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Special Issue on:

5G Media Production, Contribution and Distribution

The media landscape is undergoing unprecedented transformations. Content creators and service providers had been for decades in control of how technology tailored to media applications was deployed and adopted in networks and devices to serve audiences. Disruption started when the Internet and global technologies and networks enabled content delivery and consumption at anytime, anywhere, and by means of any device. This new paradigm, where the Internet is fully accessible to the media industry, creates opportunities for innovation across the entire value chain, involving new services, innovative products, and a direct relationship with users.

The worldwide introduction of 5G network technologies is the next step in such a growing ecosystem, where media content, in particular video, is expected to account for 79 percent of the mobile data traffic in 2027 [1]. 5G is not only about smartphones and mass media delivery. 5G technologies are the basis for next generation mobile networks combining a range of extraordinary technical capabilities in terms of throughput, latency or reliability [2], and support of smart network features such as edge computing or network slicing [3]. 5G does not just represent a new air interface technology, NR (New Radio). NR is just a part of a complete ecosystem, complemented by computing capabilities integral to networks [4], highly softwarized functions [5], new ways of traffic management and isolation together with an increasing disaggregation between processes, equipment, network operators, service providers and spectrum license holders. Moreover, while previous mobile technologies were mainly tailored to the need of mobile operators, 5G introduces a paradigm shift with respect to industry engagement, new services and business opportunities in many market sectors. The global media industry is one of these sectors, where opportunities are identified along the entire value chain, from media production and contribution to media distribution and consumption [6].

The changing media distribution landscape

Delivering television, radio services and new rich media formats to a wide range of devices including smartphones, tablets, connected cars, or smart TVs is becoming more and more important. Users, in particular young audiences, make increasing use of such devices, both at home and on-the-move [7].

The delivery of content over the Internet is currently based on over-the-top (OTT) platforms where media traffic is not treated in any particular way, therefore similar to other data types [8]. This means that the specific requirements of the media data, mostly in terms of low latency and large bitrate, are not always addressed [9]. Additionally, these platforms suffer from the lack of scalability as content, delivered using unicast connections, cannot easily be offered to large audiences without suffering some degradation. This way of delivering content is trivial for on-demand approaches, as every user can make a selection of the desired program at the specific time they want to consume it. Multiple independent connections are unavoidable although some efficiency might be possible by means of caching. However, when it comes to live or linear content distribution, where users connect and receive exactly the same content at the same time, possibilities for improving delivery efficiency are worth consideration.

The situation becomes challenging in mobile networks given the scarcity of radio resources, which need to be shared by many users, and additional issues such as interferences from other cells or the need to guarantee mobility among them [10]. At the same time, consumption habits are changing with OTT platforms not only being used for on-demand consumption, but also becoming reference platforms for the consumption of live events such as sports or music shows.

The 3rd Generation Partnership Project (3GPP), the global mobile technologies standardization organization for mobile telecommunications, is working on solutions under the umbrella of 5G with different technical solutions to address the future needs in terms of media distribution. Among them, Terrestrial Broadcast using 5G Broadcast, multicast as a network optimization tool or a media streaming architecture to enable different collaboration scenarios between different stakeholders are alternatives considered. It should also be noted that the scope goes even beyond, including satellite connectivity or edge computing processing within the network.

5G technologies will therefore be able to support the distribution of media services as a combination of linear (e.g. current TV and radio services) and non-linear (e.g. on-demand, podcasts) components. In particular, tools may enable these services to reach the final users with a high degree of control and ensure certain end-to-end quality of service (QoS) guarantees.

Long Term Evolution (LTE)-based 5G Terrestrial Broadcast, commonly referred to as 5G Broadcast [11], was specified to fulfill requirements for TV and radio broadcasting [12]. The system grants service providers control over linear content delivery, enables configuration of radio carriers with almost 100% capacity for broadcast services and supports large area Single Frequency Networks (SFN) with topologies beyond cellular networks [13], [14]. All this is accompanied by a significant change, as neither uplink capabilities nor registration to the provisioning network is required to consume broadcast content. This eliminates the need for a SIM card and effectively enables free-to-air reception.

