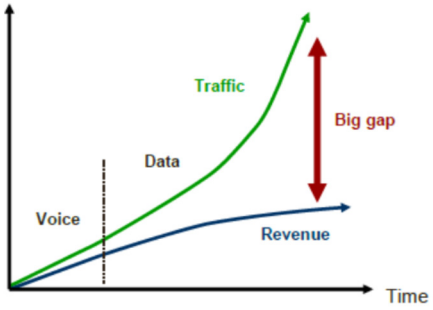
Tutorial T-1: Designing 5G Networks: an Energy Efficient Perspective

Presenters: Fabrizio Granelli (University of Trento), Marco Di Renzo (University of Paris), Christos Verikoukis, (Telecommunications Technological Centre of Catalonia) & Abbas Jamalipour (University of Sydney)

Tutorial Overview

With the increasing growth of mobile access to the Internet and its services, 5G wireless networks represent a key communication infrastructure for ubiquitous connectivity of the future. The need to support exponential growth in data traffic as well as availability of several mobile devices (smartphones, tablets, etc.) is leading to a sharp increase in the number and density of base station devices as well as in their complexity, leading to a consequent increase in power usage and consumption. Indeed, high power consumption could represent a limiting factor for the scalability and deployment of 5G wireless networks and one of the possible causes of the cost-revenue gap depicted in the figure below:



The tutorial is aimed at providing an energy efficient perspective on the design of 5G networks, by first introducing the 5G scenario and providing an overview of power consumption in cellular networks, aimed at identifying the major sources of power consumption and to understand the basic tradeoffs in energy efficient design of 5G networks.

At the beginning or during the early section of the tutorial, a questionnaire will be proposed to the audience in order to adapt the following sections of the audience based on their expectations.

Based on the 5G scenario of heterogeneous coexisting wireless technologies, the tutorial will then target the most relevant future and emerging technology supporting energy efficiency, and in particular:

• Physical layer design: a high percentage of power consumption in wireless networks is often associated to the radio-frequency interface and the power amplifier. In this framework, the tutorial will present techniques for achieving low-energy requirements via optimized coding and modulation schemes at the transmitter, opportunistic power allocation mechanisms to exploit the randomness of the wireless channel, and low-complexity implementations of detectors and channel estimators at the receiver.

• Energy-neutral wireless network design: Wireless Powered Communication (WPC) is an emerging concept, where Radio Frequency (RF) signals are exploited for information transmission and for

powering wireless devices. WPC, in particular, constitutes a key enabling technology for realizing truly perpetual wireless networks, where energy-neutral devices may remotely harvest the energy needed for their transmission from intended and unintended RF signals available over the air. In simple terms, WPC broadly refers to the capability of wirelessly transmitting power from one place to another and of using the harvested energy for subsequent information decoding and data transmission. In WPC, the transmission of power and information, which is referred to as Wireless Power Transfer (WPT) and Wireless Information Transfer (WIT), respectively, may occur by using either orthogonal or the same time/frequency channels. The joint transmission of energy and information by using the same channel and the same waveform constitutes a promising and spectrum-efficient paradigm towards the design of energy-neutral wireless communication networks, which is referred to as Simultaneous Wireless Information and Power Transfer (SWIPT). In the tutorial, we will introduce the fundamentals of WPC and will propose a methodological approach for their analysis and optimization with the aid of stochastic geometry tools. We will show that network densification and antenna-elements densification constitute two enabling approaches for realizing WPC. Furthermore, the optimal operational point for various cellular networks setups will be identified and discussed.

• 5G networks planning: efficient planning of 5G networks in scenarios of extremely dense coverage and multi-owner infrastructure can enable relevant power saving. The tutorial will present how connectivity between base stations in a cellular network can be used to shape interference and minimize power consumption while maintaining QoS and minimizing energy consumption. Different strategies will be proposed, able to face the issue of inter-owner interactions for overall power saving.

