5G NETWORKS: END-TO-END ARCHITECTURE AND INFRASTRUCTURE

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The forthcoming 5G infrastructure, defined as the ubiquitous ultra-broadband network enabling the future Internet (FI), is not only about new releases of current network generations and services, but, more significantly, will be associated with a true revolution in the information and communications technologies (ICT) field: the network will efficiently and effectively take forward new-fangled services to everyone and everything, such as cognitive objects and cyber physical systems (CPSs). A "full immersive (3D) experience" enriched by "context information" and, in particular, "anything or everything as a service (XaaS)" are the main business drivers for massive adoption and market uptake of the new fundamental enabling technologies, beyond today's "client-server" model, where the network has been reduced to a ubiquitous "pipe of bits." XaaS refers to those services — beyond the current models of software as a service (SaaS), infrastructure as a service (IaaS), and platfore as a service (PaaS), SPI models, of cloud computing — such as data as a service (DaaS), security as a service (again, SaaS), network as a service (NaaS), knowledge as a service (KaaS), machine as a service (MaaS), and robot as a service (RaaS), which could be delivered over the advanced 5G infrastructure, without the need to own hardware, software, or even the cognitive objects themselves. Communication services, such as voice and video telephony, will be enriched and bundled with other services. The network infrastructure is expected to become the "nervous system" of the actual *digital society and digital economy*. This challenge calls for a complete redesign of services and service capabilities, architectures, interfaces, functions, access and non-access stratum protocols and related procedures, as well as advanced algorithms (e.g., for unified connection, security, mobility and routing management, and reconfiguration of ICT services; and any type of resource of cyber physical systems). The expected transformation will be especially true at the edge, that is, around the end user (or *prosumer*), where the "intelligence" already started migrating a few years ago, and where massive processing, memory, and storage capacity are gradually accumulating.

As of today, many challenges remain to be addressed to meet the expected key performance indicators and new services in terms of, for example:

- Throughput: 1000× more in aggregate and 10× more at link level
- Latency: 1 ms for remote control of robots or tactile Internet applications, and below 5 ms for 2–8K change in view at 30–50 Mb/s
- Ultra-high reliability
- Coverage suitable for a seamless experience
- Battery lifetime: 10× longer
- Spectrum utilization: all spectra, from cellular bands to visible light

The redesign of the radio access nodes will required innovation in multiple areas of basic radio technologies, such as a new air interface, new virtualized radio access networks, new radio frequency transceiver architecture, and new device radio architecture. New radio backhaul/fronthaul and new fiber access for the fixed network to support 5G wireless are also required as an integral part of the solution. The software defined 5G architecture running on a fully integrated wireless/optical infrastructure will be the de facto platform for future carrier networks on the horizon of 2020 and beyond. This *plastic* architecture will unify connection, security, mobility, and routing management, especially for supporting diverse vertical industry applications. Full compatibility with current and future incremental 4G releases will be guaranteed by the possibility of instantiating any type of virtual architecture and installing any kind of network and service application efficiently.

In *IEEE Communications Magazine*, this timely Feature Topic brings together key contributions of researchers from industry and academia that address the above challenging issues, and presents the fundamental peculiarities of the advanced 5G infrastructure to be open and flexible enough to meet defined (current) and unidentified (future) stakeholders' requirements. It also presents how the widespread adoption and utilization of cloud computing at the edge, software defined networking (SDN), services, and network function virtualization (NFV) will make the 5G infrastructure technically feasible and, especially, business viable.

In response to our Call for Papers, 30 submissions were received. The submissions underwent a rigorous review process, following which only four outstanding contributions were selected for publication. The four articles are in the broad area of 5G network architectures, mobility and routing management, and device-to-device (D2D) communications. These articles are expected to stimulate new ideas and contributions within the research community, in addition to providing readers with relevant background information and feasible solutions to the main technical design issues of future 5G networks.

The first article, "Design Considerations for a 5G Network Architecture" is by Patrick Kwadwo Agyapong, Mikio Iwamura, Dirk Staehle, Wolfgang Kiess, and Anass Benjebbour. The authors present a two-layer 5G network architecture consisting of a radio access network and a network cloud, which integrates many enabling technologies such as small cells, massive MIMO, SDN, and NVF to facilitate optimal use of network resources for QoE provisioning and planning. In this article, an initial proof of concept is also presented in order to demonstrate the technical feasibility of the proposed architecture. The crucial issues that need to be addressed and resolved to realize a complete 5G architecture vision are also thoroughly discussed.

The second article, "A New Control Plane for 5G Network Architecture with a Case Study on Unified Handoff, Mobility, and Routing Management by Volkan Yazıcı, Ulaş C. Kozat, and M. Oğuz Sunay, proposes an all-SDN network architecture with hierarchical network control capabilities as a simplified and unified approach to mobility and routing management for 5G networks. Beyond this, the novel architecture supports connectivity management as a service (CMaaS), which may be offered to provide QoS differentiation with a range of options to protect flows against subscriber mobility at different price levels without the utilization of tunneling protocols. Performance results show the proposed architecture to be a viable solution for mobile D2X communications with end-to-end latency below 5 ms.

In the third article, "Terminal-Centric Distribution and Orchestration of IP Mobility for 5G Networks," Alper Yegin, Jungshin Park, Kisuk Kweon, and Jinsung Lee first describe the efficiency issues of the current Third Generation Partnership Project (3GPP) centralized approach to mobility management using core anchoring. Then they present and discuss multiple dimensions of distributing the mobility functions, and suggest how the mobile terminal can utilize them (terminal based solution) in orchestration for efficient communication over a 5G flat mobile network. An L4+ mobility solution is the preferred choice when a flow requires session continuity and both endpoints support at least one common L4+ mobility protocol that is applicable to the flow. Remote anchoring is preferred over access anchoring as the former does not create a triangular data path. Access anchoring acts as a supplement when an L4+ solution or core/remote anchoring is used, and provides the optimal data path between the terminal and its peer (remote end) only at the beginning of the communication, when the terminal is still close to the anchoring point.

