

COST CA15104 (IRACON) Training School: *Network Models, Architectures and Applications for 5G*

7 – 11 October 2019

RUDN University, Moscow, Russia

Scope

The Training School features a program of lectures delivered by leading experts in the area of 5G networks, from both academia and industry. The objective of the School is to give attendees a global view, with an insight into some specific aspects, on research in key features of the emerging 5G technologies from the networking perspective, addressing models, architectures and applications. Attendees will have an opportunity to participate in stimulating discussions with lecturers, obtain useful feedback, and initiate new collaborations. Lectures will provide the background on 5G wireless communications networks concepts, ranging from the more fundamental ones related to concepts and mathematical modelling to experimental and applied ones connected to the incoming standardisation features.

Targeted Audience

The School is aimed at Ph.D. students, targeting COST institutions participating in Action CA15104 (IRACON), but open to other institutions as well. Moreover, participation is also open to other researchers and students, who actively work on or are interested in future mobile networks.

Dates

The School will take place from Monday, Oct. 7th, to Friday, Oct. 11th, 2019.

Speakers

The list of speakers is as follows:

- Andres Gonzalez, Telenor, NO
- Carles Antón-Haro, CTTC, ES
- David Calligaris, Huawei, DE
- Fedor Chernogorov, Ericsson, FI
- Hamed Ahmadi, Univ. Essex, UK
- Konstantin Samouylov, RUDN Univ., RU
- Luis M. Correia, IST – Univ. Lisbon, PT
- Roberto Verdone, Univ. Bologna, IT

- Silvia Ruiz, UPC – Polytechnic Univ. Catalonia, ES
- Yuliya Gaidamaka, RUDN Univ., RU

Programme

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

- *“Understanding 5G NR Air Interface”*: Sílvia Ruiz Boqué (UPC, Spain)
- *“AI and ML for Physical Layer Designs of 5G and Beyond Networks”*: Carles Antón-Haro (CTTC), Spain)
- *“The architectural design of a nationwide 5G Network”*: Andres Gonzalez (Telenor, Norway)
- *“An Approach to Cloud and Virtual Radio Access Networks”*: Luis M. Correia (IST – Univ. Lisbon, Portugal)
- *“Resource Management, Self-organising Networks, and Massive MIMO in 5G and beyond”*: Hamed Ahmadi (Univ. Essex, United Kingdom)
- *“Internet of Things and Unmanned Aerial Vehicles in the 5G Ecosystem”*: Roberto Verdone (Univ. Bologna, Italy)
- *“Internet of Things Security & Insecurity”*: David Calligaris (Huawei, Germany)
- *“5G for Industrial Machine-Type Communications”*: Fedor Chernogorov (Ericsson, Finland)
- *“Mathematical Modelling Issues in the Future Multiservice Networks”*: Konstantin Samouylov and Yuliya Gaidamaka (RUDN Univ., Russia)
- All-Russian Festival of Science at RUDN University: Open Lectures & Masterclasses

General Schedule

The overall schedule is given below:

8th COST IRACON Training School on Network Models, Architectures and Applications for 5G Program at a Glance