• 5G networks operation: previous sections of the tutorial were mostly focused on the wireless access section of 5G networks, while also backhaul and backbone represent challenges from the point-of-view of energy efficiency. This section of the tutorial will introduce the usage of resource and infrastructure virtualization and Software Defined Networking as a mean for providing flexible management of the 5G networks. Then, the usage of this paradigm will be explored in terms of energy efficiency.

• Cognitive radios and cognitive radio networks in 5G: Effective utilization of 5G spectrum is expected to support the introduction of the concept of cognitive radios and cognitive radio networks. In this scenario, it is crucial to understand the potential benefits and actual performance of cooperative spectrum sensing protocols for cognitive radio networks by considering realistic channel conditions. Both achievable performance and energy consumptions should be considered as metrics of interest in this scenario. The tutorial will take the resource management decision in cognitive radio networks one step beyond by including energy efficiency metrics into resource allocation decision. In detail, algorithms and protocols will be illustrated to take into account equipment and network capabilities which enable energy efficient, effective, fast and transparent decisions for resource allocation in a cognitive radio context. The tutorial will also explain how to utilize the concept of cognitive radio networks to introduce energy efficient mechanisms for exploitation of white spaces in order to enhance the potentials for radio resource sharing by extending the concept of fairness for power control presented in resource allocation and sharing in heterogeneous networks.

Also the vertical handover decision will be evolved by including energy efficiency into the handover decision “equation”, by taking into account the current battery status (consumption, remaining life) in order to meet these constrains while retaining the current QoS and QoE requirements. This will

effectively enable the mobile terminal to discover the availability of other Radio Access Technology cells in the vicinity of the user in a multi-owner environment and to select the most appropriate to meet its QoE requirements.

All major solutions will be analyzed and compared by offering the unique vision provided by the combined experience of the speakers, encompassing theoretical and industrial research, advanced research concepts and relevant testbed experiments.

At the end of the tutorial, the speakers will summarize the major points and leave time for additional discussion involving directly the audience.

Outline of the tutorial:

1. *Introduction to 5G and motivation (9:00-9:30)*
    a. From 4G / LTE to the 5G scenario (including traffic trends and typical operator's power consumption breakdown)
    b. Design issues in 5G
    c. Focus on energy efficiency and 5G (why is energy efficiency relevant? why wireless? a taxonomy for green wireless networking techniques (time, space, scope, method, performance)
2. *Energy efficient PHY design in 5G networks (9.30-10:00)*
    a. Large-Scale Single-RF vs. multi-RF MIMO: The case of Spatial Modulation MIMO (SMMIMO)
    b. SM-MIMO: Motivation and operating principle
    c. SM-MIMO: Fundamental trade-offs (spectral vs. energy efficiency, performance vs. complexity)
    d. SM-MIMO: Experimental results and channel measurements from a testbed platform
    e. SM-MIMO: Research challenges and opportunities
3. *Energy-Neutral Wireless Networks Design: Motivation and Challenges (10:00-10:30+break)*
    a. Self-Powered Wireless Communications
    b. Simultaneous Wireless Information and Power Transfer
    c. System-Level Analysis and Optimization of Self-Powered Cellular Networks: A Stochastic Geometry Approach
4. *Energy efficient Infrastructure Management (10:45-11.30)*
    a. Base Stations Switching off Schemes in Single-operator networks
    b. Base Stations Switching off Schemes in Multioperator networks
    c. Base Stations Switching off Schemes in Heterogenous networks
5. *Energy efficient Planning of 5G wireless networks (11:30-12:15)*
    a. Tradeoffs in terms of energy saving vs. performance, coverage, QoS, spectral efficiency, etc.
    b. Traffic-based energy efficiency in cellular networks
    c. Cellular network energy efficiency through sectorization
    d. Biologically-inspired techniques for energy efficiency in cellular networks
6. *Energy efficient 5G networks operation (12:15-12:35)*
    a. Virtualization and SDN approaches
    b. Enabling SDN over 5G: an energy efficient vision

