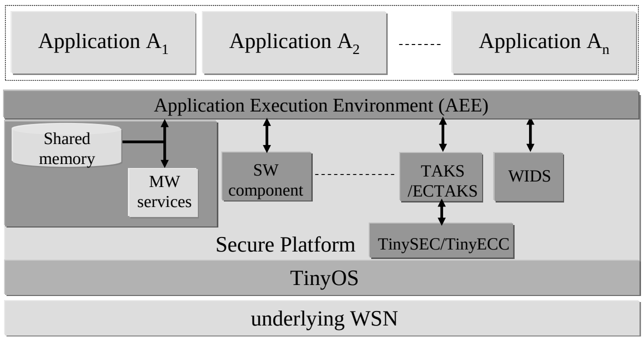


Figure M2.4: The "Secure Platform" reference architecture

In this case at least two functional blocks are provided: the cryptography module TAKS/ECTAKS, which implement TAKS (Topology Authenticated Key Scheme) or, alternatively, ECTAKS (Elliptic Curve-based TAKS), the extension of TAKS to elliptic curve cryptography (ECC) and the intrusion detection module WIDS. Both schemes are based on hybrid cryptography and the generation algorithm of the shared keys is based on vector algebra over Galois fields and party authentication is based on network topology. TinySEC and TinyECC modules respectively represent the basic security packages in WSN as native integration with TinyOS and its extension to support ECC. A recent result consists in defining a simplified version of the “Secure Platform“ over IEEE 802.15.4 networks: it has been implemented without a specific middleware layer and just standard Zig-Bee primitives have been used. Demo trials of TAKS / ECTAKS module embedded in the “Secure Platform“ in WINSOME project have been presented in several international events. Future activities involve a more detailed analysis of AEE choices. Up to now the AGILLA middleware has been the considered choice and some enhancements have been added to this framework. However, a possible alternative approach could be to build up an ad-hoc “lighter“ middleware suited for WSN as well as LR-WPAN. In this direction the approach is to develop a layer directly on top of IEEE 802.15.4 network stacks.

2. Both TAKS and ECTAKS schemes are based on a 2-phase setup protocol and the shared key can be generated only when the pair nodes have exchanged a setup request. Even more expensive in terms of trasmissions and processing, an important pro of the 2-phase setup protocol is that the initiating node could ignore the address of the recipient node which can be a good feature in fast changing / growing networks. Therefore, we have proposed also the “fast“ version introducing a 1-phase setup (denoted as TAKS v.2). Moreover also TAKS v.2 (as well as TAKS / ECTAKS) could allow generation of both pair-wise / cluster-wise shared keys, a fundamental feature when operating in WSN organized in node clusters. Future activities involve a higher optimization of the scheme in terms of processing power (contrained delays) and memory usage in view of multimedia applications.

3. The WPM (Weak Process Model) approach to intrusion detection over WSN had been already proposed and denoted as WIDS (WPM-based IDS). WPMs are non-parametric versions of HMM (Hidden Markov Model), wherein state transition probabilities are reduced to rules of reachability in a graph representing the abnormal behaviours. The estimation of a threat in the case of weak processes is greatly simplified and less demanding for resources. The most probable state sequence generated by the Viterbi algorithm for HMM becomes the possible state sequence generated by simplified estimation algorithms for WPMs. The intensity of the attack is evaluated by introducing a threat score, a likelihood criterion based on weighting states and transitions. A recent advance at DEWS has consisted in developing a specific WPM model of vulnerabilities in IEEE 802.15.4. Future activities involve enhancements of the vulnerabilities modeling approach as well as the threat estimation technique. Moreover, the technical literature still lacks a strategy logic to apply the needed countermeasures once part of the network has been compromised and the suited level security cannot be provided.

4. The MVET (Mean-Variance Estimation Technique) techniques has been proposed to detect behavior anomalies in monitoring critical infrastructures through resource constrained devices specifically targeted to monitoring and alerting functionalities for homeland security, that typically enforce severe requirements to the detection process. Assuming the behavior of the characteristic operation indicators in a potentially large and complex infrastructure (such as buildings, bridges, nuclear power plants, aircrafts, etc.) to be bounded by design constraints, in MVET the sample mean and the sample variance are computed from observations and behavior classification is performed by defining regions in the MV-estimator space instead of the observations space. We have shown that this detection technique is able to provide better performance with respect to other approaches over resource constrained platforms such as WSN, and this has been widely substantiated by numerical results as well as by a detailed cost analysis. Future activities involve experimental tests for the MVET technique.

M3: Design methodologies for embedded systems

Embedded systems are pervasive in today's products and grow at an impressive pace considering instrumented, networked, intelligent, and cyber-physical systems that are at the core of the concept of smart cities and smarter planet. However, their growing complexity (multi/many cores, heterogeneous, distributed, reconfigurable, networked, etc…) could represent soon an unmanageable limit for design. In fact, apart from possible differences on composition and form factors, one consideration is always true: the design methodology, i.e. the set of adopted models, metrics and tools, plays a major role in determining the success of a product. For this reason, in the last few years, design methodologies for embedded systems have been in continuous evolution towards the adoption of model-based approaches at increasingly higher abstraction levels. In such a direction, essential parts of the proposed methodologies represent the foundations of tools for the automatic generation of HW/SW implementations, as well as other development artifacts to support different types of analyses.

The research lines on embedded system design methodologies at DEWS are based on the experience gained during past (i.e. FP5-IST COLUMBUS - http://www.columbus.gr) and current projects: up-to-date research lines and projects are described below in some details while Table 1 explicitly shows their relationships.

Projects

Research Lines	*2010-2015* *ERC-SG* *VISION*	*2011-2014* *Artemis-JU ASP* *PRESTO*	*2012-2015* *Artemis-JU ASP* *CRAFTERS*	*2014-2017* *Artemis-JU AIPP* *EMC²*
Embedded Systems Rapid Prototyping	x			x
Model-Driven Engineering for Embedded Systems	x	x	x	x

Table M3.1: Research lines vs. Projects

Research lines

Embedded Systems Rapid Prototyping

This research line is about scouting and experimenting innovative HW/SW technologies, industrial methodologies and commercial tools for the rapid prototyping of embedded systems. Its goals are mainly the following ones:

1) to develop meaningful technology transfer capabilities towards industrial domain (cf. SMILING project in Research Area A3)

2) to design novel and up-to-date academic and industrial courses

3) to support other research activities with usable design frameworks and platforms

Publications in the considered period related to the research line: [PMSP13], [PPMS13a], [PPMS13b], [PPRS13], [PRSG13], [PRST13], [RSPG13], [PPS12], [PRC12], [PRGT12].

Model-Driven Engineering for Embedded Systems

This research line is about customizing classic Model-Driven Engineering approaches to embedded systems development. In particular, DEWS is focusing on automatic models transformation (e.g. from platform-independent to platform-specific models, from development models to analysis models, from development models to C/VHDL code, etc.) while targeting (reconfigurable) HW/SW heterogeneous parallel architectures. Further, DEWS is working on the development of innovative approaches and tools, at the so called Electronic System Level (ESL) of abstraction, to support the designers in activities where they rely heavily on experience. In particular, in the context of HW/SW Co-Design, DEWS is focusing on Design Space Exploration (and related activities, like ESL Estimation and Simulation) that leads to (semi)automatic HW/SW partitioning, architecture definition and mapping of the model on the defined architecture while trying to satisfy system constraints. Finally, DEWS is working on the development of innovative approaches for ESL Verification & Validation, for both functional (e.g., formal verification and model-checking) and non-functional (e.g., dependability and power consumption) properties.

Publications in the considered period related to the research line: [P13a], [P13b], [PMPD+13], [PMS13a], [PMS13b], [PMSP13], [PPMS13a], [PPMS13b], [PDMP+12], [PPS12].

Projects

VISION

Video-oriented UWB-based Intelligent Ubiquitous Sensing

The VISION project is funded by FP7 "Ideas" Specific Programme (European Research Council Staring Grant Agreement). VISION proposes to develop an innovative infrastructure (Figure M3.2) for strengthening future wireless sensor networks (WSN) with the capability of supporting intelligent services for ubiquitous sensing, with particular emphasis on real-time 3D video sensing. Since the requirements for high-quality video transmission cannot be easily satisfied in a sensor field, the complexity and the cost of sensor devices have up to now discouraged the use of real-time video sensing services. VISION exploits full system adaptability to the context as a ground-breaking approach to overcome these limitations. VISION adopts a dynamic QoS management that relay on a specific ultra-flexible middleware (MW) which links together all HW components of the system.

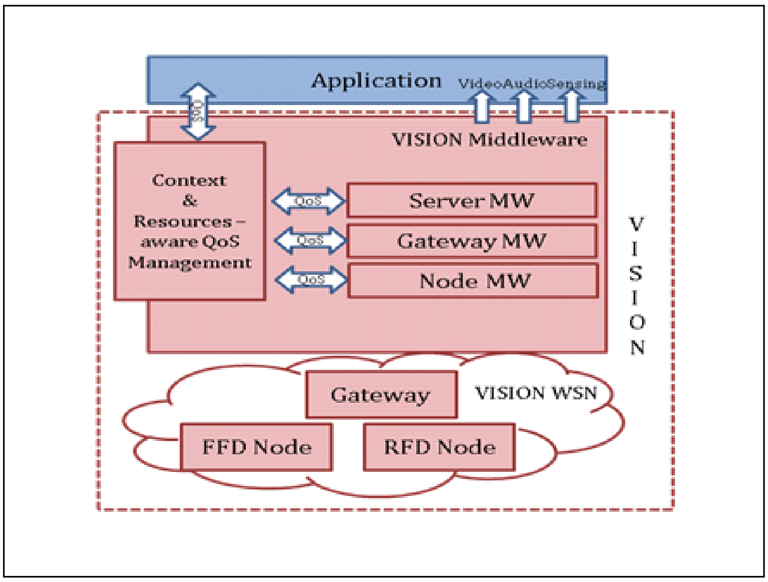


Figure M3.2: VISION Framework

The main contribution of DEWS (in collaboration with DISIM - http://www.disim.univaq.it), in the considered period, is related to such a middleware layer. In fact, the project has led to the development of an innovative mobile-agent based MW. Such a MW is based on an existing one (i.e. Agilla - http://mobilab.wustl.edu/projects/agilla) that has been ported (i.e. from TinyOS 1.x to TinyOS 2.x) and enhanced (Agilla 2.0, will be available by the end of the project at http://dews.univaq.it/vision) as described below. Then, the Agilla Instruction Set Architecture (ISA) has been characterized with respect to timing and energy consumption to allow proper UML-based modeling and simulation activities. In particular, we have experimented the fUML environment for the non-functional analysis of Wireless Sensor Network applications [PMPD+13] to extend an existing UML-based approach for the design and code generation of Agilla applications [PDMP+12] with functional simulation and timing analysis capabilities through executable UML models. The proposed approach makes use of both a UML profile and an executable model library for Agilla. Execution times, annotated on Agilla instructions and patterns in the library, are given as additional input parameters during the model execution to carry out a timing analysis of the simulated Agilla applications. Figure M3.3 sketches the proposed approach, where boxes represent artifacts whereas rounded boxes represent operational steps.

