The 3rd International School on Enabling Technologies, Applications, and Methods for Emerging 5G Systems

4 - 8 November 2019

IST, Lisbon, Portugal

Scope

The School features a program of lectures delivered by leading experts in the area of 5G networks. The objective of the School is to introduce key features of the emerging 5G technologies from the networking perspective. Attendees will have an opportunity to participate in stimulating discussions with researchers, present their own work, obtain useful feedback, and initiate new collaborations. Lectures will provide the background on 5G wireless communications concepts, with a particular emphasis on the IoT paradigm, broadcast and multicast convergence in 5G networks, as well as D2D/M2M communications in 5G systems. In the course of the lectures, connections will be made to network architectures and protocol design, including radio resource management issues, while also introducing the mathematics associated with analysis and optimisation of the emerging wireless communication systems.

Targeted Audience

The School is aimed at Researchers, and Ph.D. and M.Sc. Students, who actively work on or are interested in future mobile networks.

Dates

The School will take place from Monday, Nov. 4th, to Friday, Nov. 8th.

Programme

The programme is composed of the following lectures and lecturers (a detailed description is provided at the end of this document):

- "*Statistical Detection of Internet Traffic Anomalies*", M. Rosário Oliveira (IST - University of Lisbon, Lisbon, Portugal)
- "*Numerical Simulation of the Interference for Wireless Device-to-Device Communications Using the Fokker-Planck Equation*", Yuliya Gaidamaka (Peoples' Friendship University of Russia (RUDN), Moscow, Russia)
- "*Application of financial and stochastic modelling to telecommunication and IT companies*", Sergey Shorokhov (Peoples' Friendship University of Russia (RUDN), Moscow, Russia)
- "*An Approach to Cloud and Virtual Radio Access Networks*", Luis M. Correia (IST - University of Lisbon, Lisbon, Portugal)
- "*Internet of Things*", Augusto Casaca (INESC-ID, Lisbon, Portugal)

- "Enabling Massive IoT Applications through Low-power Wide-Area Networks (LPWAN)", Jiri Hosek (Brno University of Technology, Brno, Czech Republic)
- "*Increasing Power and Spectral Efficiencies in Wireless Communications - A 5G Challenge*", Rui Dinis (FCT - New University of Lisbon, Lisbon, Portugal)

General Schedule

The following general schedule will be held daily for the lectures:

- 09h30 – 11h00: lecture
- 11h00 – 11h30: break
- 11h30 – 13h00: lecture

Besides the lectures, students will be involved in presentations and seminars for individual and group work.

The overall schedule is given below:

Time	Day				
	Monday, Nov. 4th	Tuesday, Nov. 5th	Wednesday, Nov. 6th	Thursday, Nov. 7th	Friday, Nov. 8th
09:30 - 11h00	Registration (10h30 / 11h00)	Yuliya Gaidamaka	Luis M Correia	Jiří Hošek	Student Seminar
11:00 - 11:30	Opening	Break	Break	Break	Break
11:30 - 13:00	M Rosário Oliveira	Sergei Shorokhov	Augusto Casaca	Rui Dinis	Student Seminar
13:00 - 14:00	Lunch	Lunch	Lunch	Lunch	Lunch
14:00 - 15:30	Student Seminar	Student Seminar	Student Seminar	Student Seminar	Student Seminar
15:30 - 16:00	Break	Break	Break	Break	Break
16:00 - 17h30	Student Seminar	Student Seminar	Student Seminar	Student Seminar	Student Seminar
20:00 - 22:00			Dinner		

Duration

The School will have a total duration of 10.5 hours of lectures.

Supporting Texts

Attendees will get a PDF version of all presentations, during the School.

Language

The School will be entirely held in English.

Location

The venue is "Centro de Congressos" at the Alameda Lisbon campus of IST (Instituto Superior Técnico), in room 02.3 at the ground floor.

A map of the campus is available at http://grow.tecnico.ulisboa.pt/wp-content/uploads/2017/01/IST_Campus_6.pdf, "Centro de Congressos" being located at the ground floor of "Pavilhão de Civil" (building #2 in the map).

General information on the location of the campus can be found at http://grow.tecnico.ulisboa.pt/local-info/address.

Accommodation

There is a wide choice of hotels nearby the campus. Take a look into http://grow.tecnico.ulisboa.pt/local-info/accommodation.

