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5G FOR PROFESSIONAL MEDIA PRODUCTION AND CONTRIBUTION

TECHNICAL REPORT

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Abstract

The use of radio services in production is widespread, from microphones to cameras radio links have become critical to providing coverage of events. Often these services use different technologies and spectrum to deliver a high-quality bespoke solution that supports the complex use cases involved in programme making and special events (PMSE). Production technologies are also generally moving to IP supported workflows and radio links need to be updated to support these workflows.

The performance characteristics of existing IP based radio systems have never fully met the professional production requirements. On mobile networks, latency, quality and power consumption all play against a wholesale transition and these factors need to be rectified before the end users can adopt 5G into their workflows. Conventional PMSE solution will continue to be important and the existing spectrum allocations for PMSE activities will need to continue for many years to come.

The scope of this document is to explore the possibilities provided by 5G rather than other forms of wireless solution.

There are many use cases in a production environment that may incorporate 5G in the workflow over time. Some are a natural evolution of existing 4G applications, some will enhance or replace other forms of contribution such as ISDN, microwave and satellite links and some will be completely new ways of creating and delivering content. As a key connectivity enabler alongside WiFi[1] and fibre 5G improves on existing technologies by adding in more reliability, flexibility and mobility. Additionally, 5G fits well with the process of adoption of IP-based workflows, cloud-based and distributed production.

There will be a variety of different 5G deployments models that will be used dependent on the type and scale of production. For a single camera news or radio contribution the public networks will be adequate to move content around. Where sufficient 5G coverage and capacity are available, newsgathering and similar workflows could migrate from bonded LTE solutions to a single 5G connection.

A more complex environment such as larger live events may better be served by non-public networks (NPN) that are more capable and robust. These can be tailored to the service requirements and offer guaranteed quality of service. NPNs can be deployed in isolation - where all infrastructure is physically separate form public networks - or in conjunction with public networks.

For large sport and cultural events 5G will also provide new methods of capturing content. This may include low-latency radio cameras with extremely high mobility and quality requirements.

5G is one of the enablers that can support low cost remote or distributed production. For example, if unmanned cameras are deployed in a political chamber to provide an automated feed of a meeting or in a small cultural venue to cover an arts event, then 5G might provide reliable connection for the cameras and microphones to the data centres where applications such as live mixing or content pre-selection may occur.

In many cases media productions are done on an ad-hoc basis. This often requires the short-term deployment of equipment at multiple locations.

[1] In particular, WiFi 6 (802.11ax) and WiFi 6E (802.11ay).

It is therefore very desirable to have different network deployment options available to support production.

The data flow on these networks is primarily in the uplink direction, while many IP radio networks are primarily designed or regulated for large downlink traffic. These factors, coupled with the need for very high quality of service, mean that services currently deployed by the mobile industry offer only limited potential for professional content production. Network slicing of public networks could also offer benefits but the operational and business models to support slicing have yet to emerge.

Spectrum availability remains essential for conventional wireless production equipment as well as for 5G-based solutions. However, the way spectrum is currently allocated for mobile services means that access is provided on a long-term basis (e.g. several years) in specific locations (e.g. a factory or studio) but there are limited suitable options for temporary deployments. In contrast, PMSE spectrum can often be allocated over short periods of time for specific locations.

It should also be noted that there will always need to be a trade-off between the achievable bandwidth, coverage and reach, mobility and signal penetration. While some frequencies will support high bandwidth applications, they are limited in their reach. Other frequencies that have better range and penetration may not provide the bandwidth benefits. The move to IP for transport of these signals may go some way to mitigate the bandwidth/coverage compromise through a combination of compression and multiplexing of different signals to achieve suitable bandwidths for a given frequency range.

Locally, 5G cannot compete with fibre in terms of performance but may do so on the cost of deployment for short term use. Over greater distances, the cost of fibre media links, largely driven by large sporting events, are excessive. There is therefore an opportunity for MNOs to carry compressed media signals in public networks in a cost-effective manner and for the producers to operate 5G NPNs for local operations.

5G represents an opportunity and challenges for the content creation industry. 5G offers much in terms of bandwidth, reduced latency, timing and quality of service. It is expected that standardised 5G-based solutions would bring down the costs and increase the flexibility of production. To this end, several challenges need to be addressed and these can be broken down into four key areas: standardisation, technology availability, regulation, and business models.

While the mobile telecom standards bodies are open to a number of industries (known as 'verticals') proposing use cases and requirements, the commercial environment is still dominated by MNOs who seek to profit from their services which are tuned for the consumer market but currently don't offer viable or flexible models suitable for the media production industry.

Large-scale public networks are traditionally built by MNOs using equipment supplied by a small number of Tier 1 vendors focusing on the global mobile telecommunications market. This focus means potential customers for smaller-scale, non-public networks are not prioritised. Nevertheless, there is a number of new approaches and initiatives associated with 5G such as network function virtualisation (NFV), software defined networks (SDN), software defined radio (SRD), and open radio access networks (O-RAN) aiming to enable vendor-neutral solutions based on general purpose hardware and software, that is, an alternative to Tier 1 lock-in. The combination of these initiatives results in greater flexibility for MNOs, who are free to integrate best of breed components from multiple suppliers and benefit from reduced equipment costs.

These initiatives also make NPNs easier to implement and more affordable. The ability to implement only the functions required greatly reduces the complexity of deployments and makes it possible to integrate 5G solutions in existing capabilities and workflows.

5G may reduce the barrier of entry for a number of these solutions and the technology has been developed to support them but there is a gap in the operational and business models that support them. Therefore, self-provision of services, in the way currently done with conventional wireless production equipment, needs to be a viable option. Broadcasters and producers need to have access to services and deploy them in a cost-effective manner and be allowed to exercise their own expertise rather than being limited to solutions delivered by an MNO. Regulatory conditions for such deployments need to be defined.

This also means that the media production industry needs to engage with a range of stakeholders to make sure that their requirements are adequately taken into consideration. Without their engagement the mobile industry will not automatically deliver a system that suits the needs of the media industry.

Continuing engagement is required at several levels, in particular:

- with standards bodies;
- with national and international regulatory bodies;
- with national and international 5G initiatives;
- collaboration within the content production sector, including PMSE[2] equipment manufacturers;
- alignment of requirements between PMSE industry and other sectors, i.e. work together to give manufacturers and service providers a clear picture of the market;
- tests and trials to demonstrate the capabilities of 5G, this will educate production teams on how 5G can enhance their workflows;
- development of production workflows integrating 5G technology;
- commercial and operational models for the deployment of NPNs;
- commercial and operational models for network slicing, including across multiple suppliers.

These initiatives are underway in several territories. This needs to continue to deliver the full potential of 5G in the professional media production sector.

In summary, connectivity solutions including 5G are constantly evolving and will offer significant benefits to production workflows. The success of 5G technology in the media production sector will depend on its ability to fit into existing workflows and satisfy the technical, operational, and commercial requirements in content production, and the availability of the equipment. At the time of writing, there is no guarantee that 5G technology will ever fully meet some of the more demanding requirements of the media production industry.

The 5G roll-out is a gradual evolution and will take time to achieve the capabilities promised by the marketing hype, if it ever does. The media industry is engaging well with the standards bodies and regulatory bodies. Innovative ways of using the radio spectrum, improved compression techniques and always-on connectivity will change how the professional production industry works in the future, but only if it continues to engage at all levels and works together to ensure that technology, regulation and business models can support future workflows.

[2] Programme Making and Special Events (PMSE) - see the definition in § 2.1.

This report is a result of collaboration between stakeholders in the media sector, including public and commercial broadcasters, broadcast and telecom network operators, equipment manufacturers, and technology providers.

The views presented in the report do not necessarily reflect a formal position of the EBU or any of the contributing parties.

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List of Acronyms and Abbreviations

The following acronyms and abbreviations are used in this report.

Term	Definition
2G	The 2nd Generation of mobile telecommunications systems (also known as GSM)
3GPP	3rd Generation Partnership Project - a global standardisation organisation for mobile technologies including 5G; www.3gpp.org
4G	The 4th Generation of mobile telecommunications systems (also known as LTE)
5G	The 5th Generation of mobile communications systems
5GC	5G Core network
5G NR	5G New Radio
5G-MAG	5G Media Action Group, www.5g-mag.com
ADSL	Asymmetric Digital Subscriber Line
AI	Artificial Intelligence
AR	Augmented Reality
AV	Audio-Visual
B2B	Business to business
B2C	Business to consumer
CBRS	Citizen Broadband Radio Service
CEPT	European Conference of Postal and Telecommunications Administrations
DECT	Digital Enhanced Cordless Telecommunications
DIT	Digital Imaging Technician
DoP	Director of Photography
DV	Digital Video
ECC	Electronic Communications Committee of CEPT
EU	European Union
eMBB	enhanced Mobile Broadband
FTTH	Fibre to the Home
GPS	Global Positioning System
GPU	Graphics Processing Unit
HEVC	High Efficiency Video Coding

IEM	In-ear Monitor
IMEI	International Mobile Equipment Identity
IP	Internet Protocol
ISDN	Integrated Services Digital Network
KPI	Key Performance Indicator
LSA	License Shared Access
LTE	Long-Term Evolution, the 4th generation mobile telecommunications system
MEC	Mult-access Edge Computing
MIMO	Multiple Input Multiple Output
mMTC	massive Machine-Type Communications
MNO	Mobile Network Operator
MWC	Mobile World Congress
NaaS	Network as a Service
NDI	Network Digital Interface
Network slice	Virtual network that provides adequate communication resources for a specific user group
NMOS	Networked Media Open Specifications by AWMA, www.amwa.tv
NPN	Non-Public 5G network
NRA	National Regulatory Authority
NVF	Network Function Virtualisation
OB	Outside Broadcast
O-RAN	Open Radio Access Networks
PLMN	Public Land Mobile Network
PMSE	Programme Making and Special Events
PNI-NPN	Public network integrated NPN
PTP	Precision Time Protocol
QoS	Quality of Service
RAN	Radio Access Network
RTP	Real-time Transport Protocol
RRS	Reconfigurable Radio Systems
SDI	Serial Digital Interface
SDN	Software Defined Networks
SDR	Software Defined Radio
SNPN	Standalone Non-public Network
SIM	Subscriber Identity Module
SNPN	Standalone Non-public Network
SMPTE	Society of Motion Picture and Television Engineers, smpte.org
TR xx.xxx	3GPP Technical Report xx.xxx
TS xx.xxx	3GPP Technical Specification xx.xxx
UAV	Unmanned Aerial Vehicle
UAS	Unmanned Aerial Systems

UGC	User-generated Content
UHD	Ultra-high Definition
UPF	User Plane Function
URLLC	Ultra-reliable and Low latency Communications
VC-2	Low-latency Video codec
VFX	Visual Effects
VoLTE	Voice over LTE
VR	Virtual Reality

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5G for Professional Media Production and Contribution

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1. Introduction

5G is a collection of mobile communications technologies, currently at an advanced stage of standardisation, pre-commercial trials, and early commercial deployments. 5G aims at a seamless integration of different kinds of applications and services, including new use cases around end user industries, known as verticals, in one single ecosystem.

Technical performance capabilities of 5G are expected to be superior to those of the earlier generations of mobile systems. Improvements over earlier generations are characterised by:

- Greatly improved mobile broadband connectivity providing users with much greater throughput [3]
- The ability to define reliable, predictable end-to-end mobile network services with very low latency[4]
- A step change in the number of devices able to connect to the network, supporting the Internet of Things[5]
- Improved service availability in densely populated places.[6]

Characteristics such as very high throughput, low latency and high reliability have the potential to improve the way audiovisual media content is produced, distributed, and consumed. The 5G system, and in particular its new radio access technology (5G New Radio) has target key performance indicators as mentioned in footnotes 2 - 5 below. Performance in real-life deployments will depend on real-world implementations and configurations.

Furthermore, 5G comes with several deployment options including public mobile[7] and non-public[8] networks and can be combined with emerging technologies such as multi-access edge computing[9].

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[3] Known as enhanced Mobile Broadband, or eMBB. Bandwidth is provided on a best effort basis. Theoretical maximum throughput values are 10 Gbit/s uplink and 20 Gbit/s downlink.

[4] Known as Ultra Reliable Low Latency Communications, or URLLC, with theoretical minimum end-to-end (one way) latency <1 ms.

[5] 'Internet of Things' is often abbreviated as IoT, and sometimes as IIoT for 'Industrial Internet of Things'

[6] Known as massive Machine-Type Communications, or mMTC, with theoretical maximum density of 10^6 connections/km^2

[7] Also known as Public Land Mobile Network or PLMN, this deployment model is associated with Mobile Network Operators (MNOs). It involves connecting their subscribers' User Equipment (UE) to a Radio Access Network (RAN) in spectrum licensed from the regulator. Typically, a public network will operate nationally.

[8] Non-Public Networks (NPN) 5G networks are intended to be used solely by the organization operating the network. Typically, an NPN RAN will operate over a limited geographic area.

All these characteristics make 5G a good candidate for use in IP-based content production and contribution applications.