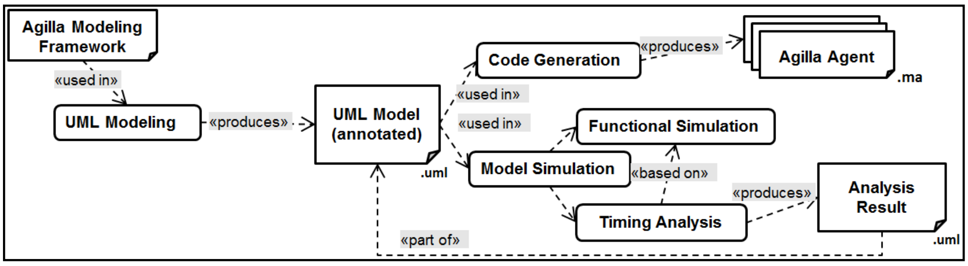


Figure M3.3: Modeling and Timing Simulation of Agilla Agents for WSN applications in Executable UML

Moreover, the Agilla MW has been enhanced to provide resource monitoring and reconfiguration support to the VISION QoS Manager [PDMP+12] [MT12] while advanced audio services have been developed to be integrated in the VISION MW and WSN [PRC12]. Finally, advanced WSN security services, i.e. light-weight keys management schema for feasible cryptography and Weak Process Model (WPM) based Intrusion Detection System has been developed to be integrated in the VISION MW and WSN [PMSP13] [PPMS13a] [PPMS13b] [PPS12] [PPMS13b] [PPS12].

PRESTO

Improvements of Industrial Real Time Embedded Systems Development Process

The PRESTO project, funded by Artemis-JU ASP, addresses improvements on test-based embedded systems development and validation, while considering the constraints of the industrial development processes. This project is based on the integration of (Figure M3.4): test-traces obtained by test execution in the software integration phase that is carried out in common industrial practice to validate the requirements of the system; application and HW/SW platform models; design space exploration techniques.

In the context of PRESTO project, during the considered period, DEWS (in collaboration with DISIM) has been working on trace-based non-functional analysis of software/hardware systems, with a particular emphasis on properties specification and performance properties.

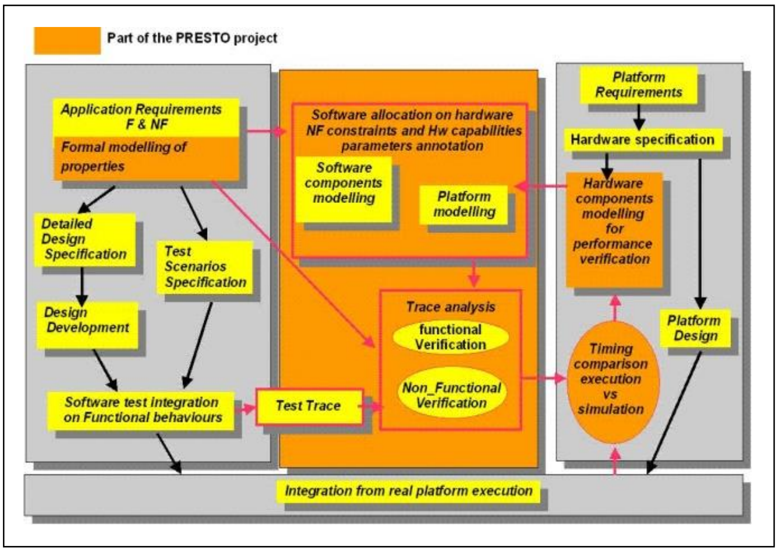


Figure M3.4: PRESTO Framework

Beside this, we have been working in a formal model-driven context in order to investigate how model-driven support can be useful to overcome non-functional limitations of software/hardware systems. In particular, we have worked within the fUML (i.e. foundational UML, a recent OMG standard) modeling notation that, while keeping the standard characterization of UML, provides a subset of UML diagrams that can be formally analyzed [FBLM+13]. So, we have shown how the analysis of certain NFPs can be performed solely based on UML models without translating them into, e.g., queuing networks. Therefore, we leverage the execution semantics of fUML to gain execution traces from UML models and, based on these traces, compute indices, such as response time, taking into account the contention of resources, as well as different resource management configurations, such as balancing and scaling strategies. As sketched in Figure M3.5 here below, we have proposed to: (i) trigger executions of UML models according to specific workloads for obtaining execution traces that reflect the runtime behavior of jobs (i.e., which services are requested in which order), (ii) annotate the arrival time to each of the resulting execution traces, and (iii) compute, based on known service times of consumed services, the temporal relation of concurrently running jobs. Based on the temporal relation of executed jobs, we can step-wise derive their temporal overlaps and compute waiting times in each queue and, in further consequence, the overall response time, throughput, and utilization indices.

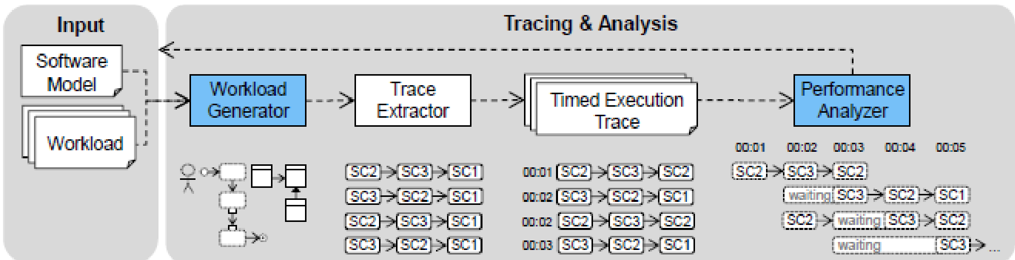


Figure M3.5: Trace-based non-functional analysis of software/hardware systems

Thereafter, we have studied how to combine fUML and Profiles for non-functional analysis based on model execution traces [BLM13]. In particular, we have introduced a framework for bridging the gap between executable fUML models and UML profile applications that are required for model-based analysis using a dedicated integration layer. Finally, other relevant ongoing activities are related to the integration of the proposed trace-based non-functional analysis approach with automatic HW/SW mapping techniques [P13a] [P13b] [PMS13a] [PMS13b].

CRAFTERS

Constraint and Application Driven Framework for Tailoring Embedded Real-time Systems

The CRAFTERS project, funded by Artemis-JU ASP, faces the problem that ICT-based service and product innovation is curtailed by the growing vertical chain of dependence on poorly interoperable proprietary technologies in Europe. The focus of the project spans the different domains of real-time applications for heterogeneous, networked, embedded many-core systems. These applications suffer from the lack of trusted pathways to system realization and application deployment. Service and product development efforts are high with many uncertainties. Industry is discouraged from engaging in such ventures, leaving the market opportunity unexploited. For this, CRAFTERS proposes a computing environment for many-core systems derived from vertical domains that will enable the evolution to horizontal domains by providing common methods, tools and reference platforms for embedded many-core applications. Final goal of the project is to realize a predictable and flexible many-core platform with a run-time scalable execution environment.

In the context of the CRAFTERS project, during the considered period, DEWS (in collaboration with DISIM) has been working on the design of the architecture of a validation suite for software embedded systems, and on the performance-based selection of system features under uncertainty. In fact, Verification and Validation of the produced artifacts are one of the key issues, as they ensure that the pieces of software meet the functional and non-functional requirements envisioned by the designer. In CRAFTERS, the problem is exacerbated since the overall goal is to provide a multi-core solution, so the proposed approach must alleviate this by design including an adapted V&V layer that collaborates with the rest of the software production tools, runtimes and platforms to be developed in the project. Figure M3.6 shows the preliminary architecture of the CRAFTERS Validation Suite.

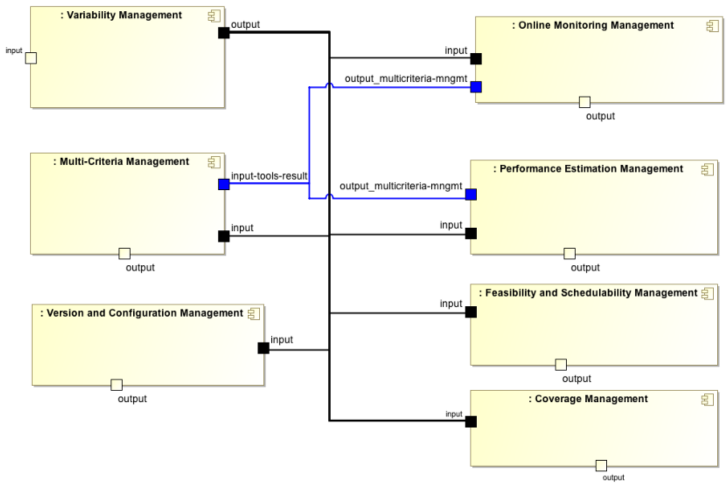


Figure M3.6: Architecture of the CRAFTERS Validation Suite

Within this architectural design, we have started to contribute by considering the performance-based selection of software and hardware features under parameter uncertainty [ETCS14]. In particular, we have introduced an approach to analyze the correlation between selection of features embedding uncertain parameters and system performance. We provide best and worst case performance bounds on the basis of selected features and, in cases of wide gaps among these bounds, we carry on a sensitivity analysis process aimed at taming the uncertainty of parameters.

Another ongoing activity is related to the exploitation of an existing framework (i.e. DUALLy) to create interoperability among diferent modeling notations (as well as UML profiles) used in CRAFTERS. DUALLY allows system engineers to transform concepts of system-level design models into semantically equivalent concepts in other models. Conceptually, DUALLY (http://dually.di.univaq.it) proposes a star architecture for managing all the system-level modelling languages that must interoperate. Figure M3.7 shows the proposed architecture and its main entities.