Registration

You can register by contacting Vera Almeida, until Friday, Oct. 25th, 2019.

The registration fee is 150 €, covering attendance, coffee-breaks, lunches, and a dinner.

Social Event

A dinner will be offered to participants and lecturers on Wednesday, Nov. 6th.

Contacts

If you need any information or help, contact:
Ms. Vera Almeida
Email: vera.almeida@inov.pt
Tel.: +351 213 100 432

Organisation and Programme Committee

The School is organised jointly by:

- Luis M. Correia, IST - University of Lisbon, Lisbon, Portugal
- Konstantin Samouylov, Peoples' Friendship University of Russia (RUDN), Moscow, Russia
- Jiří Hošek, Brno University of Technology, Brno, Czech Republic

The School is organised with the support of the "RUDN University Program 5-100"

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Detailed Programme

Augusto Casaca (INESC-ID, Lisbon, Portugal): Prof. Augusto Casaca got the Ph.D. in Computer Science at the University of Manchester, UK, and the degree of Aggregate in Electrical and Computer Engineering at the University of Lisbon, Portugal. Full Professor at Instituto Superior Técnico (IST), Lisbon, Portugal, presently he is a researcher at INESC-ID and at INOV, Lisbon, Portugal. At the scientific management level, he has been President of the Electrical and Computer Engineering Department at IST, President of the Scientific Council of INESC-ID, Leader of the Communication Networks and Mobility Group at INESC-ID, and Chairman of the IFIP Technical Committee 6 (Communication Systems). After the Ph.D., his scientific activity was in the area of Digital Systems Design. In this context, he was Research Associate at CERN, Geneva, Switzerland, for one year and Visiting Research Associate for four years. Afterwards, his scientific activity was directed into the area of Communication Networks. He has participated in many projects of the European Research Programs in Telecommunications and he has also participated in several research projects at Eurescom, Heidelberg, Germany. He has actively participated in standardization activities in the area of Networking at ITU-T and ETSI. He has consulted with the main Portuguese companies in telecommunications and with the European Commission. He has more than 150 scientific publications and has co-chaired five international conferences on Networking. He is a Life Senior Member of IEEE. His present research interests are in network architecture, Internet of Things (IoT) communications, and IoT vertical applications for smart grids and smart water infrastructures.

Internet of Things: The Internet of Things (IoT) is a global infrastructure, enabling advanced services by interconnecting physical and virtual things based on interoperable information and communication technologies. The lecture starts by giving an overview of the IoT concept and of the main reasons that are driving its fast implementation. A short analysis of the main types of sensors and actuators, which are the best examples for the instantiation of things, will be made and will be followed by a detailed study of the IoT network architecture and its relation to the Internet protocol modelling. A key part of the IoT network architecture is related to the link and physical layer communication protocols to be used, therefore a state of the art review of the most important protocols to be considered will be made. The second part of the lecture is focused into the service platforms required to run the IoT applications. For some near real- time applications, the latency is a relevant parameter, which invalidates to rely only on the cloud infrastructure processing of the data collected by the IoT platform. The new concept of fog computing, which runs between the cloud and the local IoT platform, permits reducing the latency of the IoT operations and will be analysed. Then, the IoT vertical markets for the applications will be discussed and some deployed IoT application examples will be presented. The lecture ends with a review of the open issues in IoT, namely security, privacy and standardization.

Jiri Hosek (Brno University of Technology, Brno, Czech Republic): Jiri Hosek is an Associate Professor and Deputy Vice-Head for R&D and International Relations at Department of Telecommunications, Brno University of Technology, Czech Republic. Jiri is also coordinating the WISLAB research group (http://wislab.cz), where he deals mostly with industry-oriented R&D projects in the area of future mobile networks, Internet of Things and home automation services. Jiri (co-) authored more than 80 research works on networking technologies, wireless communications, quality of service, quality of experience and IoT applications including those published in the IEEE Communications Magazine. Jiri is an experienced speaker regularly participating and actively presenting his research work on premier international conferences and workshops.