The large variety of audio and video applications potentially cover a wide range of 5G scenarios, settings and requirements. However, current versions of 5G[10] can meet only a limited set of requirements for media production. These are mainly in newsgathering and less demanding contribution use cases. To realise the potential of 5G to support more demanding content production use cases and complex workflows, further development and standardisation will be required. Some might be technically possible with upcoming 5G standards releases[11] , other applications will need a much longer development time.

Current work in 3GPP aims to define technical and operational requirements in professional content production and contribution to be accommodated in technical specifications. The process started in 2018 with the *Feasibility Study on Audio-Visual Service Production (AV_PROD)* [1], which resulted in a Technical Report TR 22.827 *Study on Audio-Visual Service Production* [2], which describes relevant use-cases together with their respective technical and operational requirements. The study also identified those technical requirements that 5G must meet to support the described production and contribution use cases. Although the normative work in 3GPP continues there are no guarantees that all AV_PROD requirements will be included in final specifications.

Furthermore, while some of these requirements will be considered in 3GPP Release 17 the work on other requirements is likely to span several future releases.

Therefore, improvements in the capability of the 3GPP 5G system will become available gradually, provided that the media industry remains engaged. Nevertheless, it is not certain that all proposed and standardised features will be implemented in chipsets and devices as this will be largely driven by their commercial viability and the perceived market potential. Other aspects such as regulation, spectrum, and availability of suitable equipment will also be required. These issues are being addressed in industry groups such as 5G-MAG and in the appropriate EBU groups.

As any new relevant technology emerges, areas of the production chain will take advantage of the lower costs and more ubiquitous availability of this new technology. This happened in the past with digital video (DV) cameras and the emergence of ever-improving camera phones and the use of bonded cellular as a contribution mainstay for news. It is therefore expected that 5G will have a significant impact on the way content is produced. In a similar way to the move from bespoke baseband signal (SDI) video environments to a common technology base using IP, it can be expected to see specialist use of IP-based radio links becoming less common and the increased adoption of commodity solutions.

To achieve this 5G will need to provide benefits to the audio-visual production industry that can justify a migration from conventional approaches. Furthermore, 5G will compete with alternative technologies such as conventional radio solutions which continue to develop.

The primary aim of this document is to identify those non-technical issues, such as spectrum availability and business and operational models and propose, where possible, how they could be

[9] Multi-access Edge Computing is often abbreviated as MEC

[10] As per 3GPP Release 16

[11] 3GPP - The 3rd Generation Partnership Project is a global organisation that develops technical specifications for mobile communications technologies including 5G (www.3gpp.org). When this report was written the most recent release is Release 16 which was completed in June 2020. The work on Release 17 and early discussions are taking place about the scope of Release 18.

addressed. It is intended for the professionals in the media industry that are concerned with content production.

2. State-of-the-art - current issues in content production

Reliable and flexible connectivity is essential for live broadcast, content production and contribution. Wireless communications are increasingly important as they allow for greater artistic freedom, more agility, increased safety, and reduced costs.

In this section the current state of audio-visual content production is considered that relies on wireless communications.

2.1 Programme making and special events (PMSE)

'Programme Making and Special Events (PMSE) describes radio applications used for broadcasting, newsgathering, theatrical productions and special events, and applications used in meetings, conferences, cultural and education activities, trade fairs, local entertainment, sport, religious and other public or private events for perceived real-time presentation of audio-visual information[12]' [3].

Wireless PMSE applications[13] fall into three broad categories:

- audio links, e.g. wireless microphones, in-ear monitors, talk-back systems
- video links, e.g. wireless cameras
- service links, e.g. telemetry and remote control, effects control

In professional content production PMSE equipment is assessed on its ease of use, cost and the capabilities of the device.

PMSE equipment is used in a variety of situations. Consequently, quality, capacity, and reliability requirements in PMSE applications can vary depending on the application; for example, compressed video frequently used in news contribution is accepted at lower a quality and bandwidth than a high-value live UHD production. The means of guaranteeing the required level of reliability, such as dual signal paths, are balanced against cost.

Content producers are particularly concerned with acquiring the source of the content with as much detail as possible (i.e. requiring least compression and highest bit-rate audio and video), as this determines the highest quality level that can be achieved later in the production chain. Other concerns include the setup time required before the production (which should be as short as possible), flexibility and reliability.

While state-of-the art PMSE equipment uses proprietary technologies and dedicated spectrum this may require specialist know-how to deploy, which broadcasters may self-provide or outsource. Certain cost-sensitive audio PMSE applications have been realized using standardized wireless technologies (e.g. DECT, Bluetooth, WiFi). They allow for sufficiently high QoS and acceptable link latency and may include technology-inherent automatic frequency planning and interference management. These solutions are not dependent on any particular commercial model.

[12] Source: *Spectrum use and future requirements for PMSE* - ECC Report 204, 2014 https://www.ecodocdb.dk/download/1f1d1819-5ca2/ECCREP204.PDF.

[13] Typical PMSE use includes theatrical wireless microphone use, wireless camera newsgathering operations and fixed point-to-point microwave links, talk-back systems and in-ear monitors.

2.2 Spectrum for PMSE

Conventional wireless PMSE equipment is purpose-built and requires dedicated access to the radio spectrum. In wireless productions the quality and the setup will depend upon enough clean spectrum being available at a given production location.

While 5G does offer acceptable solutions in some scenarios (e.g. single camera contribution) it is several years away from being able to offer a comparable service to a conventional radio microphone or in ear monitor. Some productions require many parallel services, for instance a large music festival may use up to 300 microphones for a short period of time. For this reason, it is imperative that existing PMSE spectrum is available to service these requirements.

At large events where multiple production teams typically operate adjacent to each other, the available spectrum needs to be shared and, in some cases, individual equipment licensing may be needed on site. However, production teams must have the flexibility to change their PMSE setup quickly, often within seconds, without the need for repeated frequency co-ordination.

The number of events that are broadcast has increased steadily over time and productions are becoming more complex and sophisticated, sometimes including new approaches such as individualized audio mixing capability, immersive 3D recording setups, and different camera angles. These factors have led to an increase in demand for wireless production systems and, consequently, more spectrum or more efficient use of currently available spectrum.

However, the spectrum available for professional content production has been significantly reduced in recent years as the frequencies have been allocated to mobile communications services; a threat that is unlikely to diminish in the foreseeable future. Consequently, media organisations face difficulty in maintaining their current spectrum allocations and sourcing additional spectrum when and where needed. Therefore, regulators need to ensure that a specific amount of suitable spectrum is retained for professional content production in the longer term.

In this matter, different regulators have different views. In some countries, in CEPT and at an EU level, efforts are being made to find alternative spectrum for PMSE. While this is a move in the right direction, both equipment manufacturers and users need a long-term certainty to invest in the equipment capable of operating in the new frequency bands.

In most frequency bands PMSE are a secondary service which means that access to spectrum is provided on a non-interference non-protection basis. Frequency ranges for PMSE applications are listed in the ERC Recommendation 25-10 [15].

Further information on the related regulatory issues in Europe is provided by CEPT/ECC.[4]

2.3 Complexity and costs

Use of wireless equipment can add considerable complexity and cost to the production scenarios.

Complex productions such as large sporting and cultural events require planning and often involve long, detailed preparations and set-up, particularly where no suitable communications infrastructure is readily available (e.g. Tour de France, Glastonbury Festival, Eurovision Song Contest). This complexity results in high production costs and limited flexibility.

In some scenarios cost-effective solutions that provide adequate quality are preferred over technically superior alternatives. An example is the use of LTE in newsgathering operations where a journalist equipped with a smartphone may be doing a job that previously required a crew and specialised equipment.

2.4 Transition to IP-based production workflows

The production technology industry is going through a huge amount of change at present. For nearly a century they have designed, specified and built technology to support high quality, high bandwidth content production. There have been countless milestones in technology starting from the original analogue audio and video signals. Through the introduction of colour and later the digitisation of audio and video, media organisations have innovated and driven change, and have built specialist knowledge in creating technically high-quality content.

Over the last 30 years the development of the Internet and the proliferation of the use of the IP-protocol have revolutionised daily life and changed everything from e-mails to social interaction and media. In the same time frame, the ways in which content is created have been undergoing a constant evolution, built on specialist equipment, connectivity and workflows.

Nevertheless, over the last 10 years there has been a shift away from static workflows based on specialist, dedicated broadcast equipment towards IP workflows that are based on commoditised, multi-tenanted software solutions, which are more cost-effective and which allow greater flexibility. This shift has brought profound changes to the ways that content is produced, processed and stored, and it is an area where many developments are currently taking place.

Several IP-based workflows are currently emerging, ranging from high-end, uncompressed UHD video production supported by the SMPTE ST 2110 video standard [5] to lower-cost IP solutions such as the Network Digital Interface (NDI) protocols on smaller scale deployments.

The broadcast industry is finding its way through this change but as can be seen from EBU Tech 3371 [16] there are gaps in capabilities that need to be filled.

In 2020, the COVID-19 situation has challenged many of the existing content production models. A rapid adoption of cloud-based and distributed production techniques has been witnessed. Many broadcasters are looking to adopt these technologies for future ways of working. Short-term implementations to keep productions on air have been successful but will need more robust, integrated workflows if they are to be permanently adopted at scale.

2.5 The evolution of cellular technologies in production

The use of mobile technologies for content contribution, especially newsgathering, is well-established.

There has also been an increase in the use of LTE cellular bonding technologies combining multiple SIM cards to provide higher throughput and more reliable connections, i.e. aggregating the bandwidth from multiple SIM-cards in a 'backpack' with best-effort quality. Whilst these devices have been available for over a decade, it is developments in mobile and fixed broadband that have enabled them to complement traditional broadcast contribution.

Cellular bonding solutions do, however, suffer from several compromises as they require signals to be compressed and they can have a significant latency. While they may be suitable for a single-source contribution, it is more complex to deploy multiple remote sources that may require specialist on-location infrastructure. Another issue is that of access to sufficient network capacity in congested areas, which prevents cellular bonded technologies being used in high profile, high value productions.

Uplink capacity has significantly increased in fixed broadband (with the move from ADSL to FTTH) and improvements in mobile broadband throughput going from sub-megabit to tens of megabits per second mean both broadband options are a practical and cost-effective alternative to some satellite and microwave links in applications such as newsgathering and grass-root sports. These technologies have increased broadcasters' ability to go live without the need of specialist connectivity for radio and television. Their use is still largely limited to single-source contribution due to relatively long latency experienced and the challenges in source synchronisation.

Another area that has seen significant growth is the area of mobile journalism. Not so long ago a TV journalist would be teamed with specialist camera, sound and edit staff to tell a story. The advent of smartphones with audiovisual capture capabilities and software tools to craft a story has changed how many newsrooms operate. In recent years, the combination of high-quality video from small devices paired with cheap, always-on connectivity means that it is possible to instantly go live from practically anywhere, without the need to wait for resources. This has also led to a growth in 'citizen journalism' both in mainstream outlets and on social media platforms.

3. Vision - the potential of 5G for professional content production

The adoption of 3GPP 5G technology for professional content production will depend on its ability to satisfy the technical, operational, and commercial requirements and on the availability of equipment. As an example, live audio production is one of the PMSE applications with the most stringent latency requirements and it is currently served with specialised PMSE equipment.

5G New Radio (5G NR) may be able to satisfy live audio production requirements with ultra-reliable low latency communication (URLLC) profiles. However, currently available 5G systems do not fully meet these requirements. Furthermore, several complex aspects such as technical feasibility, economics and business models and the ability to monetize audiovisual content production use cases at scale remain sufficiently unclear that investments in chipset technology and deployment rollouts are difficult to justify. 5G may not be the only solution and other technologies such as PMSE-specific technologies, Bluetooth, DECT, or WiFi may also find their place in production.

Nevertheless, as media companies move to IP there is a desire to maintain current digital wireless capabilities that can be integrated into the workflow, and 5G might be able to support these wireless elements. The vision of 5G as an enabler for "convergence and automation of workflows" is worth pursuing. Commercially available 5G chipsets that can meet the corresponding technical and operational requirements will be essential for the manufacturing industry to provide 5G-enabled PMSE equipment.

Integration of PMSE equipment into the 5G ecosystem will take place gradually, as shown in Figure 1.