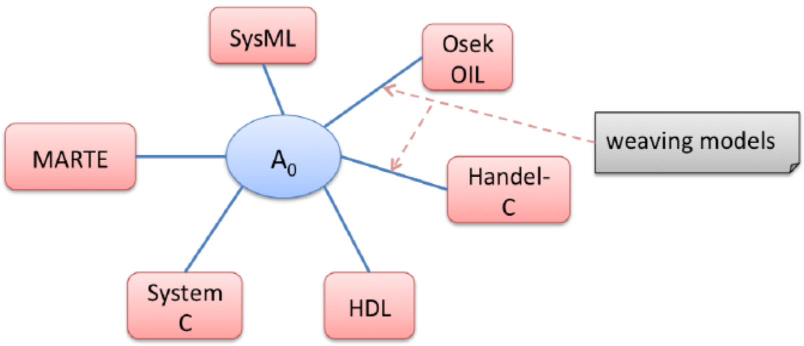


Figure M3.7: DUALLY architecture for managing all the CRAFTERS system-level modelling languages

Finally, since CRAFTERS topics are related also to HW development on FPGA, in this context, DEWS has contributed to two main tasks: the development of HW mechanisms to support off-line and run-time profiling for metrics evaluation, and the development of one of the reference many-core platforms on FPGA (based on ZedBoard - http://www.zedboard.org/product/zedboard) to be used in the development of projects demonstrators.

EMC²

Embedded multi-core systems for mixed criticality applications in dynamic and changeable real-time environments

EMC²project, funded by Artemis-JU AIPP, just started (April 2014). It focuses on the industrialization of European research outcomes and builds on the results of several previous ARTEMIS, European and National projects. It provides the paradigm shift to a new and sustainable system architecture which is suitable to handle open dynamic systems. EMC² is part of the European Embedded Systems industry strategy to maintain its leading edge position by providing solutions for: dynamic adaptability in open systems, utilization of expensive system features only as service-on-demand in order to reduce the overall system cost, handling of mixed criticality applications under real-time conditions, scalability and utmost flexibility, full scale deployment and management of integrated tool chains, through the entire lifecycle. The main contributions of DEWS will be related to provide contribution to the development of a MW for service interoperability support, to provide contribution to the definition and the integration of innovative design space exploration approaches and, in collaboration with Thales Alenia Space Italy, to perform the evaluation of different multi-core architectures on FPGA platforms and related development methodologies and tool chains (including RTOS and/or Hypervisor) in order to assess their suitability for space (i.e. satellite) mixed-criticality applications, opening new application domains to the use of multi-cores.

A1: Intelligent transportation systems

Traffic flow modeling, identification and control

Road mobility is crucial in modern life, so that traffic congestion is becoming more and more a high-priority problem in most countries all over the world. For this reason researchers are currently investigating solutions to maintain traffic far from congestion or to optimally balancing traffic density distributions, so that secondary problems, such as pollution and safety, are mitigated.

Traffic control centers monitor and manage the traffic evolution on the basis of video images and measurements acquired on the road. In such centers, the control actions are also computed. Normally, the control center is located far from the traffic system and the control variables are transmitted, through a wireless communication channel, to the actuators placed along the road.

The communication network is a dynamical system with peculiar features and the transmitted information may be affected by time delays and packet loss. Various models have been studied and utilized to describe time-delays and packet loss in the literature, so that the relevant network features suitably modeled can be explicitly considered in the controller design, thereby obtaining a Networked Control System (NCS).

In the context of the EU FP7 NoE HYCON2, multidisciplinary research at the DEWS Centre of Excellence on a real world case study has been performed. In particular, on a portion of the Grenoble South Ring traffic system (see Figure A1.1), research on traffic modeling, identification and control has been addressed. In Grenoble, the traffic control center is situated downtown, far from the traffic system, and the control variables are sent, through a wireless communication network, to the actuators placed along the road (the actuators being, in our case, traffic lights, since, in this paper, we adopt the so-called ramp metering control approach). This is the reason why the effects of transmission delays and packet loss on the controlled traffic system performance can be significant.

In collaboration with Prof. Antonella Ferrara, Università di Pavia, Italy, in [BFDB13a] and [BFDB13b] two networked Model Predictive Control (MPC) algorithms are proposed and analyzed via simulation for ramp metering control. Both algorithms rely on the use of a buffer to circumvent the drawbacks due to the presence of a communication channel between the control center and the traffic system itself.

The first algorithm is characterized by a constant buffer length, while the second one by a buffer length which is adaptively tuned on the basis of an estimate of the transmission delay in order to reduce the computational load. A simulation analysis of the two algorithms is performed using an instance of the adopted traffic model identified on the basis of data produced by a microscopic simulator of the Grenoble South Ring.

Simulation evidence relevant to the considered case study confirms the validity of the idea, and encourages us to proceed with the experimental test phase, as soon as the sensors will be positioned on the road.

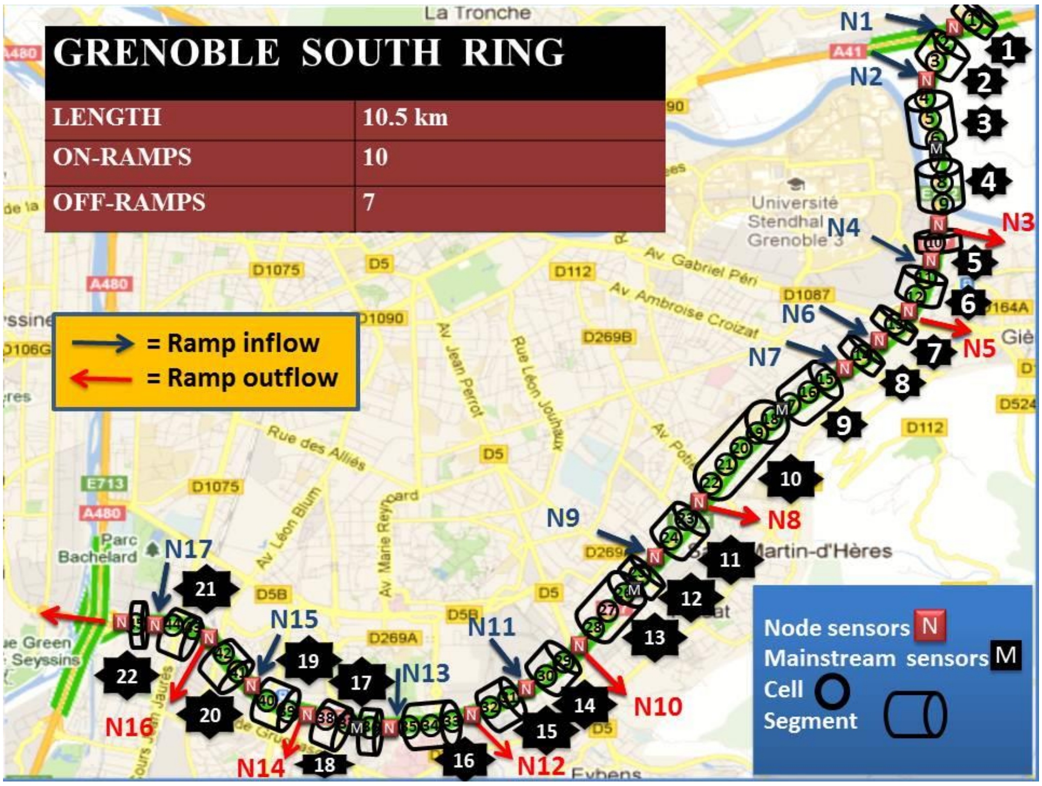


Figure A1.1: The Grenoble South Ring

Air Traffic Management Systems

Air Traffic Management (ATM) is an important application domain exhibiting many features of CPS such as heterogeneity, complexity, and human operators in-the-loop.

Several disciplines are being used to assist ATM experts in the design of robust procedures; among these, of particular relevance is Resilience Engineering (see e.g. Resilience Engineering Perspectives, Preparation and restoration, Vol. 2, Ashgate, England, 2009.). Resilience indicates that operations and organizations are capable of resisting a variety of demands and capable of recovering from variations, degradations, disruptions, and any condition affecting the stability of the operation or organization. In other words, Resilience Engineering addresses the design of joint cognitive systems, both in nominal and non-nominal conditions. However, because of the complexity of ATM joint cognitive systems, Resilience Engineering as applied to ATM is at an early stage of development. Formal mathematical models and analysis methods offer a key complementary approach that is needed to render Resilience Engineering effectively applicable to ATM systems. Making Resilience Engineering applicable to ATM was the main goal of the SESAR WP-E Research Project “Mathematical Approach towards Resilience Engineering in ATM (MAREA)”.

Among the topics included in MAREA, of fundamental importance in the analysis of novel ATM procedures was the study of the impact of non-nominal operating modes on the safety of the overall system. To tackle this important problem we proposed in [DEDB+13, PPDS+13a] and in the MAREA reports publicly available at http://complexworld.eu/wiki/MAREA a formal approach that is based on the use of a number of relevant hybrid systems’ techniques, including compositional hybrid systems’ modelling and hybrid observers’ synthesis.

While aircraft dynamics is commonly described by differential equations, pilots’ and air traffic controllers’ behaviours are well modelled by finite state machines, whose discrete states and transitions mimic the procedure the agents are requested to follow. Hybrid systems' formalism, featuring both discrete and continuous dynamics, is characterized by an expressive power that we proved to be general enough to adequately describe ATM systems, both in nominal and non-nominal conditions. While nominal modes of operation are dictated by the procedure the agents are requested to follow, non-nominal modes may originate from several causes, including malfunction or disruption of technical devices or unpredictable behaviour of human operators in-the-loop. To study the impact of non-nominal operating modes on the safety of the ATM procedures we used the notion of critical observability. This notion corresponds to the possibility of detecting whether the current discrete state of a hybrid system is in a critical set, representing unsafe, un-allowed or non–nominal situations. When a hybrid system exhibits this property, a hybrid observer can be constructed which automatically detects the criticality of the current discrete state.

Our first investigation of critical observability considered each agent of ATM systems in isolation. However, in multi-agent ATM scenarios, agents cannot be considered in isolation because their interaction is responsible for the occurrence of unsafe situations that cannot be captured when considering agents in isolation. For this reason, we proposed a compositional hybrid systems framework that describes the behaviour of each agent as well as their interaction. This framework can be viewed as a generalization of the classical notion of serial composition to a multi-agent setting, and provides a systematic way to study critical observability of multi-agent systems. More precisely, models are first created of each agent with a hybrid system, then, by applying the compositional rules, a unique hybrid system is obtained. A critical relation is then defined which describes the occurrence of safety-critical situations in the composed hybrid system. Studying safety in multi-agent ATM scenarios then translates to studying critical observability of the obtained (composed) hybrid system with respect to the critical relation.