Enabling Massive IoT Applications through Low-power Wide-Area Networks (LPWAN): The Internet of Things (IoT) is becoming a pervasive paradigm that will have a significant impact on future generations of

applications in many fields, including (but not limited to) automation, computer science, telecommunications, e-health and industrial engineering. The impact of IoT is particularly evident in the increasing research and development activities in the field of industrial models and processes, as well as in the forthcoming 5th generation (5G) technologies in different areas like the wireless low power communications. To enable a massive connectivity while still keeping long lifetime of end devices, the Low-power Wide Area Networks (LPWANs) have been introduced and recently become a hot topic for a broad range of M2M and IoT applications. This happened thanks to LPWA-enabled low-power consumption, secure data transmission and advanced protocols for wireless sensor networks. This lecture will provide a practical perspective on dominant LPWAN technologies including Sigfox, LoRa and NB-IoT, while challenging them to fulfil the key requirements of nowadays' IoT applications. Moreover, we will reveal our prototype design of the NB-IoT device and outline the architecture challenges as well as the configuration required on the side of a mobile operator to have NB-IoT communication ready to take off. Finally, we summarize the NB-IoT radio coverage as well energy efficiency results obtained during the extensive measurement campaigns undertaken within the long-term cooperation with our industrial partners.

Luis M. Correia (IST - University of Lisbon, Lisbon, Portugal): Luis M. Correia was born in Portugal, in 1958. He received the Ph.D. in Electrical and Computer Engineering from IST (University of Lisbon) in 1991, where he is currently a Professor in Telecommunications, with his work focused in Wireless/Mobile Communications in the areas of propagation, channel characterisation, radio networks, traffic, and applications, with the research activities developed in the INESC-ID institute. He has acted as a consultant for the Portuguese telecommunications operators and regulator, besides other public and private entities, and has been in the Board of Directors of a telecommunications company. Besides being responsible for research projects at the national level, he has participated in 31 projects within European frameworks, having coordinated 5 and taken leadership responsibilities at various levels in many others. He has supervised more than 200 M.Sc./Ph.D. students, having edited 6 books, contribute to European strategic documents, and authored more than 500 papers in international and national journals and conferences, for which served also as a reviewer, editor and board member. Internationally, he was part of 36 Ph.D. juries, and 63 research projects and institutions evaluation committees for funding agencies in 10 countries and the European Commission. He has been the Chairman of Conference, of the Technical Programme Committee and of the Steering Committee of various major conferences, besides other several duties. He was a National Delegate to the COST Domain Committee on ICT. He was active in the European Net!Works platform, by being an elected member of its Expert Advisory Group and of its Steering Board, and the Chairman of its Working Group on Applications, and was also elected to the European 5G PPP Association. He has launched and served as Chairman of the IEEE Communications Society Portugal Chapter.

An Approach to Cloud and Virtual Radio Access Networks: The talk addresses the concept of cloudification and virtualisation of Radio Access Networks (RANs). One starts by giving the motivation for the virtualisation of networks, from the services' and users' viewpoint. Then, the concepts of Cloud-RAN and Virtual-RAN are presented. Network architectures are presented for Cloud-RAN and Virtual-RAN, enabling operators to have multiple roles compared to today's reality, and to serve as multiple Virtual Network Operators by sharing the resources among them, and to split the functionalities with Infrastructure Providers. The split of Base Stations into Remote Radio Heads and Baseband Processing Units is presented. An overview of some models and algorithms for managing virtual radio resources and for deploying cloud architectures are presented, aiming at the optimisation of the usage of resources, depending on the services offered by users, on the radio channels experiences by users, and on the Service Level Agreements existing in between Virtual Network Operators and Infrastructure Providers, among others. Constraints like physical capacity, maximum latency, multiple access technique, are also taken into consideration. It is also shown that allocation of resources

should be done according to the type services, and their classes on quality of service. Some reference scenarios are put forward, together with some application examples, upon which some results are presented. Conclusions are presented at the end.

M. Rosário Oliveira (IST - University of Lisbon, Lisbon, Portugal): M. Rosário Oliveira graduated in applied mathematics and computer science at Instituto Superior Técnico, in 1992, received the M.Sc. degree in Applied Mathematics from Technical University of Lisbon in 1995, and obtained the Ph.D. degree also in Mathematics at the Technical University of Lisbon in 2002. She has been working at Instituto Superior Técnico (IST) since 1990, where she is Assistant Professor at the Mathematics Department, and has been a full member of the Centre for Mathematics and its Applications from IST since 2002. She has been involved in teaching, research and consulting in the areas of data science and statistics, and in national and international projects/consortiums, including European Networks of Excellence Euro-NGI, Euro-FGI, and TEMPUS project Applied Computing in Engineering and Science. Her current research interests include data science, robust statistics, multivariate analysis, and biostatistics.

