Dipartimento di Elettronica, Informazione e Bioingegneria Scientific Project

Politecnico di Milano

Section 1 – Foundations

The Dipartimento di Elettronica, Informazione e Bioingegneria (DEIB) aims at being recognized as a worldclass scientific institution fully committed in forefront research, education, and technology transfer in bioengineering, computer science and engineering, electrical engineering, electronics, systems and control, and telecommunications fields. The DEIB builds upon the competencies and the experience of three previous departments: Dipartimento di Elettrotecnica, Dipartimento di Elettronica e Informazione, Dipartimento di Bioingegneria.

The Electrical Engineering area brings to DEIB the legacy of one of the most ancient departments of this University and the most ancient Italian School of Electrical Engineering: the Dipartimento di Elettrotecnica, that was established on 1886, thanks to a donation of the famous industrialist and pharmaceutical research chemist Carlo Erba, under the name of “Istituzione Elettrotecnica Carlo Erba”. The research and teaching interests of this department have been, since the beginning, the very fundamental fields of the Electrical Engineering. The first two courses activated by the “Istituzione” were “Electric dynamo-machines” and “Electrical measurements”, followed, a couple of years later, by “Technology of electrical systems”.

Together with Electromagnetism and Circuit theory, these subjects are still the backbone of today Electrical Engineering all over the world.

The scientific roots of the previous Dipartimento di Elettronica e Informazione date back to the 1940’s when some visionary steps brought the Politecnico di Milano to lead the run in new emerging fields:

- In 1945, Ercole Bottani, Professor of Electrical Engineering founded the “Centro di Studio sui Modelli Elettrici” (Center for the Study of Electrical Models), aimed at fostering research activities on electrical networks for automated calculus.
- In 1951, Gino Cassinis, Chancellor of the Politecnico di Milano, established the “Istituto di Calcoli Numerici” (Institute of Numerical Calculus), which was equipped with a CRC102A, the first Italian computer. Here Prof. Luigi Dadda and some of his collaborators achieved pioneering results in numerical computing, programming languages and computer hardware.
- In 1961, the Electronic Engineering Degree was established, with curricula in electronics, computer engineering, telecommunications, and system theory.
- In 1963, the “Istituto di Elettrotecnica e Elettronica” is founded.
- In the 1970’s, the institute’s research interests were widened through fertile interactions with the CNR (National Research Council). Headed by Prof. Emanuele Biondi, the “Centro di Teoria dei Sistemi” (Center of Systems Theory), started new research lines, such as model identification, process control and applications of systems theory to environmental, biomedical and economic systems.
- In 1977, Prof. Francesco Carassa, pioneer of telecommunication technologies, led the Sirio mission to the path of success. The geostationary Sirio satellite was launched from Cape Canaveral, which opened the way to a line of experiments on propagation and communications at 11.6 and 17.4 GHz.
- In 1982, the Istituto di Elettrotecnica e Elettronica became the “Dipartimento di Elettronica”, and was joined by a group of EE Professors, formerly with the Physics Department. The group was led by Prof. Emilio Gatti, who had played a pioneering role in Electronics since the 50’s. His group brought expertise on analogue circuits and signal processing and on nuclear radiation detectors, as well as novel strategic activities in microelectronics.
- In 1984, the Dipartimento di Elettronica starts the first cycle of PhD programs.
- In 1992, the department changes its name in “Dipartimento di Elettronica e Informazione” (DEI).
- In 2000, DEI starts a comprehensive PhD Program in Information Technology, structured in the areas of Computer Science and Engineering, Electronics, Systems and Control, and Telecommunications.

These events shaped the department into a unique environment, a blend of competences and disciplines that are usually found in separate CS and EE departments elsewhere. Despite in the past few decades the exponential growth of ICT has boosted an impressive expansion of DEI’s pool of researchers and activities, the department has been able to preserve a unique scientific identity.

Bioengineers joining the DEIB in the Bioenginering area are the large majority of the former Dipartimento di Bioingegneria founded in 1991 (http://www.ventennalebioing.polimi.it/), who see the opportunities offered by a rich and varied environment and a challenge for scientific and teaching development. The first director was Prof. Emanuele Biondi, already mentioned above.

The Dipartimento di Bioingegneria was founded upon competences in Electronics and Information Technologies, Mechanics, Materials, which had been progressively specialized (starting from the 1960s) in the Biomedical field. This unification gave rise to the Bioengineering Discipline (alias Biomedical Engineering), which was experiencing a vast international development.
The new department impacted also on the CNR at the Politecnico di Milano, where, at that time, similar skills were present in the Centre of Systems Theory and were conveyed to the newly borne Institute of Biomedical Engineering (IsIB-CNR). Since then IsIB works in deep synergy and mutual cooperation with the Dipartimento di Bioingegneria.
A PhD course in Bioengineering already existed (since 1983) as well as courses and tracks in Bioengineering.
Briefly a short program (three year Diploma, 1992) and a full university program (five-year Laurea, since 1995) were opened.
A quick growth from the 15 founders up to 35 faculty followed, which presently leads to join a new major department with the goal of playing a proactive and significant role in its future development.

Mission

The mission of the DEIB aims at broad research, educational and societal goals:
- To be at the cutting edge of research, generating innovative ideas, gaining international recognition, exploiting the synergy among researchers from different Information and Communication Technology (ICT) areas and from other disciplines, namely bioengineering and health science technologies.
- To contribute to the European Research Area through collaborations with world-class institutions; to become a key node in research networks of excellence and to participate to challenging international projects.
- To provide talented young professionals with a sound scientific background, a strong problem solving mindset, and a truly multi-disciplinary vision of their work.
- To strengthen collaborations with national and international industrial partners, to support technology transfer of research results and generate spin-off and start-up companies.
- To promote a more advanced and technology-based economic environment and, more generally, to pursue ICT applications aiming at the advancement of the society at large.
- To pursue a multidisciplinary approach to methodological and technological problems in all the research fields of interest in the department.

Researchers at DEIB thus want to be active part of the information revolution, by:
- Performing fundamental research so as to progress in the understanding of the unique cultural contribution that information technology have brought to science, life, and society; consolidating and improving the recognition of DEIB as a key research hub at the international level for the value of its scientific production.
- Exploring the boundaries where information technology meets application domains and other disciplines, to promote visionary research that applies DEIB’s models, methodologies, techniques, and architectures to the resolution of a broad spectrum of real-life problems.
- Educating a generation of engineers with a solid methodological background and a strategic vision of how to apply innovation to a variety of industrial sectors.
- Transforming research results into real-world innovation, in cooperation with an ecosystem of partners that together can address the entire lifecycle of innovation, from early stage research to product and service deployment.
- Meeting the challenges of a radically changing industrial ecosystem, where emerging research opportunities rise from new application domains and societal needs.

To achieve our mission a new approach to research is required, in continuity with the past, but also pointing to new directions:
- Maintain a focus on long-term, basic and visionary research. To achieve excellence, research has to be radical, exploring new directions, unconstrained by short-term goals, funded by agencies and initiatives such as ERC, FET, EU Flagships, or PRIN at national level.
- Enhance our involvement in medium-to-short-term research focusing mainly on those projects that transfer cutting-edge research results into improved products and services. Due to the evolving nature of

information technology, the transfer from research results to innovation is a very fast process and thus such bridging has excellent potential of generating technological solutions of relevant impact, leading to spin-offs, start-ups and product innovation.

- Enhance our involvement in interdisciplinary research, opening to collaborations with other departments. Such trend is fully in line with the Horizon 2020 framework program to be launched in the next years, and focuses on a variety of societal challenges, from supporting the ageing society and public health, to improving transportation, addressing the climate change to support energy-aware society, and strengthening education, cultural heritage and entertainment.
- Support and contribute to the innovation processes of industries, public administrations, the network of biomedical institutions, and the society in general, by understanding needs and problems, analyzing and interpreting market opportunities and challenges, identifying technological trends and directions, providing expertise and methods to design and develop disruptive solutions. This complex activity will be carried out taking into account the intrinsic characteristics and constraints of innovation processes: speed, market impact, technology transfer, human capital, and organizational development. To address these complex issues, DEIB will also exploit the partnership with CEFRIEL and with the spinoffs and startups that have been created over the past years. In turn, the results and experiences derived from innovation projects will be instrumental to continuously feed the stream of research problems addressed by DEIB.

Vision

The vision of DEIB is to promote and drive the impact of information and communication technology on society at the national as well as at the international level, by pursuing excellent long-term and interdisciplinary research and by committing to innovation and technology transfer and to education, so as to be part of the worldwide community of actors who believe in the potential of information science and technology for inventing a better future.

In the last ten years, advances in information and communication technology have caused the most radical changes in human life. Most of the individual or social activities and most of the goods produced by mankind heavily exploit information technology. Huge masses of information, produced both by humans and by devices, are captured, processed, and transmitted; computing devices that directly interface with the physical world forecast increasing (although possibly non perceived) influence on everybody’s life. The advent of Internet has radically changed everybody’s habits, on the workplace, at home, and in mobile contexts; while the beginning of the information revolution mainly addressed the needs of working and businesses organizations, the trend of the last ten years sees information availability as the enabling factor for the entire society.

While it is not easy to predict the future use of information, the next decade will certainly see even more dramatic changes, as Information Technology (IT) will find new ways of spreading to an increasing number of contexts and of adopters. In this setting, the Dipartimento di Elettronica, Informazione e Bioingegneria is grounded on four solid pillars:

- A tradition of excellence in fundamental research, yielding to a clear vision of its role and mission in promoting the advancement of the discipline for “inventing our future”.
- An increasing engagement into interdisciplinary research, by accepting challenges generated by the massive injection of information technology into every scientific and technological domain.
- A commitment to teaching in the challenging context of a rapidly evolving discipline, by balancing stable foundational principles with tumultuous changes in models, languages, technologies, and standards.
- A commitment to applied research and to technology and knowledge transfer, through joint research projects with local and international industry and through many spin-off activities.

Values

Our vision, mission, research and education challenges result in a consistent set of values that are shared by the members of DEIB:

- A continuous endeavor towards high-level research so as to advance the frontiers of science and engineering, measured through publishing in top international venues and evaluated by the top academic peers.

- A commitment to providing the best-quality education to students at all levels, with attention to attracting top-quality national and international students, in order to produce the excellent human capital needed for competitive growth in our society.
- A cooperative and open attitude towards other cultures to promote interdisciplinary research, especially with the other disciplines of our department.
- An inter- and multi-disciplinary approach towards the whole set of disciplines concurring to the Polytechnic Culture of Engineering, Architecture, and Design and also towards Sciences and Technologies in general.
- A strong passion towards advancing our discipline when it plays the role of “inventing our future”, creating Intellectual Value as well as Intellectual Property.
- A pledge to serve human society by anticipating the needs and requirements that emerge from striving towards a better quality of life, in full respect to individual security and privacy.
- A commitment to the main foundational role of Politecnico di Milano to develop innovation and support high quality production and services with a high social impact in our territory.

Organization

DEIB is currently organized in six research areas:

- Bioengineering
- Computer Science and Engineering
- Electrical Engineering
- Electronics
- Systems and Control
- Telecommunications

Section 2 – Competences, research lines and technology transfer

The aim of this section is to provide a detailed overview of the research activities carried out within DEIB, as well as an outlook into its future developments.

State of the art and research vision

Bioengineering

The actual background of research activities in bioengineering is structured in four research lines spanning from fields related to the molecular and cellular scale to bio-mechanical and bio-electronic technologies, and finally to soft methodologies.

Biomimetics and micro-nano-technologies address the bio-molecular and cellular scale to support: regenerative medicine; design, development, and characterization of biomimetic systems; the study of biomolecular bases of pathologies; microinterfaces in diagnostic and therapeutic devices. Computational chemistry techniques are used to correlate structure and function of biomolecular complexes, while molecular imaging is used to localize pathological districts and pharma efficiency. Microfluidics, models of particulates and optoelectronic interfaces are used for cell cultures in a controlled environment. Culture platform enhancing cell growth for tissue engineering is also studied.