Although formally sound, this approach is hardly applicable to realistic scenarios because of the large number of variables involved. To overcome these difficulties we proposed algorithms based on bisimulation theory, widely used in the area of formal methods to mitigate software verification.

We analysed the Terminal Maneuvering Area (TMA) T1 operation, a procedure selected within the MAREA consortium as a benchmark, exhibiting most relevant features arising in the novel SESAR 2020 Concept of Operation. We considered a scenario involving 25 agents, comprising more than 10^{18} discrete states. We showed that this procedure is not critically observable. This implies that there are safety-critical configurations which cannot be detected by pilots or air traffic controllers. In other words, in some situations, not only is the human operator's awareness of a safety critical situation incorrect, but furthermore, it cannot be improved before a safety-critical situation occurs. This analysis also proposed alternative solutions which ensure safety of the procedure.

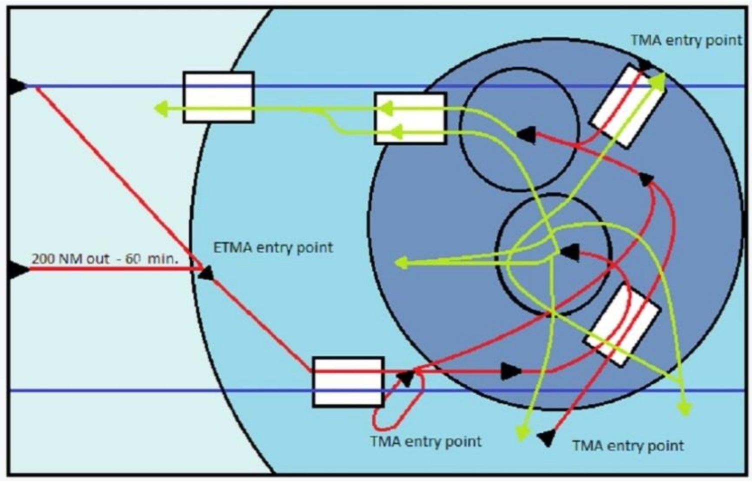


Figure A1.2: A possible scenario of the TMA T1 operation.

Standard instrument departure routes are depicted in green, standard terminal arrival routes in red, and cruise routes at a lower flight level in blue.

A2: Energy

Model predictive control for energy saving in energy efficient buildings

In the context of Cyber-Physical Systems an important application is in the energy field. In particular the building sector consumes approximately 20% of world energy use, which is 40% in the United States. Therefore, it is economically, socially, and environmentally significant to reduce the energy consumption of buildings. Achieving substantial energy reduction in buildings may require rethinking the whole process of design, construction and operation of a building. Hence, the aim in controlling such a process is to save as much energy as possible while guaranteeing comfort for their occupants. Due to the scale and heterogeneity of control systems for large buildings, the design of the control algorithms and communication networks for these systems becomes very challenging and difficult to be carried out manually. The challenges in this control design are to take into account in the feedback control loop the time-varying user loads, renewable energy availability and weather predictions while abiding by the comfort constraints for the occupants. Model Predictive Control (MPC) naturally enters in this scenario as a control methodology that can improve building thermal comfort, decrease peak demand and reduce total energy costs by using all the aforementioned predictions. When one deals with this problem, there are two main areas to consider: energy conversion and energy distribution.

In collaboration with the University of California at Berkeley we performed research focused on the energy distribution system. In particular we aim to use Model Predictive Control (MPC) to perform energy optimization in Heating, Ventilation and Air Conditioning (HVAC) systems as depicted in Figure A2.1, while guaranteeing comfort for occupants.

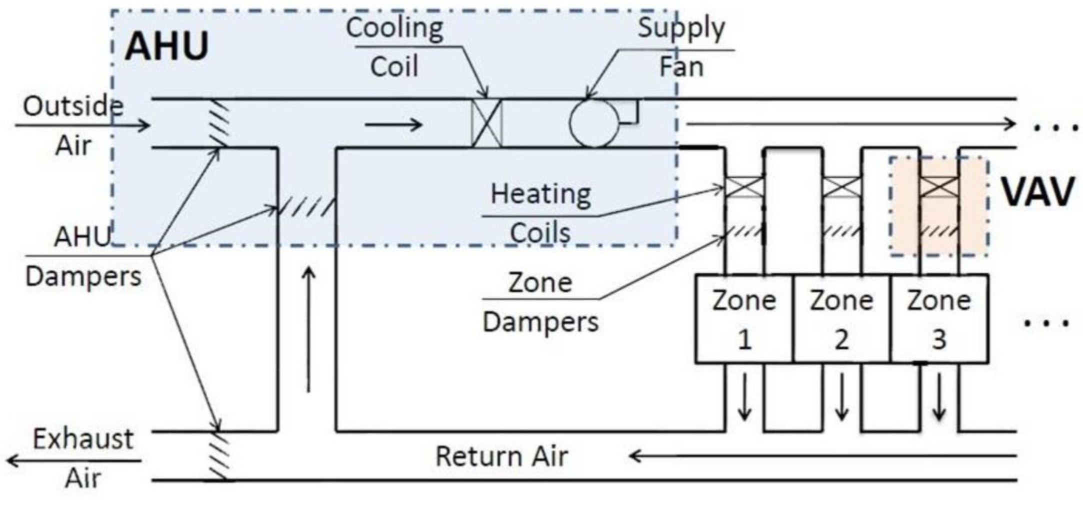


Figure A2.1: HVAC system structure.

In collaboration with Prof. Francesco Borrelli, University of California at Berkeley, USA, we are developing a MPC strategy based on a hybrid model describing the room temperature dynamics (F. Smarra et al. "Switching MPC for HVAC systems", in preparation). The continuous dynamics of each discrete state of the hybrid model are linear. Since the hybrid MPC is well known to be NP-Hard, we proposed a strategy that is a relaxation of such problem. In particular, we propose a control strategy that consists of a switching between linear MPC controllers, each based on the linear dynamics of the corresponding discrete state of the hybrid model. The advantage of this methodology is the use of a more accurate model and a faster control algorithm with respect to classical control strategies based on non-linear or linearized models. We implemented our algorithm for the temperature control in the MPCLab at University of California at Berkeley, obtaining the results showed in Figure A2.2.

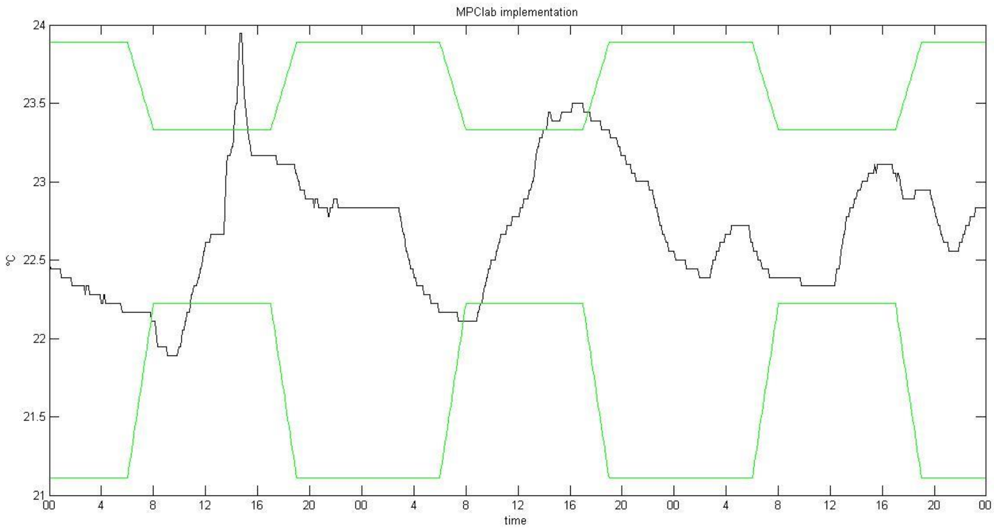


Figure A2.2: Temperature in the MPCLab.

The algorithm has been running from February 14th 2013 at 00.00 to February 16th 2013 at 23:59. The black line represents the room temperature. The green lines represent the comfort bounds for the temperature. We can see how the temperature is contained in the bounds except for small violations, which are allowed in the algorithm for feasibility reasons.

In future research we wish to compare this methodology to existing ones, which consider bilinear and linearized model, from the points of views of bounds violation and energy consumption.

Supervision, control and protection systems for novel nuclear plants

The generation of electricity from nuclear energy allows reducing pollutant gases (CO2 and others) and present important advantages (among the others: little amount of fuel and more economic transport, virtual geo–political independency, continuity of electricity production, small amount of waste – although radioactive) over electricity produced from fossil fuels. Among the disadvantages, the critical one is the security of nuclear plants. Human errors (Chernobyl), improper accident management and old plants (Fukushima) require the development of reactors of new generation, where the safety and security issues are central. From a general perspective, control systems design has to satisfy all requirements imposed by process, safety and operational constraints, at the same time. In the case of nuclear plants, safety becomes the most important parameter that must guide the design phase, as underlined by the lessons learned from the Fukushima accident. Control systems are the basic instruments the operator can use to guarantee that all process parameters are kept inside a given safety range, or to ensure that protective actions are actuated to lead them back into the range. The problem, when dealing with nuclear plants, becomes of utmost importance when a failure occurs. In this case, the operator must rely on robust control systems able to guarantee a rapid, effective feedback action to put the system in a safety mode, as prescribed by the regulatory procedures. Then, the problem of a proper controller design reveals crucial and, in fact, has been considered of primary importance in the design of Generation III/III+ Nuclear Power Plants (Areva 2008, Mitsubishi 2011, UK–EPR). To this aim, the design phase can be strengthened in terms of reliability by using a simulation environment able to reproduce the behavior of the plant control systems, and to evaluate the controller performances before implementing it in a real device.

