PhD in Information Engineering

Mini-courses Calendar a.a. 2025/26

n.	Title of the Minicourse	N. of ETCS	Description of the minicourse	Eval.
1	Wavelets and their applications	*2*	*Wavelet analysis is a powerful mathematical tool which, in recent years, has found application in various contexts of applied mathematics and engineering, in particular for their ability to provide a local time-frequency analysis of signals. The goal of this course is to present the basic concepts of wavelets, multiresolution analysis and filterbanks, as well as the construction of orthogonal and bi-orthogonal wavelet systems. We will also illustrate the possibilities of their application in typical signal and image processing problems: de-noising, compression, etc. Some experimentation will be carried out by making use of the Matlab Wavelet Toolbox.*	Y
2	Statistical analysis of experimental data	*2*	*The course aims to give the fundamental knowledge to apply the correct statistical analysis of the experimental data. The training contents include: Basic concepts - Introduction to concepts in probability. confidence intervals distributions. Descriptive and inferential statistics - Estimating population parameters and testing hypotheses, Probability, compare means, correlation, regression, outliers. Multivariate statistical analysis - variables' standardization, Principal Component Analysis, Cluster Analysis. Applications - use of application software for the execution of multivariate statistical tests and the related graphic representation.*	Y
3	Foundations of Quantum Mechanics and applications	*2*	*The purpose of the course is to introduce the basic concepts of Quantum Mechanics and its most important applications. The first part covers the basic quantum ideas and the formalism of Quantum Mechanics. The second part describes two-level systems (atomic and spin 1/2) and their interaction with electromagnetic fields, of great importance for magnetic resonance applications, basics of light-matter interaction, principles of gas and semiconductor lasers. A look is directed to the recent applications of quantum mechanics to quantum computing and entanglement.*	N
4	Computational Algebra and Geometry: graphs, simplicial complexes, singularities (Part I)	*2*	*We give basic notions of computational Algebra introducing Groebner basis theory and we apply it to study problems of graph and simplicial complex theory. We introduce the Jacobian matrix to study the singularities of certain surfaces.*	Y
5	Computational Algebra and Geometry: graphs, simplicial complexes, singularities (Part Ii)	*2*	*In the second part of this course, we introduce a software of symbolic computation, Macaulay2, to solve problems in graph and simplicial complex theory and to establish if certain surfaces are singular or not.*	Y
6	Variational Inequalities and Network Equilibrium Problems	*2*	*Variational Inequality theory represents an excellent tool in the study of real world problems. Indeed, it is a powerful unifying methodology for formulating a variety of equilibrium problems, qualitatively analyzing them in terms of existence and uniqueness of the solution, stability and sensitivity analysis, and providing us with algorithms with accompanying convergence analysis for computational purposes. The course aims at presenting the fundamentals of the theory of variational inequalities and some applications to network equilibrium problems.*	Y
7	Inverse problems for engineering: fundamentals and recent developments	*3*	*The course will first define the concepts of well-posedness, ill-posedness, and ill conditioning, and the relevance of these concepts in all those application where one wants to infer something about some physical quantities by measurements of some other related quantity. Then, the course will review the different methods for overcoming the above problems and come to some related 'well posed' problem. In particular, the more classical regularization techniques (Tichonov truncated SVD) will be reviewed first. Then, the new possibilities offered by the very recent Compressive sensing paradigm will be also covered.*	N

8	Mathematical modeling and simulation for programmable networks	*2*	*The rapid growth of digitalization, Internet of Things (IoT), and mobile technologies presents a significant challenge in the form of massive data processing, storage, and network traffic. To address this, a long-term solution involves shifting towards distributed and programmable wireless networks, minimizing unnecessary data transfer and cloud traffic. This course provides a foundation for mathematically modeling programmable wireless networks and highly demanding distributed services. The focus will be on establishing mathematical frameworks to analyze and predict system performance, including computational and communication resource allocation, management, and optimization across the cloud-edge continuum. Monte Carlo simulations, a powerful tool for statistically analyzing the behavior of such systems under various conditions, will be explored to validate the analytical results. To provide insights into the mathematical modeling, the MATLAB tool will be exploited to run simulations.*	N