Functional assessment and rehabilitation technologies concern methodologies and instruments for the evaluation, recovery, and augmentation of the main human physiological systems. This topic relies on solid bases concerning motion capture, functional motor analysis, processing and modeling of biomedical signals and images, biomechanics, biomedical technologies, and prosthesis technology. It addresses several medical specialties: neurology, orthopedics, movement disorders, pneumology, cardiology. Applications are relevant to clinics, rehabilitation, home-care, ergonomics, ageing, extreme environments (e.g., microgravitational).

Therapy technologies concern the design, prototyping, and application of technologies for assisted surgery and radiotherapy. They involve techniques for: spatial localization, navigation in mini-invasive surgery by tele-manipulators, robotics and micro-robotics, target localization, surgical planning. Biomechanical, fluidynamic, and physical models are developed for the simulation and prediction of outcomes. Strategies are developed for the characterization of soft tissues and their interaction with surgical instrumentation.

Radiotherapeutic procedures are studied for robust and patient specific treatment planning, movement of target and organ-at-risk measure and compensation of target and organs-at-risk, therapy personalization, estimate and control of local toxicity. Multimodal images acquired in the planning and intra-operative phases permit patient specific and image guided therapy adapted to the real geometry of the organ district during the intervention phases.

Physiological modeling, clinical diagnostic, e-health and description of health systems apply modeling, processing, information management, and data fusion to health technologies and systems. Modeling of physiological systems (cardio-vascular, respiratory, neuro-sensory, autonomic) and the processing of relevant data, signals, and images addresses diagnostic parameters, monitoring of vital signs, prevention, therapeutic planning and follow-up, through a minimal invasive and evidence based approach. Information from medical instrumentation, biotechnologies, molecular medicine, surgical and intensive-care monitoring, wearable and domotic devices is integrated by a multi-parametric, multi-source, multi-scale approach. It relies on data, signal, and image processing and system analysis methods. E-Health addresses the improvement of public health as well as personalized procedures and services, by means of ICT and process modeling approach.

Computer Science and Engineering

The Computer Science and Engineering area is organized in five disciplinary research lines which are well situated at the front edge of the state of the art in their respective fields, as detailed in the following.

Advanced Software Architectures and Methodologies: the state of the art in the areas of dependable and self-adaptive systems is rapidly evolving but it is still far away from consolidation. The contributions available in the literature can be classified as follows.

Specific approaches to enable self-adaptation: In this area we can classify the following: i) middleware that hard code some adaptation strategies triggered by some specified events; ii) development and execution approaches that offer specific languages for expressing adaptation policies that can be reprogrammed with human intervention when this is needed; iii) monitoring approaches that support the recognition of the need for adaptation; iv) prediction mechanisms that enable the execution of self-adaptation before some undesired event happens.

Approaches focusing on the usage of formal methods for dependable systems: in this area the attempt is to overcome the classical limitation of formal methods, that are typically suitable for small-scale problems, by refining powerful compositional techniques and by developing well-established and robust analysis tools offering good performances.

Experiments with dependable and self-adaptive systems: real case experiments are being developed in a field which is getting more and more mature. Interesting application domains include the so called Internet of Things, were special-purpose devices (mobile end-user devices, sensors, actuators, …) are incorporated into complex hardware and software systems to enable independent living of the ageing society, optimization of public transportation, reduction of pollution, better use of energy, and the like. Another domain interesting and promising for software engineers is Cloud computing, where self-adaptation is required to ensure an optimal usage of computational, storage and network resources still guaranteeing certain levels of Quality of Service.

Compiler support for parallel heterogeneous architectures: The state of the art in Compiler Technology is moving towards compiler-assisted management of architectural heterogeneity (in terms of memory model, instruction set architecture and even non-functional aspects) in increasingly parallel architectures resulting from the converging evolution of high-end embedded systems and high performance computing systems.

Dynamically reducing the power envelope and improving resilience and security against attacks aimed at recovering secret information from a chip will become increasingly important in the near future. While pure performance-oriented compiler optimization has been thoroughly investigated, the portability of performance remains a goal to achieve, especially when parallel architectures are involved.

Parallel parsing: innovation in parallel parsing is still ongoing, in an otherwise mature research area, stimulated by the need to parse large amounts of semi-structured data.

Natural Language Processing methodologies will be used to enrich the application areas in different directions: discourse and dialog analysis, multimodal communication, personalization related to different user profiles and contexts (educational, clinic, and legal).

The research fields of interest for the **Artificial Intelligence and Robotics** research line cover five scientific areas that, although slightly overlapped, have been rather independent in their evolution:

Artificial Intelligence: One of the crucial open problems in multi-agent systems concerns the development of solution concepts for the interaction of rational agents able to be deployed in real-world situations.

Indeed, currently available solution concepts present computational problems and/or are based on unrealistic assumptions.

Autonomous Robotics: Robots are becoming autonomous enough to perform tasks in unknown environments, modelling them from sensors, and acting appropriately to achieve goals. One of the main problems still to be faced to enable the robots to widely spread in applications is the ability to perform a task in a way satisfying market constraints, which implies reliability, safety, power self-sufficiency, and cost/effectiveness, among others. Moreover, as soon as autonomous robots crawl out of the simulator box into the real world, find themselves face to face with unforeseen situations and (sometimes) unpredictable action outcomes. They soon realize the world being a very uncertain place. Robotics in the real world requires us to rephrases autonomy in terms of robustness, reliability and uncertainty management in the whole path that go from perception to action. Robust perception, rich world modelling, planning under uncertainty, and learning will become the key aspects to be faced. In this regard, efforts are being devoted in the direction of better integrated HW/SW architectures, of improvement of sensors and sensor interpretation, and of better interaction with people and with environments (including smart sensors, mobile devices, and other robots). Also the cognitive abilities are starting to move from the situation in which autonomous robots decide how to achieve user-specified goals, to a situation in which the robots themselves autonomously decide what do to, namely their goals.

Computer Vision: Many geometric aspects of Computer Vision are now understood. Visual analysis of complex scenes, where the essence of the present objects cannot be captured by purely geometric models, is one of the most challenging problems in the present and future research. Given the relevant quantity of available mathematical tools, part of the fruitful effort can be aimed at identifying the subtle approximations/simplification making a problem tractable and generalize to different setups. In the realm of complex scenes understanding the next step will be the semantic one; being able to detect a moving object indeed is something different from recognizing what object is that, what is the purpose of the movement and what is going to happen then. This kind of semantic understanding starts from the being able to recognize objects and moves to their behaviour classification.

Machine Learning: Reinforcement learning was born several years ago as a bio-inspired approach to enable agents/robots to autonomously achieve complex behaviours in unknown environments. During the last ten years, such long-term vision has been partially replaced by a more practical perspective, putting this field at the intersection of machine learning, control theory and operation research. Currently, the field is reaching a more mature state, both from a theoretical point of view and from the applicative one. In the next future, reinforcement learning techniques will provide effective solutions to many real-world applications that are too complex for state-of-the-art approaches. In a more biologically-oriented perspective other kinds of learning have gained importance in modelling neuronal architectures. In this case, learning often has a role in setting internal parameters of the robot, or sometimes in making associations in different spaces. In those cases the “one shot learning”, where an association is created without the need to explore the entire space, is the wanted target.

Philosophy of Computer Science: The philosophy of AI has gained credibility as an autonomous field of research on the foundational and critical issues posed by AI. Traditionally, the different contributions to the discipline can be grouped in three areas. The philosophical problems that have to be preliminary afforded at the beginning of AI, the issues deriving from the interaction between philosophy and AI, and the present and future consequences of that interaction. In the last years, further attention has been posed not only on philosophical problems typical of AI, but on more general issues emerging from the whole field of computer science (e.g. what kind of discipline is computer science? What kind of things are programs? Should programs be considered as scientific theories?). Moreover, ethical issues of both Artificial Intelligence (and Autonomous Robotics) and Computer Science has gained further attention.

Data, Web, and Society: Data, besides being fundamental in the organization of business activities, are now outreaching to reshape every individual and collective activity of people’s life. Availability of data through the Web, accessibility of information resources anytime-anywhere through mobile devices has changed everybody’s habits; every citizen is at all times both managing and producing information sources through friendly interfaces and “natural” forms of interaction. Social computing takes many possible formats, from explicit involvement through social networks or crowd-sourced interactions, to implicit methods of data analysis, which understand and explain social behaviours. Data are not only produced by humans: very small, cheap, and low power devices, connected through wireless networking, have made it possible to design and build "pervasive systems" which relieve people of a cumbersome interaction with passive tools, by embedding the processing power in the environment and making it proactive with respect to the user.

The availability of huge amounts of data (“big data”) is changing our attitude towards science, which is moving from specialized to massive experiments and from very focused to very broad research questions.

This approach is also extended to business organizations, who are investing a large fraction of their IT resources in monitoring and anticipating market's reactions to their products and services. A data-centric vision of the world is fundamental for advancing towards the European view of the Horizon 2020 program.

The vision of an empowered and inclusive society requires the availability of secure, easy-to-use, effective methods for data production and management. Progresses in health, well-being, natural resource usage, and education will mostly stem from making good use of the vast amount of information which is already available, but often misused. Climate, energy and transportations are all areas whose progress depends on a strategic use of data, e.g., for building prevision models, for managing emergencies, for improving the management of smart cities and building on-line alerting systems about traffic, road conditions, hazards, and so on. Thus, computer science is facing a "data deluge" problem of unprecedented size and relevance.

The line's identity has been in the last 30 years the ability of proposing new models and languages, of abstract and conceptual nature. They describe data and processing abstractions and are used for coping with the new needs of information design and management. We think that the future will even more need modelling abstractions, e.g., in *crowdsourcing* and *genomic computing*, and conceptual tools that help designers and developers master the complexity of applications that are both data- and interaction intensive.

Models and languages are put in action by means of *pervasive systems*, which integrate independent, heterogeneous, distributed, sometimes transient information, often made available through mobile devices. Along with the user characteristics, including their mobility, data and service management functionalities must take into account time, location and physical environmental parameters, to provide users and applications with the knowledge and services that are most appropriate to their active context, which in turn should be used to regulate and adapt the computations. Languages and middleware, are being developed in order to manage data coming from any kind of device, from RFIDs to "pseudo-devices", such as social networks, from a database-like perspective.

Humans, with their perception, judgment and social behaviour, can contribute to elicit and collect data, to validate and refine data gathered with automatic tools, to sense physical or social phenomena. *Human computation tasks* need to be designed, with the help of new conceptual models and tools, deployed, on new pervasive systems, and monitored for quality, with yet to define data and behaviour analysis techniques.

Once models are set and systems are developed, there is a need of putting them to work, by effectively covering *data search*, exploration, visualization, analysis, and communication. With huge amounts of data, it is essential to retrieve information in a fast and effective way; data search often needs to be focused upon specific domains in order to be able to understand the user's intentions and goals. This in turn calls for extending inference reasoning in a way, that we regard as ranked reasoning, in which methods can use data ranking as a key improvement factor.

Complementary to search, another important aspect is concerned with how *big data* can be effectively: i) explored - new "explorative" user experiences must be devised, enhancing effective access to large bodies of structured and unstructured information also in contexts of user's soft goals; ii) visualized, i.e., rendered in a visually effective way, so as to facilitate understanding of properties of aggregated data and relationship among them, thus improving decision making processes.

A similarly important research chapter is concerned with *data analysis*, i.e., the capability of extracting information from data so as to build provisional models or explain phenomena whose structure and semantics is hidden within the data. A promising research direction is the principled use of crowd wisdom to innovate data analysis techniques, by integrating human judgement, object recognition capacity, classification power, and even sentiment in the enrichment of data semantics on a massive scale.