The research activities at DEWS, in collaboration with ENEA Casaccia, focused on the design of dynamic controllers for the primary circuit of a PWR, using a simulation environment to test the effectiveness of the control actions [CCD12], [CCDMS13], [CCDS13], [CDMS13a], [CDMS13b], [CCD14], [CDM14]. The model used to derive the control is accurate enough to capture the nonlinear, time–varying, and switching nature of the system. An important feature of these controllers is that they do not use direct measurements of the pressurizer pressure or temperature. In fact, they rely only on pressurizer wall temperature measurements, while the pressurizer temperature and pressure are reconstructed by the controller dynamics. Hence, it can be also used as a simple decision support tool in case of pressure sensors failure. A further advantage of such a dynamic controller is that it can attenuate the classical drawback due to the long response of temperature sensors, which may cause some troubles to pressure control. Moreover, disturbances and parameter variations are compensated by the use of sliding–mode terms, which guarantee further robustness to the control scheme. The designed controllers are then implemented in Simulink, and it is shown that they ensure good performance even in the presence of unmodeled uncertainties and disturbances. The switching nature of the controller, reflecting the switching nature of the pressurizer dynamics, and the nonlinear terms implemented in the controllers, along with classical PI terms, ensure better transient behaviors. Hence, they represent an evolution and an improvement with respect to classical PID controllers, usually implemented in standard control actions.

A3: Advanced monitoring and control

The methodological research activity and especially the one in M2 (Communication and Protocol Design for Pervasive and Cognitive Networks) and M3 (Design Methodologies for Embedded Systems) is strictly related to various application domains in which wireless sensors and actuators networks provide the technical enabler for advanced applications. : In this context, A3 investigates the following application areas:

- Environmental monitoring and control
- Home automation
- Structural monitoring
- Homeland security
- Support to education and art

The main objective of A3 is to develop intelligent methodologies and innovative systems for monitoring and control of critical infrastructure systems (e.g. civil infrastructures, telecommunication networks, and water distribution systems) and efficient support for the improvement of everyday life (e.g. ambient assisted living systems, support for art and education etc.). This action brings together expertise from different fields in order to develop methods for managing and protecting critical infrastructures, especially those of major interest for the society.

Although research activities have been performed in all these areas, in the specific period 2012-2014 no projects on the "Environmental monitoring and control" application area have been carried out.

Besides all the activities to support the development of applications and prototypes, illustrated in the description of the most recent projects in the remainder of this section, DEWS researchers performed international coordination activities on application domains of relevant interest.

Home automation

In recent years, the gradual development in the field of electronic devices and communications has led to a widespread use of smart devices capable of communicating over dedicated networks and on the Internet. This has led to a gradual diffusion of advanced devices within the home, with the development of control systems and home automation. The applications of these systems are numerous, from remote monitoring and control of household appliances to ambient assisted living. Home automation problems have been specifically addressed in the context of two projects: Casa+ and Smiling. Design and verification activities specifically applied the principles defined under the M3 methodological research line (Design Methodologies for Embedded Systems).

Casa +

Recent technologies applied or explicitly developed for assisting people with physical disabilities or weaker individuals that need particular attention, are becoming an emerging research topic. The final goal of the Casa+ project is the development of a smart house providing active support for people with the Down Syndrome by means of advanced hardware and software tools; the Casa+ environment is a smart apartment providing functionalities for monitoring the environment and its guests, giving indication signals, audio messages or even alarms in case of incorrect actions. Through exploitation of the most recent technologies, keeping in mind the trade off with costs, we developed the following functionalities: security, time management, assistance for daily activities, monitoring and remote control, tracking.

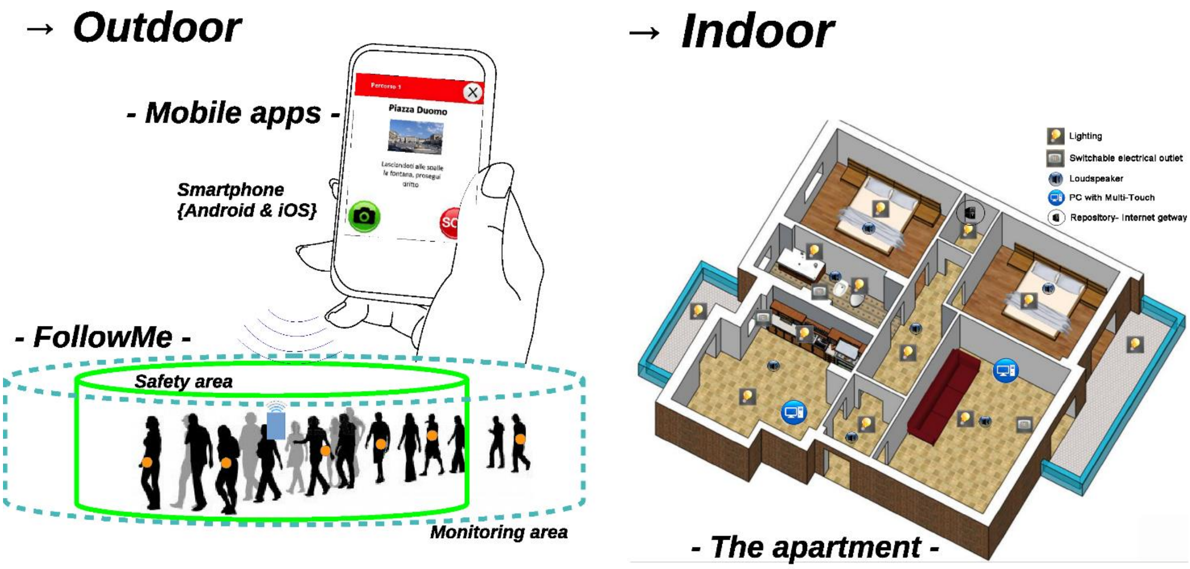


Figure A3.1 - Casa+ technological aids

We briefly present a list of issues addressed during the project.

- **Domestic safety** - The apartment is equipped with specific units in charge of verifying the presence of people inside each room for a double aim: control and authentication. In particular authentication devices have to be hidden (e.g. inside a watch), which is able to communicate in a wireless fashion to another device collecting all data.
- **Time management** - is a critical aspect for people affected by the Down syndrome because they often take too much time to carry on daily actions. In order to efficiently organize and schedule these actions we introduced duration's indicators helping Casa+ guests to become aware of the passing time. These indicators can be of various types: tactile, auditive, visual or a combination of them. The basic idea is to remove these devices in a progressive manner while guests improve their sense of the flow of time.
- **Daily actions assistance** - The aided daily actions are: preparing food, taking care of the house, doing the groceries etc. In particular, audio/video devices are used to send data and suggestions with the primary aim of progressively reducing their presence.
- **Remote monitoring and control** - The process of increasing awareness on potentialities and capabilities is a procedure that has to involve also the families of directly interested persons. With this objective in mind and in order to provide for personal safety, we equipped the apartment with remote monitoring and control devices. This way it is possible to remotely access a part of Casa+ data and educators can eventually use previously described devices to send messages to guests and parents can convince themselves of potentialities and capabilities of their sons.
- **Communication infrastructure from and to the outside** - We provided a communication infrastructure in order to guarantee the previously described

monitoring and control functionalities as well as to send messages to the guests. Various communication protocols and an alternative power supply are assumed to avoid absence of service.

- **Tracking** - The geographic position survey is an essential element to guarantee mobility support to a person affected by the Down syndrome. We exploited the use of a small and simple device supporting indoor position traking. This allows the educators to supervise these data depending on the level of autonomy of each person as well as his/her improvements due to the increasing experience. Additionally, an outdoor tracking service (Follow-me) for monitoring and supporting guests in outdoor experiences (e.g. short trips) has been provided. The system is able to send an alarm message to educators in case someone move far from the rest of the group.

In the 2012-2014 period the main activity has been the maintenance and improvement of all facilities [AGMR+13]. In particular for Mobile app and follow-me, we developed a Mobile application both for iOS and Android, that offers all the features of the web applications optimized for smartphones and tablets and can receive push notification from Casa+ system for example when the shopping list has changed. The follow-me service is an integration between the mobile apps and the WSN; the smartphone is the gateway of the sensor network constituted by the previously described watches that are worn by the guests. The app reports information on the watches wearing and the distance from the educator and the guests.

SMILING

This ability to introduce interesting new elements in the context of home automation through a wise insertion of wireless components is also a key element of a national project , funded by the Ministry of Economic Development in 2012, aiming at innovating the home automation context, entitled SMILING (SMart In home LIviNG: Innovative technologies for sensing and automation in Home Automation).

The project aims at creating a "laboratory" for the transfer from research to the industries involved in developing technologies of advanced automation and sensors, in the field of home automation. These technologies allow the development of innovative products and the delivering of new services to improve housing quality and energy efficiency. The laboratory consists of three operating units distributed in south-central Italy. The coordinator is in the Marche Region (Fabriano, AN), while other places involved are located in Abruzzo (L'Aquila) and in Campania (Napoli) Regions. The two involved universities, Università Politecnica delle Marche (as leader) and Università degli Studi dell'Aquila (DEWS), provide their expertise and research in order to upgrade the product offerings of many SMEs in those territories that are currently operating in the fields of mechanics, electronics, mechatronics, information technology, furniture and systems for energy production and management. The distributed laboratory performs three main tasks:

- serve as a demonstrator of the innovative proposals coming from the involved research centers;
- stimulate and support, at both technical and management levels, the creation of new high tech enterprises;
- support new enterprises in carrying out tests and act as a meeting and exchange point.

The following items summarize the main current contributions from DEWS (and related publications in the considered period):

- Analysis and characterization of current ICT research activities performed by the Abruzzo Region universities. The results of such an analysis will be published in early 2015 in a book (Italian language) about "Abruzzo Region and ICT" edited by Polo ICT Abruzzo;
- Support to the creation of start-ups. DEWS has organized several local events to publicize its availability, to provide technical/management support to start-uppers (especially in fund-raising activities). Up by now DEWS is supporting near 10 start-up projects. Thanks also to such a support, three of them have already obtained funding by means of regional/national grants;
- Task force for auditing and assessment of existing enterprises. DEWS has joined a task force, , that will support existing enterprises to effectively scout and exploit proper ICT technologies to innovate processes and products;
- Laboratories and demos. DEWS is building a physical lab to fully support project activities and goals (i.e. serve as a demonstrator of the proposals coming from the research centers, stimulate and support the creation of new high-tech enterprises, support enterprises in carrying out tests and as a meeting and exchange point). The focus is on embedded SW for wireless sensor networks. The SMILING Lab will act as a remotely accessible test-bed composed of more than 100 sensor nodes (similar, for example, to WISEBED). Such a lab will be further integrated with other ones developed in the context of other UNIVAQ projects (i.e. RICOSTRUIRE).

DEWS is developing some demonstrators showing how to exploit the technologies provided by the lab itself. Currently the focus is on: indoor/outdoor localization and tracking by means of WSN and networked embedded systems [PRST13]; WSN for secure monitoring applications [PMSP13], [PPMS13a], [PPMS13b], [PPS12], [PRC12]; support to new arts (in collaboration with the Research Line "Smart Education and Art" of this Research Area) [PPRS13], [PRSG13], [RSPG13], [PRGT12].

