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Special Issue on:

5G for Broadband Multimedia Systems and Broadcasting

The upcoming fifth-generation (**5G**) of wireless communications technologies is expected to revolutionize society digital transformation thanks to its unprecedented wireless performance capabilities, providing speeds of several Gbps, very low latencies well below 5 ms, ultra-reliable transmissions with up to 99.999% success probability, while being able to handle a huge number of devices simultaneously connected to the network. The first version of the 3GPP specification (i.e. Release 15) has been recently completed and many 5G trials are under plan or carrying out worldwide, with the first commercial deployments happening in 2019.

Since 5G will be able to offer a wide range of applications, the International Telecommunication Union (ITU) has defined three main types of its services: enhanced Mobile Broadband (**eMBB**), massive Machine Type Communications (**mMTC**) and Ultra-Reliable and Low Latency Communications (**URLLC**) [1]. Critical among the different type of services that 5G might provide, is the delivery of future media. Public demand for immersive media expands to 4k/8k Ultra-High-Definition Television (UHDTV) including HDR (High-Dynamic Range), HFR (High Frame Rate) and wide colour space, object-based content, Virtual/Augmented/Mixed Reality (VR/AR/MR), 360° visual media and Next Generation Audio. Indeed, although 5G is expected to make an effect in the digital transformation of so-called vertical industries such as automotive, manufacturing, eHealth, energy or public safety, ***Media and Entertainment (M&E)*** *is also* considered as one of the main vertical industries that can benefit from 5G.

5G had a strong appearance in the 2018 edition of the IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB) organized in Valencia, Spain [2]. The conference was co-located with a one-day tutorial on emerging 5G broadcast technologies and applications and counted with several workshops on 5G. The tutorial and workshops were organized by 5G-PPP research projects. The 5G Infrastructure Public Private Partnership (5G-PPP) is a joint initiative between the European Commission and European ICT industry to accelerate research and innovation in 5G technology [3].

As for 5G development worldwide, **Europe** aims the commercial launch of 5G in at least one city per Member State by 2020 and comprehensive rollout in all cities and along major transport paths by 2025. Europe is focusing on advanced 5G services beyond conventional broadband services, paying a lot of attention to new vertical industries [4]. One particular example is a number of 5G corridors that have been agreed among Member States for testing Connected and Automated Mobility [5]. The European 5G Observatory was launched in 2018 to monitor market developments and preparatory actions taken by industry stakeholders and Member States in the context of 5G rollout in Europe [6].

In **North America**, the main wireless service providers in the US have been busy with trials and scaled deployments, while preparations are being carried out over the border in Canada. Verizon began 5G customer trials across seven US cities in early 2017, turned on the world's first 5G networks in Houston, LA, Sacramento, and Indianapolis in 2018, and plans to launch mobile 5G service in 2019. Although without mobile handsets available for end users, AT&T introduced in 12 cities its “standards-based mobile 5G” to its customers by the end of 2018 and plans to introduce 5G-capable smartphones this year. T-Mobile aims to launch its 5G mobile services in 30 cities in second half of 2019, plans to support the first wave of 5G smartphones starting 2019, and aims to deliver nationwide 5G by 2020. Its 5G equipment will be deployed in the 600 MHz,

28GHz and 39GHz bands. Sprint launched massive MIMO TD-LTE connectivity in three cities in the second quarter of last year using 2.5GHz band for its rollout. As for the spectrum auction in the US, the FCC revealed a tender for 28GHz mmWave licenses began in November 2018, with a 24GHz auction in plan, which came out with a total of 1.55GHz spectrum across the two bands for auction. The 28GHz licenses are also offered for auction. In Canada, the first commercial services will likely start 2020 and Telus has begun trials. The 600MHz spectrum auction will be held in spring 2019, and 3.5GHz auction has been planned for 2020 in Canada.

As a pioneer in 5G industrialization, **China** has made a lot of efforts in the application of 5G, especially in the broadband multimedia and broadcasting systems. In 2018, China Telecom launched the "Hello 5G" project to build a 5G ecosystem that enables innovative applications such as artificial intelligence, drones, autonomous driving, precise positioning and stadium VR. In April 2018, the demonstration of the first flight of 5G drones was completed in Shenzhen, which successfully realized real-time 5G network transmission of drone 360 degree panoramic 4K HD video. In 2019, China Telecom also performed a real-time 4K live broadcast of the Spring Festival Evening in Shenzhen and VR converged multimedia live broadcast in Beijing through 5G networks. The world's first 5G-based digital indoor system was launched at Shanghai Hongqiao Railway Station in Feb. 2019, which is an important milestone in Shanghai's 5G commercialization.