9	Deep Learning: fundamentals and applications in Information Engineering	*2*	*In recent years, Deep Learning (DL) methodologies has emerged as a pervasive methodology in a plethora of topics in Information Engineering, and obtained numerous successes in the analysis of complex data from multiple sources, including, images, audio, and videos. In this course module, the principles of DL are presented, starting from Machine Learning (ML) approaches, by focusing on both the most recent architectures and algorithms for DL, like CNNs, Transformers, and Graph NeuraL Networks on CNN. Some innovative approaches, like Generative Adversarial Networks (GAN) will be discussed with reference to practical problems, in order to face some limitations of available data, in particular for e-health and mobile continued diagnosis and monitoring of remote patients.*	Y
10	Multicast in 5G	*2*	*Mobile network providers are in front of an increase in multicast traffic load, and this growth is forecasted to continue in 5G networks. The major challenges come from the fact that multicast traffic not only targets groups of end-user devices, but it also involves machine-type communications (MTC) for the Internet of Things (IoT). This lecture provides a brief overview of 5G challenges in the view of effective management of multicast applications. The discussion highlights the key challenges and the open issues to be considered in future research to enhance the capabilities of machine-type multicast service to support a wide variety of 5G multimedia and IoT use cases.*	N
11	Network security for Digital Twins	*2*	*The concept of the Digital Twin has gained considerable popularity in recent years, reflecting the ongoing trend of technological evolution that is bringing the virtual and real worlds closer together. The Digital Twin is a virtual replica of a physical entity that is realized through the continuous and real-time collection of data on the real twin. Ensuring network security is crucial to protect the sensitive data and the integrity of the Digital Twin. The course will begin with an introduction to the Digital Twin, defining what it is and briefly explaining the implementation process and possible applications. Following this, useful techniques and paradigms for ensuring network security in the creation and management of Digital Twins will be explored in depth from both theoretical and practical perspectives.*	N
12	Improving communication efficiency in edge intelligence: a networking perspective	*2*	*The huge amount of data collected and generated by smartphones, laptops, and Internet of things (IoT) devices and the increasing popularity of interactive applications, like EXtended Reality and Autonomous Driving, has led to a surge of interest in the deployment of Machine Learning (ML) at the network edge. To limit privacy and reliability issues, novel approaches like Federated Learning (FL) have been recently proposed that enable ML models to be executed by distributed end-devices under the coordination of a central aggregator server. However, the performance of distributed intelligence largely depends on the communication opportunities of the end-devices, which may experience connectivity issues with the server, e.g., due to unreliable and lossy links, mobility, and energy constraints. The course will provide an overview of networking solutions specifically designed to improve the communication efficiency in distributed edge intelligence environments. By scanning the state-of-the-art, the analysis will show the potential of paradigms like information-centric networking, software-defined-networking and peer-to-peer networking, and will provide future research perspectives.*	N
13	Edge Machine Learning techniques for data analysis on low computational capacity devices	*2*	*Edge machine learning is gaining popularity as it enables the deployment of AI models in low computational capacity devices as microcontrollers. The course aims at introducing and describing some popular edge machine learning model implementations, in particular for regression analysis and classification of signals coming from on-board sensors such as accelerometers and microphones. In particular, the students will learn how to deploy a desktop developed ML model in an ARM® based tiny microcontroller architecture using specific software tools.*	Y

14	Non-Terrestrial Networks in 5G & beyond	*2*	*The course will introduce the concept of non-terrestrial networking, review 3GPP Non Terrestrial Network (NTN) features and discuss their potential in satisfying user expectations in 5G & beyond networks. State of the art, current 3GPP research activities, and open issues will be described to highlight the importance of NTNs in next-generation wireless communication systems.*	N