More details on the performed work can be found in referenced publications and in the available project deliverables.It is worth noting that some of the previous activities are strictly related also to the Research Area M3 and, in particular, with the Research Line: "Embedded Systems Rapid Prototyping" and the VISION European project. Finally, it should be highlighted that DEWS activities in the SMILING project have been often performed with the support of other project partners and collaborators. In particular, they are the other partners from Abruzzo Region (i.e. Fondazione MIRROR[1] and Confindustria L'Aquila), Partner and Fabbrica della Conoscenza[2].

Structural Health Monitoring

In recent years, structural health monitoring emerged as a useful tool for assessing the condition of civil structures and rapidly determining a safety level for their users. Traditional monitoring systems are composed of grids of sensors distributed along the structure to be monitored and connected to a central acquisition and processing unit through cables. Lately, Wireless Sensor Networks (WSN) emerged as a possible attractive alternative solution. Indeed, the replacement of cables with wireless connections along with the use of modern sensors allows to obtain significant benefits in terms of cost, size, ease of installation and invasiveness (a key issue, for example, in the case of historical buildings).

[1] http://www.fondazionemirror.it
[2] http://www.fabbricadellaconoscenza.com

Structural monitoring systems design and implementation problems have been addressed in the context of a collaboration between the DEWS Center of Excellence and the Center for Research on Earthquake Engineering (CERFIS)[3] of the University of L'Aquila. An ongoing experimental setup, the structural monitoring of the Basilica S. Maria di Collemaggio (L'Aquila) allowed a detailed analysis of such problems [FGFG+12]. Prototype development and on-field experimentation activity is framed within the M3 methodological research line (Design Methodologies for Embedded Systems).

Structural Monitoring of the Basilica S. Maria di Collemaggio

The L'Aquila April 6, 2009 6.3 Mw earthquake seriously compromised the integrity of most of the city's structures. The Basilica of Santa Maria di Collemaggio (L'Aquila's most important church) suffered serious damage. There has been a partial collapse in the transept area and the total collapse of the dome. External walls and the inner aisles reported deep fractures.

The Basilica of Santa Maria di Collemaggio had already been object of several campaigns of studies conducted by the Department of Structural Engineering of the University of L'Aquila. On the basis of prior acquired knowledge and with the aim to investigate further the causes of the collapse, as well as to verify the possible modifications of the structural behavior consequent to the restoration of the structure, the installation of a permanent structural monitoring system in the Basilica has been promoted [GGFP+13].

With the aim to assess the possible benefits of using innovative technologies, such as wireless sensor networks and MEMS accelerometers, the CERFIS promoted a collaboration with the Center of Excellence DEWS of the University of L'Aquila for the development and implementation of a wireless sensor network for vibration monitoring.

a) b) c)

Figure A3.2 - Structural Health Monitoring of the Basilica S. Maria di Collemaggio; a) Front view of the Basilica, b) a wireless sensor node installed on internal wall, c) wireless sensor node installed on the façade rear

The project involved two different phases: development and installation of an acceleration monitoring system and the development and installation of a crack width and wall inclination monitoring system.

Design, development and implementation of vibration monitoring network has been based on a system already available on market and already targeting structural health monitoring applications. The use of a commercial solution allowed to quickly put in place a working solution for the vibration monitoring. This brought two major advantages: the possibility to start the monitoring action immediately after the implementation of structure retrofitting,

[3] http://www.cerfis.it

and the possibility to explore the possible advantages and disadvantages of a wireless sensor network applied to vibrational monitoring starting from a consolidated solution.

Main focus of the Collemaggio monitoring system is vibrational and seismic monitoring, with 16 nodes including a tri-axial MEMS accelerometer deployed along the church. Data from accelerometer sensors are collected and uploaded on a remote server on a daily basis. Vibrational and seismic data allowed both the identification of main structural parameters and the determination of the structural behavior of the church under a seismic excitation.

The results of this study allowed to highlight the main problems of a wireless network. Furthermore it has been possible to characterize the main modifications of the structure after the earthquake occurred, and carefully assess the safety of the structure [GGFP+14]. Periodically updated results are available online in a dedicated technical report[4].

Figure A3.3 - WESTmote sensing platform with IP-65 compliant packaging

The second phase of the Basilica S. Maria di Collemaggio monitoring project involved the design, development and implementation of a crack width and wall inclination monitoring system. Developed solution does not rely on COTS nodes, but on a full-custom wireless sensing platform [FACG+13].

The goal has been both to develop an optimized solution targeting final application requirements and to relay on the experience gained from the first monitoring phase to develop a flexible node for structural health monitoring applications [FACG+14]. Moreover, key requirements for the final implementation were flexibility, high energy-efficiency and long operating lifetime.

A custom wireless node (the WESTmote, Figure A3.3) targeting described application has been designed in strict collaboration with WEST Aquila Srl. The platform is IEEE 802.15.4 standard compliant and explicitly targets structural health monitoring applications, supporting operation in harsh environments and long-term operating lifetime.

Development of advanced solutions based on designed custom platform, along with the extension of the monitoring action to multiple buildings distributed on a metropolitan area will be considered in the next future [GPGF+14].

Homeland security

Maximum attention is paid to the issue of homeland security and, in particular, on how the technologies of heterogeneous and cooperative networks can provide a significant contribution in monitoring and control of land and/or sensitive perimeters. The specific aim

http://www.cerfis.it

of this research area is to maximally exploit wireless technologies to increase efficiency and resiliency of security related systems and functionalities in this challenging scenario. Design and implementation problems of homeland security systems have been explored in the context of two projects (Seaport and GRETA) and of internal research activities (e.g. localization solution design and verification). All these activities are strongly related to M2 methodological research line (Communication and Protocol Design for Pervasive and Cognitive Networks).

Seaport

The primary goal of the research project, carried out in collaboration with Thales Group[5], consists of studying and developing advanced technologies applied to the management of wireless sensor networks integrated in distributed communication infrastructures.

Most applications relevant for Thales involve distributed system architectures that integrate communication components, embedded systems, and data processing technologies, to ensure seamless user access to sensor data.

The technological challenge is considerable and affects several research areas:

- passive and active sensors together with query and control devices;
- wireless communication networks;
- distributed middleware;
- data management;
- operating systems oriented to energy savings.

The research activities will be directed to supporting complex applications, such as chain processes optimization, and supplying chains value improvements. Advances in technology can be reused in other applications, such as Homeland Security and logistics in port operations, in particular for what concerns the Livorno port area.

In this context, the project's main goal could be the creation of a platform able to allow a rapid and efficient development of applications for sensor networks monitoring and control in distributed architectures.

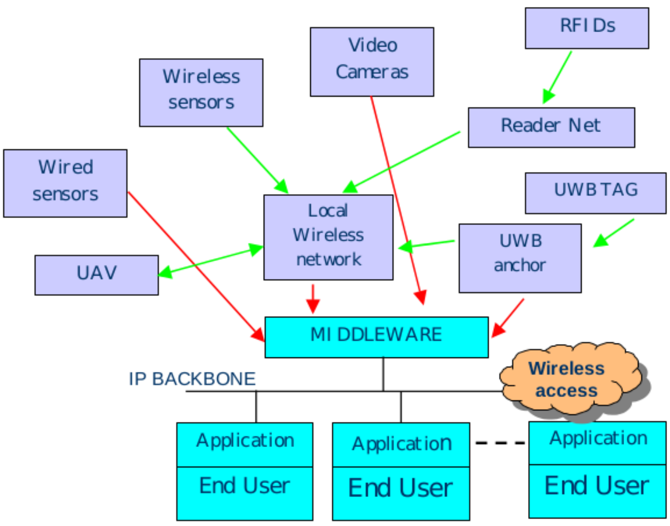


Figure A3.4 - Seaport architecture schematization

[5] http://www.thalesgroup.com

The newest and most important character in this study is represented by the multidisciplinary approach. Thales Group is the only venture supporter with following actors acting as consultants:

- University of L'Aquila by means of three major research facilities:
  1. The Department of Business, Information and Industrial Engineering (DIIIE), which carries out research in the field of Electrical and Information Engineering;
  2. The Department of Information Engineering, Computer Science and Mathematics (DISIM), which carries out research in the field of Computer Science and Information Engineering;
  3. DEWS Center of Excellence, which carries out research in sensor networks.
- WEST Aquila Srl, a SME founded as spin-off of University of L'Aquila, based on knowledge and skills acquired over the years by the Center of Excellence DEWS in the field of wireless sensors networks and control systems.
- Beep Srl, another SME founded as spin-off of University of L'Aquila for research in the computer industry.

The project started in January 2014 and will last 3 years. The activities performed during four months have been focused on the definition and analysis of the following aspects:

- network architecture;
- middleware features in relation to distributed filtering processing, event detection, tracking, security management, and gateway features;
- available services at the interface with application layer;
- interface with the several radio network components.

Greta

The GRETA project (funded by PRIN under Grant 2010WHY5PR) is focused on innovative solutions and disruptive technologies aimed at the realization of a distributed system for identification, localization, tracking and monitoring in indoor scenarios, based on environmentally friendly materials, where the tags must be:

1. localizable with sub-meter precision even in indoor scenarios and in the presence of obstacles;
2. small-sized (flat, with an area in the order of a few square centimeters) and working without cumbersome batteries;
3. made with recyclable materials, to be integrated in goods, clothes and packings.

This project aims at realizing a network of wireless ecological devices for identification, tracking, and monitoring of mobile entities (persons and things), as shown in Figure A3.5. The intention is to employ zero-power UWB communication techniques, eco-compatible materials and energy harvesting solutions that help to store the energy from the surrounding environment. The new system herein proposed is expected to provide, among all, the trajectory of observed objects, to sense, store and share in the network the associated parameters, in a non-ambiguous fashion and for a great number of objects. This goal will be achieved through the development of systems composed of a multiplicity of readers connected in a network (Network Green RFID - NG-RFID) and capable to interrogate a large number of green tags offering sensing capabilities.

The project started on February 2013 and will last 3 years[6]. In the first year of activity we are mainly involved in the development of the following activities:

1. Analysis of reader and tag architecture solutions;
2. Implementation of investigated tag architectures;
3. Support for different signal formats (UHF and UWB);
4. Analysis of tag timing and synchronization schemes.