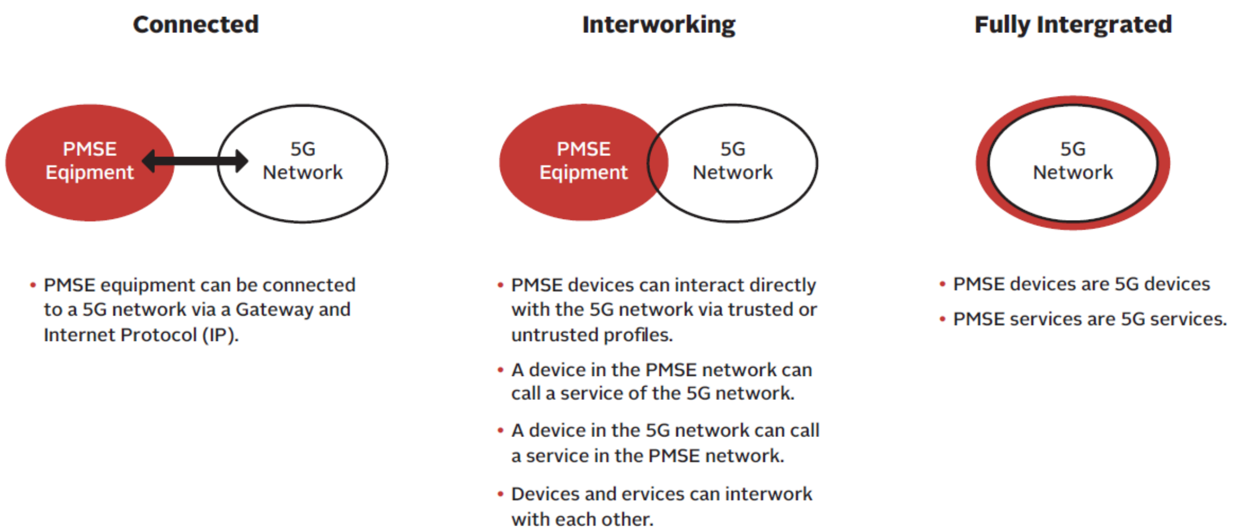


Figure 1: Levels of integration of PMSE equipment into the 5G ecosystem

5G-based PMSE equipment, once available, will also require spectrum to operate, but access to spectrum might be authorised differently than for conventional PMSE. Spectrum for conventional PMSE was licensed either individually for each piece of equipment or through a general authorisation. In the 5G context spectrum access is licensed for a network rather than an individual device. For public 5G networks MNO-owned spectrum will be used. Non-public 5G networks (see § 4.1) for PMSE purposes will require spectrum to be available locally and often on an ad-hoc basis.

New licence models are emerging with regulatory bodies making spectrum available for non-public 5G networks in different bands or allowing the licence of unused MNO-owned spectrum where available [14]. However, the PMSE hardware required to support these frequencies is not yet available. Ideally, the same hardware would be able to operate in both public and non-public 5G networks. Furthermore, the currently considered licence models tend to be focused on a longer time frame i.e. a. minimum of a year. While this may work in a fixed location such as a studio, a venue, or a frequently visited news location, most requirements depend on ad hoc availability of spectrum.

In the long term, wide availability of 5G network slices in public networks and the possibility to set up non-public 5G networks for media production may drive down the cost of remote production and enable more flexible workflows.

Having a technology capable of serving a range of use cases in audio-visual content production, contribution and distribution is attractive in terms of economies of scale and the potential to develop ground-breaking applications, services and business models. As 5G becomes widespread, more growth in this kind of activity is expected with contributions from a range of end users such as the skilled (professional journalists) the semi-skilled (media trained experts) and the general public all having access to new tools and services to contribute live content.

3.1 Use cases that may be supported by 5G

The development of 5G-based solutions for professional content production is still at an early stage. This chapter outlines some of the most important use cases that may be supported by 5G, including both live and non-live workflows as well as remote and distributed production, which bear an important distinction. It is also likely that the first workflows supported by 5G will be light-weight, low cost productions. These make use of semi-professional equipment and over time opportunities will grow to support different types of production.

3.1.1 Newsgathering

Newsgathering is already exploiting mobile network improvements. Simple, fast file transfer enables journalists in the field to access content from multiple locations, download archives or interviews in seconds before uploading packages for news bulletins. However, the potential of 5G suggests that workflows beyond news contribution could be considered.

Planned events could benefit from dedicated connectivity between location and newsroom, operating over of a public network, assuming an avoidance of contention regardless of how busy the location is. At well-attended events, network slices will provide this functionality, removing the need to be tethered to an Outside Broadcast (OB) truck and to rely on dedicated satellite links.

There will also be a rise in ‘distributed production’. The need for large, centralised facilities will reduce as improved connectivity will enable the use of services based in edge compute or cloud environments, enabling journalists, producers and technical staff to access a wider range of systems from anywhere, to reliably and flexibly create higher quality content.

One area that 5G has the potential to facilitate is user generated content (UGC) production. There is a proliferation of high quality audiovisual devices in the population and people are clearly capturing more audio and video than ever before. Aside from newsgathering, where quality, cost and complexity compromises can be made to tell the story, UGC is often seen as difficult to incorporate into professional productions. 5G should be able to reduce these barriers through improved bandwidth and quality of connections as well as through reduced costs and increased speed in sending large files over mobile networks. This should contribute to more widespread use of UGC across a range of both live and pre-recorded productions.

3.1.2 Live video production

Mobile technologies have been adopted for small-scale live events and newsgathering but this is a subset of the overall potential for 5G in a production environment. Since the end of 2019 there has also been a dramatic move to distributed production. This has led to an increase in demand for new forms of connectivity and cloud-based compute.

Both studio and OB workflows are migrating to IP-based solutions and wireless devices currently used in these workflows, such as cameras, microphones, monitoring and reverse video will all require integration. The logical way to do this is through wireless IP, and while some solutions such as WiFi may be available now, they are often limited in their functionality and only offer unmanaged services. 5G will go some way to improve this and, over time, a move to unified radio services should emerge.

Typically, a single AV source contribution is derived from several operations on location. These may be centred around a studio or OB track or around a single camera depending on the scale of the production. In addition to the video signal output it can include a return video feed, camera control, tally light and intercom, amongst others illustrated in Figure 2.

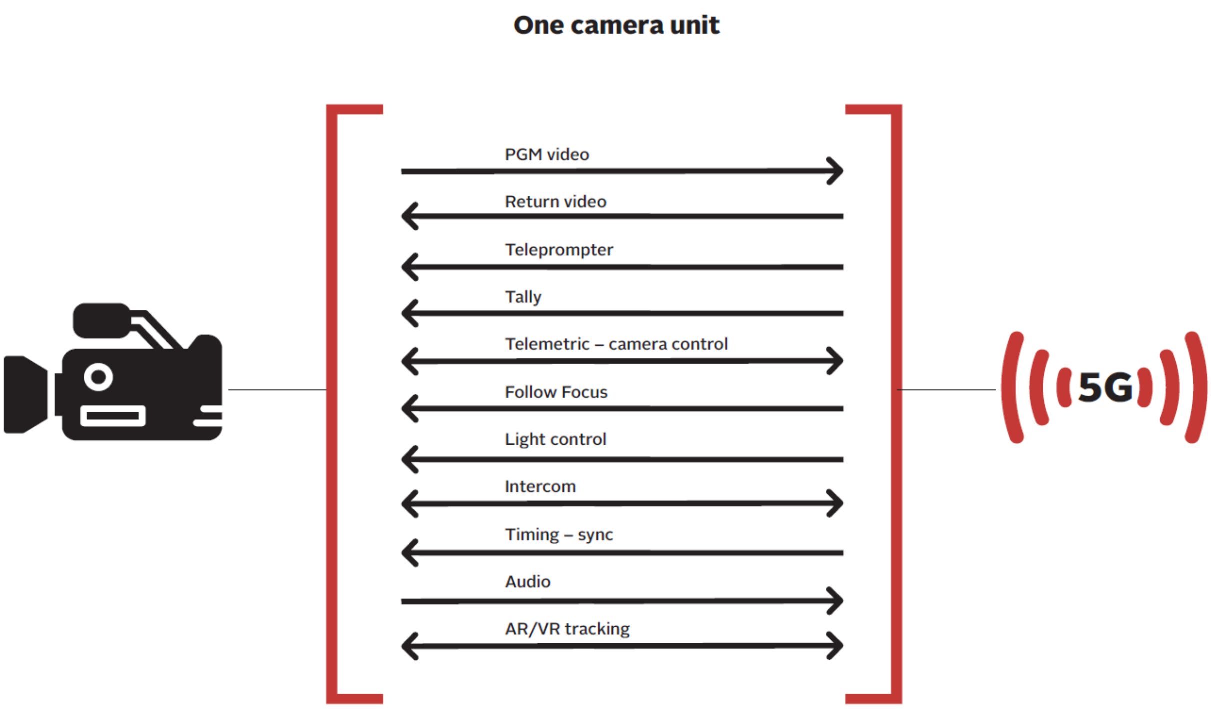


Figure 2: Different signals connected to a camera

The signals have the following characteristics:

Table 1: Characteristics of camera signals

Data	Bandwidth	Direction	Latency	Application
Programme Video	High (>50 Mbit/s)	uplink	Low (<20 ms)	Main video output from camera
Return Video	Medium (5 - 10 Mbit/s)	downlink	low	Reverse video feed for monitoring
Tally	Very low	downlink	low	Red lights on active camera
Telemetrics	low	bi-directional	low	Remote controls for exposure and colour control, possible PTZ
Follow Focus	low	downlink	low	Focus control
Lighting control	low	downlink	low	Control onboard camera lights
Intercom	medium	bi-directional	low	Allows director to talk to camera op. May be two feeds
Timing and sync	low	downlink		Provide timing data to camera to allow for video synchronisation and IP time stamps
Programme Audio	medium	up link	low	Audio from any on board microphones
AR/VR tracking	low	bi-directional	low	Positional data for virtual sets

In a conventional setup these signals may be carried on separate radio links and in different frequency bands. It is hoped that they can all be combined in a single 5G.

Current solutions have evolved to meet the needs of specific applications, as an example, radio mics and reverse video feeds work quite differently. Moving to a single, IP-based radio system that can be deployed as required may mean more efficient use of spectrum provided that a solution can meet the demanding technical requirements of media production.

There are also many different scales of live video production. These can range from social media using a mobile handset, to live contribution using a single camera up to a large multi-camera, high profile event. There is unlikely to be a ‘one size fits all’ solution and different users should be able to choose the right level of service based on their ambition and budget.

As very low latency and high-quality links are necessary for live audio and video production the 5G NR URLLC profile characteristics are required. The number of devices involved in a production may mean that massive machine type communications (mMTC) might also be required.

There is always a trade-off between the quality of the contributed content and how it is transmitted from the production location to the broadcast centre for onward processing.

Uncompressed contribution offers the best audiovisual quality and the lowest latency, but with uncompressed UHD video requiring more than 12 Gbit/s this will be reserved for use cases that require the absolute maximum contribution quality. They will likely involve short hop, point-to-point links within the production environment.

In most cases, audiovisual compression of some sort will be used to provide a balance between quality, speed and available bandwidth.

For use cases such as sports and events that either have a high archive value or that may be used in a more produced workflow, lightweight 'mezzanine' compression that has very high complexity and very low latency will be used to maintain as much quality as possible within the constraints of the network. An example of such a codec is VC2, specified in SMPTE ST 2042 [6].

In other areas such as news contribution, more compressed formats such as HEVC [7] will be appropriate as it will go straight into a programme with little or no further signal processing. Speed is more important that quality in this use case.

3.1.2.1 Single source contribution

When working remotely, producers, journalists and camera crews need to contribute audio, video and other data such as location, script information and still pictures over a link back to a broadcast centre for inclusion in a TV or radio programme.

This content is of a high quality, using professional equipment and ranging in scale from a single camera (see Figure 3) to possibly including larger scale multi-camera Outside Broadcast facilities that nevertheless produce a single signal source as a contribution output (see Figure 4). Both live pictures or pre-recorded and edited segments of content may be implicated.

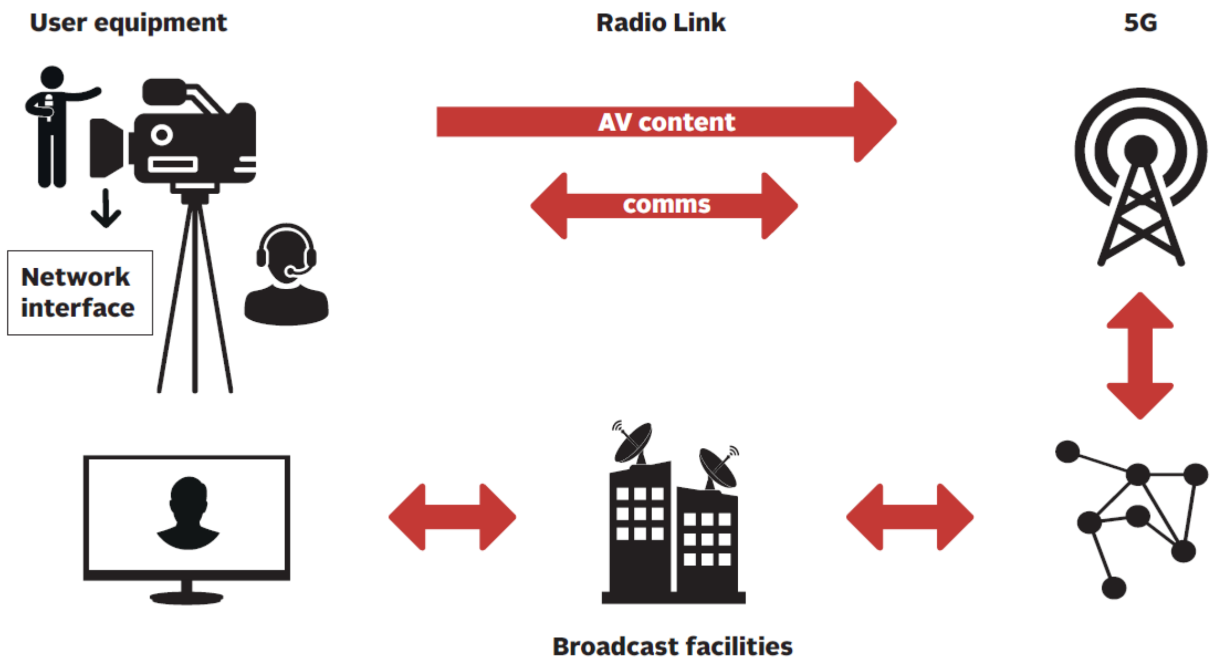


Figure 3: Single AV source contribution use case

Figure 4 illustrates the case where signals from multiple cameras are combined in a single source, possibly in an OB truck, that is sent over a contribution link to the broadcast centre.