Orthogonally to all the above research challenges, there is the need of offering users the most suitable ways of *interacting with the data* and their presentations that encompass emerging social habits (e.g., the diffusion of online gaming to address also serious purposes and problem solving tasks) and take advantage of novel paradigms of interaction – multi-touch, bodily, touch-less & gesture-based, aural - which are facilitated by the availability new interactive devices. This in turn calls for new methodological approaches that can support the systematic design and evaluation of all technological solutions from a "user

experience" perspective, in terms of conventional functional attributes such as usability as well as more hedonic attributes such as aesthetics, pleasure, satisfaction, or fun.
Finally, understanding the complex plethora of requirements involved in real application domains must inform the design of all methodological and technological solutions, and will enable the evaluation of the effectiveness and impact of research results. Combining different research approaches (basic, development, application, technology transfer) and real-life experiences in several application domains can provide a vibrant and challenging research environment.

Information Systems: Research on service-based systems is still an important research topic. In addition to designing reliable service-based systems with guaranteed Quality of Service, themes relevant to the research line are: services in green information system, people-based services, security and risk analysis, and spatial information systems. A common paradigm will be the analysis and management of monitoring data, from a variety of sources, to activate actions to achieve and maintain predefined goals.
In *Green IT*, a service-based approach can be the basis for measuring Green Performance Indicators in realizing energy-aware information systems. The energy efficiency of services in data centres and in cloud environments requires setting goals and selecting strategies to maintain them.
An important research challenge is raised by the generalization of the "internet of things" to the "*internet of services*." The nodes of the internet can be both "things" and "people" equipped with mobile devices; this coupling draws a bridge between the internet of things and the social network of people. We can envision an emerging trend of services based on the integration between the information gathered automatically through mobile devices (sensors) and the information provided by people across different social networks (crowdsourcing). The ability to leverage the advantages of this integration, possibly by leveraging Web 3.0 technologies such as sentiment analysis, can create a variety of new service opportunities.
Securing applications and their data regards employing *cryptographic functions* to innovative areas, such as to Smart (micro) grids and energy distribution. Cryptographic schemes for smart grid architectures regards authenticating systems, protecting against replay network-based attacks or load shedding and ensuring the availability of system resources, authenticating meter assets to ensure that only "trusted" devices are connected, and encrypting meter data to protect consumers' privacy. The research is to obtain CIA (confidentiality, integrity and availability) properties via authenticity and non-repudiation security services.
Risks and safety in dangerous environments can be solved technically through *smart sensors*, ad-hoc devices and suitable service software for empowering the individuals' lives. The related solutions are based on monitoring devices, among which wearable devices. Emphasis is on the use of key decision structuring steps and analytical tools to ensure the systematic treatment of fact-based and value-based risk knowledge claims. The overall problem of risk and safety, with particular attention to the way of communicating risks to people and companies is addressed through monitoring and simulation techniques. Related research areas are sensor networks, wearable objects and ambient intelligence.
Spatial Information is becoming more and more integrated with other information in order to respond to the requirements of many application areas of growing interest: e.g smart cities, environmental risk control, transportation and so on. In order to support these applications spatial data must be collected and systematically updated through the cooperation of many different institutions. In our vision, research on Spatial Information Systems design needs to find a balance between the degree of technical innovation and the state-of-the-art of available technologies, in order to support the experimentation of solutions in the real world taking care also of organizational aspects.

Computing System Architectures: The major trends concerning the computing system architecture are related to the introduction of the many-core parallelism, the needs of fully automated design flows, the cloud computing architectures and a need for security models that can embrace ubiquitous, always-on, mobile computing devices. The current trend in computing architectures is to replace complex superscalar architectures with small homogeneous processing units connected by an on-chip network. This trend is mostly dictated by inherent silicon technology frontiers, which are getting as closer as the process densities levels increase. The number of cores to be integrated in a single chip is expected to rapidly increase in the coming years, moving from multi-core to many-core architectures. This trend will require a global rethinking of software and hardware design approaches. This class of computing systems (which we call Many-core Computing Fabric) promises to increase performance, scalability and flexibility if appropriate design and programming methodologies will be defined to exploit the high degree of parallelism exposed by the architecture. Benefits of Many-core Computing Fabric architectures include finer grained possibilities for energy efficiency paradigms, local process variations accounting, and improved silicon yield due to voltage/frequency island isolation possibilities.

Fully automated design flows are the key enablers for improving the design efficiency of computing systems architectures. In fact, the increment in system complexity towards the different technology nodes requires the development of helping tools to support the designer in maintaining high levels of design-productivity.

In particular, the EDA world is currently moving towards the automation of the higher levels of abstractions, such as the system-level. System level design focuses on aspects beyond RTL such as efficient HW/SW modeling and partitioning, application mapping and architectures design. Nowadays the system level design is currently driven by the embedded systems community, while considered only for the predesign phases in the high-performance community. However there are numerous opportunities for cross-fertilization between the two worlds. Techniques used within the high-performance community, such as fast simulation and efficient compilation techniques, are going to be used in the embedded system world and embedded system techniques dealing with low-power design and application specific methodologies are moving in the opposite direction.

Cloud computing architectures are a natural evolution of current data centers and supercomputers technologies. The computing and storage resources belong to companies that sell these services. The difference with previous architectures is the possibility to play with the elastic characteristic of the resources presenting an on-demand nature. This type of systems follow the current trends, such as access from everywhere, social media and increment in digitalization, taken by the new generation of user that are the driving of a broad ranges of changes in the computing system architecture area.

Securing computer architectures that scale from wireless sensor nodes, to mobile devices, to standard computers up to the large scale infrastructures of the cloud is a daunting task, that will require to review and overhaul our current approaches to information protection. The increasing interconnection to the physical world in ubiquitous computing and cyber-physical systems will also open up new attack surfaces at the boundary of the digital and physical world, which are still far from being completely investigated.

Those trends have pushed the semiconductor industry and software companies to revise several previously established research areas and priorities. In particular, parallelism, runtime adaptability, power dissipation and ubiquitous data management have grown importance in the design flows and in the system architectures, from the application level down to the hardware. Those changes, involving the entire computing spectrum, from the mobile segment up to the data centers, in turn requires a completely rethink of current design tools, architectures and methods for the application development, especially in the light of the ever-increasing complexity of devices.

Electrical Engineering

The disciplinary research lines in this area are well placed at the front edge of the state of the art in their respective fields, as detailed in the following.

Electrical and Electronic Measurements: the state of the art in this field is constantly evolving, as new measurement techniques, new materials and new devices enter the scientific and technical scenario. They play a twofold role: on one side they represent a new measurement application field, with new challenging measurement problems to solve, and, on the other side, they also offer new opportunities to develop new instruments and sensing elements. The probably clearest example of this twofold role has been played, in the last decades, by the development of the digital systems, that have offered new measurement problems (let’s think of the logic state analyzers), but have also offered the platform on which the digital signal processing techniques have evolved.

Signal analysis and *digital signal processing* in particular represent the common denominator of the activities of this research line. The researchers of this group have pioneered the DSP techniques for measurement applications and have developed several innovative methods and algorithms for both the time-domain and the frequency domain signal analysis. All proposed techniques have been experimentally validated with practical applications in the field of electrical measurement and in other fields. In particular, the main application topics covered by this research line are the following.
Electric power analysis and *power quality measurements*: this is a very hot topic, especially in the new *smart grid* scenario, and requires the development of new methods for the characterization of power consumption in the different nodes of the network, new methods for the characterization of the energy meters and innovative, wide-band sensors for high voltages and currents. The research activity done in this field is at the frontier of the international research.
Diagnosis of components and systems: the increasing cost of outages due to failure of critical components, as well as the increasing cost of maintenance, require new, real-time, on-line measurement methods capable of assessing the *health state* of the monitored devices or systems. Innovative methods have been developed, mainly based on electric signature analysis techniques. Innovative sensors have been developed as well.
Metrology: the recent evolution of the measurement methods and systems, more and more based on complex analysis and algorithms, have seriously challenged the present methods employed to evaluate and express measurement uncertainty. More general mathematical models are necessary, and research activity has been developed in this field.

Electromagnetic compatibility: Over the past decades, fast and relentless evolution of electronics engineering science and the consequent significant development of electronic and electrical engineering technologies have dramatically increased the importance of electromagnetic compatibility (EMC) both in the scientific community and across the industry. As a result, nowadays EMC underpins almost all electronic/electrical engineering activities and influences our daily life more than ever in a time that sees a continuous drastic change of the electromagnetic environment. Looking ahead, unrestrainable use of highspeed digital devices for faster processing of data, and the greater need for power electronics applications for the control and conversion of electric power will, without well-timed and properly informed action, result in further worsening of electromagnetic interference (EMI) problems in a huge variety of different environments. In addition to this, intentional electromagnetic threats are also now emerging to which unprotected systems will be vulnerable. As EMC has become a challenging target in the design cycle of each complex electrical/electronic system, and it is intimately connected to front edge technology, state-of-theart in this field is continuously evolving. Additionally, its inherently interdisciplinary nature makes EMC a key issue in many important application areas of electrical and electronics engineering. In this context, the main application areas that are covered by this research line are briefly described in the following.
Transportation (Automotive & Railway) EMC: The new era of electric/electronic systems for the transportation sector puts new demands on the manufacturer to prove reliability and safety. Standards and test procedures that earlier have been used to prove EMC compliance at the unit/component level, are no longer adequate to prove immunity against electromagnetic disturbances at the system level (complete vehicle). Indeed, even though all sub-systems are developed following an EMC compliant design, their integration may create many sources of potential hazards for the overall electromagnetic behavior.
Therefore, mastering EMC aspects in the early-design stages is becoming a must to avoid the limited technical and economic efficiency coming from late-stage management of EMC issues. This makes more and more acute the need for: (a) a new generation of system-level EMC testing techniques; (b) reliable prediction tools for EMC-oriented design. The research activity in this field is at the frontier of the international research and includes contributions to immunity characterization using bulk current injection (BCI) test methods, and novel experimental procedures/setups (and simulation techniques) for radiated emission assessment.

Aerospace EMC: The current and next future scenario of spacecraft is characterized by an increasing design complexity in term of amount of mass memory, data throughput and on-board processing capabilities.
Central processing units running at hundreds of MHz are used as central core of payload computers and their high performance is able to acquire data from large detectors, process and transmit huge amount of data. In particular, since high speed could be the source of EMC issues, suppliers and manufacturers in the aerospace industry are facing continuous pressure to meet increasing regulatory requirements. They need to accommodate more and more sophisticated technologies and services and to reduce costs and time in the procurement process. In this scenario, this research line is committed to search for advanced approaches and techniques in modeling, design, and testing with the ultimate objective of achieving builtin-design EMC and avoid costly fixes for the integrated systems. In this sector, innovative prediction tools for conducted emission and radiated susceptibility assessments of wiring harnesses on-board spacecraft have been developed. EMC-oriented design of innovative Power-Line Communications (PLC) systems to be operated in the near future on-board spacecraft have been developed as well.
EMC in Smart Grids: As electric power networks are the link between electricity producers and consumers, a higher degree of embedded intelligence is needed into the transmission/distribution system to allow the consumers to play a part in optimizing system operation, facilitating connection of generators of all sizes and technologies, and allowing delivery of sustainable, economic and secure electricity supply. Combining electrical and communication grids in the so-called "Smart Grid" requires interoperability, reliability, safety and fault-tolerance. For the Smart Grid to function properly and coexist with other electrical and electronic systems it needs: (a) design guidelines with due considerations for electromagnetic emission from the grid itself and for a sufficient immunity to various EMI phenomena; (b) reliable communication techniques both wired (e.g., the power-line communication technology) and wireless for network monitoring and control. In this sector, the main contributions include optimal design of low-cost magnetic current sensors, prediction models for conducted emission along power cables, and characterization of the Power-Line Communications (PLC) channel in distribution grids.