	Monday, October 7, 2019	Tuesday, October 8, 2019	Wednesday, October 9, 2019	Thursday, October 10, 2019	Friday, October 11, 2019
Venue	RUDN University 3 Ordzhonikidze str., 115419 Moscow				
Room	Room 219 2nd floor				Lecture Hall 2 7th floor
08:30–09:00	Registration Room 221, 2nd floor				
09:00–09:30	Opening	Luis M. Correia <i>University of Lisbon, Portugal</i> An Approach to Cloud and Virtual Radio Access Networks	Roberto Verdone <i>University of Bologna, Italy</i> Internet of Things and Unmanned Aerial Vehicles in the 5G Ecosystem	Fedor Chernogorov <i>Ericsson, Finland</i> 5G for Industrial Machine-Type Communications	Visit to the laboratories
09:30–10:00	Silvia Ruiz Boqué <i>Polytechnic University of Catalonia, Spain</i> Understanding 5G NR Air Interface				
10:00–10:30					
10:30–11:00	Coffee Break Canteen, 3rd floor				
11:00–11:30	Carles Antón-Haro <i>Technological Center of Telecommunications of Catalonia, Spain</i> AI and ML for Physical Layer Designs of 5G and Beyond Networks	Luis M. Correia <i>University of Lisbon, Portugal</i> An Approach to Cloud and Virtual Radio Access Networks	Roberto Verdone <i>University of Bologna, Italy</i> Internet of Things and Unmanned Aerial Vehicles in the 5G Ecosystem	Fedor Chernogorov <i>Ericsson, Finland</i> 5G for Industrial Machine-Type Communications	Networking sessions
11:30–12:00					
12:00–12:30					
12:30–13:00	Lunch Time Canteen, 3rd floor				
13:00–13:30	Lunch Time Canteen, 3rd floor				
13:30–14:00	Andres Gonzalez <i>Telenor, Norway</i> The Architectural Design of A Nationwide 5G Network	Hamed Ahmadi <i>University of Essex, United Kingdom</i> Resource Management, Self-Organizing Networks, and Massive MIMO in 5G and Beyond	David Calligaris <i>Huawei, Germany</i> Internet of Things Security & Insecurity	Konstantin Samouylov and Yuliya Gaidamaka <i>RUDN University, Russia</i> Mathematical Modelling Issues in the Future Multiservice Networks	All-Russian Festival of Science at RUDN University Opening Ceremony
14:00–14:30					
14:30–15:00					All-Russian Festival of Science at RUDN University
15:00–15:30	Coffee Break Canteen, 3rd floor				
15:30–16:00	Andres Gonzalez <i>Telenor, Norway</i> The Architectural Design of A Nationwide 5G Network	Hamed Ahmadi <i>University of Essex, United Kingdom</i> Resource Management, Self-Organizing Networks, and Massive MIMO in 5G and Beyond	David Calligaris <i>Huawei, Germany</i> Internet of Things Security & Insecurity	Konstantin Samouylov and Yuliya Gaidamaka <i>RUDN University, Russia</i> Mathematical Modelling Issues in the Future Multiservice Networks	Open Lectures & Masterclasses
16:00–16:30					
16:30–17:00					Closing
		Gala Dinner from 18:00 to 21:00 <u>Location (at 18:00):</u> Restaurant of Russian cuisine "Ilya Muromets" 37 Leninsky Prospekt, 119334 Moscow http://www.restoran-muromec.ru/en/restaurants/ <u>Meeting Point (at 17:20):</u> RUDN University, Entrance 3 Ordzhonikidze str., 115419 Moscow	Moscow City Walking Tour from 18:00 to 20:30 <u>Starting Point (at 18:00):</u> Monument to Cyril and Methodius 25/1 Lubyansky Prospekt, 101000 Moscow https://goo.gl/maps/YESRHnWNC9uDfbrw7 <u>Meeting Point (at 17:20):</u> RUDN University, Entrance 3 Ordzhonikidze str., 115419 Moscow		

Supporting Texts

Attendees will get an electronic version of all presentations, during the School.

Language

The School will be entirely held in English.

Location

The venue is RUDN University (<http://rudn.ru>), at the Applied Mathematics & Communications Technology Institute (AMCT) (<http://amct.rudn.ru>), Ordzhonikidze St., 3, Moscow, 115419 Russian Federation, in Rooms 110-114 at the 2nd floor. A map of the location is available at <http://amct.rudn.ru/about-institute/contacts>. General information about RUDN University can be found at <http://eng.rudn.ru/about>.