One of the key challenges to multi-camera working is timing. Cameras need accurate timing to provide synchronised feeds that can be intercut, and audio requires timing to maintain synchronisation and stereo or 5.1 spacing. The effects of either video or audio devices being out of sync can be very disorientating for the end user.

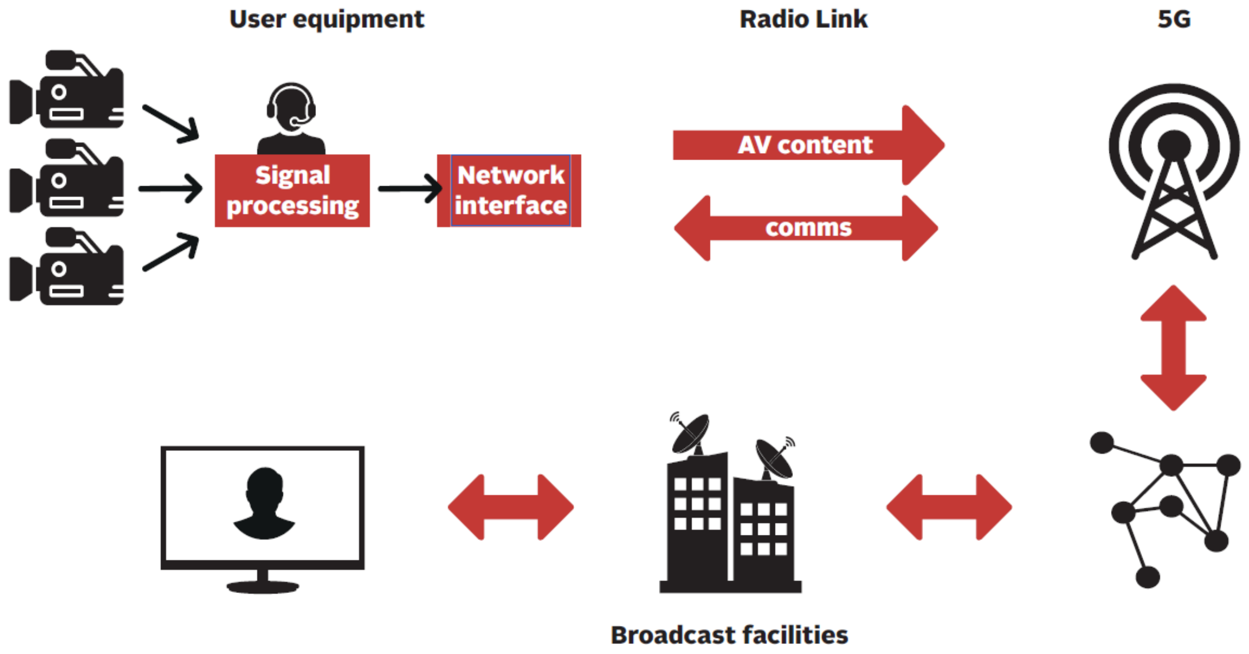


Figure 4: Multiple camera single source contribution use case

In current IP workflows, accurate time stamps are used for the synchronisation of RTP streams. A time source can be derived from GPS and used to provide an accurate clock for these applications, but GPS is usually restricted to outdoor use and must be connected to a master clock somewhere in the network.

A 5G system would ideally distribute this clock to all devices on a network and would make deployment of remote production solutions simpler.

3.1.2.2 Remote large event production

§ 3.1.2 posits that single source contribution is an obvious early candidate for the use of 5G in production. As 5G technology evolves and as production moves even more into IP-based workflows the desire for true 'remote production' will become greater.

Remote production is different from an outside broadcast in that most of the functional operations of the production are carried out away from the location of the event. This has several advantages that include the ability to centralise technology resources and skills and therefore enabling improved utilisation of assets.

For instance, a replay device can be used on several events during a weekend rather than being assigned to a truck on location where it is used for the duration of a single event but otherwise sits unused. Remote production can also significantly reduce staff travel and accommodation costs as well as reducing overall environmental footprints.

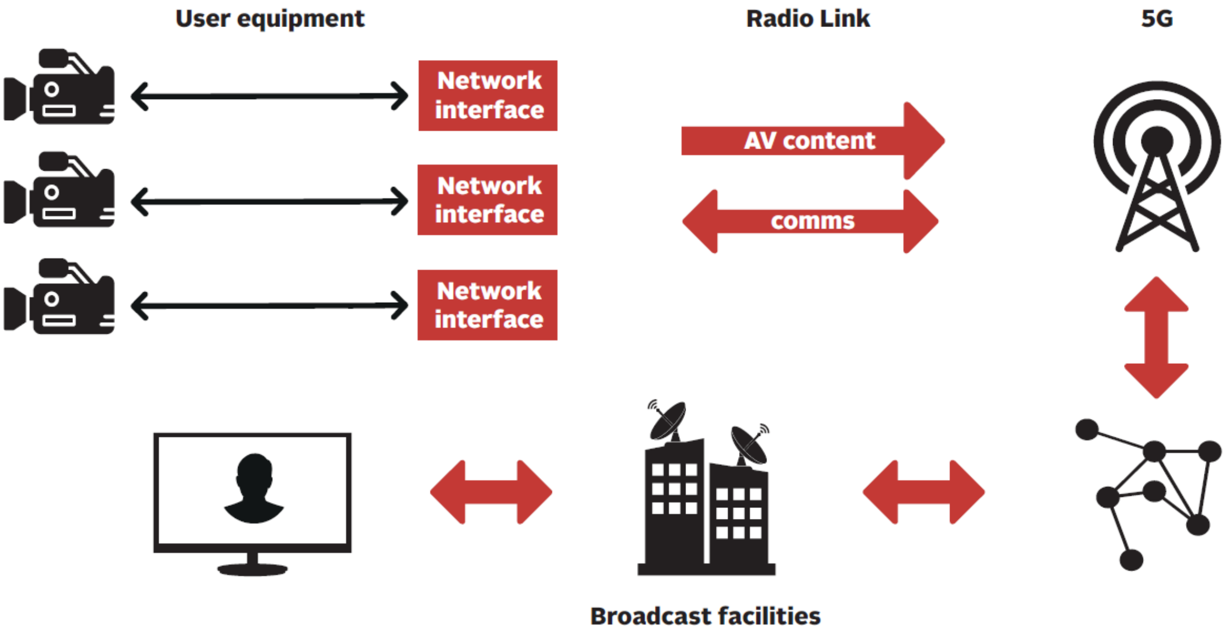


Figure 5: An example of a multi-camera outside broadcast where contributions are independently fed back to a remote production gallery complete with return communications

Furthermore, a de-facto adoption of distributed production can be realised in this scenario. This is facilitated by IP technologies enabling processes to be done in multiple places at the same time. It is no longer necessary to have all your facilities based in a single geographical location. In this way, a director may be in a different building or city to other members of the production team, for instance.

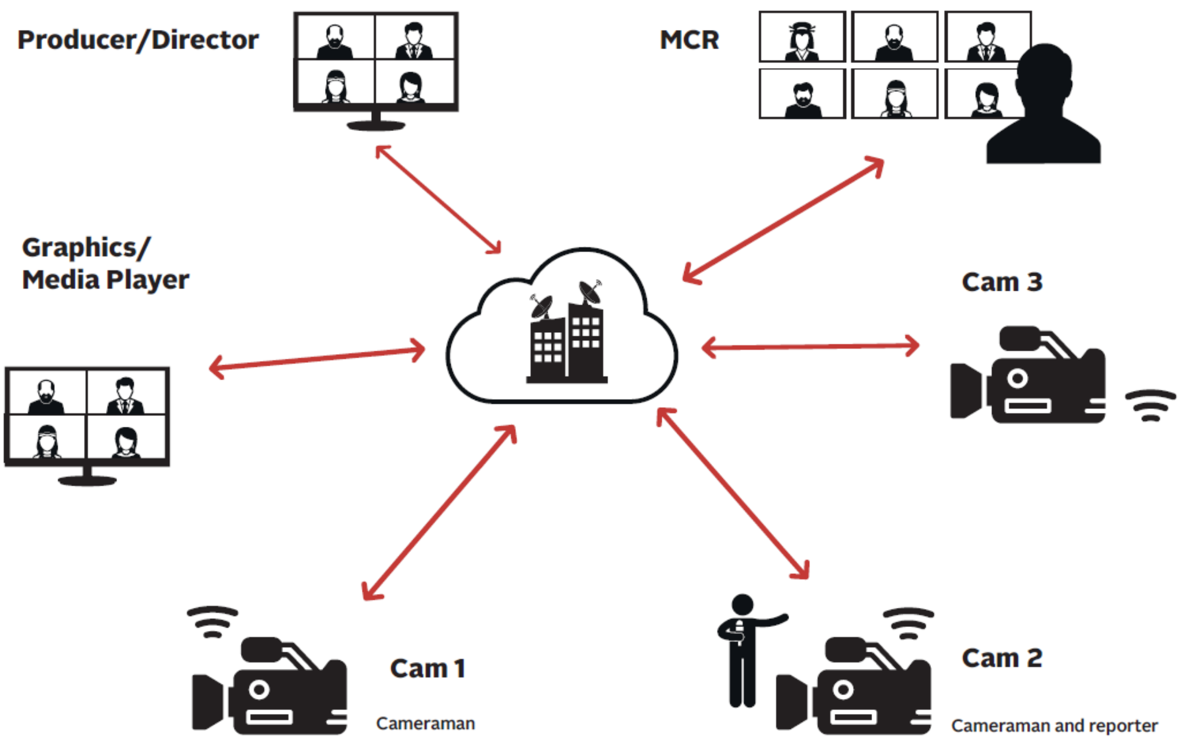


Figure 6: An example of distributed multi-camera production

To make this possible several solutions have been developed over the past few years that rely on IP connectivity. There are various means of operating in this environment, from, e.g., separating control surfaces and interfaces from equipment, to using the cloud to run virtual services.

The common factor in all these remote workflows is connectivity. Typically, a solution will require dedicated bandwidth of known latency that has a very high Quality of Service (QoS). In some scenarios this may be a combination of networks with 5G deployed for radio cameras, fibre deployed for fixed cameras and backhaul provided by an internet service provider.

3.1.2.3 Wider area event coverage

One of the challenges around covering large scale sporting events, such as cycle racing or marathons, is how to follow the action.

Current workflows may deploy radio cameras on motorbikes that transmit to airborne radio relays that convey the live signal back to a ground station for onward transmission. This is often combined with helicopter coverage as well as fixed camera points at key places on the event route.

In recent years, some cellular relays have been added to this workflow.

One of the key benefits of a 5G network is enhanced mobility, and solutions are being explored that would support the deployment of moving 5G coverage. This would mean that the radio links currently being used may be replaced by an IP-based wireless solution in the future.

Improved functionality for unmanned aerial vehicle (UAV - drones) deployment is also expected with non-line-of-sight operation becoming possible. This will allow multiple drones to cover points along the route without requiring an operator at each point.

3.1.3 Live audio in production

In a typical live audio production, such as a concert, musical or theatrical event, one or more artists perform (i.e. act, dance, sing or play music instruments) in front of an interested audience. Backstage, the technical crew (lighting, sound, video), a production team and the security staff support the successful realization of the live event. They are usually connected to each other via an intercom system.

For the live audio content, reception of the wireless communication service is only required locally, limited to the event area, and all audio processing such as audio mixing is done in real time during operation. To optimise the efficient usage of resources (equipment, radio spectrum, working time of the artists and crew), set-up and configuration of the PMSE local network must be as fast and as easy as possible.

A number between 5 and 300 simultaneously active wireless audio links can be expected. Each wireless audio link is streamed to or from a central audio mixing console. Typical data rates are 400 kbit/s for compressed audio and 1.5 Mbit/s for uncompressed audio. The packet error ratio of the wireless transmission needs to be kept equal to or preferably lower than 10^{-6} to assure that no audio dropouts or audible interference occur.

In this type of production, the commercial pressures on producers are especially significant and, as there is no opportunity for recovery (no possibility to ask the singer to repeat), the tolerance for disturbance to the QoS is extremely low.