Components for energy conversion: This research line includes the methods, the applications and the technologies for the electrical machines, the actuators, the static converters and the electrical drives. The application fields are the sectors of energy, civil and industrial applications and transports.
The electrical sensors, actuators and machines are studied as for the design methodologies, the model, the performances, the joule and iron losses and the thermal aspects. The aim is also the optimization of the machine design to improve the efficiency. In this contest, the research group does not only design and support the construction of traditional machines as the motors for domestic appliances. It is also involved in the innovative machines, as the permanent magnet generators for wind energy conversion.
Other aspects deal with power electronic converters and electrical drives, as for example sensorless drives applied to doubly fed induction machines.
Another research line deals with MagLev, i.e. the magnetic levitation for transportation systems.

Electric Power Systems: The research topics addressed in the studies of the electrical energy systems are substantially related to the impact exerted on them by power electronics, automation and computer science.
In particular, the main research activities have been focused on the quality and continuity of the electricity supply, the use of renewable energy sources and a more rational use of electricity.
The need to provide a contribution to the transition towards sustainable and competitive energy systems, while available resources are progressively decreasing, the growing need for energy and the concerns on climate change—high priority issues according to the Horizon 2020 Program—have driven the research team to deal with the studies on the impact of the distributed energy sources (solar, wind, ...) on medium and low voltage electrical distribution systems. In this context studies have been developed focused on the introduction of the energy storage devices in electrical equipment and in electrical systems to enable energy recovery during the braking phase of industrial drives of electric vehicles, and to decouple, partially

at least, end-users load demand and production of electrical energy especially from renewable energy sources.

Electronics

The relentless development in the integrated circuit technologies over the last 40 years has made possible a tremendous increase in their functions and performance which has in turn led to an unprecedented pervasivity of such technologies in everyday life. From computers to cars, from cellular phones and multimedia to health, down to the very heart of the fundamental research in physics, biology and many other disciplines, it is hard to underestimate the key role played by the microelectronics. Its historical evolution is well represented by the Moore's law, which predicts the rate at which more transistors are placed into an integrated circuits or – equivalently – at which device dimensions are scaled: today's technology node is 22 nm, ushering the conventional microelectronics into the new world of nanoelectronics. However, a significant and ever-increasing effort is required to maintain the historical rate of improvement while dealing with nanoscale devices: such field of activity is known as *More Moore*. Over the last ten years or so, moreover, a development line departed from Moore's law, aiming at a set of technologies that enable non-digital micro/nanoelectronic functions. Such activities are known as *More than Moore* and include, among others, radio frequency, biochips and microfluidics, electronic imaging, sensors and actuators on CMOS platforms. While these two fields are often represented as distinct, their boundaries are indeed blurred, both being related to a convergence of physics, technology and design. It is then not surprising that both are covered in the ELN area, with the addition of a group specifically devoted to the development of design methodologies that can found cross-boundary applications.

The latter group, **Circuits and systems theory and applications**, is mainly active in methodological and fundamental research aspects of circuits and systems theory that are relevant for modeling, analysis, simulation and design of electrical and electronic circuits. The research will be oriented to the development of tools to numerically handle state of the art electronic applications and to the challenging area of smartgrids, renewable energy sources and energy storage. In this context, the intrinsic multi-physics nature of these "smart-grids" can produce complex dynamics among various energetic systems, and consequently the numerical analysis and simulation play, and will play an important role for a long time.

Groups working in **Sensors and Instrumentation** (More than Moore) are active in development of MEMs, image and radiation detectors. They will take advantage of their in-depth knowledge to move not only toward the sensor miniaturization, but also toward the increase of smartness in sensing systems, to allow new functionalities, increase the performance and thus to enable applications in new areas. In singlephoton detectors, silicon SPADs with "red-enhanced" sensitivity (for operating up to 1.0μm) and InGaAs/InP III-V detectors (for covering the range from 1 to 1.7μm) must be properly studied and developed. For enabling imaging with high sensitivity and fast throughput, an effort is necessary for obtaining chips with higher number of pixels in a custom high-performance SPADs technology and developing the associated circuitry in a compatible technology. Wide efforts are also necessary for developing denser 2D arrays in standard CMOS with smart pixels including SPAD with improved performance and processing electronics, as urgently required by many applications. There is also widespread interest to multi-spectral and hyper-spectral solutions and this is a theme that requires developing even more complex and sophisticated technologies, such as advanced multi-wafers and threedimensional technologies that make possible to integrate Silicon, InGaAs/InP, electronics and microlenses in a compact and reliable module. Groups working on radiation detectors will target the development of new imaging detectors for ionizing radiation (X-rays, Gamma-rays and charged particles) and related electronics, permitting both compatibility with high magnetic fields and more compact designs, suitable for use in standard magnets for either clinical or preclinical MRI systems. Other applications include the opening of novel proton beam facilities for oncological treatment, that imposes challenges on the detectors required for treatment monitoring, the research to find nanoparticles acting as biological markers, requiring new imaging techniques to map cellular radio-sensitivity, in order to guide radiation dose prescription in intensity modulated radiotherapy.

The **Microelectronics and emerging technologies** (More Moore) activities, on the other hand, target nonvolatile memories, organic semiconductors and integrated circuit design. The former activity is facing the limitations of the current Flash technology and is working toward the exploration of alternative technologies for solid-state storage, including PCMs, RRAMs, capacitor-less DRAMs and 3D devices. In organic electronics, research is targeting the development of large-area electronics on virtually every substrate, enabling ubiquitous integration of advanced opto-electronics functionalities.

Finally, the **Integrated circuit design** group will strive to push the CMOS technology at its best in the field of RF circuit design. For example, design of high-efficiency polar transmitters for wideband LTE, which is considered almost impossible today; the design of very high-efficiency clocking circuits for multiple applications, such as microprocessor clocking, frequency synthesis; the replacement of the area-consuming LC oscillator with a ring one.

Systems and Control

The Systems and Control area is devoted to teaching and research in various fields related to control system science and engineering, industrial automation, systems theory, environmental systems, ecology, operations research, and electronic measurements.

Despite the rich variety of topics, both theoretical and application-oriented, a unifying system -level viewpoint is generally adopted, which enables the analysis, the design, and the management of complex systems through the powerful theoretical tools of mathematical modeling.

Indeed, the field of systems and control has a long history of mathematically rigorous research combined with successful application to diverse branches of science and engineering: methods, algorithms and tools developed by researchers in systems and control have been used to solve problems of practical importance with enormous impact on society. Among other things, control concepts have been crucial in the design and development of manufacturing and process plants, electric power generation and distribution, vehicles (e.g., high-performance aircraft, fuel-efficient automobiles) and many other applications across various sectors of industry. In these and other domains of engineering, systems and control theory, and its technological counterparts, are now widely used to ensure reliable, efficient, and cost-effective operations.

Even though the large variety of topics covered within the SC area makes it difficult to outline a comprehensive state of the art of the research in the different fields, some consolidated as well as some emerging research themes can however be identified.

In the area of **control systems** theoretical developments are anticipated in the fields of: switching systems and uncertain hybrid systems; "cyber-physical" systems, i.e., systems with integrated computational and physical capabilities; large-scale systems, characterized by decentralized, distributed, networked compositions of heterogeneous and (semi)autonomous elements; model identification and data analysis, with cross-fertilization among diverse approaches in order to provide new efficient solutions to advanced problems of black box and grey box identification, randomization and learning, Kalman filtering and prediction. On a more application-oriented perspective, some important areas of development are identified within high-performance vehicles and transportation networks and systems, medical devices, factories of the future, energy conservation and efficiency, and renewable energy integration for the power grid.

Robotics research has been in the last years progressively less centered on *mechatronics* problems (except for some developments in variable stiffness actuators) and more on the chain perception-reasoning-action, while *industrial automation* is focused on extensive use of formal models as well as on the integration of different control layers and the adoption of cognitive models. As for the efficient energy management at the user side, a systemic approach is now required rather than optimization of single components and devices.

The field of **optical measurements** is experiencing widespread applications of optical sensors in contactless measurement of mechanical or physical properties, while frequency stabilized solid state lasers allow ultra high quality optical interferometry and optical metrology with unprecedented figures.
During the last two decades, the focus in the research on **complex systems** has moved from the single unit (isolated dynamical system) to the interaction of many units (network of systems). In the next few years, related research is expected to develop along two directions. On one side, it will have to fill some withstanding theoretical gaps. On the other side, it will have to translate the elegant theoretical results into powerful and easy-to-use tools for the everyday activity of applied scientists and engineers. Also **optimization** has significantly progressed over the past decade, in terms of both methodology and range of application areas. Methodology-wise, exact and heuristic approaches have been improved, and important trends include hybrid methods (e.g., combining Integer and Constraint programming) and optimization under uncertainty. Application-wise, optimization models and methods have proved to be fundamental in dealing with a variety of complex decision-making problems arising, e.g., in telecommunication networks, health care management and transportation. New application areas are emerging such as energy, where optimization can play a significant role as well.

Finally, **environmental modelling** and control has taken advantage from the enormous progress in computer technology and in collecting data locally and globally. The emerging issues in this field are the development of hierarchical models of highly complex systems (e.g. for climate change), the downscaling of global models to suit the demand of policy makers, the integration of the socio-economic components into large-scale environmental models, the application of adaptive and robust control techniques in the management of uncertain and non-stationary environmental systems.

Telecommunications

In the past twenty years the development of the Internet and, more generally, telecom infrastructures has caused unprecedented changes in human society, which today affect many sectors of life, ranging from business, production, entertainment and social activities. An even greater impact on our lives is to be expected for the near future, as the amount of information that is being produced by humans or gathered by devices grows. Information is being captured, processed, and transmitted by devices of all sorts, which are distributed everywhere and directly “interfaced” with the physical world in a multimodal fashion. The information society of the future is envisioned to be characterized by a growing level of attention towards the citizen, in terms of health and wellness, food safety, renewable energy, intelligent transportation, climate control, inclusiveness, and more, the development of which will be greatly depend on advancements in telecommunications. Experts forecast a third Industrial Revolution, characterized by the fact that "manufacturing is going digital." Again, the new production scenarios that are envisioned (additive manufacturing, collaborative manufacturing, etc...) will only be possible through the development of a wide range of new TLC services.
In all of these emerging scenario the role of telecommunications technologies will be crucial. Extreme levels of pervasiveness, flexibility and adaptivity in the information society cannot be achieved by thinking of TLC technologies as mere commodities. A massive effort is, in fact, needed in research and development to meet these new challenges. The evolution of ICT toward on-demand service models (Managed Internet Service such as Cloud Computing) can only be enabled by the virtualization of the communication networks using heterogeneous infrastructures that mix wireless and wired connectivity. New and emerging applications will stress the architecture and the performance of existing network systems beyond conventional boundaries, demanding for networks of growing capacity, pervasiveness, energy and latency awareness. In this process all telecommunications sectors are to be massively involved.
As far as the physical layer (both fixed and radio networks) is concerned, telecommunication sciences will focus on pushing the boundaries of transmission rates and distance. Parameters that were neglected before (e.g. dissipation and latency) will take on a renewed importance. As for the other layers, new types of networks will be needed to enable the plethora of new devices that will populate the environment to seamlessly interact with each other and with us. Networks will be expected to scale up or down in dimension and complexity: meshes will become increasingly denser (with distances between nodes in the

orders of centimeters); networks will become more collaborative, cooperative, dynamic, conscious, "smart”. The dominant paradigm will become that of the Internet-of-Things, a concept that will radically transform the current network technology not only in size (with a number of nodes that is today inconceivable) but also in operation and management. Internet of Things will be the underlying network both of the new digital production scenario and of the fields mentioned above. In summary, the challenge will be to plan and to manage communications networks in an environment that is extremely dense with connections and nodes for critical applications.
In addition to the above technical issues, TLC holds valuables methodological resources that can be effectively exported to other domains. Among these, the network paradigm, that can be exported into non-TLC networks, such as transport networks, urban mobility, and so on; the same information paradigms can be used for analyzing communication fluxes within natural and artificial organisms. The above scenario encompasses problems that would also greatly benefit from expertise in Computer Science and Engineering, Electronic devices and Enabling Key Technologies, and knowledge from other areas of Industrial Engineering. This will offer opportunities of effective collaborations with other areas of our department and of the Politecnico di Milano.