Visa

Most of foreign participants of the Training School should obtain a visa to enter the Russian Federation. Visa is not required for citizens of visa-free countries entering Russia for a specific period (from 30 to 90 days) and for specific purpose (tourism, business, etc.) and with some restrictions; the duration of their stay in Russia being limited. The list of countries that have a visa-free regime with Russia is regularly changed and supplemented, depending on how successfully international relations develop. For information about visa requirements for Russia, please visit your local Embassy of the Russian Federation. For U.S. citizens, please visit the Embassy of the Russian Federation in the U.S. for instructions on how to apply for a visa.

The Organising Committee will provide an invitation letter. For a request, please contact Daria Ostrikova (dyostrikova@sci.pfu.edu.ru).

It is advised that you request your visa at the local embassy at least 1 month in advance, so you should request the invitation letter to the Organising Committee at least 1 ½ month in advance.

Travel

Moscow is served by 3 main airports, from where the venue can be reached:

- Domodedovo International Airport (<https://www.dme.ru/en>):
 - 45 min AEROEXPRESS (~7 €) to Paveletskaya metro station + metro (~1 €), stop at Shabolovskaya/ Leninskiy Prospekt/ Tuskaya metro station;
 - or 1.5 hours by taxi (~21 €).
- Sheremetyevo International Airport (<https://www.svo.aero/en/main>):
 - 35 min AEROEXPRESS (~7 €) to Belorusskaya metro station + metro (~1 €), stop at Shabolovskaya/ Leninskiy Prospekt/ Tuskaya metro station;
 - or 1 hour by taxi (~17 €).
- Vnukovo International Airport (<http://www.vnukovo.ru/en>)
 - 35 min AEROEXPRESS (~7 €) to Kievskaya metro station + metro (~1 €), stop at Shabolovskaya/ Leninskiy Prospekt/ Tuskaya metro station;
 - or 1 hour by taxi (~17 €).

Detailed information on AEROEXPRESS can be found at <https://aeroexpress.ru/en/aero/prices.html>.

From metro stations to AMCT, one should take:

- from Shabolovskaya metro station, trams # A, 14, 26, 47 till Serpukhovskiy Val station (2nd station);
- from Leninskiy Prospekt metro station, trams # 14, 39 till Rossiyskiy Universitet Druzhby Narodov station;
- from Tulsкая metro station, trams # A, 38, 39, 47 till Serpukhovskiy Val station (2nd station).

Detailed information on public transportation in Moscow can be found at <http://transport.mos.ru/en>.

Accommodation

There is a wide choice of hotels nearby the venue.

- **Astrus Hotel** (<http://www.astrus.ru/en>) is 4-Star Moscow hotel. It is located in one of the most prestigious and green districts of Moscow, “Troparevo-Nikulino”, which gives our guests an advantage of staying in ecologically safe area while having easy access to main business and cultural centres of the megapolis. The hotel is located in about half-an-hour drive from the Vnukovo and Sheremetievo International Airports and the Kievsky Railway Station. Room rates start from ~60 €/night.
- **Courtyard Moscow Paveletskaya** (<https://www.marriott.com/hotels/travel/mowpv-courtyard-moscow-paveletskaya>) is 4-Star Moscow hotel. A 3-minute walk from Paveletsky Train Station in the business area, this hotel features a modern interior, an on-site restaurant with business lunches, and a 24-hour front desk. Domodedovo International Airport is a 45-minute ride by Aeroexpress train. Room rates start from ~70 €/night.
- **Hotel Serpukhovskoy Dvor** (<http://sdhotel.ru/eng>) is 3-Star Moscow hotel. The hotel is located in a quiet, green area in Donskoy district of Moscow, on the territory of the business centre «Serpukhovskoy Dvor. Metro stations: - Shabolovskaya, Leninskiy Prospekt, Tul'skaya - a ten-minute walk from the hotel. Room rates start from ~30 €/night.
- **Ibis Moscow Paveletskaya Hotel** (<http://ibis-moscow-paveletskaya.moscow-hotels.org/en/>) is 3-Star Moscow hotel. The hotel is conveniently located close to Serpukhovskaya subway station. A 15-minute walk from Paveletsky train station. Room rates start from ~45 €/night.