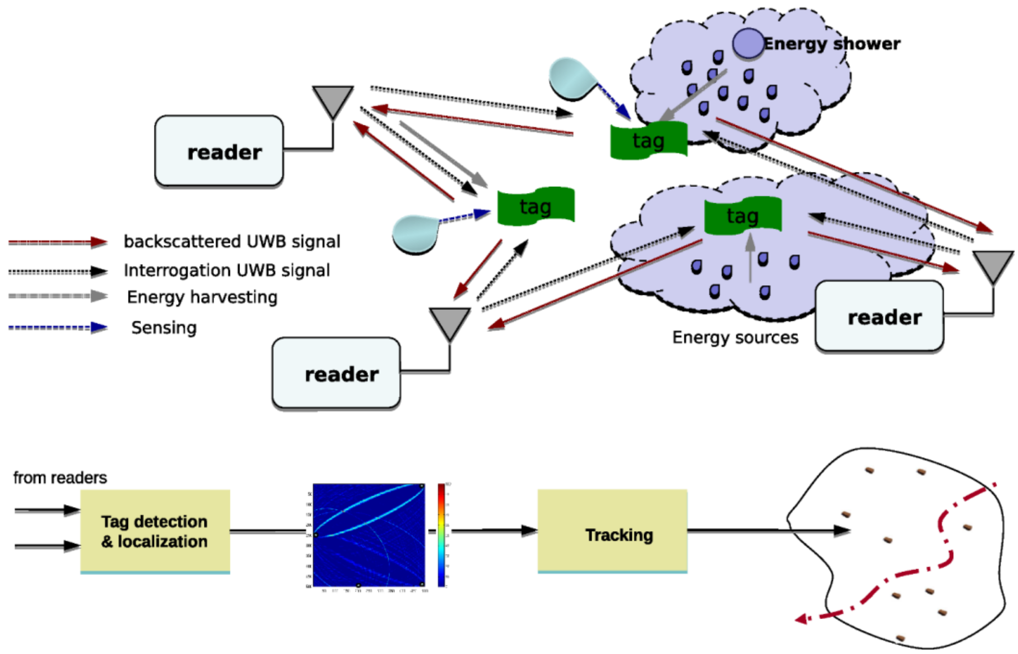


Figure A3.5 -The proposed NG-RFID system architecture

Localization

In the frame of the Homeland Security area, a novel mechanism of cooperative and device-free localization technique has been studied. A network composed of 40 TelosB nodes has been setup in the laboratory of DEWS of this University and performance of the localization accuracy assessed in several distinct scenarios.

[6] Green tags (GRETA) project deliverable D1 (Report on the First Half Year of Activity, 2013) and D2 (Report on the First Year of Activity, 2014) are available online at: http://www.greentags.eu/

Figure A3.6 - Experimental Setup at DEWS Lab

Figure A3.6 sketches this setup. Forty nodes have been deployed along the perimeter of a conference room at around 1 meter above the ground. These nodes were configured to transmit beacon signals in a collision-free and scheduled fashion on an IEEE 802.15.4 compliant channel (i.e., channel 26 in the 2.4 GHz frequency band) and each time a node transmits, the other nodes record the received signal strength (RSS) measurement of the link. Through the analysis of the variations of such RSS measurements on each link when a person is steady or moving inside the area covered by the network, it is possible to identify the position of the person with an accuracy ranging from 5 cm to 95 cm.

This study and the experimental setup has been carried out during an undergraduate student's thesis work and the outputs of this activity are currently being organized into a paper to be submitted to the first incoming International Workshop on Wireless Sensors Networks for Mobile Health[7].

Smart Education and Art

The contamination between scientific knowledge and artistic components is too often limited to chance, mainly stemming from the convergence on the same research group of technical and artistic interests. In this scenario, one of the main interests has been the integration of wireless communications and audio waves (as they are both characterized by the same propagation medium, even if with substantially different propagation modes). Moreover, the use of technology as an effective support for learning has been explored, with specific reference to the methodologies developed in the context of M3 research line (Design Methodologies for Embedded Systems).

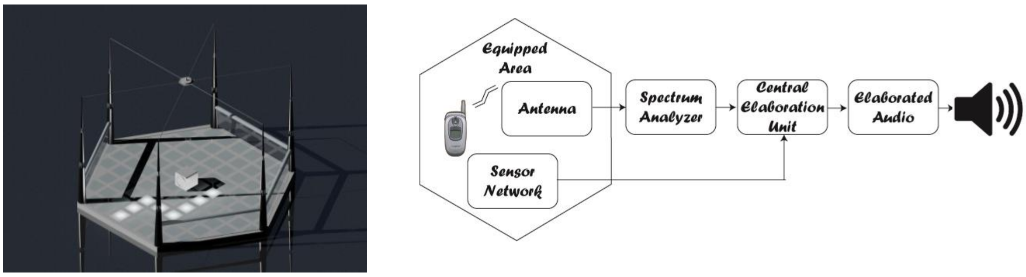
RF Sounding

RF Sounding is an open space installation that comprises both artistic and technological innovations: its aim is to provide the user, while entering a specifically defined area, with awareness of radio frequency signals characterizing the cellular networks band. Indeed, radio signals are shifted, with proper elaboration, to the audible band and the result is spread all over the specific area through a certain number of loudspeakers.

The aim of this project is twofold. Indeed, from one side we want to increase end users knowledge of the strength of the power emitted by their cellular phones with respect to the

[7] https://sites.google.com/site/wsn4health2014/

electromagnetic fields produced in the environment, on the other hand we want to provide for an artistic and interactive installation that can also be remotely joined through a web interface.



a) b)

Figure A3.7 - RF Sounding: a) axonometric view, b) dataflow diagram

The main project comprises a hexagonal area that is equipped with gate sensors, a subwoofer, six loudspeakers, a receiving antenna for RF sensing and six sensor nodes for localization. The RF signals gathered by the antenna and the localization data coming from the sensor network are sent to a spectrum analyser and an elaboration unit in order to process sound and spatialization algorithms (Figure A3.7).

A first prototype (Figure A3.8) has been successfully implemented and approved by various Italian contemporary music composers. With respect to the general project the spectrum analyser is replaced by a GSM engine (Siemens TC35), the localization algorithm is achieved through an active target and sound spatialization is simplified in stereophony.

The active localization is achieved through the use of Crossbow Crickets motes and a proper developed algorithm. These nodes establish a network where a certain number of anchors (called Beacons) send to the node to be localized (called Listener) both RF and ultrasonic signals. By computing the time difference of arrival of the two signals, the Listener is able to estimate its distance from each Beacon.

The sound produced by loudspeakers is depending on BSs channel frequencies and Rx powers, as well as user position in space. The sound is elaborated in real time on a laptop that receives data from the listener and the TC35. A proper implementation of Open Sound Control (OSC) protocol has been developed to guarantee these connections.

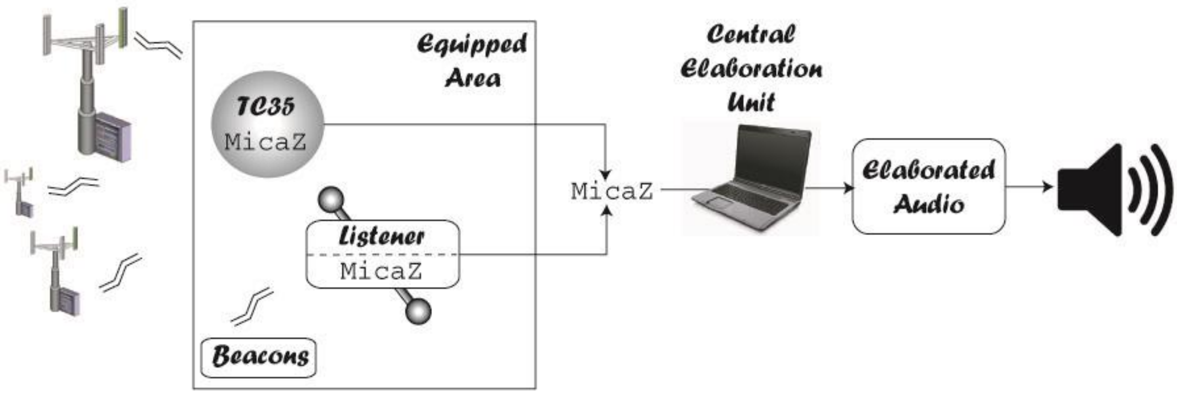


Figure A3.8 - Dataflow of the implemented prototype

A step ahead with respect to the first developed prototype has been done by replacing TC35 is with a spectrum analyzer and realizing the localization through the use of a Microsoft Kinect (Figure A3.9). In this way, two important issues of the project can be addressed: exploitation of uplink and downlink channels and passive localization. Moreover, two different processing units are connected respectively to the spectrum analyzer and to the Kinect, this allows to increase remoteness and system flexibility which in turn could widespread uses' applications [RSPG13], [PRSG13].

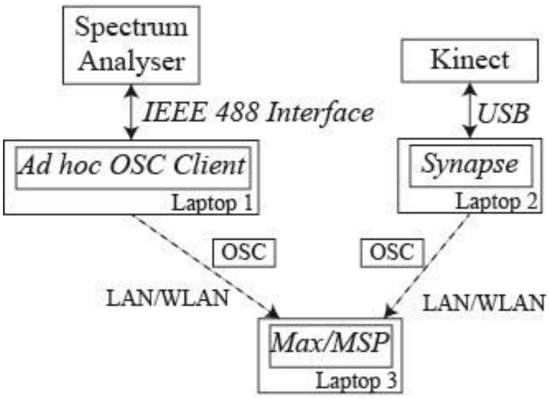


Figure 9 - RF Sounding revised architecture

CrazySquare

Crazy Square [PPRS13] is an interactive environment for music learning that is specifically developed for children approaching music and a musical instrument for the first time. The learning game is based on recent educative directions toward a direct approach to sound instead that to musical notation alone and it has been inspired by a *paper* procedure that is currently used in an Italian middle school. Crazy Square, represents a valid aid for teachers who want to engage their students in a playful dimension of learning rhythmic notation and pitch, thus following game procedures which are now very common. Indeed the project has been pushed by the fact that current students belong to the digital natives generation.

The Crazy Square is a musical game originally thought for (but not limited to) children that approach the study of music and of a musical instrument for the first time. The main purposes of the crazy square are the following:

- to offer to the students a playful and creative approach to the study of a musical instrument;
- to avoid the study to be discouraged and sometimes prevented by the use of educational books requiring, from the first exercises, a complete knowledge of musical signs;
- to overcome the problem of the separation between the study of musical symbols and the study of the musical instrument.