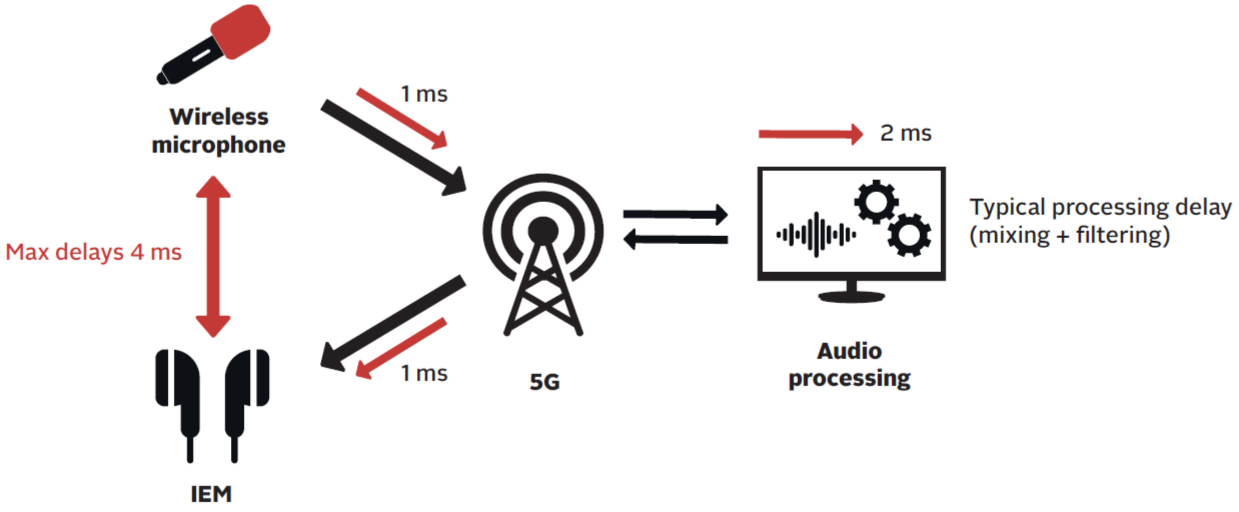


Figure 7: Mouth-to-Ear latency requirement in live audio production

In today's typical professional live audio production setups, one of the most critical technical requirements is the mouth-to-ear latency between microphone and in-ear monitoring (IEM) equipment used by the artists, which typically ranges from 0.125 to 2 ms and cannot exceed 4 ms. The mouth-to-ear latency is measured as the maximum end-to-end latency between the analogue input at the audio source (e.g. wireless microphone) and the analogue output at the audio sink (e.g. IEM); thus, it includes the audio application, the application interfacing latency and the latency introduced by the wireless transmission path (see TR 22.827 [2]). Additional technical challenges are the expected high reliability of the data transmission and the strict time synchronization required at the application layer, i.e. the requirement to synchronise all audio devices strictly and accurately over the network. All audio sources (inputs) and destinations (outputs) of one production setup should be synchronised to one system reference clock within a range of ±500 ns.

The PMSE-XG project [9] demonstrated that cellular 4G (LTE) technology is not suitable for professional live audio production since it is not able to fulfil the stringent QoS requirements of the use case. 5G may be able to fulfil the requirements by means of improvements on the radio technology (URLLC in 5G-NR) and exploitation of local computing capabilities (e.g. mobile edge compute and local breakout architectures).

The use of 5G as a common radio standard for the interconnection of professional wireless audio equipment could simplify the planning and setup of large live audio events therefore reducing costs.

Due to its high-quality requirements a standalone non-private network (NPN) is the preferred network deployment option for this use case. A standalone NPN can clearly define the user group, guarantee high QoS, security and isolation from other networks.

3.1.4 Production of distributed live events

This use case pursues the idea of building realistic joint performances of musicians at different places. The goal is to merge live events happening at different locations into one single production platform. In so doing, audiovisual content from multiple places can be synchronized live and combined into one feed, providing a new immersive experience for artists, live audiences and even for users at remote locations.

Audio is a vital element of any immersive production. Regardless of the quality of video, scene lighting or other visual effects, good audio can bring the audience deeper into the experience.

The requirements for live audio production at distributed locations are the same as described in § 3.1.3. In order for the participants to enjoy a plausible and immersive audio experience, modern techniques of spatial audio capturing and reproduction can also be used.

In general, the lowest audio latency and strict synchronization (<1 ms) between the two locations is crucial for the interplay of the performers. Therefore, suitable wide area connectivity must be established between the locations.

This use-case pushes the boundaries of what is possible today within network performance. 5G has the potential to offer a solution for immersive and interactive content and services to the performing artist and the live audiences.

To make this use case possible, the ability to capture performances of artists at remote locations and share them as an immersive experience with latency low enough that will enable them to perform in sync has to be proven. Therefore, suitable recording studio setups are required, in which recordings (volumetric, 360°) of both the visual and audio elements of each artist's performance can be captured and put together. This area may benefit from further developments in 5G-NR URLLC and NPNs.

Regarding distribution, 5G must prove its ability to efficiently reach live and remote mass audiences as well as its capability of increasing the interactivity between the artist and the audience.

3.1.5 Non-live production

5G offers great potential for live workflows but there are several other areas where productions will benefit from better connectivity. One such area is a temporary on-location production, whether it be non-scripted entertainment, a month long multicamera reality-show production on a Caribbean island, a documentary, a fiction series, or a whole movie production.

One of the biggest challenges for location-based productions is connectivity. When a large production with a crew of 100+ are on location for days or weeks, connectivity is crucial for all activities from crew coordination, communications, security, production-planning and logistics to a central location office, art department or post-production area, etc.

Good connectivity has a significant overall impact on the production as it can potentially speed up time-to-air by reducing manual media handling through having a reliable and fast way to share content and monitor audiovisual streams.

Shooting on location is nomadic by nature and therefore demands a temporary means of connectivity wherever the shooting is happening. This is often provisioned by buying local connectivity on a contract basis, which can easily result in paying for connectivity for a year whilst only being needed for a week or two. Furthermore, drama production often takes place in rural or historic areas where connectivity is limited and current solutions such as 4G dongles or satellite broadband are common.

The advent of file-based production created an increase in connectivity requirements. A Digital Imaging Technician (DIT) will often be required to download content from cameras, prepare them for post-production and send previews for review back at base. This is often at different resolutions or formats depending on the workflow for the production or on any connectivity limitations at the location.

5G connectivity combined with elements such as Multi-access Edge Computing (MEC) and easy access to cloud-based tools will go a long way to enhance these processes. Connecting all the production technology – camera, dolly and crane, audio-multitrack recorder, wireless microphone, tracking sensors, lighting – in a low latency and high-bandwidth network will enhance the overall workflow, just as with any other process in a factory.

By having a seamless flow of content through production, but also with the tracking of all vital processes and keeping everything referenced and in-sync, it will be possible to simplify complex technical tasks such as 3D visual effects and more advanced virtual and augmented reality content.

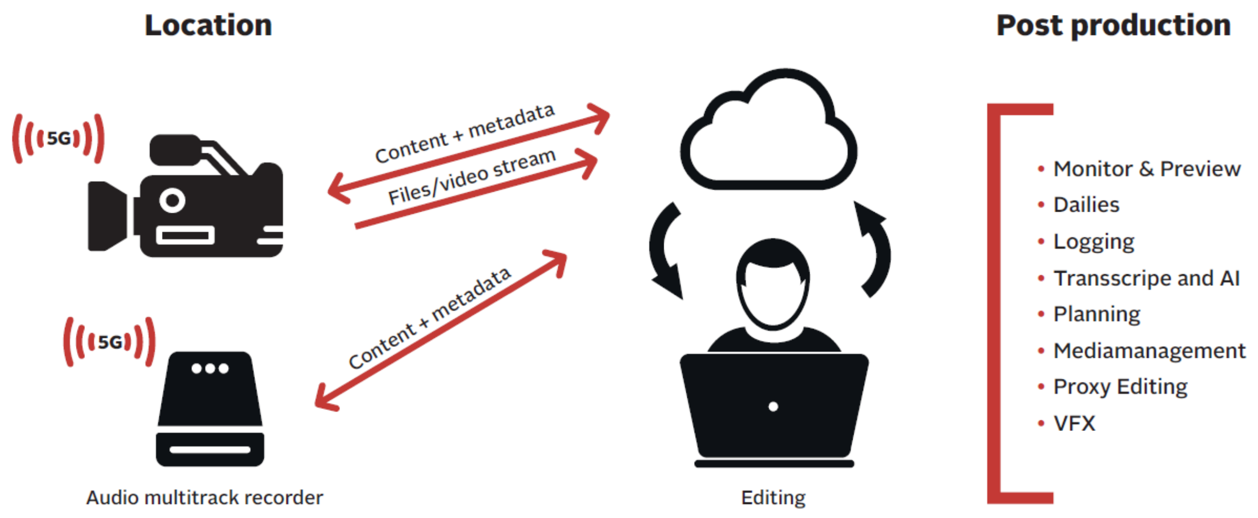


Figure 8: Connected camera workflow – store & forward

MEC may well also have benefits in other areas. Work is ongoing to explore the use of these services as a way of enhancing pre-vis (pre-visualisation). By using the render power of edge compute nodes, it will be possible to render wireframes or colourise elements in real time, thus allowing directors and directors of photography (DoPs) to see their vision in real time.

Today's professional production cameras can be connected to IP networks and, given sufficient bandwidth, can upload recorded content to production centres or the cloud. Settings and configuration can be remotely-controlled, and a built-in encoder can live-stream video directly as a monitor feed to anywhere in the world. This facilitates a variety of new production possibilities:

- Monitor and preview recordings, locally or remotely, giving editors and producers access to real-time captured content. There are already commercials produced in this way, having a director in the USA, the customer in Germany and production in Sweden.
- Fewer staff on site, with distributed production, particularly useful for documentary styles.
- Logging and tagging can be done remotely, without the need for specialists on location.
- Instantly commence editing and post-production, reducing time-to-air. This even has potential to create and develop new formats, like day-to-day or interactive shows, with audiences.
- Automatic or semi-automatic media management, including remote preview for control and adjustment of production parameters and offloading of content for secure remote backup.
- Visual effects (VFX) will be possible in real time, allowing immediate adjustment of framing and tracking, resulting in less post-production time. Power-hungry GPUs can be left back in the office and their output monitored directly on location.

- 5G connectivity enables the use of AI in production.
- Connectivity and MEC facilitate VR and AR productions.

Some of the abovementioned features are already implemented in commercially available devices.

3.2 Specific audiovisual requirements for a 5G system

Some of the use cases described in § 3.1 have demanding requirements in terms of bandwidth capacity, latency, reliability, and the need for deterministic transmission of live audio and video data over 5G networks. Others put the emphasis on high capacity up-link requirements or on the support of service continuity in nomadic and ad-hoc scenarios.

Any wireless solution for audiovisual production needs to support several demanding requirements. Different productions will prioritise certain functions over others, e.g. for news production quality may be sacrificed over speed and flexibility but for a large sporting or national event then quality, reliability and camera synchronisation become a core requirement.

An ideal solution will support the following:

- provision of pre-defined data capacity;
- maximum permitted end-to-end latency and other QoS requirements;
- low power consumption of mobile terminals;
- dependability assurance and related topics (isolation, QoS monitoring …);
- tight time synchronisation of up to thousands of devices (cameras, microphones, in-ear monitors, etc.) at application level[14];
- airborne equipment;
- high speed mobility
- short set-up time for production equipment with consideration to self-organising / self-awareness;
- adaptation of quality to available bandwidth, especially while using hundreds of devices;
- special and regular audio / video codecs;
- audio / video equipment management systems;
- secure transmission with end-to-end media encryption;
- broadcast of a production-based master clock (time code generator / inserter);
- simultaneous multi-network connectivity and service continuity;
- local breakout and mobile edge computing

It is unlikely that these requirements will ever be met at the same time and everywhere. Individual productions will prioritise different requirements depending on their scope, budget, and the time available to deploy a solution.

Audiovisual production will always have demanding requirements and some of these can be supported by 5G. Those listed below are critical to the adoption of any technology that supports AV production.

[14] For live audio production the synchronisation requirement is <1 us.

3.2.1 Key parameters

Certain key technical parameters such as system latency, data throughput and timing are of high priority for any media operation. Other operational parameters such as reliability and security will also be critical to the adoption of 5G.

System latency

The overall system latency has an important impact on audiovisual content production applications. In video production, overall system latency is referred to as imaging system latency and has an impact on the timing of synchronized cameras. For audio applications, overall system latency is referred to as 'mouth-to-ear latency[15] and it is critical to maintain lip-sync and avoid a performer being put off by hearing their own echo. The mouth-to-ear latency which typically ranges from 0.125 to 2 ms and cannot exceed 4 ms.

It should also be noted that predictable latency is more critical than very low latency in a number of applications. A multi-camera set up with a constant 20 ms latency across all sources can be engineered to work but one with sources with latency that drifts between 2 and 15 ms may have lower latency but would be a lot harder to work with.