Grants

There are a limited number of grants available, with priority given to Ph.D. students and ECIs, to attend the Training School. The grants, up to 450 € each, do not cover all the costs. Grants will be transferred after the school, so those that are awarded a grant must register prior to the school start in regular conditions. The general conditions are available at <http://www.iracon.org/training-schools>.

Applicants should send an email to Alice Baldini (a.baldini@unibo.it) and Laurent Clavier (laurent.clavier@imt-lille-douai.fr) with the following information:

- Subject: IRACON 8th TS grant application
- Applicant's Name, Affiliation and Country
- Applicant's career status: Ph.D. Student, PostDoc, Research Assistant, Industry Researcher, ...
- Applicant's CV in attachment

Key dates:

- 2019-Aug-26: applications open
- 2019-Sep-06: applications close
- 2019-Sep-13: notification of acceptance

Applications received before Aug 26 will not be considered!

Registration

The registration fees cover electronic copy of presentations, coffee breaks, lunches, a city tour and a gala dinner, but no other expenses, such as accommodation or transportation. They are as follows:

- 150 €: Students
- 175 €: Academic employees
- 200 €: Industry or other institutions employees

Fees can be paid via one of the following options:

- Bank Transfer, until 2019-Sep-27:
Account Holder: Euracon, AISBL, Avenue Georges Lemaitre 4-6, 1348 Louvain-la-Neuve, Belgium
Bank name: BNP Paribas Fortis NV (Louvain-la-Neuve)
Bank address: Place de l'Université 6, 1348 Louvain-la-Neuve, Belgium
IBAN: BE84 0016 9348 0459
SWIFT-BIC code: GEBABEBB
REFERENCE: [Your first name] [Your last name], registration at IRACON 8th TS Moscow
- PayPal, until 2019-Sep-27:
EURACON accepts PayPal payments by adding 3% + € 0,35 for transaction fees.
To use the online payment, please send an email with subject "EURACON Online Payment – 8th Training School Moscow" to a.baldini@unibo.it.
You will then receive an email from PayPal including the invoice and the payment instructions.
Please note that PayPal accepts Visa, MasterCard, American Express, Discover, or PayPal account payments, a PayPal account not being required for online credit card payments.
- Cash, on site, until 2019-Oct-07.

The number of trainees is limited. You should register as soon as possible. The registration deadline is 2019-Sep-27.

You can register by contacting Daria Ostrikova (dyostrikova@sci.pfu.edu.ru).

Social Events

A dinner and one of the two excursions will be offered to participants and lecturers at their preference.

We appreciate that at registration you indicate if you will attend the following social events:

- Gala Dinner on Tuesday, Oct. 8th, 18:00-22:00, Restaurant of Russian cuisine "Ilya Muromets" (Leninsky Prospekt 37) <http://www.restoran-muromec.ru/en>.
- Moscow City Walking Tour on Wednesday, Oct. 9th, 18:00-20:30

It will help us to plan effectively.

Contacts

If you need any information or help, please contact:

Dr. Daria Ostrikova

Email: dyostrikova@sci.pfu.edu.ru

Tel.: +7 495 952 3743

Organisation and Scientific Programme Committee

The Training School is organised jointly by:

- Konstantin Samouylov, RUDN Univ., Russia
- Silvia Ruiz Boqué, UPC, Spain (COST IRACON DWG3 Co-Chair)
- Hamed Ahmadi, Univ. Essex, United Kingdom (COST IRACON DWG3 Co-Chair)
- Luis M. Correia, IST - University of Lisbon, Portugal

The Training School is organised with the support of the “RUDN University Program 5-100”.