As this broadcast system is part of the 3GPP family of standards, it can be fully integrated into any 3GPP equipment, with the same chipset architecture and even be complemented by mobile broadband data.

Notable is that LTE-based 5G Terrestrial Broadcast includes features to support: receive-only mode with free-to-air services as well as encrypted services including authentication mechanisms; dedicated High Power/High Tower (HPHT), Medium Power/Medium Height Tower (MPMT) and Low Power/Low Tower (LPLT) broadcast networks; SFNs; fixed, portable and mobile reception; QoS defined by service providers; standard APIs for easy design and integration of media services in applications in devices.

LTE-based 5G Terrestrial Broadcast could be used to distribute public and commercial linear TV and radio services, encrypted and unencrypted (free-to-air), even public warning alerts [15], to 3GPP compatible devices such as smartphones, smart TVs, or car infotainment systems. It also enables hybrid TV/radio offers by delivering linear broadcast content alongside catch-up and on-demand content, as well as addressable TV services, using the same family of standards. The system can integrate broadcast distribution of linear TV and radio services into existing media applications with 3GPP-defined APIs.

5G Broadcast represents a pragmatic approach to broadcasting based on 3GPP technologies in order to reach fixed, portable and mobile devices [16].

Leveraging the high potential of 5G enhanced mobile broadband connectivity with increased data rates and low latency together with new network features to allocate services within the network, 3GPP is developing different features to address media distribution at scale. This could position 5G networks as an important delivery path, even more so when 5G coverage becomes ubiquitous. Within different tools, a media architecture fully integrated within the 5G system is being developed. This aims at supporting the most recent advancements in terms of media and video content providing augmented quality of service for traditional audio and video services as well as emerging formats for virtual/augmented/mixed reality. The 5G Media Streaming Architecture (5G-MSA) is the state-of-the-art solution which enables different business arrangements between on-line media service providers (e.g. CDN providers), broadcasters, and mobile network operators. With the 5G-MSA, network and device functionalities are exposed to third-party providers enabling the use of 5G capabilities in the best way to ensure increased QoS levels for connected users. The new architecture has been a reality in 3GPP since 5G Release-16.

The 5G-MSA introduces the concept of trusted media functions, which are implemented in both the network and user device and also defines APIs to interface with external media servers and functions. This effectively means that functions commonly deployed outside the network domain can be integrated within it. ABR encoders, streaming manifest generators, segment packagers, CDN servers and caches, DRM servers, content servers for advertisement replacement, manifest modifications servers, or even metrics servers can now be allocated within the 5G network to improve the service delivery. For instance, metrics collection and reporting may provide information related to the user experience, streaming sessions can be monitored on the user device and reported back to the service provider or even to the network, where the relevant information may be used for potential transport optimization within the mobile network.

This opens the door to use 5G not just as a better 4G network, but most importantly as an option shaped to cover future needs for media distribution and help resolve many of the problems that IP distribution via mobile networks is currently facing.

Multicast capabilities may also play a role in 5G as a network off-loading mechanism in mobile networks [17]. This feature may address the need to make content distribution scale according to demand, therefore providing sustainable quality of experience for content consumed by massive audiences.

3GPP has introduced multicast capabilities for the 5G system architecture in Release 17 [18], initially targeting an architecture to fulfil requirements associated to IoT, Public Safety, V2X or IPTV, among others. This work also covers the radio access network (RAN), which should involve the possibility to use multicast and broadcast at cell level or between a small group of cells. In this way, the 5G network may be able to select the most appropriate delivery mode under different circumstances like concurrent audience demand.

Media production and the transition towards IP and Cloud

Media production and contribution workflows are increasingly moving towards IP. Actually, not only IP, but full integration of the Internet into workflows, enabling remote and distributed production. 5G may represent an opportunity to obtain enhancements in at least three areas: improved throughput and decreased latency by leveraging the newly-specified radio and core technologies; better flexibility and mobility which reduce the need of wires; and increased reliability in third party networks thanks to security and integrity features. Overall, 5G may enable simple connectivity workflows for newsgathering or single-camera contribution to more complex environments such as large live events.