Objectives and development lines

Each research area has identified some objectives and research topics which are worth investigating in the coming years. Some of them pertain to single groups, other have an interdisciplinary nature and will be addressed by several groups. A short description of the main research topics of future interest is provided hereafter.

Bioengineering

Biomimetics and micro-nano-technologies

Molecular and cellular engineering developments are seen in biomimetic interfaces and their functionalization, ligand receptor interaction in drug design, coarse grain and simulation studies of molecular dynamics. Tissue engineering for regenerative medicine will be fostered by platforms for cell and tissue growth with sensorized control and actuation systems and also by optimized protocols of cell stimulation (mechanical, electrical, physical, and bio-chemical). A specific focus will be given to neuronal growth for in-vitro studies of neuronal processes and pathologies and for neuro-engineered interfaces. Micro-fluidic platforms for micro-structured substrata and Lab-on-Chip will be developed both for cell/tissue coltures and molecular analysis in high-throughput regime. Micro-fabrication technologies as well as studies of micro- and particulate fluidynamics will play a major role for these realizations. Molecular imaging will address both the design of smart markers and nano-particles and localization systems and methods.

Technologies for functional assessment and rehabilitation

HW and SW platforms integrating robotic devices and electrical neuro-muscular stimulation will be developed for the clinical and remotely controlled home-care environment. Smart prostheses and auxilia will coordinate bio-mechanical features to sensorization for control and assessment. Domotic devices will play a major role for home-care in ageing and rehabilitation. Multi-factorial evidence based approaches will address neuro-motor recovery and functional re-training. Assessment of recovery and neurological correlates in neuro-motor and cognitive rehabilitation/follow-up processes will integrate functional signals and images.
Motion capture, movement analysis, virtual reality, functional electrical simulation, automated and robotic assistance will be progressively integrated into systems, the impact of which is foreseen in rehabilitation and functional assessment, in the study of motor-schemes and learning, as well as in the animation and entertainment fields.
Extreme conditions, such as the micro-gravitational environment in space offer both unique conditions for physiological insight and specific challenges for functional assessment and support. The approach to long term space expeditions poses also severe issues to the cardio-vascular and respiratory functions, which are experimentally studied in simulated and real micro-gravitational environments for the study of functional losses and the development of countermeasures.

Development of diagnostic and monitoring methods and instruments for the respiratory system will further integrate motion capture for optoelectronic pletismography, air fluidynamics and imaging. Assessment and monitoring will be the basis for assistive devices in various chronic pneumological pathologies. Monitoring of respiratory, cardiovascular, autonomic, and neurological disorders will be developed to personalized, wearable, and home assistance.

Technologies for therapy

Patient specific modeling is based on multimodal images, image fusion, automatic detection of clinical landmarks, and individual bio-mechanical and functional models, will be applied to surgical planning for the development of surgical devices/techniques, the evaluation of stress in organs and endo-prostheses, the prediction of fluidynamic features, design of new therapeutic approaches (e.g., in cardio-vascular surgery and neurosurgery).

Surgical navigation will also develop further integration of several localization technologies with pre-surgical images through sensor fusion techniques. Modeling is foreseen to enter the real time of surgical phases and provide remarkable anatomical and functional information. Cooperative robots and telemanipulation will augment their reliability and adaptation to intra-surgical reality and changes from planning. Further growth in the design of mechatronic devices for mini-invasive surgery (mainly abdominal) is pursued by means of miniaturization and integration of actuators and sensors.

Assisted radiotherapy will also develop robustness in planning and stereotactic registration and enhance intra- and inter-fraction adaptivity to movement, target and organ-at risk-changes by means of the integration of in-room information and internal-to-external modeling.

Physiological modeling and clinical diagnostics

The study of the autonomic cardiovascular regulation and cardiac dynamics is planned to develop its outcomes towards monitoring in chronic pathologies, recovery, critical care, surgery. Namely, mechanisms are considered of supra-ventricular and ventricular arrhythmias, reflex responses, peripheral to systemic circulation interactions. On the diagnostic side, these analyses will be further integrated with anatomical and functional imaging (US, MRI, CT).

Fusion of anatomic and functional images, signals, and biomolecular data is playing an increasing role in the study of structure-to-function relationship in the central nervous system, cognitive processes, damage due to pathology and/or ageing. Fusion of molecular, micro-structural, functional, and anatomical imaging is at the cutting edge in this field and also in other diagnostic applications, mainly for tumor diagnosis and staging. In the general framework of diagnostics and system biology the methods and technologies for bioinformatics and computational genomics and proteomics will play a major role. Methods for the functional specification of gene sequences, gene expression analysis, modeling of gene interactions and regulation, genomic and proteomic data processing, statistical genetics will be developed, in this regard.

Health systems and e-health

Health systems will be analyzed at territorial and national level, with an increasing attention to developing countries. Quantitative indexes will be developed relevant to the efficacy and efficiency of governance, management of the clinical risk, transparency. The spread out of ICT inside the network of health services down to home-care will be fostered. Safety, reliability, usability of procedures and structures will be addressed by: specific process modeling approaches; the standardization and portability of procedures (e.g., electronic health record) and lexicons (e.g., terminologies, ontologies, data banks). The development of smart mobile technologies will be increasingly transferred to heath services for personalized procedures and individual interfaces to overcome barriers relevant to usability, reliability, and costs. Medical informatics methods will be applied to address the whole process from domain analysis, to design, implementation, and validation phases.

Computer Science and Engineering

Within the Computer Science and Engineering area there is a long tradition in interdisciplinary and collaborative work in the following application themes:

- Biology and health: systems for the prediction of biological properties from chemical structure; systems for genomic data management; affective computing; biological data interpretation; visual and audio systems for people with different abilities.

- Energy and power management: design of energy-aware information systems and of green data centers; power and energy management in software and embedded systems; energy-efficient architectures.
- Entertainment: systems for automatic generation of high-quality content for computer games; robot games; recommender systems for TV applications.
- Intelligent transportation, spanning from railway diagnostics to urban traffic and risk management, to autonomous vehicles.
- Security, safety, and dependability: systems for integrity management in power grids; emergency management information systems; systems for anomaly detection and emerging threat analysis.
- Smart environments: indoors and outdoors intelligent monitoring systems.
- Smart learning: innovative formats for supporting e-learning technologies; edutainment.
- Smart organizations: solutions and applications based on innovative ICT platforms and technologies in industries, services, and government.
- Support to cultural heritage through the use of multimedia, multichannel communication systems; high-level haptic interaction models and tools.

The area has identified some *action lines*, shortly described in the following, which are deemed strategic for the future development of the discipline.

Big data for life, environment, and society

The vision of an empowered society which makes access to data at anytime and anywhere entails the availability of secure, easy-to-use, effective methods for data production, management, analysis and mining, so that individuals and organizations can extract relevant and current information effectively. The availability of huge amounts of data ("big data") is changing our attitude towards science, which is moving from specialized to massive experiments and from very focused to very broad research questions. Such data-centric vision is also an important ingredient of the European view of the Horizon 2020 program.

Robots of the future

In the next years, autonomous robots are expected to spread in the society in the form of autonomous vehicles (wheelchairs, autonomous cars, public transportation, flying drones, military vehicles, etc.), personal assistants, co-workers, co-players, autonomous domestic appliances, and smart homes. The pursuing of this pervasive robotics revolution will involve innovative software and hardware techniques, sensors, as well as specific technologies from artificial intelligence, machine learning and sensor data interpretation, needed to obtain "intelligent" and "adaptive" behaviours that can be accepted by people as natural companions.

Cyber-physical systems

Cyber-physical systems (CPS) provide tight conjoining of, and coordination between, computational and physical resources. The cyber-physical systems of tomorrow will need to satisfy stringent requirements of adaptability, autonomy, efficiency, functionality, reliability, safety, and usability. They will fully realize the so-called Internet of Things. Research advances in CPS will develop autonomous and continuously running systems that will transform our world, by supporting intelligent traffic management, energy-aware behaviours and efficient power management, and societal wellbeing through assistive technologies and ubiquitous/pervasive healthcare monitoring and delivery. These capabilities will be realized by embedding computational intelligence, communication, control and new mechanisms for sensing, actuation, and adaptation into physical systems with active and reconfigurable components.

Genomic computing

The technology for fast DNA sequencing is the main innovation factor in biology and medicine of the next decade. While current genomic data management is struggling with the problem of storing the data which are fast produced by DNA technologies, a powerful data infrastructure is required for going beyond pure storage, to enable viewing, querying, analyzing, mining and searching over a world-wide available collection of genetic data. Research will be conducted in co-operation with IEO-IFOM-IIT.

Energy-aware systems

The study of models and technologies for energy-aware systems has the goal of making IT systems and applications more energy-efficient. Researches range from the analysis and design of information systems to controlling IT software and hardware resources, to embedded systems and technologies. Monitoring and adaptivity paradigms are investigated, in particular for the management of large quantities of data and data-intensive applications. The CSE researchers collaborate also with other areas in the department, in particular in the Systems and Control and Networking areas.

Smart learning

“Learning” (whether at school, at the work place, or for individual needs) is being greatly affected by the rapid progress of IT: devices, networking, social environments, multimedia content, services (as cloud computing), authoring tools, and interactive tools. The CSE area is very active in developing tools, services, methodologies, and “formats” that support novel ways of learning, especially in formal education settings.

Ongoing projects are carried on in partnership with prestigious education academic institutions, teachers (more than 5,000 so far), and students (more than 100,000 so far), mostly in Italy but also involving 18different European countries.

Interaction for all

Progress in the field of human-computer interaction has introduced innovative technologies that enable people to communicate remotely, share resources, and interact with multimedia contents, using a variety of large and small devices, in increasingly intuitive and natural ways. Novel interaction paradigms have an intrinsically “inclusive” nature. They can be superimposed over all technological back-ends, in all domains where people need to be actively engaged with technology, facilitating all, irrespective of disability or disadvantage. As such, novel interaction paradigms raise a number of challenges, both in relationship to how we design and implement applications, and to the way we make these solutions parts of people’s everyday life.

Electrical Engineering

One of the Horizon 2020 objectives is to pursue a ***secure, clean and efficient energy***. There is no doubt that *clean energy* implies ***changing the paradigm of energy generation***, from a generation based on the exploitation of fossil and nuclear sources to a generation more and more based on ***renewable sources***.

There is also no doubt that every single aspect of this change is closely connected to the Electrical Engineering: a surely non exhaustive list of problems may consider the need for better models of the electric system, the need for new generators to be coupled to the wind turbines, the need for new power electronics devices to couple different parts of the grid, the need for more accurate measurement to estimate the state of the grid, …

Another Horizon 2020 objective is related to ***health, demographic change and wellbeing***. Though in a less direct way than with the previous objective, the Electrical Engineering and its research fields can significantly contribute to the achievement of this objective too, as detailed in the following, for the different active research lines.

Electrical and Electronic Measurements: as Lord Kelvin stated, there is no science without metrology. Therefore, the development of innovative measurement methods is a necessity, and not only an option, to achieve the above mentioned goal. In particular, the exploitation of renewable energy sources has to refer, due the very nature of these sources, to *distributed generation* and has to face the fact that generation itself becomes largely *unpredictable* and *unrelated* to the energy demand, being related to *local meteorological* conditions. Dealing with this new scenario requires a deep change in the way the energy system, and the electric one in particular, is controlled and operated, and this requires, in turn, also a deep change in the measurement systems employed to get the quantitative values of the input quantities to the control system.