7. Energy efficient Design of 5G cognitive radio networks (12:35-12:50)

a. Green spectrum access in 5G through cognitive radio

b. Regulatory models

c. Green spectrum management

8. Final remarks, and open discussion with the audience (12:50-13:30)

Presenter Biographies

Fabrizio Granelli is *IEEE ComSoc Distinguished Lecturer for 2014-15*, and Associate Professor at the Dept. of Information Engineering and Computer Science (DISI) of the University of Trento (Italy). From 2015, he is Delegate foeìr Education at DISI. He received the «Laurea» (M.Sc.) degree in Electronic Engineering and the Ph.D. in Telecommunications Engineering from the University of Genoa, Italy, in 1997 and 2001, respectively. In August 2004 and August 2010, he was visiting professor at the State University of Campinas (Brasil). He is author or co-author of more than 150 papers with topics related to networking, with focus on performance modeling, wireless communications and networks, cognitive radios and networks, green and 5G networking and smart grid communications. Dr. Granelli was guest-editor of ACM Journal on Mobile Networks and Applications, ACM Transactions on Modeling and Computer Simulation, and Hindawi Journal of Computer Systems, Networks and Communications. He was General Chair of the 11th and 15th IEEE Workshop on Computer-Aided Modeling, Analysis, and Design of Communication Links and Networks (CAMAD'06 and IEEE CAMAD'10). He is TPC Co-Chair of IEEE GLOBECOM Symposium on "Communications QoS, Reliability and Performance Modeling" in the years 2007, 2008, 2009 and 2012. He was officer (Secretary 2005-2006, Vice-Chair 2007-2008, Chair 2009-2010) of the IEEE ComSoc Technical Committee on Communication Systems Integration and Modeling (CSIM), and Associate Editor of IEEE Communications Letters (2007-2011).

Marco Di Renzo (SM'05-AM'07-M'09-SM'14) received the Laurea (cum laude) and the Ph.D. degrees in Electrical and Information Engineering from the Department of Electrical and Information Engineering, University of L'Aquila, Italy, in April 2003 and in January 2007, respectively. In October 2013, he received the Habilitation à Diriger des Recherches (HDR) degree majoring in Wireless Communications Theory, from the University of Paris-Sud XI, France. From August 2002 to January 2008, he was with the Center of Excellence for Research DEWS, University of L'Aquila, Italy. From February 2008 to April 2009, he was a Research Associate with the Telecommunications Technological Center of Catalonia (CTTC), Barcelona, Spain. From May 2009 to December 2009, he was an EPSRC Research Fellow with the Institute for Digital Communications (IDCOM), The University of Edinburgh, Edinburgh, United Kingdom (UK). Since January 2010, he has been a Tenured Academic Researcher ("Chargé de Recherche Titulaire") with the French National Center for Scientific Research (CNRS), as well as a faculty member of the Laboratory of Signals and Systems (L2S), a joint research laboratory of the CNRS, the Ecole Supérieure d'Electricité (SUPELEC), and the University of Paris-Sud XI, Paris, France. His main research interests are in the area of wireless communications theory, signal processing, and information theory. Dr. Di Renzo is the recipient of a special mention for the outstanding five–year (1997–2003) academic career, University of L'Aquila, Italy; the THALES Communications fellowship for doctoral studies (2003–2006), University of L'Aquila, Italy;

the Best Spin–Off Company Award (2004), Abruzzo Region, Italy; the Torres Quevedo award for research on ultra wide band systems and cooperative localization for wireless networks (2008–2009), Ministry of Science and Innovation, Spain; the “Dérogation pour l’Encadrement de Thèse” (2010), University of Paris–Sud XI, France; the 2012 IEEE CAMAD Best Paper Award from the IEEE Communications Society; the 2012 Exemplary Reviewer Award from the IEEE WIRELESS COMMUNICATIONS LETTERS of the IEEE Communications Society; the 2013 IEEE VTC-Fall Student Best Paper Award from the IEEE Vehicular Technology Society for the paper entitled "Performance of Spatial Modulation using Measured Real-World Channels"; the 2013 NoE-NEWCOM# Best Paper Award; the 2013 Top Reviewer Award from the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY of the IEEE Vehicular Technology Society; the 2013 IEEE/COMSOC Best Young Researcher Award for the EMEA Region; and the 2014 IEEE ICNC Best Paper Award for the IEEE Wireless Communications Symposium of the IEEE Communications Society for the paper entitled " Performance Analysis of Spatial Modulation MIMO in a Poisson Field of Interferers”. He currently serves as an Editor of the IEEE COMMUNICATIONS LETTERS and of the IEEE TRNSACTIONS ON COMMUNICATIONS (Heterogeneous Networks Modeling and Analysis).