Data throughput

Video and imaging applications have extremely high bandwidth requirements and while compression may be used to mitigate this in certain user cases it often degrades the picture to the extent onward processing required by some applications is compromised. For video production certain standards have been determined which indicate the maximum allowable compression for a given type of production.

Wireless IP-based solutions also tend to be tuned to prioritise downlink over uplink. Content creation workflows often require high bandwidth uploads. To compensate for this, higher bandwidth connections than required may be provisioned at increased cost and a significant part of the downlink bandwidth will be under-utilised. Non-public network architectures may enable deployments to be more efficient in this respect.

Reliability

Reliability is another key parameter for audiovisual production. Late or lost packets can result in dropped audio/video frames or inconsistency of motion which can degrade a video or audio signal to below acceptable levels. Current wireless camera solutions have a very high reliability compared with that provided by a mobile network.

Timing

Audiovisual production workflows also require accurate timing protocols for two reasons

- To enable multiple cameras and microphones to be synchronized, thus avoiding the capture of mismatched audio and video.
- To provide a timing signal that is used for the accurate time stamping of packets in some IP-based production solutions

[15] The overall system latency comprises a sum of the following contributing elements:

- Time for image or audio frame generation
- Time Delay through 5G Network, defined as the end-to-end latency in TS 22.261 [18]
- Application processing time
- Time for image display or audio playback

It is anticipated that a 5G system could act as a master clock and media clocks will be generated by the production hardware or applications.

Security and onboarding

As an IP network, 5G needs to support any security protocols that are commonly used by the industry or mandated by local, national or international regulations.

In addition to this, 5G devices need to integrate into other IP workflows. Protocols such as NMOS, which have been developed by the media industry, should also be common in 5G deployments, thus allowing the discovery, registration, and management of any device.

Onboarding requirements for different types of device and network have also been specified within the 5G standards [18]. These requirements detail how user equipment is managed on the network from a 5G perspective; for instance, time-to-connection and roaming across different networks. For media purposes these will need to run alongside the specific protocols required for PMSE operations.

4. 5G evolution - how 5G networks will support content production

As 5G is to be considered as a mobile solution based on IP technologies, the aim should be to use the same workflows that are in use for existing IP productions, rather than introduce new ones for 5G. To that end the EBU project groups[16] have been working with colleagues with specialist knowledge in this area to ensure compatibility.

The broad challenges to be solved to improve how 5G systems could be used are based around maintaining a high-quality, low latency contribution feed with a known quality of service that can be tuned to particular production requirements.

Mobile cellular technology can no longer be thought of as a circuit-switched telephony network. Today's networks are designed from the ground up as data networks. Older architectures were limited to voice and text messages (SMS), and these are often still carried over legacy infrastructure. When sending a text message, technology introduced with the 2G network is used. Making a phone call will either be enabled by the 2G/GSM network, or on 3G, or using the Voice over LTE (VoLTE) function introduced in 4G.

When an operator builds a network, they need to maintain these and other services. This requires the maintenance of legacy infrastructure and services.

This model is not sustainable and consequently much of the work on 5G has been designed to replace this architecture with a much more modern, all-encompassing solution. From a technological point of view, 5G is an evolution of the existing 4G mobile cellular networks that aims to incorporate the applicability to vertical markets already into the architecture design.

5G attempts to bring three key enhancements to mobile IP networks:

- Greater bandwidth
- Faster connections
- Higher device density.

[16] EBU 5G in Content Production group (https://tech.ebu.ch/groups/5gcp) and 5G Deployments group (https://tech.ebu.ch/groups/5gdeployments)

All these areas have potential to improve the way audio and video content is produced, distributed and consumed. Broadcasters have been involved in exploring how this technology will impact both the audiences and the content creators.

Benefits will be achieved by several improvements to the 5G system architecture as well as efficiencies in the use of spectrum and New Radio (NR) techniques. Moving compute power closer to the radio link reduces latency and having massive MIMO (multiple-input multiple-output), beamforming antennas means that many more devices can connect concurrently.

But this technology and associated benefits will not arrive all at once.

There is a phased release of standards and specifications and companies are working globally to these release patterns. There will be pre-release kit for testing and in labs, and the evolution is continuous, but there are some core design elements that can be called out and explained to allow greater understanding of what will be possible by when.

5G networks will be deployed in different ways as the technology evolves. Over the next 5 years the capabilities may develop to run even the highest quality use cases over dedicated 5G networks, but this is dependent on suitable business and operational models to support commercial rollout. Some use cases may not be possible until future generations of cellular technology are developed.

4.1 5G network architectures

The deployment of 5G networks will vary over time as they utilise the latest stable technology. Currently the media industry has seen and tested 5G Non-Standalone Public Land Mobile Networks (PLMN) with some success, but not without frustration. As standalone PLMN and standalone Non-Public Networks (NPN) become available new user cases will be explored.

4.1.1 Standalone versus non-standalone networks

A mobile network consists of two main parts - the core network and the radio access network (RAN). 5G brings updates to both with a new 5G Core (5GC) and new radio access technology called 5G New Radio or 5G NR.

4.1.1.1 Non-standalone networks

The first phase of 5G-labelled technologies that have been deployed commercially are upgrades to the radio links on mobile base stations. This means that while the radio link is used more efficiently and new spectrum can be used, the back-end infrastructure is 4G. The 5G traffic is therefore carried over the core network alongside all the 4G traffic. In this setting, 5G does not work on its own. This configuration is known as a non-standalone 5G network.

This is the most common type of network found in the early commercial 5G rollouts.

It is motivated by a widely shared goal among the telecom industry stakeholders to offer a rapid and non-disruptive way to launch 5G services. This type of network maximizes the reuse of the 4G architecture. Indeed, the 5G NR access is only used for user data transmission, for everything else 4G/LTE is used. It relies on 4G radio access for all signalling between the user equipment (UEs) and the network and across the 4G core network.[17]

[17] A detailed treatment of different network architecture options is provided in the GSMA White paper *'Road to 5G: Introduction and migration'*, [17] https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

Pros

- By more efficient use of the radio link and access to new spectrum there is a corresponding increase in data throughput to the end user device.
- Enables a technology rollout that is at least, in part, 5G thereby stimulating the market.
- Faster rollout, as it makes use of the existing core network infrastructure.
- Facilitates a smooth introduction of 5G, mainly in terms of eMBB services
- Upgrade of the hardware first, enabling simpler software-only updates when new 5G features become available.

Cons

- This method can only be deployed where LTE core network infrastructure exists.
- Risks creating unrealistic expectations of 5G features too soon.
- Slower connection speeds than later 5G deployment will deliver.
- Greater contention with existing 4G networks.
- Reliance on older infrastructures restricts ability to build non-public networks or testbeds unless LTE core network is available.
- End to end network slicing is not supported in non-standalone networks.
- Feature set limited by 4G core: QoS handling, edge computing, and flexibility of the core network for extensions, such as adding applications and functions.

Rollout

Non-standalone 5G networks are currently available on several public networks. Some testbeds are also built on 4G (LTE) core.

4.1.1.2 Standalone networks

As well as having the 5G NR upgrades these networks also have a 5G core network. This means they are built on an end-to-end 5G infrastructure. Therefore, they can be deployed independently of LTE networks and are often able to deploy single small-scale networks and indoor coverage.

Pros

- No reliance on legacy networks.
- Software upgradeable when new standards arrive.
- Non-public network deployments, like WiFi, are available, with significantly improved performance.
- Support of network slicing enabling dynamic UE policy control for different services.
- The ability to build small-scale non-public networks independent and isolated from public networks or interconnected with public networks.
- Unlocks release 16/17 capabilities such as URLCC and VIAPA.
- The ability to use the full set of 5G capabilities.

Cons

- Limited commercial deployment as of the time of writing.
- Needs extensive further testing for media applications.

Rollout

The expectation was to see some of these network types on show at MWC 2020 before its cancellation. The media industry is currently exploring architectures that would use this type of network. A typical architecture for content production may be a network deployed as a hub with different production spokes and onward connectivity over fibre back to a broadcast centre, if required.

4.1.2 Public networks v non-public networks

There are several tiers of how a mobile network may be deployed. These can be thought of as a public commercial network or PLMN, a non-public (private) network (NPN) or as a slice of an existing network. Other descriptions such as 3rd party network also exist within the 3GPP specifications. All these networks have the same technical capabilities, but their functionality is limited by commercial models or scales of operation.

A **Public Land Mobile Network** (PLMN) is the name given to the type of mobile network that is most prevalent today as operated by a Mobile Network Operator (MNO). As these networks service the general requirements of a commercial mobile phone network, end users have limited control of quality of service (QoS) as, in common with most packet networks, traffic is delivered on a best effort basis. Subscribers identify themselves to the network using a SIM. Devices identify themselves to the network using a unique code (IMEI).

Likely PLMN network uses for content production:

- News contribution
- Mobile journalism
- File transfer
- Provision of PTP for timing

These networks are distinct from similar, planned public networks, such as maritime, airborne or satellite, all of which may be built on a 5G core but configured to the specific application.

A **Non-Public Network** (NPN) - sometimes referred to as a private network - is a network that is dedicated to a specific set of devices which identify themselves using a dedicated set of credentials. Networks can be tuned for performance or uplink/downlink balance. The NPN may be local or deployed over a wide area. Examples of NPN network architectures are provided in **Annex B**.

Likely NPN network uses for content production:

- Dedicated studio networks
- High bandwidth throughput
- A production hub with backhaul provided by a PLMN
- Airborne video production relays (e.g. for the Tour de France)

NPNs offer the possibility to support nomadic and ad-hoc audiovisual content production applications and workflows, independently of PLMN coverage availability. For instance, a touring event would benefit from using PMSE equipment beyond country borders without having to take care of the negotiation of contracts and service level agreements, etc. with multiple national MNOs.

NPNs could be used to support the front end of the production and still require a connection to a backbone network, which could be wired data links or satellite connections, if a direct connection to the studio is planned. PMSE users will need to determine the type of network that is more cost-efficient than individual audio, video, or talkback solutions. This decision will depend on the individual scenario, including the redundancy required to run the equipment smoothly and without interruption.

The requirements of the media industry have been included in the 3GPP specification *Video, Imaging and Audio for Professional Applications* (VIAPA) [8]. Non-public networks may be operated under several different business models.

Non-public networks may require spectrum licences when deployed (dependent on deployment options and local conditions).

4.2 Network slicing

Network Slicing is a concept that enables specific parts of a network to be logically set aside for different purposes, allowing virtual networks to be built for specific uses. Therefore, each network slice shares the same network infrastructure and support systems but with distinct, isolated instances of them. The isolation can be used to provide guaranteed resources for a specific user or service and specific properties also, for example, in terms of latency, throughput, QoS, etc. Orchestration, automation and management processes enable the creation, modification or deletion of individual services while managing the assignment of resources among services and users' needs.

For slices to support specific use-case requirements, the underlying virtual/cloud and physical infrastructure is crucial. End-to-end 5G network slicing requires that every part of the 5G architecture is ready for such purpose. This includes specific domains (core, transport, RAN) as well as the underlying virtual/cloud or physical (e.g. fibre) infrastructure.

Core. When there is a virtualized core there are no resource limitations to be considered, the core functions can scale as needed. It is possible to increase and decrease the virtualized computing and storage resources as needed.

Transport. On the transport side there is a physical limitation related to fibre and routing capacity. The transport network is well understood and with the help of statistical multiplexing it is possible to avoid significant over-dimensioning. The higher it is in the physical network hierarchy, the more stable the transport load is. Separating traffic for different network slices is a well-known technology in the transport network as it has been used in fixed networks for decades. Transport network limitations will mean that network slices might have a different capacity at the different parts of network.

RAN network slicing is a new concept implemented in 5G. A RAN slice is defined by resource blocks rather than bandwidth, meaning that throughput is not managed directly at the base station level. In practice resource blocks are allocated to individual data streams inside the slice, not actual capacity. An end user requires a stable, high reliability connection measured in Mbit/s.

The resources available for network slicing, physical and/or virtual, can be dedicated to a particular network slice or shared between multiple slices. User equipment may also be able to support handling multiple networks slices for different services at the same time. The management of network slices can be restricted to network operators or exposed to customers so that they can configure them.

Network slicing also provides a significantly easier way to create and operate highly secure radio networks because the user authentication process can be separated from the slice. Network slicing enables a Network as a Service (NaaS) concept that meets the highest security standards.

A ***Slice*** can be part of either a PLMN or an NPN that is dedicated for a particular purpose. A virtual core can be managed by the slice tenant, e.g. content producer, to have full control over who is allowed to use the slice(s), what kind of traffic flow templates are used, what kind of RF level requirements there are, how to manage a network congestion situation and policies around integrating content to the network. It is also important to note that a single content producer could use slices from several networks. Network authentication is performed by a network operator, but as a load balancing or resilience measure, a content producer could change the slice provider for a single user (eSIM).