Although operators already displayed 5G at the Winter Olympic Games in early 2018, **South Korea** plans to offer commercial 5G services at a national level in 2019. Deployments already started, since the three main mobile network operators, i.e. KT, SK Telecom and LGU+, launched their services in April 2019. The first 5G UEs were also launched that month in this country. Operators are first deploying their networks in crowded areas with high data requirements, such as universities, stadiums, subway lines or trains. In **Japan**, Softbank and NTT DoCoMo mobile operators will launch pre-commercial 5G services in 2019. They will also deploy commercial services by 2020, taking advantage of the Summer Olympics held in Tokyo. Other areas of interest for the future is the use of the 28 GHz band to trial mmWave equipment.

Regarding 5G in other areas in the world, both Qatar and UAE claim to be the first ones deploying 5G in early 2019. Since there were no commercial 5G devices by that time, the deployment is only focused on 5G infrastructures. India is also supporting 5G deployment in the near future and strategic initiatives have been launched by the government. **South America** is focusing on 5G trials for remote area coverage for broadband Internet access. This use case has a significant social and economic impact since a considerable percentage of the global population living in a low populated area does not have Internet access and the communication infrastructure in rural areas can be used to improve agribusiness productivity [7]. Also, the coexistence of the use of the 3.5 GHz band to the 5G with the satellite that operates in the range of 3.4 GHz to 3.6 GHz with the extended C/C band is mandatory because many people that live in these areas receive analogue/digital satellite TV. Mitigating studies are currently being performed to establish whether it is possible to operate the 5G on this spectrum without affecting satellite communications at the same frequency.

This special issue contains 11 articles addressing the main innovations and topics related to the use of ***5G for broadband multimedia systems and broadcasting***. Each paper is related to a specific 5G-PPP project. The projects represented are 5G-Xcast, 5G-MEDIA, SaT5G, 5GCity, IoRL, 5G ESSENCE, NGPaaS, Bluespace, SliceNet, 5GCAR and 5G-TRANSFORMER. Such varied number of projects faithfully represents the whole 5G ecosystem. These papers mainly focus on broadcast and multicast technologies as a cornerstone for the future delivery of M&E services, but they also cover a wide range of topics such as 5G transport, virtualization, cloud, V2X, visible light communications or optical communications. The corresponding papers are detailed below.

The first paper in this special issue [8], "*5G New Radio Terrestrial Broadcast: A Forward-Looking Approach for NR-MBMS*," by J. J. Gimenez *et al.*, is related to the 5G-Xcast project. The authors present the design of a transmission mode suitable for the distribution of audiovisual services (linear radio/TV) based on the physical layer of 5G New Radio. The paper leverages some features already included in LTE enTV Rel-14 (e.g. 100% allocation of resources to broadcast services, use of SFN, receive-only mode) combined with the benefits of the more flexible and efficient air interface of the current 5G-NR specifications. This paper evaluates the proposed solution in terms of flexibility, capacity, mobility and coverage.

The second paper [9], "*An Edge-to-Cloud Virtualized Multimedia Service Platform for 5G Networks*," by F. Alvarez *et al.*, comes from the 5G-MEDIA project. It presents a novel service virtualization platform for media-based applications. The platform is based on the principles of NFV and SDN and has been validated against three media use cases, i.e. immersive virtual reality in 3D gaming applications, remote broadcast content production with user generated content, and dynamically adaptive Content Distribution Networks (CDNs) for Ultra-High Definition (UHD) content. Results show that, compared to the current practice, the platform provides enhanced functionalities for operators and ensures better network service performance.

The third paper [10], "*QoE-Assured Live Streaming via Satellite Backhaul in 5G Networks*", by C. Ge *et al.*, is associated with the SaT5G project and proposes a 5G oriented network architecture supported by GEO satellite link as backhaul and also multi-access edge computing (MEC) to provide eMBB services such as 4K/UHD live video streaming. This work assures Quality of Experience (QoE) of HTTP-based live streaming users by using satellite links and realizing transient holding and localization of video segments at 5G mobile edge. The paper also performs for the first time experiments to systematically evaluate 4K live video streaming over a 5G core network that supports geostationary satellite backhaul.