The Crazy Square is thus an educational instrument that allows merging the study of rhythm and its representation, with the technique on the musical instrument through a preparatory, creative and playful approach. In its digital version, the game aims to cover some different levels of difficulties in terms of the understanding and the execution of rhythmic patterns and melodic sequences.

The game prototype (Figure A3.10) was mainly implemented using *Processing*, an open source programming language whose code can be easily exported as Java applet or to mobile platforms. In particular, the library *Minim* has been chosen for SP purposes. Moreover, for sound synthesis we exploited the use of *SoundCipher*.

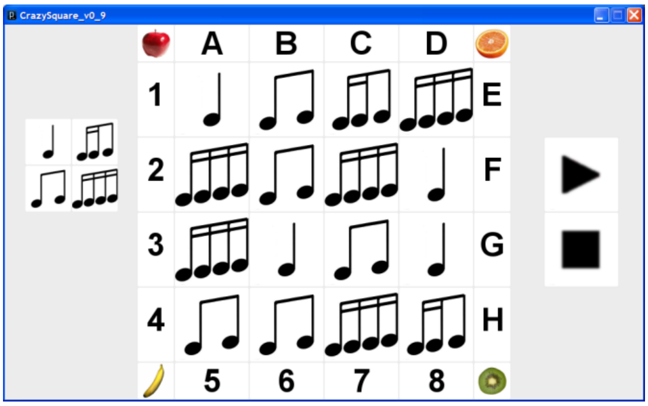


Figure A3.10 - Screen shot of the developed prototype

Intelligent Transportation Systems

Monitoring solutions developed in the context of A3 research line found a specific application also in the case of intelligent transportation systems study and analysis (Line A1). Specifically, the KHE-STO project will address problems related to the implementation of advanced services for monitoring and entertainment on local transport vehicles.

KHE-STO

The KHE-STO project ("Know-how enhancement for sustainable transportation organization"), targets the enhancement of know-how in the organization of local transportation systems. The project is funded by the second call for ordinary project proposals of IPA Adriatic cross-border cooperation program, an international program promoting territorial cohesion and competitiveness across the Adriatic Sea (project code: 2°ord./0042/1). After the earthquake that struck the area of L'Aquila on April 6 2009, more than 40 thousand people were forced to leave their homes and move to temporary residences in the coastal area. Most people, however, were forced to travel daily between the coastal area and the interior (e.g. for working reasons or related to the post-earthquake management of their possessions). This caused a notable and sudden increase of the number of cars on the main traffic routes, and therefore considerable consequences for what concerns stress for travellers and air pollution. Sustainable mobility, with the possibility of easily reaching the city of L'Aquila from the other areas of the Abruzzi region, has been considered as a target goal in the process of post-earthquake reconstruction. From this point of view, the KHE-STO project represents a pilot initiative exploring the efficient use of ICT tools and know-how for the implementation of a smart local transport service. Through these connection resources, exploiting wisely a multi standard (3G cellular networks, WiFi networks, satellite networks) gateway, the traveling people can be projected within their school, university or work networks and they can access to all the services provided by these networks, more over many workers will be in the position of partially exploiting transfer time as working time. The design and implementation of monitoring systems based on Wireless Sensor Network technology will support advanced telemetry on bus vehicles, allowing to provide useful information on bus geographical position and environmental conditions. Finally, the implementation of people tracking systems will support efficient mechanisms for statistical profiling of transportation lines (for example, with the use of on-board people counting systems) or travellers' security (for example, with the use of RFID identification systems on school buses).

Graduate School in ICT

Contents and Strategic Areas

Some major areas have been carefully identified and promoted, to provide the basis for an interdisciplinary education in the area of pervasive computation, communication and control systems:

- Advanced devices and integrated electronic systems, that encompass microelectronics and advanced digital systems, programmable HW and HW/SW co-design,
- Communication and networking technologies, that include wireless communication and software defined radio, cognitive and cooperative radios, heterogeneous networks and service platforms, Internet of Things,
- New generation computing, that refer to both architecture (cloud computing, web 2.0) and algorithms/content (computational complexity, advanced algorithms and data structures, mathematics of optimization),
- Networked embedded systems and control, including control and hybrid system theory, model-based design and embedded software,
- Advanced software engineering, including model-based service-oriented development and run-time verification/monitoring.

The first step for the establishment of an Advanced ICT School on pervasive computation, communication and control systems was the completion in 2011 of a proposal that received a very positive feedback from the local academic community, consisting of a multi-disciplinary group of about 40 faculties and tens of post-docs and research associates. Further, the proposal gained enthusiastic support from industry, because of its goal of connecting the two communities to elevate the knowledge basis of industry on the topics of interest to the School. The acceptance of the proposal had a number of important outcomes: i) the ICT School was considered as a founding pillar of the Innovation District (Polo di Innovazione) "ICT Abruzzo", ii) it was fully endorsed by OCSE as an enabling initiative to reinforce/innovate the local economic context after the 2009 earthquake, iii) joint research initiatives and laboratories have been funded by industry in recognition of its potential economic impact.

A side effect (nonetheless very relevant) on the academic side consisted in the definition and startup (since July 2012) of a new department at the university of L'Aquila in the frame of the global restructuring process that the Ministry of Education and Research (MIUR) have imposed to italian universities: the new Department of Information Engineering and Science, and Mathematics has been founded on a research and education project that heavily relies on the ICT School project.

Integration with Innovation District "ICT Abruzzo" and fund raising

After a competitive call issued by the local government (Regione Abruzzo) in agreement with the EU policy for stimulating the creation of innovation districts (Poli di innovazione) in the globalized economy, the Center of Excellence DEWS has been very active in preparing a successful proposal for the foundation of "ICT Abruzzo". ICT Abruzzo started its activities at the end of 2011 and now includes 55 companies (among those Micron Technology, Selex-Elsag, Telespazio, Fastweb, several SMEs) while other companies have recently applied to join. In this context the ICT School has been included as a founding pillar for promoting and implementing innovation through advanced training at the doctoral level: the School is intended also as a fundamental environment for improving cooperation among companies and between companies and universities/research centers as well. In 2012 ICT Abruzzo and the University of L'Aquila successfully applied to a competitive call launched by the national unions and association of industries (Confindustria) with a project intended to support start-up and early stage development of the ICT School in the period 2012-2015: the overall budget is 1.2 M€ with 50% co-funding.

State-of-the-art in implementation

As planned, the formal definition of the structure and regulation of the ICT School within HYCON2 and Innovation District "ICT Abruzzo" has been carried out, with a related plan of technical activities, funding and the first cycle recruitment procedures. Particular care has been devoted to emphasize the international target of the school, both in terms of recruitment, mobility of students and programs for joint titles wherever applicable. In August 2012 the formal institution of the new Doctoral Program in Information Engineering and Computer Science (with the second name of ICT School on Pervasive ICT infrastructures) has been completed at the University of L'Aquila and it was an essential step for setting up the academic framework that is required to implement the ICT School project.

For the academic year 2012-2013, the Call for application has been launched soon after August. Although a very short window (30 days) has been kept open for applications, a good number of applicants (23, of which 2 from foreign countries) have been attracted and 12 students have been finally admitted with each of the five areas covered by at least one student. We decided to proceed anyway with this quite tight schedule in order to meet the deadline for starting the Doctoral Program in the academic year 2012-2013 and avoid to wait for the next academic year; indeed, the current regulation in Italy imposes just one recruitment window per year.

In summary, the 12 positions are supported by the following grants:

- 4 PhD scholarships funded by ICT Abruzzo under the framework depicted above;
- 2 PhD scholarships funded by the national MIUR program "Fondo Giovani";
- 1 PhD scholarship funded by the RICOSTRUIRE project, that deals with technology transfer in the ICT domain;
- 1 PhD scholarship funded by MICRON Foundation;
- 1 PhD position supported by Thales under joint projects with UAQ.

For the academic year 2013-2014 we have been able to recruit 10 students within a set of more than 20 applications. In particular, 4 students are supported by a regular scholarship provided either by MiUR or by University of L'Aquila (thus, we have gained two regular scholarships with respect to the previous academic year), 4 students are supported by grants from specific research projects and 2 students are provided with their own scholarships as they come from extra-UE countries. All recruited students have relevant CVs.

For the academic years 2012-2013 and 2013-2014 a list of courses offered to all Ph.D. students of University of L'Aquila included:

- Regular courses (shared with the second year of Master programs in Automation and Computer Engineering, Telecommunications Engineering, Computer Science), that provide research oriented and interdisciplinary training to newly enrolled Ph.D. students in fundamental topics of the School, e.g. Embedded Systems, Wireless

Communications, Hybrid Systems, Optimal Control, Advanced Digital Systems Design. These modules are taught by DEWS affiliates.

- Short courses and seminars on advanced topics held in close cooperation with the Doctoral Program in Computer Science involving instructors from partner universities and companies: two modules have already been scheduled on 1) Advanced signal processing for multimedia; 2) Software defined and cognitive radio and other modules are being planned.
- Modules taken from International Schools, e.g. from the EECI Graduate School in Control, two of which will be held at UAQ:
- 20/05/2013 – 24/05/2013: Optimality, Stabilization, and Feedback in Nonlinear Control. Given by Prof. Francis Clarke, Université Claude Bernard Lyon 1, France;
- 27/05/2013 – 31/05/2013: Modeling and estimation for control. Given by Emmanuel Witrant, Univ. Joseph Fourier, GIPSA, Grenoble, France.
- 27/05/2013 – 31/05/2014: Convergence theory for observers: Necessary, and Sufficient conditions, Given by Prof. L. Praly, Centre Automatique et Systèmes at École des Mines de Paris.

Future developments

Major efforts will be spent in the short-medium term along the following main directions:

- To complete the structure of the School with a program of the modules that will be taught during the current academic year: we have planned a mix of modules taught by local academic, colleagues from partner universities and partner industries. These activities will be supported through the funding provided by Polo ICT Abruzzo. Furthermore, we aim at establishing a close cooperation with a newly founded graduate institution on fundamental sciences that will be based in L'Aquila.
- To make the doctoral school fully compliant with the new regulations imposed by the Ministry of Research of Italy, we do not expect to introduce any relevant changes. We can say that all relevant requirements have been implicitly taken into account in our proposal and we are particularly glad about that.
- We are planning financial resources for the next round of recruitment in the summer 2013, with a likely plan to increase the number of scholarships. Moreover, we are revising the internal regulations at UAQ in order to launch a full international call and apply worldwide recognized selection procedures.

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2014

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