Detailed Programme



Andres Gonzalez (Telenor, Norway): Andres Gonzalez is Research Scientist at Telenor Group since 2013. He received his PhD in Telecommunications from the Norwegian University of Science and Technology NTNU in 2013, and his Master in Telecommunications Engineering from The National University of Colombia and the Vienna University of Technology in 2008. He is currently part of the team in charge of exploring next generation technologies towards the deployment of 5G and beyond in Telenor, working on the elaboration of architectural design, research projects and proof of concepts. He is also working on the design and implementation of the Norwegian Facility in the H2020-ICT-17-2017 European Community 5G-VINNI project. His main focus areas are 5G, NFV, SDN, and Network Slicing, as well as the analysis of dependability issues in emerging network technologies, analysis and simulation of fault tolerant systems, dependability modelling, failure data processing and analysis, and reliable networks design. Andres is an experienced speaker and have taken part in several academic and commercial conferences, as well as other venues, and he is member of the Board of the Telenor 5G-vLAB.

The architectural design of a nationwide 5G Network: This lecture is focused on the architectural principles to design a nationwide 5G Network. There are three main references for this lecture. First, the related ongoing efforts on standardization bodies such as 3GPP, MEF, ETSI-NFV, ETSI-ZSM. Second, the architectural design elaborated by Telenor for the Norwegian Facility in the EU-H2020 5G-VINNI project. Third, some of the architectural plans for the Telenor 5G network implementation during the coming years. This lecture is structured in six parts. First, an introduction of the new requirements and enabling concepts behind 5G are presented. The second part deals with the overall description of a 5G architectural design, where several aspects go beyond current implementation plans, and hence research activities will play a relevant role. Third, technical details of the most relevant 5G network domains (RAN, Transport and Core) will be explained. In the fourth part are illustrated the existing management and orchestration challenges to achieve the 5G vision, and how they are addressed by standardization bodies and real implementation projects. The fifth part provides a brief understanding on how the new expected 5G-services can be specified and offered in the context of the technical concepts previously described. Finally, the lecture concludes by providing a summary of the main points to be considered in a 5G architectural design, the 5G roadmap to follow in the coming years, and the challenges that need to be addressed.



Carles Antón-Haro (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain): Carles Antón-Haro holds a Ph.D. degree in telecommunications engineering from the Technical University of Catalonia (UPC). In 1999, he joined Ericsson Spain, where he participated in rollout projects of 2G and 3G mobile networks. Currently, he is a Senior Researcher and Director of R&D Programs at the Centre Tecnològic de Telecomunicacions de Catalunya (CTTC). As a Senior Researcher, his research interests are in the area of signal processing and estimation theory for communications, this including machine learning, sensor and IoT networks, M2M communications, array signal processing, MIMO, energy harvesting, and Smart Grids. He has published +130 technical papers in IEEE journals, books/book chapters and in international and national conferences. He is a recipient of the 2015 Best Paper Award of the Transmission, Access, and Optical Systems (TAOS) Technical Committee's (Green Communications Track, ICC), and the Best Paper Award of IEEE GLOBALSIP15 conference. He has supervised 5 PhD Theses (1 in progress). He is an Associate Editor to EURASIP's Journal on Wireless Communications and Networks (JWCN). He is also an appointed member of the International Scientific Advisory Board of the

Internet Interdisciplinary Institute (IN3, Open University of Catalonia, 2017-present time). He was an elected member of the Steering Board of the Network2020 European Technology Platform and representative at the 5G Industry Association (2014). He is a Steering Board Member of the 5G Barcelona Association. In recent years, he has been actively involved in the organization of major conferences such as the IEEE Wireless Communications and Networking Conference 2018 (General Chair), Workshop on Integrating Communications, Control, and Computing Technologies for Smart Grid @ ICC17 (TPC Chair), or European Signal Processing Conference 2011 (General Vice-chair). He is an appointed member of the Steering Board of the IEEE Wireless Communications and Networking Conference (WCNC, 2019-2021). He is a Senior Member of the IEEE.