15	Ensuring Trustworthiness in Federated Learning	*2*	*Ensuring trustworthiness in AI models can be a challenging task due to their brittleness, difficulty in adapting to new domains, and inability to generalize outside of the same distribution of data points. This can result in inaccurate predictions, unfair treatment of groups, and difficulties in interpretation, thus reducing human trust. To improve the trustworthiness of AI models, it is essential to increase transparency, interpretability, and generalizability. One way to maintain data privacy and security while improving the trustworthiness of AI models is through the use of federated learning (FL). FL enables the training of AI models using decentralized data, which helps to preserve the privacy and security of sensitive data while allowing for the creation of more accurate and robust models. By leveraging FL, AI models can be trained on multiple sources, leading to improved generalization and performances in real-world applications.*	Y
16	Blockchain for smart city applications	*3*	*This course presents some innovative solutions based on the blockchain technology to fit the new requirements of the smart city paradigm. First, the blockchain technology is introduced, focusing on its most popular public and permissionless implementations: Bitcoin and Ethereum. Then, some architectures and solutions that exploit such technology are presented to provide new or better services in the smart city context. These solutions address some major issues of this new context, such as energy consumption, access to sensitive information, service delivery and trustworthiness on online social networks.*	Y
17	Cybersecurity and e-government	*2*	*Cybersecurity is one of the main challenges of the digital transformation, due to the continuous growth of cyber-attacks and the need of guaranteeing robust, reliable and trusted services. This aspect is particularly critical in the context of e-government, in which digital services implement processes involving the public sector, citizens and companies, for legally relevant activities. The course offers an overview on the main tools coming from the field of cybersecurity and aimed to provide online services with the above security features, to achieve a secure and smart digital transformation. Therefore, the course will introduce notions like digital identity, digital signature, blockchain, secure emailing, accountable systems, secure outsourcing of data, digital archives, etc.*	Y
18	Privacy Issues in the Digital Society	*3*	*The digital transformation is involving all the segments of the society, from the public administration to the production and business system. This exposes the citizens to serious privacy threats, due to the processing of (sensitive) personal data. The course is centered on introducing some basic notions useful to give a quantitative measure of data and communication privacy. Moreover, some specific application domains in which users' privacy is a critical issue will be analyzed, such as location-based services, proximity-based services, digital contact tracing, as well as the problem of anonymous communications.*	Y
19	Digital Identity	*2*	*This course presents the concepts of digital identity and identity management and introduces various technologies and processes that support personal identity information. The first part is about authentication, authentication primitives and protocols, emphasizing the importance of Single Sign On also from the regulatory side (eIDAS regulation). Then, some solutions to support digital identity, such as OAuth, OpenID Connect, and Windows CardSpace, are discussed. Finally, Blockchain-based solutions for digital identity are presented, focusing on the new approach of self-sovereign identity. Two practical experiences are also proposed, 1) to understand the importance of credentials in authentication and 2) to create a self-sovereign identity.*	Y
20	Intelligent Agents for the Web	*2*	*The course deals with agent-oriented models and technologies to support the activities of Web users, with particular attention to Trust and Reputation models, Recommender Systems and Social Networks. The main theoretical concepts about the agent-oriented paradigm will be presented, and some architectural principles will be described, using the well-known JADE platform as an actual reference framework. Finally, some practical applications of trust-based intelligent agent systems in different application domains will be illustrated.*	Y

21	Health management	*2*	*Nowadays, even in health environments requirements of services' quality and cost saving have been becoming more and more important. So, the course aims to describe the main methodologies currently employed in healthcare environments to manage processes flows, technologies and staff. The objective of such methodologies, born in manufactural industries, is mainly to avoid wastes, to increase the patient's quality of life and to support health managers in decision making. For example, the main characteristics of the SSN will be introduced, the meaning of health's measurement and some indexes will be defined, and signs of risk management will be provided.*	N