Two measurement problems appear to be critical in the future energy grids and will represent one of the evolution lines of the research in the EE measurement area:

(i) the detection, analysis and location of the disturbances - both transient and permanent - and their sources, in order to ensure acceptable levels of Power Quality , and hence achieve the objectives of *secure and efficient* energy;

(ii) the on-line and real-time diagnosis of the state of the distributed generation, in particular that of the photo-voltaic (PV) generators, that are prone to a loss of efficiency, caused by soil deposit on the PV panel surface due to atmospheric agents and pollutants in the air.

As far as *health* and *wellbeing* is concerned, measurements are expected to play an extremely important role, both in the early diagnosis of illnesses and in the assessment of the illness state, and in monitoring the environment, to detect the presence of pollutants (biological, chemical, electromagnetical, …) before their concentration becomes dangerous. The development of reliable measurement methods and their metrological characterization, so that the confidence on the measured values can be evaluated, will be an important part of a new scenario, based on a more conscious awareness of the importance of prevention, both for the human and environment health. The research activity already started in the sensor area will develop to cover the above topics.

Electromagnetic compatibility: EMC will present a greater challenge in the future than it does today. Present trends make it clear that electrical/electronic devices will produce, and must survive, a more complex electromagnetic environment. Immunity/emission should be designed into products at early design stages and confirmed through rigorous testing. Safeguards must consider not only the potential sources of interference that exist today, but also those on the horizon. According to such a scenario, the following development lines will be crucial for the future research activity in this area.
EMC impact of new technologies: Development of new EMC prediction models, measurement techniques, and guidelines for EMC-oriented design in application fields undergoing rapid changing and developments, as new breakthrough technologies are implemented. These includes power-electronics, smart grids, sensor and communication technologies, and their impact on the transportation (automotive and railway), aerospace, and energy sectors. Ongoing research activities involve collaborations with international organizations and companies in the forefront of the aforementioned sectors.
EMC standardization/control: Development of novel measurement/testing techniques to address modern needs for optimized, accurate, and cost-effective EMC assessment. In particular, this activity encompasses: statistical versus deterministic data evaluation, methodologies for translation of EMC requirements between various sub-system levels, strategies for in-situ EMC testing of large equipment and systems, measurement/compliance uncertainty in EMC testing, fast emission measurements in time and/or frequency domain.
Electromagnetic modeling & simulation: EMC modeling of complex distributed-parameters structures (e.g., cables and wiring harnesses) via statistical techniques. Development of optimized computational methods for EMC predictions (e.g., inverse EM problems aimed at EMC analyses) and virtual EMC prototyping.
Electromagnetic Safety/Security: Theoretical and experimental analyses aimed at assessing human exposure to electromagnetic fields in harsh environments, and development of mitigation techniques.

Electric Power Systems: The primary objectives of the research activity on electrical energy systems can be summarized in the following activities:
– Modeling of both traditional and innovative energy storage devices and their deployment in the distribution networks and in maritime and land transportation systems. In particular a statistical approach in energy storage devices sizing will be followed and the analysis of the effect of the different uses on life-time reduction will be investigated.
– Analyses of the issues related to the transformation of the current passive distribution networks into active ones (due to the increasing presence of renewable energy sources) and the study of their evolution towards smart grid. In this context the studies will concern the evolution of medium and low voltage distribution networks towards architectures in which advanced control techniques and negotiations between end users and distribution system operators to obtain higher efficiency and safety standards will take place.
– Studies of innovative solutions for maritime and land transportation systems.
– Analyses of the issues and the opportunities related to the diffusion of the electrical vehicles. In particular the issues regarding grid’s hosting capacity and ancillary services provision by the distributed storage devices (V2G) will be investigated.

– Introduction of direct current distribution architectures and implementation of test grids. In particular the studies will concern issues concerning electrical safety during fault operation and a review of the protection selectivity criteria.
– Studies on power quality, with particular concern on security, propagation of disturbances, filtering and design of advanced control systems for power converters in order to obtain low harmonic absorption.

Electronics

Circuits and systems theory and applications

The main target of the group is to develop "horizontal" and "vertical" approaches to modeling and simulation of energy production systems, storage systems and smart distribution grids. The meaning of "horizontal" is that the research unit will apply the developed approaches, algorithms and tools to simulate complex systems composed of several different blocks (generators, DC/DC converters, controllers, load, storage systems) described at different levels of abstraction. The meaning of "vertical" is that the research group will apply and develop approaches to accurately simulate and predict performances of single blocks composing a complex system. Unfortunately, these two modeling and simulating approaches are often in contrast, for example from the standpoint of overall simulation efficiency. This triggers the group to study and find new basic approaches to build up efficient and accurate models and algorithms. The intrinsic multidisciplinary nature of various units operating in the smart-grid infrastructures, allows to highlight various cross-curricular synergies and possible future cooperation both at intra-department and interdepartment level. At intra-department level, possible cooperation can deal with the integration of renewable sources, smart-grid and ICT in contexts like smart-buildings (e.g. Campus Sostenibile). At inter26 department level, possible cooperation could involve the Chemistry Department for storage technologies (like redox batteries), Energy Department for Photovoltaics and Wind-based generators modeling and simulations, Mathematics Department for numerical algorithms.

Sensors and instrumentation

In the field of MEMS, it is foreseen that 3-axis magnetometers will be integrated in the same process in the next 2-3 years, to add functionalities that will allow to correct the loss of absolute orientation over time.
Even more smartness would be added if we could also measure height variations, forming a 10-DOF (degree of freedom) unit using a MEMS pressure sensor. On a horizon of 5 or more years, the objective is the integration of this high-precision motion sensing devices with devices that can measure the surrounding environment. Such a complete unit would be extremely useful for industrial instrumentation (smart factory) and for blind people help. New MEMS-based ultrasound transducers could also be applied in the medical field for micro echograms. In CMOS image sensors, the objective is to develop direct color image sensors with tunable spectral responses. A specific implementation of the pixel has been invented and developed by the group of Politecnico di Milano, allowing to capture up to five different spectral channels at the same position and to quickly tune the spectral responses simply by changing the biasing configuration. These two features open new possibilities: the implementation of sensors with a High Color Accuracy, with applications in medical imaging or food inspection; the use of the sensor for multispectral image capture, allowing the estimation of the reflectance spectrum of an object. Multispectral imaging has indeed potentially several applications in the medical field, like the early detection of skin diseases and of age-related eye diseases through multispectral image capture. Finally, the proposed kind of sensor can be used to combine information from the visible and the infrared bands, with applications in smart cars or more in general transportation systems.
The *single-photon detector* group will work to design silicon SPAD structures and technological processes for obtaining high quantum efficiency in the 600-850 nm range. For extending the range to 1550nm, as required by quantum cryptography, the group intends to tackle the development of new InGaAs/InP singlephoton SPAD detectors. The device design is remarkably complex (it includes III-V heterojunctions) and the processing technology is much less developed, but the interest is very high worldwide and advanced detectors for QKD are badly needed. Very few players have obtained significant results on InGaAs avalanche diodes (in first line in the US Princeton Lightwave Inc and the MIT Lincoln Lab) and there is ample room for progress. To this aim, it is necessary to establish efficient collaboration with an advanced foundry for compound semiconductors, to be found probably in North America. The group also targets the

development of low-cost visible and Short Wave Infra-red (SWIR) multipixel image sensors with photon counting and photon timing capabilities for health, safety and security applications. Finally, the main scientific aim at equipment and instrumentation level is to develop and integrate novel biophotonic devices that can radically improve medical and genetic diagnosis. This can be pursued with systematic integration of new detectors, CMOS chips and optics in microsystems developed from converging scientific areas involving academic, industrial and clinical participants. Biophotonics devices can be targeted to breast and prostate cancer detection and characterization; optical spectroscopy microsystems can be developed by smart integration of large-area red-enhanced SPAD arrays with photon-counting and photon-timing CMOS microelectronics for non-invasive, in-vivo interrogation of human tissues and organs.

In *radiation detectors*, a goal is the development of innovative imaging detectors for nuclear medicine, X and gamma-ray astronomy, material analysis, nuclear physics experiments. These can be achieved by basing the developments on common detector solutions, SDDs array coupled to scintillator crystals, and common detector manufacturing processes. In this sense we have identified a new good collaboration with an Italian Semiconductor Laboratory, the Fondazione Bruno Kessler, located in Trento, Italy. Other areas include digital processing in reconstruction algorithms; imaging detectors based on organic materials for digital radiography; design of innovative VLSI circuits for the readout of detectors, where it is strategically important to continue or even enhance the collaboration with companies operating in the field; advanced X-ray imaging techniques, with collaborations at the Physics Department of Università degli Studi di Milano and Istituto Nazionale di Fisica Nucleare (INFN) in order to create a Center for X-ray Imaging equipped with state-of-the art instrumentation and synergy of competences; instrumental development of detectors and integrated readout for a novel femtoscopy array for nuclear physics experiments with stable and radioactive beams that will feature pulse shaping analysis capability thus allowing the identification in charge and mass even of low energy particles; development of sensitive x-ray diagnostic methods for imaging biomarkers; assessing the radiobiological impact during radiotherapy treatments; continue the study of silicon carbide detectors and application in instruments for astrophysics, plasma physics and medical diagnostic systems; study and development of ultra-low power low-noise front-end electronics for X and gamma ray radiation detector readout. All these present and future activities can count on established collaborations with leading Italian universities, research centers and companies, and foreign institutions, with which interdisciplinary collaborations will be pursued for several research paths: tissue engineering, 3D in vitro cancer models for precise delineation of mechanisms; manufacturing gold nanoparticles targeted to cancer for imaging.

Microelectronics and emerging technologies

The Electron device group needs to consolidate its well-recognized position. Such a consolidation will be needed to face the possible lack of a reliable industrial partner, due to the change in the national industrial scenario, with a loss in access to leading-edge technologies and funded projects. The group will strengthen its potentialities of carrying out scientific research, reinforcing the experimental capabilities and starting new collaborations with academic groups involved in leading edge nanotechnology (e.g. nanotubes, graphene, self-assembly, even inside Politecnico di Milano when present), to expand our area of interest in topics that may soon become mainstream technologies. The possibility to tighten links with foreign semiconductor memory companies will be also explored. In the field of Organic Semiconductors, the target is twofold. On the one hand the ability of performing detailed optoelectronic characterization and modeling of devices will be further strengthened, since this skill gives the group an identity and a peculiarity within the worldwide panorama of groups working in organic electronics. On the other hand, the group will have an active role in the emerging trend driving organic electronics from single devices to complex optoelectronics systems. To this extent, the technology of drop-on-demand Ink-Jet printing of soluble functional molecules will be explored. As a feasible and original demonstrator of this technology, the group aims at developing a large area digital X-ray imager targeted to biomedical applications. The group also aims at setting a standard in the electrical characterization of biomolecules, accessing the charge-transport properties of proteins, DNA or cells in a biosensor perspective.

The goal of the *Electronic Circuit Design* group is to keep the present position in the field and also to improve it. This goal can be achieved only by accessing to an adequate level of funding, both from private sources, and from public sources. For this reason in the next five years the effort will be focused, on one side, to reinforce the industrial links, for instance with Intel, and, on the other side, to pursue European funding. The level of the scientific proposal will be fundamental, in particular to strengthen the collaboration with companies. To this purpose the scientific objective of the research group must be ambitious, and two main objectives can be already identified: the design of an high-efficiency polar transmitter for wideband LTE and the design of very high-efficiency clocking circuits for multiple applications, such as microprocessor clocking, frequency synthesis and so forth.

Systems and Control

Concerning the research topics specific to the single groups, the main theoretical developments are expected for the **Control Systems** group in the areas of distributed control and estimation, switched control, robust and fault-tolerant control, stochastic hybrid control, randomized methods, linear and nonlinear model identification.

The **Dynamics of Complex Systems** group wants instead to investigate complex systems and networks, and to actively cooperate with scientists interested in exploiting the power of the "complex systems science" in their specific field of application.