Likely uses of network slicing for content production

- Remote production where dedicated bandwidth and QoS is required
- Planned news deployments
- Segregation of non-public networks provided by 3rd parties (e.g. a non-public network at a large event where various uses have access to different slices such as stage, broadcast, security, mission critical etc.)
- PTP timing

4.3 Open, virtual and flexible deployments

Traditionally, large-scale public networks are built by MNOs using equipment supplied by a small number of large vendors. These vendors' efforts are focussed on developing product sets that meet the requirements of the global mobile telecommunications market. This focus means potential customers for smaller-scale, non-public networks are not prioritised.

Effectively, each MNO is 'locked-in' to a vendor's product set. They deploy a vendor's equipment 'end-to-end' (radio access and core). This is disadvantageous for MNOs; ideally, they would prefer to integrate equipment from a range of vendors. Their resulting vendor-neutrality would create competition and reduce costs.

Lock-in is also disadvantageous for smaller vendors. Many do not have the capability to develop and support end-to-end product-sets and they find it difficult to integrate their systems into established networks.

Lock-in also applies to non-public networks. The cost and availability of non-public networks have, essentially, been defined by the large vendors' MNO-led product sets.

Lock-in is perpetuated by proprietary systems and interfaces.

There are several initiatives associated with 5G to provide vendor-neutrality; that is, an alternative to large vendor lock-in. The initiatives include:

- Network function virtualisation (NFV): Define network node functions and their interfaces as a set of standards, then implement these functions on commodity IT hardware rather than proprietary hardware. Standardised interfaces allow individual components, sourced from different vendors, to be integrated.
- Software defined networks (SDN): Separating the network control plane from the forwarding plane makes the management of large networks less complicated, thereby reducing MNO costs. Heterogeneous networks, with equipment from different vendors, operate under a unified control plane rather than under separate network element management systems.
- Software defined radio (SDR): Implement radio components (filters, amplifiers, modulators, etc.) in software on commodity, rather than proprietary or application-specific hardware. SDR reduces development costs and improves time to market of radio components, especially in the development of new spectrum products.
- Open radio access networks (O-RAN): By standardising RAN interfaces the number of options for centralising or distributing function nodes increase. O-RAN simplifies the integration of smaller vendors' RAN technologies.

The combination of these initiatives results in greater flexibility for MNOs, who are free to integrate best-of-breed components from multiple suppliers. MNOs also benefit from reduced equipment costs.

The initiatives also make it easier and cheaper to implement non-public networks. Vendor-neutral solutions based on general purpose hardware and software make non-public networks more affordable. The ability to implement only the functions required greatly reduces the complexity of deployments.

5. Making it happen - 5G deployments for content production

Mobile technologies up to 4G have been driven by the mobile network operators and equipment manufacturers focusing on consumer-oriented business models. The approach to 5G development has been different. New concepts have been introduced such as network function virtualization, network slicing, complete separation of control and user plane, etc. In addition, contrary to the previous generations, 5G development is open to a number of industries (known as 'verticals') proposing use cases and requirements for these technologies but often there is also a need for change in business models or regulatory frameworks to support these ideas.

5G represents both an opportunity and a challenge for the content creation industry. However, it also means that media production companies need to engage in the telecoms industry standardisation process to make sure that their requirements are adequately taken into consideration. Without their engagement, the mobile industry will not automatically deliver a system that suits the needs of the media industry.

The media industry has been used to being the dominant player when it comes to standards for audio and video production. This means they have had a lot of influence on manufacturers and suppliers specialising in this market. In the 5G domain, production companies are confronted with global market dynamics. To make an impact therein they have to come up with an attractive enough commercial proposition to convince large corporations that engaging in this market segment is a promising business opportunity, rather than neglecting it because they see content production as a niche market.

When exploring 5G technologies, the media industry will also find parallels with other industries that they could align with. Video production entails imaging requirements that align with those working in the medical domain. Connectivity requirements in media production may have similarities with those in emergency services, whilst 5G is also considered for extended reality, industrial robotics, and drones. All of these and some other functionalities may have applications in content creation. This would motivate the industry to develop and commercialise 5G solutions for PMSE applications and to create a business case for 5G-based PMSE needs to be viable for chipset and equipment manufacturers as well as for content producers.

It is expected that standardised 5G-based PMSE solutions would bring down the costs and increase the flexibility of production. To this end, several challenges need to be addressed, and these can be broken down into four key areas: *standardisation*, *technology availability*, *regulation*, and *business models*.

5.1 Standardisation

3GPP, the body that specifies the worldwide standards for mobile communications, has invited contributions from end user industries, or verticals, to identify requirements for 5G. This provides an opportunity for audiovisual content producers and the PMSE industry to engage with 5G stakeholders including the telecom industry and other verticals with similar requirements. The aim of the public service media organisations such as EBU Members in 3GPP is to define technical and operational requirements in professional content production and contribution and ensure that they are accommodated in 3GPP specifications.

The way the work is organised in 3GPP is in a series of technical reports (known as TR documents) which analyse key requirements, feasibility and impact on the existing specifications. Any new features that are identified are captured in a technical specification (TS) document that is the basis for the standards releases.

The EBU and its Members, in collaboration with the industry partners have engaged with 3GPP resulting in the *Feasibility Study on Audio-Visual Service Production* (AV_PROD) [1], published in 2019, which sought to study scenarios and use cases and propose requirements for audiovisual production in 5G as described in § 3.2.

These were captured in TR 22.827 *Study on Audio-Visual Service Production* [2]. This Technical Report also covers the implications for the 3GPP systems from wide-area media production and additional local applications, in particular:

- provision of pre-defined bandwidth capacity, end-to-end latency and other QoS requirements for e.g. larger live music events or high-quality cinematic video production;
- time synchronisation among all devices (cameras, microphones, in-ear monitors etc.), optionally using a production-based master clock or time code generator, which is broadcast;
- coverage-related issues dealing with nomadic and ad-hoc production deployments, future ways for electronic newsgathering, use of airborne equipment and support for higher ground speeds of up to 400 km/h;
- interoperability issues related to existing audiovisual production standards and protocols;
- dependability assurance and related topics (network isolation, QoS monitoring etc.).
- enhancements to the 5GS for non-public networks (NPN) to support service requirements for production of audio-visual content and services e.g. for UE onboarding and provisioning, for service continuity.

It is important to note that the use cases in TR 22.827 are designed to tease out specific requirements for 3GPP system that are not yet met by existing 5G standardisation work. These use cases do not form a comprehensive list of how 5G may be deployed by production teams.

These requirements have been incorporated in three different technical specifications: TS 22.263, TS 22.261, and TS 22.104.

TS 22.261 covers general requirements for the 5G system and includes features such as onboarding and device management. [18]

TS 22.104 covers industrial automation and now includes timing and clock synchronisation requirements for media production. [19]

TS 22.263 *Service requirements for Video, Imaging and Audio for Professional Applications* (VIAPA) [8] contains the key requirements for audio and video both from PMSE industry and other vertical applications in particular the medical sector. This specification covers different aspects such as:

- Network service requirements specific for the operation of professional video, imaging and audio for PLMN and non-public networks (NPN)
- New key performance indicators (KPIs) for PLMN and NPN
- KPIs for local Multicast and Broadcast Services

- Network Exposure Requirements
- Application Specific Requirements for video, imaging and audio
- Mobile and airborne base stations for NPNs
- Simultaneous multi-network connectivity and service continuity

All these technical specifications are being considered for inclusion in the 3GPP Release 17 (due in 2021) and the work may continue in future releases. Therefore, improvements in the capability of the system will become available gradually, provided that the media industry remains engaged in 3GPP to support their requirements. Nevertheless, it is not certain that all proposed and standardised features will be implemented in chipsets and devices as this will be largely driven by their commercial viability and the perceived market potential.

Other studies that may be of interest to content producers include studies on Unmanned Aerial Systems (UAS - drones) and 'Extended reality', which looks at specifications around AR, VR and gaming.

5.2 Technology availability

While specifying technical features to capture requirements of the media industry is a good start, it does not guarantee that suitable infrastructure and devices are available in the market. This will also require manufacturers to see that there is a market for devices that support production use cases. Media companies also need to influence the traditional content production market to explore 5G as a potential growth area.

Enhancements that 5G brings to for the media industry by 5G technology can be broken down into two main areas, infrastructure and user equipment.

Infrastructure is provided by a limited number of suppliers and their main customers are the mobile network operators. The global market for telecoms equipment is huge. This has led to several partnerships between manufacturers and network providers.

If a broadcaster wants to deploy a non-public network, it is not easy to directly purchase the required technology and manufacturers tend to expect an MNO to act as a broker for the hardware. This may be a suitable model for industries that have no skills or knowledge in spectrum and connectivity management, such as a factory. However, content production companies have long standing experience in managing their own spectrum and networks and thus the MNO-centric approach may not be the most favourable for them.

As the technology moves from hardware- to software-based solutions and regulation allows for the implementation of smaller, low-power networks. New, reduced cost options will support this type of network. The various open RAN initiatives will accelerate availability of this type of deployment.

Where functionalities such as MEC or cloud compute are required there has also been a trend for telecoms companies to partner with large technology companies to provide these. While this could work well in the consumer market, the model for production may involve the use of several networks and hence different MEC or cloud provision. There is a need to reach through to specific production-based technology, which may be hosted on private or hybrid clouds or which may interact with functionalities that are not connected via 5G and this will need to be considered as this technology develops.

User equipment is another challenge. As 5G technology develops and new releases become available the chipset manufacturers tend to focus on the handset and router market. This is useful in some ways as it means off-the-shelf kit becomes widely available at lower cost. Whether these chipsets will to be built into specialist equipment such as transmission encoders or microphones is less certain. However, there are several benefits to building 5G technologies into professional broadcast kit. These include tighter integration of IP functionality (not having to step down to analogue audio or SDI video as a bridge), size, power and robustness. If future technologies are to support the workflows described in this document, then this issue will need to be addressed.

5.3 Regulatory conditions

Suitable regulatory conditions are essential for wireless content production, whether using conventional or 5G-based solutions. Regulation traditionally covers areas such as access to radio spectrum but may also cover some new issues that are 5G-specific such as network slicing or roaming between NPNs and public networks.

Radio spectrum access is a very highly regulated area in which the media industry has extensive knowledge, expertise and experience. Increasingly, media companies are losing spectrum used for PMSE while at the same time the spectrum demand for PMSE is rising due to a trend for more and more wireless technologies being used in larger and technically more advanced productions. Thus, there is a pressure to make more efficient use of available bandwidth. If 5G systems are to be useful for PMSE, spectrum for 5G, and in particular for NPN systems should be identified with wide international availability. Bands currently used for wireless cameras may be suitable candidates.

In the case that public 5G network spectrum allocations are agreed internationally, or even at a global level with the spectrum licence normally held by an MNO. 5G-based PMSE equipment will need to access spectrum licensed to such a network, so content producers are not concerned by the associated regulatory issues on a day-to-day basis, but may wish to lobby for other desirable regulation (e.g. in relation to net neutrality, traffic management, privacy) with which they would like MNOs to be compliant with.

Non-public 5G networks for PMSE purposes will require additional spectrum to be available locally and often on an ad-hoc basis. The amount of spectrum required can vary depending on the nature of the production; the duration for which it is needed can be from a few hours to many days, or permanently. It is expected that non-public networks for content production would be deployed in different ways, including by the content producers themselves, by third-party providers on a neutral host basis, or by an MNO.

The most important regulatory issue for 5G PMSE is therefore continued, flexible access to sufficient, good quality spectrum for NPNs, thus allowing them to meet demand for even the largest productions. Another important requirement is long term access to internationally harmonised spectrum bands. This will facilitate investment and technological development of equipment able to operate in tuning ranges that can be used across many countries.

Spectrum access for PMSE needs to remain easy, affordable and timely. Different regulators adopt different approaches. Authorisation should ideally be a balance of exclusive co-ordinated assignments for high profile production through to general authorisation (licence exemption) for smaller productions where contention for spectrum is low.

According to the regulatory rules that apply, frequency clearance for routine productions can be automated and performed centrally, perhaps online. For more complex productions and events, producers may require specialists for frequency co-ordination, both before the event and on-site during the event, while the spectrum regulator may become involved in very large events (e.g. Olympics, Tour de France).

Ideally, spectrum allocations for NPNs should be defined in such a way as to allow the same hardware to operate in both public and non-public 5G networks. Furthermore, spectrum bands should be technically suitable for different PMSE applications, noting that different frequency bands have different propagation characteristics which may or may not support mobility, indoor penetration, etc.

There is a growing number of verticals that will rely on non-public 5G networks and different regulatory solutions will be required to accommodate their requirements for access to radio spectrum. For example, verticals with occasional, short-term and nomadic spectrum use, such as some PMSE applications, construction sites, or emergency services will require different access conditions from those required by verticals with long-term and stationary spectrum use, such as hospitals or factories, or PMSE use in a studio centre.

Spectrum regulators are currently considering various new licence models[18] for making spectrum locally available for non-public 5G networks. However, the currently considered licence models tend to be focused on longer time frames, often a minimum of a year. While this may work in a fixed location such as a studio, a venue, or a frequently visited news location, in many cases productions are short-term (from a few hours to some days or weeks) and ad-hoc access to spectrum would be more appropriate and short term ad-hoc licensing as already used for PMSE should continue.