AI and ML for Physical Layer Designs of 5G and Beyond Networks: Machine learning (ML) techniques have been known for a long time as powerful tools for classification and regression (prediction) problems. More recently, deep learning (DL) has emerged with more advanced tools capable of building universal classifiers and/or approximate general functions. Typical problems/scenarios where machine learning methods have been successfully applied include, but are not limited to, image restoration and identification, natural language processing, network security, customer segmentation, predictive maintenance (e.g. for machinery in industrial plants), etc. Over the last two decades, the application of ML/DL techniques to communication problems has been to a large extent confined to the field of wireless network optimization. Consequently, there exists a large body of literature devoted to problems like intelligent resource management, cell association, selection of radio access technologies, or spectrum management, to name a few. More recently, the interest in using ML/DL techniques for problems and functionalities related with the physical layer (PHY) of communication systems (e.g., coding, modulation, detection, equalization, pre-coding, among others) has dramatically increased. And, further, it is generally agreed that enhancing (or even replacing) some PHY functionalities with ML and DL approaches could help achieve the stringent requirements associated with the future releases of 5G. First, this talk will provide the audience with a short introduction to ML and DL techniques. Then, it will review a number of salient examples illustrating how ML/DL have been successfully applied to the (re)design of a number of physical layer functionalities of communication systems. Finally, some recent research work conducted at CTTC (e.g., in the areas of beam selection for mmW communications) will be presented, as well.



David Calligaris (Huawei, Germany): Currently, I'm leading the group for Automation of Security Testing for Huawei Technologies. The role of the team is to develop tools to allow automatic/easy identification of security vulnerabilities inside Huawei products. The current research activity of my team is focused on the following topics: Cloud Computing Security; Automotive & Internet of Vehicles Security; Security Testing Automation. Before this experience in Huawei, I spent several years in a Cyber Security Consultant company Emaze S.p.A. in Italy. In this company, I started to work as a Vulnerability Researcher and Exploit Developer from 2002, and archive the position of Chief Technology Officer (CTO) in 2014. I'm a sustainer of the quote from Richard Feynman "What I cannot create, I do not understand".

Internet of Things Security & Insecurity: Lecture Abstract (250 words): In the last years we saw on the market an increase in connected devices from smart scales to home assistants. How many devices in our houses are connected on Internet? With whom are connected and why? Could this influence our privacy and security? In the lecture we will explore how cybersecurity is strictly linked with the IoT world, we will discuss about: IoT Search Engines; Security Vulnerabilities on IoT devices; The danger of wormable exploits; IoT Botnets

Fedor Chernogorov (Ericsson, Finland): Fedor Chernogorov is a Senior Researcher at Ericsson Research since



2018. He received his Ph.D. in mathematical information technology and M.Sc. in mobile technology from University of Jyväskylä, Finland in 2015 and 2010, respectively. Prior to that in 2009 he graduated from Yaroslavl State University, Russia with M.Sc. diploma in telecommunications. His career in applied industrial research in wireless communication started in 2010 and since then he has been involved in studies for 3GPP LTE and 5G NR standardization and concept development, several collaboration projects with industrial partners and EU funded projects, e.g. Celtic COMMUNE. His area of scientific interests includes LTE, 5G NR, ultra-reliable low latency communications, massive MTC and overall ecosystem of communication technologies, which can enable the fourth industrial revolution, sustainability of the world and common good in the future. Fedor is also interested in advanced methods of data analysis such as machine learning, and artificial intelligence applied in various domains including telecommunication systems.

5G for Industrial Machine-Type Communications: Industrial Internet of Things is one of the hottest topics among industry players, communication equipment and chipset vendors nowadays. This lecture presents the key technologies and features of 5G cellular IIoT aimed to enable the new level of connectivity across different industrial use cases. 5G networks in addition to excellent mobile broadband performance aimed for human communications, are from the beginning designed with Machine-Type Communications (MTC) in mind. This addresses massive MTC used for creation of sensor networks, characterized by large device volumes and densities, extremely long battery life and extended connectivity range especially useful in low-power wide-area networks, e.g. applied for smart metering systems. Mission-critical services are on the other edge of MTC, which include such use cases as smart-grid mission-critical monitoring and control, remote-driving, time-sensitive networking in production environments, industrial robot control, automated-guided vehicles. We will look into the 3GPP technologies which constitute M-MTC and C-MTC, go through the use cases where cellular MTC have the highest potential, given the specific use-case requirements, touch upon 5G performance in selected verticals and outline future trends. The main objective of the lecture is to create a holistic view of the MTC domain equipped with the cutting-edge 5G cellular communications technologies.