The use of Non-Public Networks (NPN) in both its flavors: Stand-alone NPN (SNPN) or Public-Network Integrated NPN (PNI-NPN) is also envisaged. An SNPN is an isolated network whose radio access network (RAN) and core network functions and services do not rely on a public mobile network. SNPNs may be deployed as fixed or nomadic networks, managed either by the entity making use of the NPN or a third party. They have full control and management capabilities of the network functions and services provided by the SNPN. With the appropriate service-level agreements, NPNs be can deployed in collaboration with existing 5G network operators (PNI-NPN) with similar characteristics and functionalities, which may be an option depending on the type and scope of the production events, preferred business models and regulatory options.

For media organizations, SNPNs can support specific media production and contribution requirements that may not be met by public mobile networks, which usually target general public usage. An SNPN, as defined in 3GPP, has its own dedicated NPN ID and can host specific vertical industry devices (e.g. PSME equipment). All network functions are deployed inside the SNPN and are isolated from public networks. This setup does not exclude the possibility of accessing public services through a firewall or establishing roaming agreements with public network operators if required.

Such SNPNs will offer several advantages for the operators of live or special events. The operator has full control of QoS in the network and involves the configuration of key parameters like e.g. latency, throughput, reliability, and real-time monitoring. In addition, an SNPN provides isolation from other networks and the operator can control relevant parameters including device subscription data. All operation and management data is internal to the SNPN. The operator basically becomes a Mobile Network Operator with the capability to control all aspects of its own network. Dedicated spectrum outside of traditional mobile spectrum bands can also be made available.

Important applications for SNPN are on-site production and venues. Live events usually take place in theatres, concert halls, stadiums, or production studios, and can be outdoors or indoors. 5G wireless connectivity provided by an SNPN at the venue would allow wireless production equipment required to capture and produce an event to be connected on-site within a local network. Connectivity would be limited to the event area and under the full control of the media organization, with all audio and video processing done in real-time during operation. Different wireless video and audio sources and devices, such as cameras, microphones, in-ear monitoring (IEM) systems, lighting, etc., can be automatically and quickly provisioned through the network and are locally addressable. Content can be captured at the highest quality possible while ensuring its integrity and robustness. With high quality and extremely reliable radio links, tolerance of QoS impairments is very low. Audio/video streams are ingested or received into and out of the SNPN with 5G links that replace legacy OFDM technologies. It is also possible to provision computing capabilities on-site for processing, and Internet access to enable, for example, remote control.

Support for NPNs is a key enabler for the deployment of media production scenarios. NPNs are currently under standardization in 3GPP, with the first functionalities specified in Release 16. NPNs offer the possibility of providing 5G network services to organizations without entirely relying on public mobile networks. The latter may not yet be able to support certain applications, for example, those requiring very low latency, highly robust services or business-critical data privacy – since such requirements are not the primary business focus of public mobile network operators today.

Ad-hoc coverage service areas providing connectivity for media and Program Making and Special Events (PMSE) equipment may facilitate on-site control, interaction and remote access with the guarantees of security and integrity of the media flows. NPNs configured to create local area networks may reduce latency and enable interconnectivity among PMSE equipment. Applied to newsgathering, NPNs may increase the reliability of public networks and, where sufficient coverage and capacity are available, even reduce dependence on current cellular bonding solutions.

In 2019, the IEEE Transactions on Broadcasting published a special issue on *5G for Broadband Multimedia Systems and Broadcasting* [6], where some papers dealt with the use and optimization of 5G for emerging multimedia applications and services, and some other papers focused on the use of 5G for multicast/broadcast services. In 2020, a special issue on *Convergence of Broadcast and Broadband in the 5G Era* was published [19], with proposals, implementations, evaluations, and breakthroughs on broadcast and broadband convergence systems or the benefits of broadband connectivity on media services. Most of the papers of the previous two special issues are still of interest today. For example, readers interested in the media distribution part of 5G, and in particular the future extension of 5G NR and the 5GC to support terrestrial broadcast services are encouraged to look at [20], [21], [22], [23]. Readers interested on the broadcast-broadband convergence topic in 5G are referred to papers [24], [25], [26], [27]. Since then, other articles published target topics of very much traction lately. For example, researchers interested in innovative 5G solutions involving machine learning are advised to read articles [28], [29], [30], [31] and those interested in solutions targeting the latest media formats papers [16], [33], [34]. Other papers in broadcasting-related areas of focus include [35], [36], [37].