Statistical Detection of Internet Traffic Anomalies: For computers and communication networks, security has become a major concern. The cost of committing errors in Internet anomaly detection is higher than in other areas of application. Indeed, an attack not early identified and/or blocked can cause severe damage to users and organizations. Conversely, licit traffic wrongly captured by computer security, even if occurring at a low rate, can decrease the quality of service of the Internet service provider. Internet anomaly detection can be formulated as a classification problem. Mainly, we want to assign a new instance to one of a given set of classes, based on a training set of data containing observations whose class membership may be, or not, known. A set of quantifiable characteristics, known usually as features, is chosen to characterize the objects to be classified, and an algorithm that implements the classification procedure is constructed. In this course, we will discuss how principal component analysis can be used to detect anomalies and the importance of using robust estimation methods, capable of dealing with potential mislabelled observations, a strong advantage from the operational point of view. To illustrate these methodologies, we will use examples based on several network scenarios, which were designed to be capable of producing measurements under real (but controlled) traffic conditions without label mistakes. The measurements obtained allow a trustful assessment of the accuracy of the statistical methods. The results show that a pre-processing step to finding the relevant features to discriminate between licit and illicit traffic is of major importance.

Rui Dinis (FCT - New University of Lisbon, Lisbon, Portugal): Rui Dinis received the Ph.D. degree from Instituto Superior Técnico (IST), Technical University of Lisbon, Portugal, in 2001 and the Habilitation in Telecommunications from Faculdade de Ciências e Tecnologia (FCT), Universidade Nova de Lisboa (UNL), in 2010. He is an associated professor at FCT-UNL and a researcher at IT (Instituto de Telecomunicações). During 2003 he was an invited professor at Carleton University. Rui Dinis is or was editor at IEEE Transactions on Communications (2012-2017), IEEE Transactions on Vehicular Technology (since 2015), IEEE Transactions on Wireless Communications (since 2017) and Elsevier Physical Communication. (since 2013) He and is or was TPC member for some of the major IEEE conferences, and was involved in the organization of several IEEE conferences such as ICT'2014, VTC'2018-Spring and ISWCS'2018. Rui Dinis has been involved in several international and national research projects in the broadband wireless communications area. He published 5 books, over 100 journal papers and over 300 conference papers, and has 14 patents. His main research activities are on modulation and transmitter and receiver (nonlinear effects, detection, equalization, channel estimation and carrier synchronization), with emphasis on frequency-domain implementations for MIMO systems and/or OFDM

and SC-FDE modulations. He is also working on cross-layer design and optimization, as well as positioning techniques.

Increasing Power and Spectral Efficiencies in Wireless Communications - A 5G Challenge: The evolution from 4G (4th Generation) to 5G (5th Generation) wireless systems is driven by the expected huge growth in user bit rates (a 10 to 100 times increase) and overall required bit rates (about 1000 increase). This means a substantial spectral efficiency increase, which must be achieved while maintaining or even improving the power efficiency. To accomplish this one needs to employ new transmission techniques, with the most promising ones being the use of mm-Wave (millimetre Wave) bands and massive MIMO (Multiple-Input and Multiple-Output) schemes. The adoption of mm-Wave transmission is mainly due to the huge bands available. Moreover, the small wavelength means small antennas, allowing small-sized transmitter and receivers with very high number antenna elements and, therefore, enabling massive MIMO implementations. However, these frequencies present considerable challenges both in terms of propagation (high propagation free-space path losses, small diffraction effects and almost total absorption losses due to obstacles) and implementation (namely at the power amplification level). Therefore the design of mm-Wave communications with high power and spectral efficiencies presents a considerable challenge. In this tutorial we start by making an overview on the constraints on power and spectral efficiencies, as well as techniques to improve them. Then we present a massive MIMO architecture for broadband mm-Wave communications that is compatible with highly-efficient, low-cost saturated amplifiers, even for large quadrature amplitude modulation (QAM) constellations or other dense constellations with high spectral efficiency.