Christos Verikoukis got his Ph.D. from the Technical University of Catalonia in 2000. He is currently a Senior Researcher and Head of the SMARTECH at CTTC and an adjunct professor at UB. His area of expertise is in the design of energy efficient layer 2 protocols and RRM algorithms, for short-range wireless cooperative and network coded communications. He has published 85 journal papers and over 150 conference papers. He is also co-author in 3 books, 16 chapters in different books and in 2 patents. Dr. Verikoukis has participated more than 20 competitive projects (IST, ICT, CELTIC, MEDEA+, CATRENE, Marie-Curie, COST) while he has served as the Principal investigator in 3 national projects in Greece and Spain as well as the technical manager in 7 Marie-Curie and 2 Celtic projects. In addition Dr. Verikoukis has also served as an external consultant to different companies. He has served as co-editor in 6 special issues while he has participated in the organization of several international conferences. He is also a regular reviewer in a number of international journals. He has appointed to serve as a reviewer in FP7 projects funded by the European Commission and as an EU-independent expert acting evaluator in ARTEMIS-JU and as an evaluator and rapporteur in FP7 and H2020 funded programs. He has supervised 15 Ph.D. students and 5 Post Docs researchers since 2004. He was General Chair of the 17th and 18th and 19th IEEE Workshop on Computer-Aided Modeling, Analysis, and Design of Communication Links and Networks (IEEE CAMAD’12, CAMAD’13, CAMAD´14) and the TPC Co-Chair of the 15th IEEE International Conference on E-health Networking, Application & Services (Helathcom’13) and the 6th IEEE Latin-American Conference on Communications (LATINCOM) 2014. He has also served as the co-chair of the CQRM symposium in ICC 2015 and ICC 2016 and the chiar of the eHealth symposium in Globecom 2015 . He is currently Chair of the IEEE ComSoc Technical Committee on Communication Systems Integration and Modeling (CSIM). Dr. Verikoukis received the best paper award of the Communication QoS, Reliability & Modeling Symposium **(**CQRM) symposium in IEEE ICC’11 conference, of the Selected Area of Communication symposia in IEEE Globecom 2015 and the Eurasip Best paper award 2013.

Abbas Jamalipour (S’86–M’91–SM’00–F’07) is the Professor of Ubiquitous Mobile Networking at the University of Sydney, Australia, and holds a PhD in Electrical Engineering from Nagoya University, Japan.

He is a Fellow of the Institute of Electrical, Information, and Communication Engineers (IEICE) and the Institution of Engineers Australia, an ACM Professional Member, and an IEEE Distinguished Lecturer. He is the author of six technical books, nine book chapters, over 350 technical papers, and five patents, all in the area of wireless communications. He was the Editor-in-Chief IEEE Wireless Communications (2006-08), Vice President- Conferences (2012-13) and a member of Board of Governors of the IEEE Communications Society, and has been an editor for several journals. Previously he has held positions of the Chair of the Communication Switching and Routing and the Satellite and Space Communications Technical Committees and Vice Director of the Asia Pacific Board, in ComSoc. He was a General Chair or Technical Program Chair for a number of conferences, including IEEE ICC, GLOBECOM, WCNC and PIMRC. Dr. Jamalipour is also an elected member of the Board of Governors (2014-16), IEEE Vehicular Technology Society. He is the recipient of a number of prestigious awards such as the 2010 IEEE ComSoc Harold Sobol Award, the 2006 IEEE ComSoc Distinguished Contribution to Satellite Communications Award, the 2006 IEEE ComSoc Best Tutorial Paper Award.