22	Some biomedical applications of microwaves: from imaging to theranostic systems	*2*	*Microwaves can represent a very promising tool for biomedical applications, thanks to its capability to penetrate the biological tissues and interact with them. The course aims at introducing and describing some biomedical applications of microwaves, in particular biomedical imaging and hyperthermia treatment for cancer therapy. In the first application, microwaves are used as a non-invasive tool to investigate inside the body and discriminate between healthy and cancer cells. On the other hand, In the second application, microwave energy is used as a very effective and non-invasive means of heating tumors. Finally some considerations will be given about the development of innovative and possibly adaptive theranostic (therapeutic+diagnostic) systems.*	Y
23	Advanced Techniques in Antenna Synthesis for High-Performance Antennas and Smart Surface Development	*2*	*The synthesis of array antennas is a very long standing problem at the core of applied electromagnetic. Indeed, a proper selection of primary sources, as well as the choice of the number, location, and type of (meta)materials, are essential tools for shaping and engineering electromagnetic fields. This PhD course begins with a review of modern techniques for synthesizing innovative high-performance antennas for radar, defense, and satellite applications, and then focuses on the synthesis of smart surfaces, including Reflective Intelligent Surfaces.*	N
24	Inverse design for electromagnetic devices	*3*	*In 'inverse design' approaches, the shape and internal electromagnetic features of electromagnetic devices are identified (through inverse scattering problem) such that the corresponding functionalities (i.e., the scattered field) fulfill desired requirements. In this framework, after starting with a review of the properties of electro-magnetic fields as well as solution strategies for inverse scattering problems, the course will focus on the inverse design of devices of actual interest for ICT applications, with particular focus on devices with unconventional functionalities which meet the requirements of the envisaged smart environments for the next future.*	Y
25	Advanced Space Communications: Challenges, Deployment and Simulations	*2*	*This course explores the complex realm of space communications, focusing on challenges, practical implementation, and advanced simulation techniques. The course combines theoretical insights with hands-on projects and simulation exercises. Key topics include satellite network design and radio resource management techniques to enhance service delivery, communication reliability, and spectrum efficiency.*	Y
26	Towards 6G V2X for Connected and Automated Vehicles	*2*	*In the last decade, there has been a surge of interest in connected and automated vehicles (CAVs) and related enabling technologies in the field of communication, automation, sensing, and positioning, which are expected to revolutionize future transportation and quality of life. The course will provide an overview of the main milestones towards connected and automated driving, highlighting the features of the radio access technology enablers for Vehicle-to-Everything (V2X) communications (IEEE 802.11p/bd, Cellular V2X, 5G New Radio). Special attention will be given to the sidelink communication technology promoted by 3GPP, its 5G New Radio based evolution, and the perspective enablers towards 6G-V2X.*	N
27	In-network caching in the future Internet: benefits, challenges and research perspectives	*3*	*Caching plays a crucial role in improving the efficiency of content dissemination in a variety of future Internet scenarios, ranging from traditional wired networks to Internet of Things (IoT) and Internet of Vehicles (IoV) environments. Although caching is already employed in Peer-to-Peer and Content Delivery Networks, the recent Fog Computing and Information Centric Networking paradigms are pushing a new pervasive vision where potentially any network node with storage resources can offer caching services. The course will provide an overview of in-network caching techniques by considering traditional Internet contents (e.g., multimedia files) and IoT/IoV information (e.g., transient sensor data). Autonomous and collaborative caching decision schemes and replacement policies will be outlined, together with emerging challenges and research opportunities.*	Y

28	Advanced techniques for the remote control of measurement instrumentation	*2*	*Communication and interface protocols: RS232, IEEE488, Wi-Fi, Bluetooth, Ethernet, PXI, VME/VXI. Software environment dedicated to instrumentation remote control: National Instruments LabVIEW. Remote control of digital instrumentation. Hardware/software programming platforms for Real-Time applications.*	Y
29	Sensors and instrumentation in the nanoscale: methods and characterization	*2*	*The nanoscale, hence nanotechnology world, requires dedicated specifications for performing measurements, characterization and calibration. Traditional constraints related to physics and electrotechnology do not have impact on this scale. Different and significant assumptions should be adopted, and amongst them quantum approach is the major one. The course is divided in three parts; the first part is dedicated to the general concepts of nanotechnology, whilst the second one illustrates the steps from MEMS to NEMS, and the part deals with nanosensors characterization and applications.*	Y