Sergey Shorokhov (Peoples' Friendship University of Russia (RUDN), Moscow, Russia): Sergey Shorokhov received the PhD degree from RUDN University in 1989. From 1993 to 2016, he held various management positions in Russian financial sector (banking, insurance), being responsible for financial and risk management, information technology and information security. Since 2009, he held the positions in Mathematical Analysis and Function Theory Department of RUDN University, teaching courses in mathematical finance, including financial asset pricing, portfolio management and risk management. At present, he holds the position of Associate Professor in Information Technology Department of RUDN University, teaching courses in data mining and distributed systems. His current research interests include stochastic modeling in asset pricing and risk management and application of machine learning methods in finance and fintech.

Application of financial and stochastic modelling to telecommunication and IT companies: Key activities of the companies working in the telecommunication sector are closely related to proper financial and risk management. Telecommunication companies across the world are facing a new wave of capital expenditures, including investments into 5G technologies, with uncertain returns on this capex. We outline basic financial models, used in the industry for investment project selection and valuation of various classes of financial instruments issued by telecommunication/IT companies. We present both traditional and advanced stochastic models, used for asset pricing, portfolio and risk measurement. Particular attention is given to the problem of real option pricing and its application to valuation of intellectual property (licenses).

Yuliya Gaidamaka (Peoples' Friendship University of Russia (RUDN), Moscow, Russia): Yuliya Gaidamaka received the PhD in 2001 and Doctor of Sciences degree in 2017 in Mathematics from the Peoples' Friendship University of Russia (RUDN University). Since 2001, she has been an associate professor and currently a professor in the university's Applied Probability and Informatics Department. She is the author of more than 50 scientific and conference papers, co-author of two monographs on multiplicative solutions of finite Markov chains and performance analysis of wireless heterogeneous networks. Her current research focuses on performance analysis of 5G networks,

queuing theory, and mathematical modelling of communication networks. The recent topics are resource allocation in wireless networks with random resource requirements; random resource queueing systems for network slicing modelling; multiservice queueing systems for modelling the mixture of multicast and unicast traffic; stochastic geometry models in D2D wireless networks (SIR analysis, mmWave communications 3D directional deafness problem); random walk models and kinetic approach for modelling transceivers' movement

Numerical Simulation of the Interference for Wireless Device-to-Device Communications Using the Fokker-Planck Equation: The fifth-generation (5G) cellular systems rely on the set of advanced networking techniques to further enhance the spatial frequency reuse. Device-to-device (D2D) communications are one of them allowing transceivers to establish opportunistic direct connections. The use of direct communications is primarily determined by the signal-to-interference ratio (SIR). However, depending on the users' movement, the SIR of an active connection between transceivers is expected to drastically fluctuate. In this lecture, we develop an analytical framework allowing to predict the radio channel quality between two moving devices in a field of moving interfering transmitters. Assuming users' movement driven by Fokker-Planck equation we obtain the empirical probability density function (pdf) of SIR. Although the time-evolution equation for the pdf of SIR can be written in explicit form for non-stationary movements of devices, the solution cannot be obtained in closed-form. We first introduce a general kinetic based mobility model capable of representing the movement process of devices with a wide range of mobility characteristics including conventional, fractal and even non-stationary ones. We then derive the time-dependent evolution of mean, variance and coefficient of variation of SIR metric. We demonstrate that under non-stationary mobility behaviour of devices the SIR may surprisingly exhibit stationary behaviour. Using the mixed simulation-analytic approach we propose a generic methodology for performance assessment of time-dependent characteristics such as periods of stable connection and outage time periods. We propose the normalized SIR average value as an indicator of the stability of the D2D connection. Both for traditional and fractional Fokker-Plank kinetic equations we study the elasticity of the SIR moments with respect to parameters of Fokker-Planck equation, i.e. a diffusion coefficient, a drift velocity, a fractal dimension and number of transceivers. The elasticity matrix for average SIR value, SIR variance and time periods of stable connection are numerically constructed. Our numerical results demonstrate that the main kinetic parameter affecting SIR behaviour is the diffusion coefficient. The influence of the drift is approximately ten times less. For illustration, we apply the approach to the model of transmitters and receivers motion, which is mechanically determined, but the distribution function, mentioned above, is non-stationary. The empirical distribution of the time periods with continuous connection is numerically constructed for real scheme of deterministic motion of Moscow metro trains.