In the fourth paper [11], "*Deploying a Novel 5G-enabled Architecture on City Infrastructure for Ultra-High Definition and Immersive Media Production and Broadcasting*," by C. Colman-Meixner *et al*. introduces the 5GCity project and presents the main benefits of their sliceable, distributed cloud and radio 5G-platform based on neutral hosting. The proposed architecture and infrastructure address the current media demands against a set of Key Performance Indicators (KPIs) through three different use cases, i.e. video acquisition and production at the edge, immersive services, and mobile broadcasting. The solutions provided are additionally deployed in real citywide pilots to showcase their benefits for infrastructure owners and media providers.

The fifth paper [12], entitled "*Smart Television Service using NFV/SDN Network Management*," by N. Jawad *et al.*, is related to the IoRL project and is about integration of joint NFV and SDN with digital TVs to provide smart services with enhanced QoE to users. This work focuses on follow me services, which allow 5G users in indoor environments, e.g. at home, to select with their smartphones specific media content from content servers and cast it to the nearest TV, switching to other TVs while moving around the area by using UE geolocation. Since Internet of Radio Light (IoRL) systems are at early stages, the work steps forward by using the Mininet platform to integrate NFV/SDN into 5G multi-rat scenarios.

Virtualization is a hot topic that has been addressed in the sixth paper [13], "*A Cloud-Enabled Small Cell Architecture in 5G networks for broadcast/multicast services*," by M.-A. Kourtis *et al.,* as part of the 5G ESSENCE project. This work presents a cloud-enabled small cell architecture for 5G networks as well as its conformity to the 5G radio resource management architecture. This paper also explores the inclusion of an edge enabler to support VNF. The presented architecture has been additionally evaluated in public safety use cases and eMBMS enabled services.

The seventh paper [14], "*Next Generation Platform as a Service: Towards Virtualized DVB-RCS2 Decoding System*," by R. Kerherve *et al*., is related to NGPaaS and also deals with virtualization and cloud computing. The authors present the concept of next-generation Platform-as-a-Service (PaaS) cloud computing services, which need to be adapted to new use cases and scenarios. This work demonstrates that the features proposed enable the implementation of 5G oriented connectivity services in cloud data centers. It also aims at facilitating the build of a combined telco-broadcasting PaaS system on the cloud, where a DVB-RCS2 system is able to bring its own components and integrate them with the connectivity services deployed by a Telco operator.

The blueSPACE project brings the eighth manuscript [15], entitled "*High-Capacity 5G Fronthaul Networks Based on Optical Space Division Multiplexing*," by S. Rommel *et al*. The paper discusses the use of space division multiplexing with multi-core fibers in ultra-high capacity fronthaul networks as well as the introduction of optical beamforming for millimeter-wave radio access. The paper also discusses analog and digitized radio-over-fiber in scenarios featuring parallel fronthaul for different radio access technologies, showcasing their potential when combined with space division multiplexing.

The ninth paper [16], "*Enable Advanced QoS-Aware Network Slicing in 5G Networks for Slice-Based Media Use Cases*," by Q. Wang *et al*., is focused on public safety and mission critical communications for the delivery of media applications. This work is part of the SliceNet project, and presents a novel framework based on network slicing to address very innovative challenges with migrating eHealth telemedicine services to 5G. The paper also emphasizes the design of a media-centric eHealth use case in order to achieve end-to-end network slicing capabilities. The experimental results presented validate the prototyped enablers and demonstrate the applicability of this framework in media use cases.

5GCAR is a project that proposes V2X technology components for 5G. The tenth paper [17], "*Multicast and Broadcast Enablers for High-Performing Cellular V2X Systems*," by M. Fallgren *et al*., is associated with the project, and describes two of the proposed technical components. The first solution consists of a beamformed broadcast/multicast technology that builds on adaptive and robust techniques in the air interface. The second component is about improving the end-to-end 5G network architecture to enable efficient multicast and broadcast transmissions in V2X.

The last paper of this special issue [18], "*Modeling Mobile Edge Computing Deployments for Low Latency Multimedia Services*," by J. Martin-Perez *et al*. and as part of the 5G-TRANSFORMER project, presents an application of inhomogeneous Poisson point processes with hard-core repulsion to model ME infrastructure deployments. Based on the paper, mobile network operators can identify where to locate the MEC Points of Presence (PoP) and associated gNBs to support a specific set of services such as multimedia streaming, or augmented and virtual reality. The proposed model is evaluated via simulations in realistic scenarios.

To sum up, we would like to thank all the authors and the eleven 5G PPP phase-2 projects that have contributed to and made possible for this special issue. The special issue will help to provide a wide and comprehensive view of the 5G ecosystem applied to Broadband Multimedia Systems and Broadcasting.

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