Hamed Ahmadi (University of Essex, United Kingdom): Hamed Ahmadi is an assistant professor in the school of Computer Science and Electronic Engineering at University of Essex, UK. He received his Ph.D. from National University of Singapore in 2012 where he was a funded PhD student at Institute for Infocomm Research, A-STAR. Since then till August 2015, he worked as a research fellow at CONNECT centre, Trinity College Dublin, Ireland. He joined University of Essex, in August 2018 to as an Assistant Professor. Between 2015 and 2018 he was a lecture and senior lecturer at University College Dublin, and Sheffield Hallam University, respectively. Dr. Ahmadi has published more than 40 peer reviewed book chapters, journal and conference papers. He is a member of editorial board of IEEE Access, Frontiers in Blockchain and Springer Wireless Networks. He is a senior member of IEEE, and a management committee member and Networks working group co-chair of COST Action 15104 (IRACON). His current research interests include design, analysis, and optimization of wireless communications networks, wireless network virtualization, blockchain, Internet-of-Things, cognitive radio networks, and the application of machine learning in small cell and self-organizing networks.

Resource Management, Self-organising Networks, and Massive MIMO in 5G and beyond: Efficient management of resources in 5G and beyond networks is a must. Spectrum, energy, time, and backhaul/fronthaul capacity are the major ones; however, there are other resources to be considered too. In this lecture we will investigate the conventional methods of resource management in wireless systems and study the more advanced methods. We will mainly use some mathematical (AI) tools optimization, game

theory and evolution computation to reach our goals. Self-organising abilities in the networks will help the operators to save significant costs in their operational expenditure (OPEX). These features include self-optimisation, self-configuration and self-healing. The concept of self-organization has been introduced in LTE for the first time and has been standardised in LTE-A. However, it is still an important topic for industry and academia as newer self-organising methods should be considered for incorporated new technologies like mmWave and massive MIMO. Moreover, with the emergence of Machine learning we can significantly improve our existing methods. Finally in this lecture we will have a look at the fundamentals of massive MIMO and beamforming and their applications in 5G and beyond.



Konstantin Samouylov (Peoples' Friendship University of Russia (RUDN), Russia): Konstantin Samouylov received his PhD in probability theory from the Moscow State University, in 1985, and a Full Doctor of Sciences degree in telecommunications from the Moscow Technical University of Communications and Informatics, in 2005. During 1985-1996 he held several positions at the Faculty of Science of the Peoples' Friendship University of Russia (RUDN University) where he became a head of Telecommunications System Department in 1996. Since 2014 he is a head of the Applied Probability and Informatics Department, and since 2017 he also holds the position of Director of Applied Mathematics and Communications Technology Institute (IAM&CT) at the RUDN University. He was visiting professor/professor-research at Lappeenranta University of Technology and Helsinki University of Technology (Aalto), Finland; Moscow Technical University of Telecommunications and Informatics, Russia; Moscow International Higher Business School (Mirbis), Russia; University of Pisa, Italy. He was a member of the ITU-T SG11 and IFIP TC6 WG 6.7. He has worked in a number of R&D projects within different frameworks, e.g., COST IRACON, projects of Russian Foundation for Basic Research (RFBR), TEKES (Finland) and companies including Nokia, Telecom Finland, VTT, Rostelecom, etc. He is a member of editorial boards and reviewer of several scientific magazines, he is co-chair and TPC member of several international conferences. His current research interests include applied aspects of probability theory and stochastic processes, queuing and teletraffic theory, performance analysis of 4G/5G networks, resource allocation in heterogeneous wireless networks, social networks and big data analysis. He has authored and co-authored over 150 scientific and conference papers and six books. Prof. Samouylov's honours include the 2018 IEEE GLOBECOM Conference Best Paper Award.