The fourth article, "Toward D2D-Enhanced Heterogeneous Networks," by Francesco Malandrino, Claudio Casetti, and Carla Fabiana Chiasserini, argues the need to integrate functionally D2D and infrastructure-to-device (I2D) modes, and proposes a multi-modal proportional fairness (MMPF) algorithm to achieve this goal. They evaluate the impact of D2D in a two-tier scenario, where macro and micro coverage are combined. Simulation results show that although I2D retains a clear edge for general-purpose downloading, D2D is a viable solution for localized transfers as well as viral content. Ultimately, D2D can indeed be integrated in cellular networks (e.g., as far as the network control concerns for the optimized usage of the spectrum, and for authentication and authorization), but apparently cannot entirely replace the deployment of small cells: it is useful to complement them and mitigate the effects of a reduced infrastructure deployment together with enabling new services based on proximity in a scalable way.

Many initiatives on 5G are currently ongoing at the global level. For example, in the United States, the three main activities carried out on 5G are in the Intel Strategic Research Alliance (ISRA), 4G Americas, and NYU Wireless Research Center. In China, it is ongoing in the Ministry of Science and Technology (MOST) 863 Research Program (Chinese: 863计划) and IMT-2020 (5G) Promotion Group. In Japan, the 2020 and Beyond Ad Hoc Group is under the Association of Radio Industries and Businesses' (ARIB's) advanced wireless communications study committee. In Korea, the main activity is in the 5G Forum. The most important initiatives in the European Union are the 5G Private Public Partnership (5G PPP) and the 5G Innovation Centre (5G IC), at the University of Surrey, United Kingdom. The 5G PPP is within the EU Horizon 2020 — The EU Framework Programme for Research and Innovation — under one of the most important EU Industrial Leadership challenges: ICT-14 Advanced 5G Network Infrastructure. Within this research and innovation framework, the European Commission (EC), under the approval of the European Parliament (EP), has already committed €700 million of public funds over six years (2015–2021). From two to ten times higher is expected to be the investment from private parties: industry, SME, and research institutes.

Most efforts are currently focused on research and innovation work; after that, intensive standardization activities, field tests, and large-scale trials will take place to accelerate industrial pre-adoption. Commercial products will likely be available in the market beyond 2020. This approximate roadmap applies to infrastructures and devices for human and, in particular, mission-critical and massive machine communications.

In closing, we would like to thank all the stakeholders who have made this Feature Topic possible: colleagues who spread the Call for Papers around, the many authors who submitted papers to our Feature Topic, the team of reviewers, who helped us to select and further improve the outstanding papers that are published in this magazine, the Editor-in-Chief (EiC) of *IEEE Communications Magazine*,

Dr. Sean Moore, as well as the members of the Editorial Board for their invaluable help and for hosting this Feature Topic, and ComSoc's editorial staff who produced the final material.

We hope that this endeavor will meet readers' expectations, for whom this Feature Topic on advanced 5G infrastructure has been prepared.

BIOGRAPHIES

DAVID SOLDANI received an M.Sc. degree with maximum score and cum laude approbatur in electron ic engineering from the University of Florence, Italy, in December 1994, and a D.Sc. degree in technology with distinction from Aalto University, Finland, in October 2006. He is one of the top experts in multi-disciplinary, long-term, transformative frontier research and innovation. He has been active in the ICT field for more than 20 years, successfully working on more than 150 R&D projects for 2–5G, generating original contributions to all types of quality deliverables: from strategic research and innovation to modeling, simulations, emulations, and innovative proof of concepts with stakeholders. He is currently VP of the Huawei European Research Centre (ERC), Germany, and visiting professor at the University of Surrey, United Kingdom. Areas of his responsibility and expertise include, but are not limited to, future wireless, network, IoT, and multimedia technologies. He represents Huawei on the Board of the 5G Infrastructure Association and Steering Board of NetWorld2020 European Technology Platform in Europe.

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DANIELE FRANCESCHINI is currently responsible for technology, development plans, and cost analysis in the Network Planning Department, Latam. He joins other relevant departments in the definition of the group technology plan, technology network development plans, and the technical economical evaluation for cost analysis inside technology. Recently, from May 2011 to March 2013, he was responsible for the Next Generation Mobile Network strategy in Telecom Italia, in charge of all the group strategic aspects related to the Telecom Italia Mobile Broadband evolution and, in particular, the LTE introduction in Italy and in Latam. In 1998 he accompanied the UMTS standardization process, joining the ETSI SMG2 L2&3 group, and subsequently 3GPP TSG RAN WG2 and WG4, with editorship responsibilities of the specifications of the Radio Resource Management. He also worked on 3GPP SA1 and SA2. From March 2000 he joined Omnitel where he followed aspects related to UMTS. In 2001 he rejoined Telecom Italia Lab, where he worked on issues related to implementation of UTRAN, radio resource management, radio protocol architecture, and UMTS in general in Italy and for the Telecom Italia companies in Europe and in Latam. Since the end of 2005 he was responsible for wireless access innovation activities within Telecom Italia Lab with particular focus on all of the radio innovation aspects and technologies related to the radio access network and its evolution (e.g., HSPA evolution, LTE, and LTE Advanced). he holds a degree in telecommunication engineering from the University of Pisa and currently is part of NGMN as an alternate Board Director, and follows the ITU-R WP5D Spectrum Group and the GSMA SSMG (Spectrum Strategy Management Group) working group.