Software-Defined 5G Networks: Challenges, and Technologies

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***Abstract*—The commoditization of key processing components coupled with virtualization of infrastructure functions will lead to a radical change in the economics of mobile networks. The latter will help network providers (e.g., MNO, MVNO) move from proprietary hardware and software platforms towards open and flexible cellular systems based on general-purpose cloud infrastructures. In this context, 5G systems will see a paradigm shift in three planes: the data-plane, control-plane, and management-plane, in support of higher performance, efficient signaling, flexible and intelligent control and coordination in heterogeneous networks.**

This tutorial discusses all of these topics, identifying key challenges in software-defined 5G networks for future research as well as the standardization activities, while providing a comprehensive overview of the current literature. It is organized in four technical parts covering principles, challenges, key technologies, proof-of-concept prototypes and field trials of software-define 5G systems.

***Index Terms*—5G, Densification, Offloading, mmWave, Massive MIMO, Cloud, SDN, NFV, MEC, OpenAirInterface, Testbeds.**

I. Outline

The proposed tutorial will be a comprehensive guide on the background, state-of-the-art, and recent research topics in software-defined 5G systems, not only on radio interface and networking, but also on the management.

We will present fundamentals, challenges and key technologies in 5G systems considering the use cases predicted for the horizon 2020 timeframe and highlight the need for both softwarization/commoditization and virtualization/cloudification in mobile ecosystems. We will distinguish between possible enhancements in 4G technologies and those that are fundamentally different in 5G systems. The tutorial is organized in 6 parts for a duration of 3 hours (half a day) as follows:

1) **Principles (30 minutes):** In this part, we start by identifying the requirements for 5G given the target use-cases, main design elements of software-defined 5G systems, current activities (including 3GPP, ETSI, NGMN, 5G-PPP projects, open-source initiatives).
2) **Challenges (50 minutes):** In this part, we highlight the fundamental trade-offs between the key requirements, namely capacity, energy, latency, reliability and the practical limits, namely computation, complexity, realtime, virtualization. We present the realworld measurements on the practical limits in the context of 4G/4G+. Implication, feasibility, and coexistence of different access technologies will be discussed.
3) **Technologies (50 minutes):** In this part, we will present a set of technologies that will play a key role in 5G systems. We start by presenting three main techniques that contribute the most to the data-plane performance (e.g. spectral efficiency and latency), namely network densification and offloading, mmWave, and massive MIMO. Then, we address the need for network programmability and unified management framework to build and control the underlying heterogeneous network as a whole with a higher level of abstraction. The role of cloud, mobile edge computing (MEC), software-defined networking (SDN) and network functions virtualization (NFV) in 5G systems will be examined and their individual implication and potentials in network management and programmability will be also assessed. Finally, we provide a comparative table to differentiate the extensions and enhancements in 4G technologies from those introduced for 5G.
4) **Testbeds and Field Trials (40 minutes):** Recent efforts have shown the feasibility of full software implementation of LTE/LTE-A radio and core network functions over General Purpose Processors (GPPs). In this part, we highlight the methodol-

ogy to design a software-defined 5G testbed as well as the main on-going efforts toward building proof-of-concept 5G prototypes and highlight their main features and objectives. Finally, recent performance results available on a subset of 5G technologies and the impact of different fronthaul and backhaul links will be presented.
5) **Conclusion (10 minutes):** In this part we summarize the efforts in software-defined 5G systems, present the main conclusions and recent achievements and future directions.
6) **References:** we provide an extensive list of publications and efforts in the area of software-defined 5G systems from the research communities as well as industries.

II. Speakers

Table below shows the tutorial speakers and the topic they will cover during the tutorial.

Speaker	Part (see Section I)
Navid Nikaein	1, 2, 4,5
Raymond Knopp	3,4

TABLE I
SPEAKERS AND THEIR ROLES

III. Brief CVs of Tutorial Speaker

Navid Nikaein is an assistant professor in mobile communication department at Eurecom. He received his Ph.D. degree (docteur és sciences) in communication systems from the Swiss Federal Institute of Technology EPFL in 2003. He is leading a research group focusing on experimental system research related to wireless systems and networking. Broadly, his research contributions are in the areas of wireless access layer techniques and networking protocols, fronthaul and backhaul transport networks, softwarization and virtualization of wireless systems, and real-time RF prototypes and scalable emulation and simulation. He is also very active in collaborative research projects related to wireless communication protocols in the European FP6, FP7, H2020 framework programmes. In particular, he served as a the technical coordinator for FP7 LOLA project and workpackage leader for FP7 CONECT. He is currently working toward software-defined 5G systems through H2020 COHERENT and Q4Health projects, where he is working toward network programmability and slicing, and FP7 Mobile Cloud Network project where he is building a true C-RAN proof-of-concept based on the OpenAirInterface LTE softmodem.

Raymond Knopp is professor in the Mobile Communications Department at EURECOM. He received the B.Eng. (Honours) and the M.Eng. degrees in Electrical Engineering from McGill University, Montreal, Canada, in 1992 and 1993, respectively. From 1993-1997 he was a research assistant in the Mobile Communications Department at EURECOM working towards the PhD degree in Communication Systems from the Swiss Federal Institute of Technology (EPFL), Lausanne. From 1997-2000 he was a research associate in the Mobile Communications Laboratory (LCM) of the Communication Systems Department of EPFL. His current research and teaching interests are in the area of digital communications, software radio architectures, and implementation aspects of signal processing systems and real-time wireless networking protocols. He has a proven track record in managing both fundamental and experimental research projects at an international level and is also technical coordinator of the OpenAirInterface.org open-source wireless radio platform initiative which aims to bridge the gap between cutting-edge theoretical advances in wireless communications and practical designs.