Mathematical Modelling Issues in the Future Multiservice Networks: Over the past few years, there has been an increasing level of research activities worldwide to design and performance analysis for the future multiservice networks. The talk outlines how mathematical models are being used to address current issues concerning quality of service and performance parameters of the modern and future networks, including 5G networks. The first problem is how to share the finite amount of radio resources serving the combination of 2 types of traffic collected by massive video surveillance systems, deployed for security and safety purposes, and low-cost and low-traffic smart meters and actuators. We propose the choice of the best resource allocation strategy to balance the analytic centric metrics, such as the session loss probability for individual data streams, with the network-centric metrics, such as the radio resource utilization efficiency, while the instantaneous values of data volumes are hard to predict. We also show how to choose the values of parameters for the one of the strategies we advocate for. The next topic presents an approach to Radio Access Network (RAN) slicing modelling based on the teletraffic and queuing theory. We propose a flexible model for Radio Access Network (RAN) slicing reflecting key objective of RAN-as-a-Service concept, i.e. to define a level of performance isolation in between the Virtual Network Operators (VNOs), which are acting as network tenants, in order to ensure that their contracted Service Level Agreements (SLAs) will not be affected by the variation of different network parameters, while at the same time, to optimise the usage of RAN infrastructure by dynamic radio resource sharing among various slices, and in a fair manner. We show

the application of this approach to the Network Slicing concept – both for optimal resource sharing of virtualized resources of an infrastructure provider between several virtual network operators and for a single VNO resource allocation between users to meet the Service Level Agreement.



Luis M. Correia (IST - University of 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 Portuguese communications operators and the telecommunications 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 of them 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 450 papers in international and national journals and conferences, for which served also as a reviewer, editor, and board member. Internationally, he was part of 33 Ph.D. juries, and 52 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 several 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.

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.



Yuliya Gaidamaka (Peoples' Friendships University of Russia (RUDN), 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). 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, mm Wave communications 3D directional deafness problem); random walk models and kinetic approach for modelling transceivers' movement.

Mathematical Modelling Issues in the Future Multiservice Networks: Over the past few years, there has been an increasing level of research activities worldwide to design and performance analysis for the future multiservice networks. The talk outlines how mathematical models are being used to address current issues concerning quality of service and performance parameters of the modern and future networks, including 5G networks. The first problem is how to share the finite amount of radio resources serving the combination of 2 types of traffic collected by massive video surveillance systems, deployed for security and safety purposes, and low-cost and low-traffic smart meters and actuators. We propose the choice of the best resource allocation strategy to balance the analytic centric metrics, such as the session loss probability for individual data streams, with the network-centric metrics, such as the radio resource utilization efficiency, while the instantaneous values of data volumes are hard to predict. We also show how to choose the values of parameters for the one of the strategies we advocate for. The next topic presents an approach to Radio Access Network (RAN) slicing modelling based on the teletraffic and queuing theory. We propose a flexible model for Radio Access Network (RAN) slicing reflecting key objective of RAN-as-a-Service concept, i.e. to define a level of performance isolation in between the Virtual Network Operators (VNOs), which are acting as network tenants, in order to ensure that their contracted Service Level Agreements (SLAs) will not be affected by the variation of different network parameters, while at the same time, to optimise the usage of RAN infrastructure by dynamic radio resource sharing among various slices, and in a fair manner. We show the application of this approach to the Network Slicing concept – both for optimal resource sharing of virtualized resources of an infrastructure provider between several virtual network operators and for a single VNO resource allocation between users to meet the Service Level Agreement.