30	Spectroscopic techniques and microscopy for the characterization of nanomaterials for optoelectronics and sensors	*2*	*The exponential growth of nanotechnologies in recent years has required rapid development of nanoscience and in particular of nanospectroscopy and microscopic techniques. Understanding, controlling and manipulating the interaction of electromagnetic radiation with matter, on the nanometer scale, has become a fascinating field of research in continuous evolution. The course will illustrate the main spectroscopic and microscopic techniques for the characterization of micro- and nano-structured materials used for optoelectronic devices and sensors.*	Y
31	Microsystems: Technology and features	*2*	*The course will provide an overview of the main techniques for the fabrication (such as optical and electron lithography, physical deposition, PECVD deposition, wet and dry etching, molding, etc.) and characterization (such as optical microscope, profilometer, SEM, AFM, etc.) of multifunctional integrated microsystems, i.e. systems in which electronic, optical and fluidic functionalities can be included. For each technique, the basic operating principle and main features are described, and some application examples are also given. Finally, a description of a complete flowchart for the realization and characterization of some examples of microsystems will be presented. If possible, the course could also include access to the ISASI Institute's clean room and the use of some of the technologies described during the course.*	Y
32	Design and numerical simulation of photonic integrated devices and circuits	*2*	*A photonic integrated circuit (PIC) is a microchip which internally contains photonic devices that interact with each other to form a more or less complex circuit, characterized by the fact that the signals processed are in the form of light radiation. Photonic integrated circuits are closely related to electronic integrated circuits, sharing with them the manufacturing technologies typical of Complementary Metal-Oxide-Semiconductor fabs. The wavelengths treated are typically in the near infrared (1300 - 1600 nm), although the spectrum close to 850 nm is sometimes used. Through a hands-on experience, the course intends to introduce students to the use of software platforms commonly used for the design and simulation of micro- and nano-scale optical devices, the extraction of their characteristic parameters, and their subsequent integration into complex photonic circuits.*	Y
33	Smart roads Part I	*2*	*Smart roads, intelligent transportation systems, electric and driverless vehicles have become an outstanding area of potentials for industry, research, scientific projects, and career opportunities. This fascinating course focuses on how smarter infrastructures, self-monitored environmental systems, better-managed transportation assets, electric vehicles, and driverless vehicles can allow having a safer, more efficient, and more sustainable world. As for the previous years, interesting job and research perspectives could emerge and be developed. Devices and systems for monitoring and maintenance will be addressed. The course includes two parts. Each part is organised into two units. Students may choose one part or two. UNIT I. Intelligent mobility, intelligent transportation systems, smart roads, smart cities. Transportation infrastructures. Analysis and decision-making techniques and tools (Cost–benefit analysis, multi-criteria analysis/ ELimination Et Choix Traduisant la REalité, analytic hierarchy process technique, fuzzy techniques, etc.). Environmental impacts (noise, pollution). Environmental impact assessment (European approach, EIA versus strategic environmental assessment; scoping, Life cycle cost analysis, etc.). UNIT II. Project work and report .*	Y

34	Smart roads Part II	*2*	*UNIT III. Sensors, ICT, vehicles, infrastructures, and functions. Continuous monitoring of transportation infrastructures (sensors, type, data gathered, pros and cons). Energy harvesting from transportation infrastructures (types, pros and cons, potential). Electric vehicles and autonomous vehicles impact. Information and Communications Technologies applied to infrastructure assets.* *UNIT IV. Project work and report.*	Y
35	Port generations: the dynamic evolution of ports	*2*	*Commercial ports are today one of the main pillars of the trade globalization. The necessity to respond to the ongoing drivers of the market imposes to ports a dynamic evolution, through different port generations that involve also the use of emerging Information and Communication Technologies (ICTs). The short-course presents the quantitative methods to support ports' managers and authorities in the definition of competitive strategies, starting from the current generation of the reference port, to respond to the arising forms of port users' demand. The methods are based on consolidated topological-behavioural paradigm of Transportation System Models (TSMs).*	Y