The **ORDO** group will focus not only on the mathematical models and efficient exact/approximate optimization algorithms for significant interdisciplinary applications, but also on the mathematical problem structure and complexity issues. From the methodological point of view, particular attention will be devoted to hybrid optimization methods, mathematical approaches to Mixed Integer Non Linear Problems, and optimization problems under data uncertainty.

The major themes under development for the **Optical measurements and laser instrumentation** group are application of optical sensing to biomedical subject and the development of new optical methods.

The **Environmental Systems** group's main foreseen challenges are to develop a strong interdisciplinary understanding of the role and nature of models in environmental science, to clearly place models as essential tools to understand and tackle environmental problems, and to continue the development of new local and global models that integrate the human component (typically economic considerations and health risks) which can support openness, participation and transparency.

Finally, the **Robotics and Industrial Automation** group aims at becoming in a few years a leading group in one of the emerging fields in industrial robotics, like "human-centric" industrial robotics or learning by demonstration, as well as to consolidate positioning in motion control and mechatronic analysis of machines. In the production systems control, a research direction will most probably be the investigation of diagnostic techniques. A new and emerging research topic is aimed at demonstrating that control theory and engineering are extremely useful, and sometimes enabling, to design computing systems, at all levels.

On the other hand, application-driven research topics where different research groups within the SC area will operate and hopefully cooperate concern:

Energy systems and energy management

Problems related to the control of renewable energy systems (solar, wind, and hydro, power plants) and smart grids characterized by a huge penetration of wind and solar distributed generators will be investigated from a control systems point of view. Energy management will be addressed both from the operations research perspective (by studying energy related optimization problems emerging in different fields such as domestic load management, energy-aware network design) and with extensive adoption of control techniques, as a basis for the efficient management of all energy resources and for the efficient interaction with aggregators and operators.

Transportation systems

Drivers such as safety, oil-shortage, environmental impact, and economic factors call for an innovation process in the current transportation systems, both at the level of the single vehicle control and at the level of multi-vehicle coordination. This leads to specific application-driven research lines and to new challenges to address. Among them: advanced control of new generation road vehicles, energy management in electric/hybrid road vehicles, multi-vehicle coordination in road transportation, multi-aircraft coordination in new generation air traffic management systems, performance-oriented control of aircraft and rotorcraft, unmanned rotorcraft vehicles, spacecraft dynamics and control. Control of transportation networks as complex systems will also be studied. From an operations research perspective, transportation problems will be addressed accounting for data uncertainty (e.g., the traveling times) and its relation with disruptions.

Health care systems

Model-based diseases therapy, nonlinear dynamics of heart and brain systems, epidemic diffusion patterns in societal models affected by demographic change, health care management problems (e.g., home care management and clinical pathways), taking into account uncertainty on the availability of resources and demand (e.g., ambulance availability and patient needs), and applications of robotics to surgery will be ingredients of the research of the SC area in the coming years in health care systems.

Telecommunications

The Telecommunications research lines have identified some action lines, shortly described in the following, which are deemed strategic for the future development of the discipline. These lines will provide continuity over the research lines investigated so far, and will maintain the balanced mixing between fundamental and applied research in close interaction with the next evolution of the industry.

Managed Internet Service

In order to let the Internet adapt to the new scenarios and provide the required services a change of paradigm is needed. New pervasive services can be enabled only by the virtualization of the communication networks using heterogeneous infrastructures that mix wireless and wired connectivity; energy consumption can be reduced by introducing routing aware mechanisms; low transmission latency, high speed and reliable transmission, as needed for example by cloud computing or digital manufacturing, can only be achieved through cross-layer architectures that take care at level of the specific service requirement. These new issues are addressed mainly by the competence of the Networking group and the vital collaboration in other research lines.

Internet of Things (Internet of Things)

Internet of Things envisages the world in which the many objects that surround us in our everyday activities are connected to the big Internet. This will enable innumerable new services whose impact is expected to change to great extent our lifestyles and society itself, impacting in all the care and attentions referred in the introductory section. The network is expected to evolve in size, with a number of nodes today unimaginable and challenges will interest many basic fields, such as Applications, Sensor and Device Technology, Transmission, Routing, Integrate Operation and Management, as described in the previous point. This, in turn, calls for strict collaborations among the research units of department and Politecnico di Milano.

High Capacity Energy and Latency Aware Transmission

Managed Internet Services are part of the future networks that will be designed to take care of energy consumption and of transmission latency for novel disruptive services. Green Touch, the Consortium established in the 2010 in order to coordinate the effort in the Green TLC, set the objective of reducing 3 orders of magnitude the consumption of the whole telecommunications network within the 2015. Efforts in the most advanced research groups and consortia such as GreenTouch are devoted to set ambitious targets in energy reduction up to x1000 by 2015. Even if this objective appears today unrealistic, the theme of the energy consumption becomes more and more relevant in the consciousness of the operators and TLC consumers. Energy-aware research in TLC moves toward the exploitation of a better merging of optics and electronics processing, the innovative use of the multi-mode transmission, resource scheduling, power aware modulation and code technologies and so on. Latency reduction in all-IP communications enables delay-sensitive applications such as critical monitoring and control in industry, society, finance, and health. This area is in the early stage but it is expected to have a disruptive impact in the integration of heterogeneous delay-sensitive ICT applications.

Signal Processing for Sensing and Rendering

The variety, the pervasiveness and the sheer number of sensors that capture information today is steadily growing, which creates the need of new signal processing paradigms for extracting high-level information in an automated and distributed fashion. This process of “virtualization” of reality takes on a variety of forms depending on scale, range and application. Remote sensing and seismic processing, for example, can be used for environment monitoring, disaster management; emergency response; energy and natural resource exploitations; safety and security. Signals gathered from distributed multimodal sensors can be processed to make sense of pedestrian/vehicular flows for traffic control. On a smaller scale and closer range, signals coming from distributed microphones and/or cameras can be processed for acoustic and/or visual scene modeling and reconstruction, with applications to source/environment characterization; safety and security; biometrics, domotics, industrial monitoring, etc. Multimodal/multiband signals coming from sensors that are embedded in portable devices or distributed in the environment can be jointly processed to extract behavioral information, mobility data, and gather all kinds of statistical information. Multimodal and multispectral sensing signals can be acquired and processed for biomedical applications (patient monitoring, bio-modeling, etc.) As the information complexity and richness increases, so does the information that needs to be rendered back to the user. Again, signal processing plays a crucial role in this process. Examples are 3D scene visualization; space-time processing for acoustic scene rendering; sound synthesis; haptic feedback; mixed and augmented reality; etc.

Signal Processing for Multimedia and Pervasive Communication Systems

A key requirement for the information society of the future is global connectivity. This requires flexible multimedia communication systems of extreme pervasiveness and adaptivity. The role of signal processing is crucial for these goals as it enables the virtualization of communication systems (e.g. soft radio, cognitive radio, smart antennas); and the development of communication systems of extreme performance (distributed multiple antenna systems for virtual MIMO and more, or network MIMO for femtocells) the distribution and optimization of processing effort in the cloud; the development of cooperative, selfaware/self-configuring/environment-aware, highly adaptive networks of processing devices with distributed computing (e.g., mobile users equipped with peer-to-peer devices, vehicles with car-to-car communications), it pushes the boundaries of signal compression and coding (e.g. distributed and scalable source coding), it enables new forms of monitoring and tracking of processing stages for multimedia content quality control, for tampering detection and for digital forensics.

Information and Communication Theory

Network paradigm. The "network" organizational paradigm becomes an important opportunity for the “telecom” scientists to export their methods in other contexts. The "energy-networks" are an example. With the emergence of distributed and renewable sources and new organization of consumption, the paradigm of network management and energy will be close and closer to that of telecom networks. One can see similar developments in other major networks artificial (from transport to social networks) and natural (cellular networks, collective behaviour of animals, etc..).

Information theory. Until now, IT has been applied only to transmission networks of few individuals (far from the scale of Avogadro's number). In other words, neg-entropy has been since now substantially overlooked. The emergence of bio-sciences and of complex natural and artificial networks offers novel opportunity to re-discover concepts as entropy, neg-entropy, information, drawing from the big picture of information theory. These studies can even open the way for facing the thematic of “semantic information”.

Quantum Communications. An important chapter in connection with information theory is the "quantum communications". Although it has been proven for over 15 years the transmission of qu-bits (thus a pairs of entangled states) it has found so far only application as the transmission of encrypted keys (using the BB84 protocol). There are now the technology conditions (generation and detection of individual photons, the polarization control technology) enabling the evolution of "quantum communications" into new applications.

Enabling Technologies

Technologies: It is fundamental, strategic and far-sighted to invest in the 5-KETs[1], future innovation becoming increasingly independent of colocation of R&D and fabrication. The establishing “fab-less” scheme offers new opportunities and is vital to keep innovation and intellectual property leadership. In the future our background will be strengthened even more operating in the “More-than-Moore” direction, extending towards higher frequencies (THz), new electromagnetic phenomena, silicon photonics and

[1] 1 The European Community recognized Nanotechnologies, Photonics, Microelectronics, Biotechnologies and Advanced materials as the five Key Enabling Technologies in ICT.

photonics integration, exploiting through leading projects that will embrace different research lines of the department.
Propagation: The new challenge for the telecommunication radio system is the further increase of the transmission frequency to provide wideband for all: W (80-90 GHz) band and above are presently under study and the optical frequency systems are under development both for outdoor and indoor (VLC) applications. In this framework, the Spino d'Adda laboratory will play a key role in the next 5 years in a new experiment (Alphasat Aldo Experiment) with the aim of testing the effectiveness of future Propagation Impairments Mitigation Techniques foreseeing to redirect adaptively the power across the served territory.
Finally, the Applied Electromagnetic research line is involved in the creation of PoliFAB, a Faculty infrastructure conceived and promoted together with the Electromagnetics Area and the Physics Department PoliFAB will offer access to systems processing with micro- and nanotechnologies in an open scheme to the interested research groups focusing on a functional combination of different technologies (electronics, photonics, fluidics, biomedical…).

Internal and external positioning

All the research groups have well established connections both with different groups of the Politecnico di Milano (within and outside the department) and connections at the international level. Some groups are also particularly active at the regional level, participating in programs funded by the Lombardia Region, or establishing partnerships with local companies in research programs.
The research groups of DEIB have been recognized as either excellent or very good at the international level during the last research assessment exercise in 2007. In the subsequent years the rate of high quality publications per year has been kept high and the department has become more and more successful in achieving competitive research funds, with specific reference to European Union research grants within the 7th Framework Programme, even though with some fairly clear differences in performance among the research groups.
Finally, the scientific strength of the research lines is accounted for by the number of members who hold a leadership in their respective fields, both at the national and the international levels. In particular, researchers in the department have also promoted and contributed to the organization of top-level scientific events, including, e.g., the recent 18th IFAC World Congress, held in Milano in 2011 with more than 2800 attendees. Participation in the scientific and professional international societies is particularly significant too, with members of the department being fellows of such societies, or serving in editorial boards of top-ranked journals as well as in technical committees.

Technology transfer

DEIB had a long-standing tradition of collaborations with leading companies: private sources play a significant (and increasing) role in DEIB's research funding. Long-term strategic alliances with industries, either in the ICT field or in various application domains of interest, are fostered through the sharing of research and development activities, the joint participation to public research programmes, joint patenting and training activities. As a recent example, the AgustaWestland Advanced Rotorcraft Center (AWPARC), established in 2010 and to which DEIB contributes with a number of research projects, can be cited.
Indeed, one of the aims of the department's activity is to transform research results into real-world innovation, supporting and contributing to the innovation processes of industries, public administrations, and the society in general, by understanding needs and problems, analyzing and interpreting market opportunities and challenges, identifying technological trends and directions, providing expertise and methods to design and develop disruptive solutions.
This complex activity is carried out taking into account the intrinsic characteristics and constraints of innovation processes, including speed, market impact, technology transfer, human capital, and organizational development. To cope with these issues and boost technology transfer, DEIB will also exploit the partnership with CEFRIEL (established in 1988) and with the spinoffs and startups that have been created over the last years. In turn, the results and experiences derived from innovation projects lay a

crucial role in continuously feeding the stream of research problems addressed by the department's researchers.