IV. Importance and Timeliness of the Tutorial

A. Background

Although there is no formal specification or description of what a 5G system will be, there is no denying that towards the new 5G ecosystem, we are not really focusing on just enhancing a technology like LTE. As all the research community suggests, 5G technologies aim to provide a holistic end-to-end infrastructure that will include all aspects of the network.

The common understanding is that 5G will not be a simple upgrade of the 4G, but that it will fuel the evolution of the whole mobile Internet ecosystem to meet the needs for connected life and digital society. Given the key 5G requirements, namely 100-1000 times higher data rate, 10-1000 times more connected devices, 10 times lower latency and energy consumption with higher reliability, the network has to incorporate the key 5G technologies, e.g. densification, mmWave, and massive MIMO, and and be built and sliced in a flexible way based on abstract radio and infrastructure resources and then mapped to the underlying physical resources to tailor network to specific use-case needs. This allows network to be sliced and delivered on as-a-service basis for each vertical segments.

The goal of the network slices is to provide programmable pieces of code that on-the-fly reserve required resources, deploy and run the necessary software components, configure and program network elements according to the SDN and NFV paradigms, and provide the end-user with a 5G slice that perfectly matches the demands. The network slice is a necessity as the 5G networking opens a multitude of applications. The Next Generation Mobile Network (NGMN) association's white paper alone envisions 28 use-cases combined with multi-Radio Access Technologies (RATs) and various performance expectations, as also suggested in other proposals (e.g., Ericsson's 5G white-paper).

B. Activities

Motivated by recent theoretical and experimental progresses, softwarization and virtualization have been supported by many players, namely mobile operators (e.g. China Mobile and France Telecom), equipment vendors (e.g. Alcatel-Lucent Nokia), semiconductors (e.g. Intel NEV) European Commission 5GPPP initiative, and standardization bodies (e.g. NGMN Alliance, ETSI NTF and MEC), indicating a common industry-academia consensus toward software-define 5G systems.

C. Objectives

While a lot of attentions have been given from the wireless industry and scientific communities to the 5G systems, most of them are related to the use-cases and requirements, particular technology or design principles or patterns. Currently, there is a lack of a comprehensive guide on 5G systems and ecosystem. In addition, it is not clear how different technologies will set the scene in 5G systems. Considering 5G as a very active research area, it is important to offer to the scientific communities an analysis and evaluation of the recent achievements towards software-defined 5G systems from both academic and industrial perspective. This can promote further investigations and development in 5G systems. To this end, the main objective of the proposed tutorial are:

1) Provide a comprehensive guide on 5G and highlight the importance and timeliness of software-defined 5G systems
2) Cover a well-balanced research and development topics including challenges, key technologies, and proof-of-concept prototyping, and field trials.
3) Highlight the main international activities, and standardization perspective and efforts,
4) Discuss future direction of 5G systems.

D. Audience

The proposed tutorial falls under the following categories: Computer-Communication Networks, Network Architecture and Design, and Wireless Communication System. The tutorial is designed in such a way to provide a rich experience in 5G systems through a well-balanced and self-contained materials accessible to different audience.

- **Beginners** can learn the principle of 5G, its requirements, and the key 5G technologies to both improve the data rate (e.g. densification and mmWave) and the flexibility (e.g. SDN, NFV).
- **Experts** can catch up with the latest achievements and activities, new techniques, and open issues of 5G systems. Furthermore, they can learn about the recent efforts in 5G prototyping and field trails.

E. Competition

This is a very timely tutorial, given by speakers actively driving much of the 5G academic and industrial research efforts. The tutorial gives a big picture of 5G systems not only from the performance and management perspectives but also from the underlying technology transformation in terms of softwarization and virtualization.

Given the current interests in software defined 5G systems, it is expected that the proposed tutorial to be of wide interests.

V. Previous Lecture and Tutorial Experience

The proposers have the proven-track experience in wireless communication systems, realtime software radio platforms, prototyping and field trails in different settings including cellular, C-RAN, HetNet, and future 5G systems. With their research team, they have contributed to C-RAN from the architecture and key techniques to proof-of-concept development and field trials [1]–[4], [6].

Navid Nikaein: has an extensive experience in delivering lectures for different type of audiences ranging from graduate students to researchers and industry experts. At Eurecom, he delivers two graduate courses in mobile advanced networking and applications. He is also very active in delivering lectures for different venues such as conferences, summer schools, collaborative projects, and tutorials. He has given two talks last year, one at C-RAN Europe conference and the other at C-RAN workshop organized by Orange labs, and several half-a-day tutorials, one in public safety networks, large-scale simulations, and Cloud Radio Access Networks in 5G systems.

Raymond Knopp: has a wide range of experience in delivering lectures in various venues such as conferences, summer schools, and collaborative projects. He gives two lectures at the graduate level related to the digital communication and signal processing technologies. This year he has delivered many talks related to design and development of a full GPP LTE softmodem and its application to HetNet, C-RAN, and public safety networks.

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