36	Logistics as a Service (LaaS): Dynamic Freight Management in City Logistics through emerging ICT	*3*	*The evolution of emerging information and communication technologies (e-ICTs) has opened the road for developing and implementing a new paradigm of city logistics called Logistics as a Service (LaaS). The short-course presents the combined role of some emerging ICT components and of the Decision Support Systems (DSSs) in developing and implementing new integrated and dynamic city logistics solutions, which are the base of LaaS. The methods presented are based on consolidated topological behavioural paradigm of Transportation System Models (TSMs). The changes in the generalized path costs supported by each stakeholder are explored, and the modifications guided by e-ICTs are analyzed. The learning process due to the update for within-day and day-to-day dynamics is detailed and formalized.*	Y
37	Sustainable Mobility as a Service: Dynamic models for agenda 2030 policies	*2*	*Today urban mobility is evolving towards the concept of Mobility as a Service (MaaS). MaaS allows passengers to use different transport services as a single option by using a digital platform. The three main elements of MaaS are the design of customer-centered supply, the sustainable goals, and the emerging information and communication technologies (e-ICTs). The short-course presents sustainability as defined by Agenda 2030 with respect to urban passenger transport, then examines the role of ICT in the development of MaaS formalizing a dynamic model of demand–supply interaction explicating ICT. Finally, the advanced Sustainable MaaS, defined S-MaaS, is analyzed, evidencing the contribution to achieving the goals of Agenda 2030. The model is based on consolidated topological-behavioural paradigm of Transportation System Models (TSMs).*	Y
38	Network programmability and softwarization in 5G and beyond systems	*2*	*Fifth generation (5G) systems represent a revolution in the design of telecommunication networks, by targeting an end-to-end communication, computing, and networking infrastructure aimed to support several services with different requirements in a flexible manner. The course will present the main technologies proposed as key enablers for the programmability and softwarization of 5G and beyond systems (i.e., software-defined networking, network function virtualization, object virtualization, mobile edge computing and edge AI) as well as their evolution towards upcoming sixth generation (6G) networks.*	N
39	The Internet of things for smart Environments	*2*	*Leveraging on the global interconnection of billions of tiny smart objects, the Internet of Things (IoT) paradigm is fostering the idea of Pervasive Smart Systems (PSSs), where all the data gathered by different "things" can be analyzed and used to improve the livability, the safety and the security of the environment, and to make IoT user lives easier. However, despite the research advancements in recent years, many open issues still prevent the full realization of such vision. To meet the requirements of PSSs, telecommunication systems should deliver significantly high data rates, traffic capacity, connection density, energy efficiency, as well as small latencies. During the course the relevant state of the art as well some cutting edge research issues on this topic will be presented.*	Y
40	Enabling technologies and production sustainability: applications and use case scenarios	*2*	*The aim of the course is to deepen the applicability of enabling technologies to the productive sectors characteristic of the Mediterranean economic system. The context will be Industry 4.0 which represents a disruptive evolution of the "way of producing" and which, overcoming sectoral or dimensional boundaries, allows, thanks to these technologies, to create interconnections, to strengthen the production chains, to transform plants and processes and, therefore, the supply chains, with the superior goal of sustainability, which is the strategic goal of the millennium.*	Y

41	Vehicular Platooning: A Concise Introduction	*2*	*The course focuses on platooning which is a linking of vehicles on highways in convoy through wireless communications for the sake of safer, cleaner and more efficient transportation. Ultra-reliable low-latency inter-vehicular communication protocols are key enabler for platooning. We explain the state-of-the of this technology from the vehicular networking perspective. We outline open issues in ITS-G5/DSRC and 5G/LTE standards to be resolved in order to support platoons. We present methodology for the safety evaluation of platooning formations.*	N
42	Life Cycle Assessment for the eco-efficiency and technological innovation	*2*	*The lecture will aim at providing knowledge about methodological tools to assess sustainability of products and processes. In particular, a detailed focus will be given to Life Cycle Assessment, a relevant methodology to support the European Green Deal and the path toward the decarbonization. Such a methodology allows to assess the energy and environmental impacts, by means of a life-cycle approach, according to the ISO 1040 series standards.*	N