This Special Issue presents 11 papers on the use of 5G for media production, contribution and distribution. These papers are briefly introduced next and the audience is warmly invited to read them. The editors of this Special Issue would like to thank all the authors and reviewers for their contributions which helped make this special issue happen and wish you all have a pleasant reading.

Article [37], by A. Rico-Alvariño *et al*., provides a summary of media distribution in 5G Systems. Particular focus are the recent Release-17 activities including extensions to 5G Media Streaming and LTE-based 5G Broadcast as well as newly introduced 5G Multicast–Broadcast Services (5MBS). Radio, systems as well as user service/application aspects are covered.

Paper [38] by P. Perez *et al*., describes a field trial of live Free-Viewpoint Video production and delivery over 5G mmWave Radio Access Networks. The trial involved successful uplink video traffic and support by edge computing to process video with minimum latency and end-to-end slicing to deploy the production pipeline nation-wide with QoS guarantees.

Article [39], P. Qian *et al*., presents a 5G edge computing framework for enabling remote production in live holographic teleportation applications in order to offload complex real-time content production functions from end user premises. We comprehensively evaluated how network-oriented and application-oriented factors may impact on the performances of remote production operations in 5G environments.

Paper [40], by J. Serrano *et al*., introduces a multi-site gaming streaming use case implemented over an end-to-end 5G-enabled platform, across two different sites. It also describes in detail the scenarios that provide QoE-related metrics data and presents the results obtained.

Paper [41], by L. Richter and U. Reimers, presents an extension of the 5G NR specification that enables the broadcast of services via HTHP infrastructure. The proposed system is more efficient and flexible than its LTE-based predecessors. The solution is implemented in a software defined radio framework and tested in a real-world field trial.

Paper [42], by T. Shitomi *et al.*, introduces a specification for NR-based 5G terrestrial broadcasting for a 6 MHz-channel raster, which is used in current Digital Terrestrial Television Broadcasting (DTTB). This effort is part of the work towards the development of a future terrestrial broadcast system in a 5G-Advanced context. The paper presents results of spectral efficiency which is evaluated in physical layer simulations and compared with those obtained from a second-generation DTTB system in a fixed-rooftop reception scenario.

Article [43], by S. Ahn *et al.*, proposes an interesting idea of convergence by bridging 5G and non-3GPP broadcasting systems. In particular convergence between ATSC 3.0 and 5G Broadcast and broadcast-unicast convergence are addressed in parallel. Standard-compliant co-transmission methods are first proposed to enable time-sharing between 5G Broadcast and ATSC 3.0, and several application systems are built to show the service opportunities enabled by dual connectivity of broadcasting and 5G unicast.

Paper [44], by H. Wang *et al.*, describes an end-to-end latency model for live video generated in real time. The authors primarily focus on processing procedures, whose latency is becoming the principal factor of interest. The developed model can work on different codec methods, diverse hardware, and in various scenarios, and has the potential of significantly increasing the ratio of the time during which the latency can satisfy the given tolerance at a low cost.

The work in [45], by J. Zhiqian *et al.*, presents a tile-based panoramic video quality assessment method to optimize the transmission strategy for tile-based streaming. The method performs planar tile conversion to a spheric format and a computes a score using an objective metric to assess tile quality. Additionally, considering the impact of quality fluctuations, a tile quality loss model is established from the encoding parameter, viewport position and video content.

Article [46], by X. Ji *et al.*, focuses on emerging cloud and edge computation for immersive media production and advocates the adoption of a distributed computing framework. It takes the MPEG-Network Based Media Processing (MPEG-NBMP) architecture as an example, introduces its basic components and workflows, and presents related application instances to promote the standardization and deployment of distributed computing in 5G and beyond era.

Paper [47], by L. Zhong *et al.*, proposes an innovative solution for energy-aware multipath scheduling of remote 5G media services. The work models multipath scheduling as a Q-learning procedure and employs a novel quantum clustering approach for Q-table discretization. The solution employs the MPEG-DASH protocol and considers energy consumption in its decision making and achieves low energy consumption and reduced latency.

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