In the field of bioengineering, technology transfer is a two step process, first there is the clinical translation and second the real transfer to industry of commercial products. Translational Research is the research process that investigates and translates non-clinical research results into clinical applications and tests their safety and efficacy as well as the needs, acceptability, and effectiveness of the application of new technologies in a patient driven environment, and cost efficiency in ecological settings. To boost these challenges, most of the activities dedicated to translational research will be carried out in strict collaboration with industries, which then will complete the eventual commercialization. It's noteworthy that few successful experiences of technology transfer at Politecnico di Milano through spinoffs/start ups in the field of bioengineering have occurred since the early 1990s.

Section 3 – Teaching activities vs. reseach activities

Education is a primary mission of the department. More than 180 faculty members and research associates are engaged in the creation of fundamental and advanced knowledge in computer science, systems and control, electronics and telecommunication engineering. Specifically, 226 courses are delivered in the Bachelor and Master of Science degree programmes of five out of six Schools of Engineering of Politecnico di Milano, for a total of 1503 ECTSs and an average of 8.3 ECTS per person. Most of the courses (80%) are taught in the School of Information Engineering, with 350 ECTSs delivered at the Bachelor level and 760 at the Master level. The remaining 20% is divided among the School of Systems Engineering (25 courses), Civil and Environmental Engineering (11), Industrial Engineering (9) and at the Bachelor of Science of Industrial Process Engineering (2).

Constant care is given to keeping high-quality teaching standards and to updating the courses, that should continuously evolve to meet the advances of rapidly evolving disciplines.

Observe that, from an educational perspective, although technology is radically and continuously evolving, this occurs in the context of a solid body of cultural and scientific principles, which make computing – a term used with a broader sense than just computer science – a discipline with well-established foundations. It is therefore vital that students acquire the instruments and attitude to permanently act as learning entities, intrinsically able to expand their knowledge on the basis of the experience and changes they are exposed to. Thus, an essential role of the education in information technologies is to create the human capital that will operate in the context of a dynamically evolving disciplines; therefore the department trains students that should continuously learn from the environment and from the experience they are involved in. Within such a context, the department is engaged in the training of students at the Bachelor, Master, and PhD levels; such students are trained to master professions which are among the most requested by our society. Increasing emphasis is given to methods that enhance the ability of students to work in teams; especially in interdisciplinary studies, such methods should emphasize the ability to deal with differences in background, languages, and experience.

The department also offers a doctoral program in Information Technology focusing on the main research areas of Information Engineering and preparing graduate students for careers in fundamental and applied research both in the academy and the industry. Nearly 30 courses are offered every year by the internal faculty and by international professors. Research outcome and innovation are primarily transferred to PhD students through these courses.

PhD candidates are considered an essential factor for competing in research; they are increasing in number, thanks to numerous scholarships, paid by private sponsoring institutions or by funds of research projects, which add to public scholarships offered by the Ministry. Candidates admitted to the PhD program are therefore directly involved into the research activity of the groups, while attending dedicated classes. The success of the educational environment is testified by the employment rate of its students, particularly for the PhD candidates, for which it is not common to gather opportunities before even completing the track.

Most of our PhD students are also encouraged to spend at least six months abroad, in a university or a company, which increases their employment opportunities worldwide.

With respect to internationalization, the department is engaged in widening its share of international students and in offering to its students a wide spectrum of opportunities for international mobility as detailed in the last section of this document.

The field of bioengineering realizes a fundamental integration of teaching and research through the program of Biomedical Engineering (BME, under-graduate and graduate) and the PhD in Bioengineering track. The focus of PhD curricula is on an engineering approach to problem solving in biomedical technologies, both concerning growing knowledge and methodological/technological solutions, inside or cooperating with advanced laboratories in the international context. Conversely, doctoral students do offer an effective support to the whole research and teaching activities of bioengineering groups.

The BME program attractiveness has grown up to the admission of 300 freshmen/year, out of more than 600 applications, due to the solid in-breadth bases, the interdisciplinary features, and the opportunity of in depth studies in a variety of BME areas based on the vast skills inside the Politecnico di Milano in many applications of technologies to biomedical problems and the cooperation with the major local and international institutions in biomedical sciences. An increasing effort is devoted to the dialogue with the biomedical industry, which is experiencing a rapid evolution based on relatively new professional skills. Line guides are: 1) adapt the educational profile to technological progress and demands of productive world, though keeping a solid cultural basis; 2) highlight our educational activity and the characterizing skills of biomedical engineers; 3) offer students an early approach to industrial companies for a correct perception of the asked professional roles.

Section 4 – Laboratories and research infrastructures

The department currently accommodates more than 30 labs corresponding to about 1,100 sqm of experimental labs and 1,150 sqm of computer rooms. These laboratories do not share a unique organization and structure, they span from single room lab, managed by one professor, to labs located over different buildings and managed by a pool of professors. Furthermore, some labs are shared with DEIB's consortia and two of its major labs are located outside Milano. A short overview of the presently operating laboratories is given in the following.

Laboratories

Bioengineering. The field of computational bio-mechanics, bio-molecular modeling, bio- and micro-fluidics, micro-interfaces, cell and tissue engineering relies on three integrated labs with computation, design, prototyping and simulation facilities. Therapy procedures and devices in assisted surgery, radiotherapy, neuroengineering, and medical robotics share development and validation facilities in four labs. Movement capture and evaluation for functional analysis and rehabilitation is based on the movement capture and analysis, modeling, and virtualization. Rehabilitation technologies and modeling in the cardiovascular, respiratory, and neuro-sensory systems rely on bio-medical technology and computing structures, where also diagnostic methods are developed. E-Health and telemedicine aspects are developed in the specific lab.

The *Computer Science and Engineering* area manages several labs, mainly hosting computer rooms. In addition, it is worth mentioning the multimedia Hoc Laboratory and the WemsyLab, that has the objective is to design embedded systems with wireless and wired communication abilities, the AIRLab (Artificial Intelligence and Robotics) which is geographically distributed over three permanent sites (AIRLab/DEIB, AIRLAB/Como, and AIRLab/Lambrate) and a space kindly provided by the Rector for the development of soccer robots (AIRLab/Bovisa), and the NECST (Novel, Emerging Computing System Technologies) laboratory.

The *Electrical Engineering* area manages 4 laboratories for experimental characterization of the research activities pursued by the section. In particular, a laboratory is devoted to Electrical Drives development and characterization; a laboratory is devoted to EMC analysis and testing; a laboratory is devoted to Electrical Measurement, Diagnosis of Components and Systems, and Signal Processing, and has been accredited by ACCREDIA; a laboratory is devoted to Electrical Power Quality assessment and compensation.

The *Electronics* area manages about 10 labs for experimental characterization and numerical modeling of semiconductor devices and circuits and for sensor development, including a small clean room in ISO-8 class. Additional capabilities are expected from the new facility PoliFAB, a convergence between ELN and TLC labs.

The *Systems and Control* area manages the following main labs: MOVE, supporting research on automation and control of vehicles; MERLIN, supporting research on mechatronics and robotics and hosting some instrumented robotic manipulators; DAISY, where facilities are available for studies on industrial automation; the MEASUREMENT lab for optical measurement instrumentations; the Operations Research laboratory (ORLAB) is devoted to research in the field of mathematical optimization and to applied projects on decision-making problems arising in areas such as telecommunication, transportation, energy and health care management.; the LITA lab, for computer engineering applied to the land use and environment. Finally, there is also one computer lab, LOOMS, in Cremona that supports research on object-oriented modelling.

The *Telecommunications* area manages more than 10 labs dedicated to optical and wireless networks, image and sound processing and remote sensing. Moreover, two additional facilities are located outside Milano: the experimental station at Spino d'Adda for radio wave propagation on earth-satellite links and the CE.S.A.R.E. Lab., including a semianechoic room for electromagnetic compatibility.

Furthermore, the department is currently promoting the redesign of its physical spaces, currently dispersed over seven different buildings. In such a context, the department is promoting, in collaboration with various departments of Politecnico di Milano, the redesign of its physical spaces, where visionary methodologies enabled by Information and Communication Technology (ICT) are applied to the design, prototyping, and validation of solutions applicable to tomorrow's campuses. A very large research initiative, "The ICT

Campus as a Lab", has been proposed in the frame "Smart & Sustainable Campus" project of Politecnico di Milano. The ICT Campus will act as a live display of the potential of IT-based solutions for improving collective life for students, local decision makers, and citizens at large. The project includes energy-efficient and sustainable building management and control, innovative mobility solutions, and work and public space management.

Infrastructures

Spino d'Adda station

The Spino d'Adda station is one of the most important experimental sites in Italy (and in the world) devoted to the investigation of radiowave propagation in Earth-space links. Instrumentation of the Politecnico di Milano, the Italian Space Agency (ASI) and IEIIT-CNR is installed there. The station is currently being refurbished: in the first semester of 2013 the European Alphasat satellite will in fact be launched, that will carry two new experimental payloads; since Spino d'Adda will be the control centre for the propagation experiment, ASI is installing a new receiving-transmitting ground station at Q/V band (40/50 GHz), new radiometers and other ancillary equipment.

Anechoic chamber

The Busto Arsizio Laboratory comprises a semi-anechoic chamber (7x4x3.5 m) in the frequency band 26 MHz-18 GHz and an instrumentation set up to carry out emission measurements, EMI (electromagnetic interference) and EMS (electromagnetic susceptibility). In the lab it is also possible to monitor electromagnetic sources in the band 50 Hz-7 GHz. Moreover anechoic material is available for the floor, in order to carry out radiation pattern and gain measurements for antennas (reference antennas are available).

Section 5 – Internationalization

The department is actively consolidating and strengthening its international position, according to the strategic vision 2012-2014 issued by the academic senate, which envisions for Politecnico di Milano a role as a high-quality international university.

In particular, the following internationalization activities relative to research, teaching, and organization, respectively, are being pursued by the department.

The participation of the researchers of the department in international excellence networks and research projects is steadily strong, as it emerges by looking, for instance, at the success rates in EU projects and at the two prestigious ERC Advanced Investigator Grants awarded in 2008. The research activity of the department is recognized to be of high quality with respect to the international standards that measure research results with top-quality publications on high-quality journals and conferences. Many groups have relevant international visibility and positioning through a significant number of relevant publications and through the participation to various well-recognized international projects, working groups, and committees, as recognized in the last international peer-review research assessment exercise (2003-2006).

Also the number of international patents endorses the role of the department as an international leading research institution.

Strategic teaching relationships with renowned international universities are active, offering the Italian students the possibility of experiencing a period of time studying abroad and the foreign students the opportunity to study at Politecnico di Milano. Several exchange programs at the Bachelor and Master level are offered, including, for example, the joint Master in Computer Science with the University of Illinois at Chicago and the double Bachelor with the Tongji University at Shanghai. Most classes of the Master programs of the department are offered in English, thereby facilitating the attendance of international students, and anticipating the transition to English that is currently programmed for all Master programs of Politecnico di Milano starting from 2014. At the PhD level, candidates are internationally recruited from good universities and their international mobility is increased through agreements with top-quality universities (e.g., Georgia Tech).

The department is willing to increase the size of international faculty by actively exploiting the opportunities provided by Politecnico di Milano for recruiting professors from foreign institutions, young researchers through the International Fellowship Research Grants, and temporary lecturers for one semester. The new positions are intended both to strengthen the research fields in which the department has a leading international position and to open new research fields that are not yet represented in the department. Finally, the department is effectively offering front-office administrative services both for Italian and foreign people.