Furthermore, local spectrum licenses for content production should be technologically neutral in a regulatory sense to allow for the integration of supplementary systems with 5G or a mixed operation of conventional and 5G-based PMSE systems.

Spectrum access options for NPNs is treated in detail in **Annex C**.

Beyond spectrum there are other regulatory issues that may be relevant, including:

- roaming between different networks, including between public and NPNs;
- availability of network slicing;
- licensing conditions for NPNs (power, area coverage, type of service provided);
- international use across borders.

These issues have not been covered in this report.

5.4 Business and operational models

Perhaps the largest challenge for the adoption of any new technology is the landscape into which it is deployed. Business and operational models need to be defined that suit all parties from the incumbent providers through to the end users. To some extent these are down to individual negotiation sometimes on a contractual basis and sometimes on a pay-as-you-go model.

For mobile network operators there are number of large costs associated with maintaining existing networks and rolling out new architectures. In some instances, these costs can be offset, for instance the cost of upgrading and maintaining a more software based network is a significant saving over current operating models but future models rely on the growth of revenue models by providing new services to the vertical industries.

[18] Examples:

- Dedicated spectrum band (3.7 - 3.8 GHz) for campus networks in Germany
- Access to unused MNO's spectrum in the UK
- Licensed Shared Access
- CBRS in US, with dynamic spectrum access, allowing campus networks
- The use of unlicensed bands for 5G

Currently, data is offered on a fixed term basis that ties a subscriber to a network for a specified amount of time. Pay-as-you-go models also exist but typically the costs of data are higher. The assumption is also made that downlink will exceed uplink requirements 80/20 so for an uplink-heavy application a more expensive contract may be required providing sufficient uplink capacity while leaving unused downlink capacity.

Some roaming SIM models have emerged which support virtual SIMs and can be contracted to any available network. Also, e-SIMs are available on some networks which are device based programmable solutions.

Current operational models for productions are based on cost of opportunity, This means if it is cheaper for media PSM organisations to use 5G than a satellite-equipped OB truck for an equivalent service, they will use 5G. Production teams will seek to reduce costs or provide a better service for the same cost as long as reliability and service requirements are met.

While MNOs seek to monetise their investments and production teams seek to minimize their costs there is a potential conflict that can only be resolved by the provision of new, cost effective solutions.

Models where a subscriber is locked to a single service provider will not work for a nomadic ad-hoc production model as there is no guarantee of coverage on a universal basis.

Different architectures will drive the different business models. Where the use of the public network is suitable, and no enhanced services are required the current models can support this. Often SIM cards are purchased off the shelf and deployed with no discussion between the MNOs and the end users. The end user may have several contracts with different providers and may aggregate services from multiple networks to offer some resilience.

There are also initiatives to allow 5G to use unlicensed spectrum bands (e.g. 5G NR-U) which is primarily intended for local area networks using e.g. WiFi 6E (802.11ay). If these initiatives result in simpler and mass-market solutions this may ease the adoption of 5G in less demanding production use cases.

The potential of network slicing may allow large productions to gain access to a network better tuned to their requirements. While this is an attractive proposition the cost of an always-on slice with nationwide coverage is likely to be an inefficient and therefore costly model. This could be mitigated by multiple end users in a territory sharing a slice, but this may increase load on that slice at busy news periods. Slicing also assumes ubiquitous network coverage from the provider. Without the ability to roam to other networks this will be an operational challenge.

Slicing on demand is likely to be a more sustainable model. In this instance a production team could book a section of the network on an ad-hoc basis paying for a specific bandwidth and quality of service. This will involve the provision of new services.

Non-Public Networks (NPNs) will also offer areas of opportunity for service providers. Depending on the spectrum model provision could be made from either PMSE areas or unused mobile spectrum. Regulators are exploring the potential of dynamic spectrum sharing as well as licences for NPNs. If this would be coupled with the use of unlicensed spectrum there will be space for companies to offer spectrum as a service. This model has some precedent in the deployment of so-called campus networks and while these may be suitable for long term deployments, the ad hoc, nomadic characteristics of production may make this more difficult to operate.

The provision of NPNs and 3rd party networks is also an area of debate. Most verticals are content to buy these networks as a service and the MNOs have moved rapidly to fill this space. They can provision wireless solutions as a package to a factory or hospital where connectivity is not a core competency of the business. For production teams who are used to deploying both wired and wireless networks to support an OB or studio there is a desire to procure, deploy and support their own solutions. The large vendors are, however, reluctant to provide the equipment required to do this as it is seen as a direct competition to their main MNO customer base and so have a go to market strategy that does not support the sale of equipment outside of this framework. Smaller producers are emerging that will serve this market.

From a user equipment perspective as chipsets are developed, they will become available first to mobile handset manufacturers. These devices will be tuned to support the functions required in this space and not for equipment that supports use cases for PMSE. Manufacturers that traditionally support the PMSE industry are exploring 5G as a potential growth area but access to the hardware required means that adoption may be slower and cost more. Given the relatively small size of the market.

5.5 Industry engagement

To solve these issues, it is important that the PMSE sector engages with the 5G ecosystem at several levels. There is a need for:

- continuing engagement with standards bodies;
- continuing engagement with national and international regulatory bodies;
- continuing engagement with national and international 5G initiatives;
- collaboration within the content production sector, including PMSE equipment manufacturers;
- alignment of requirements between PMSE industry and other sectors, i.e. work together to give manufacturers and service providers a clear picture of the market;
- tests and trials to demonstrate the capabilities of 5G, this will educate production teams on how 5G can enhance their workflows. A summary of different projects has been included in **Annex A**;
- development of production workflows integrating 5G technology;
- commercial and operational models for the deployment of NPNs;
- commercial and operational models for network slicing, including across multiple suppliers.

A number of these initiatives are underway in several territories. This needs to continue to deliver the full potential of 5G in the PMSE sector.

6. Conclusions

There are many use cases in a production environment that may incorporate 5G in the workflow over time. Some are a natural evolution of existing 4G applications, some will enhance or replace other forms of contribution such as ISDN, microwave and satellite links and some will be completely new ways of creating and delivering content. As a key enabler of connectivity services alongside WiFi[19] and fibre roll-outs, 5G improves on existing technologies by adding in more reliability, flexibility and mobility.

In production there will be a variety of different models that will be used, dependent on the type and scale of production. A single camera news or radio contribution will use the public networks to move content around whereas a more complex environment such as larger events may seek to

[19] In particular, WiFi 6 (802.11ax) and WiFi 6E (802.11ay).

deploy non-public networks. For complex production such as large sport and cultural events, 5G will also enable new methods of capturing content. This may include low-latency radio cameras with very high mobility and quality requirements that can only be met by deployment of NPNs.

5G will also be key in achieving the ambitions of deploying low cost remote or distributed production. For example, if unmanned cameras are deployed in a political chamber to provide an automated feed of a meeting, or in a small cultural venue to cover an arts event, then ideally the cameras and microphones will need to be reliably connected to the data centres where applications such as live mixing or content preselection may occur.

Many production radio links are currently delivered using dedicated PMSE radio spectrum that shares bandwidth with other services, e.g. radio microphones in DTT spectrum. As these frequencies become less available and more congested it will be necessary to establish what the potential is to use emerging technologies to maintain existing capabilities.

Media productions tend to be done on an ad-hoc basis. This often requires the short-term deployment of equipment and networks at multiple locations. The data flow on these networks is primarily in the uplink direction, contrary to the public networks which are primarily designed for large downlink traffic. Both factors, coupled with the need for a very high quality of service, mean that public networks that are deployed by the mobile industry offer limited potential for production.

Different types of network deployment to support production are therefore extremely desirable. The way in which non-public networks are currently regulated is a good match for access to spectrum for a long-term requirement that will be in place for years, (e.g. a factory or a studio), but where spectrum is needed only for hours or days it usually has to be leased for a much longer period than that required. Models such as dynamic spectrum sharing, and reallocation of unused spectrum do help but they do not solve this issue. Network slicing of public networks could also offer benefits but the operational and business models to support slicing have yet to emerge.

In the professional world, where sufficient 5G coverage and capacity are available, newsgathering and similar workflows could migrate from bonded LTE solutions to a single 5G connection with predictable quality (e.g. using network slicing). 5G features such as URLLC will improve multiple-source contribution, making it more predictable, but any solution will require more accurate timing through technologies such as PTP. Wider bearer channels and the ability to manage the proportion of upstream and downstream data, allow codec latency to be reduced to a practical minimum and pass greater resolution images can be considered.

As with any radio system there will be a trade-off between the convenience of wireless and the amount of information that can be carried on a given bearer. While some frequencies will support high bandwidth applications, they are limited in their reach. Other frequencies that have better range and penetration may not provide the bandwidth benefits. The move to IP for transport of these signals may go some way to mitigate the bandwidth/coverage compromise through a combination of compression and multiplexing of different signals to achieve suitable bandwidths for a given frequency range.

Locally, 5G cannot compete with fibre in terms of performance but may do so on the cost of deployment for short-term use. Over greater distances, the cost of fibre media links, largely driven by large sporting events, are excessive. There is therefore an opportunity for MNOs to carry compressed media across slices in public networks in a cost-effective manner and for broadcasters to operate non-public networks for local operations.

Some options are emerging that enable the use of different components of 5G systems in isolation, e.g. as network function virtualisation (NFV), software defined networks (SDN), software defined radio (SRD), and open radio access networks (O-RAN) aiming to enable vendor-neutral solutions based on general purpose hardware and software. It may be possible to deploy 5G solutions that can be integrated in existing capabilities and workflows, e.g. short-hop radio links to fibre connections.

5G may reduce the barrier of entry for a number of these solutions and the technology has been developed to support them but there is a gap in the operational and business models that support them. MNOs seek to profit from their services which are tuned for B2C but currently do not offer a viable or flexible model that supports B2B activity suitable for the media industry. Self-provision of services, in the way currently done with radio enabled devices, needs to be a viable option. Broadcasters and producers need to have access to services and deploy them in a cost-effective manner and be allowed to exercise their own expertise rather than being limited to solutions delivered by an MNO that may understand a video conference call but not the complexity of a multi-camera UHD OB.

5G offers much in terms of bandwidth, reduced latency, timing and quality of service and while the telecom standards bodies understand the need to ensure that verticals have their say, the commercial environment is still dominated by MNOs.

To drive adoption, any new technology will need to fit into existing workflows. Therefore, the success of 5G technology in the media production sector will depend on its ability to satisfy the technical, operational, and commercial requirements in content production and the availability of the equipment.

In summary, connectivity solutions are constantly evolving and will offer significant benefits to production workflows. The roll-out is a gradual evolution and it will take time to achieve everything promised by the marketing hype. The media industry is engaging well with the standards bodies and regulatory bodies but there is a natural tension between various spectrum rights holders that will play out over time. More efficient use of spectrum, improved compression techniques and always-on connectivity will change how the PMSE industry works in the future, but only if it continues to engage at all levels and works together to ensure that technology, regulation and business models can support future workflows.

7. References:

[1] 3GPP Feasibility study on audio-visual service production (AV_PROD), SP-180340
https://www.3gpp.org/ftp/tsg_sa/TSG_SA/TSGS_80/Docs/SP-180340.zip

[2] 3GPP TR 22.827 Study on Audio-Visual Service Production, Stage 1, (Release 17)
https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3520

[3] Spectrum use and future requirements for PMSE ECC Report 204
https://www.ecodocdb.dk/download/1f1d1819-5ca2/ECCREP204.PDF

[4] CEPT - regulatory context:
https://www.cept.org/ecc/topics/programme-making-and-special-events-applications-pmse

[5] SMPTE ST 2110 is a suite of standards dealing with all aspects of conveying Professional Media Over Managed IP Networks : https://www.smpte.org/smpte-st-2110-faq

[6] SMPTE ST 2042 'VC-2 Video Compression'
https://ieeexplore.ieee.org/document/7290180

[7] HEVC – High Efficiency Video Coding, H.265
https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-H.265-201911-I!!PDF-E&type=items

[8] 3GPP TS 22.263 'Service requirements for Video, Imaging and Audio for Professional Applications (VIAPA)'
https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3648

[9] J. Bühlmeyer, M. Hertlein and G. Fischer, “PMSE-xG -- 5G for programme making and special events,” in International Conference on Signals and Systems, Bali, 2018.

[10] ETSI TR 103 588; 'Reconfigurable Radio Systems (RRS); Feasibility study on temporary spectrum access for local high-quality wireless networks.'

[11] ETSI TS 103 652; 'Reconfigurable Radio System (RRS); evolved Licensed Shared Access (eLSA); Multipart Document.'

[12] H. Voujala, 'Spectrum access options for vertical network service providers in 5G', https://doi.org/10.1016/j.telpol.2019.101903

[13] Amendment of the Communication’s rules with regard to commercial operations in the 3550 – 3650 MHz band, order of reconsiderations & second report & order. Federal Communications Commissions, FCC, https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-overview

[14] Statement: 'Enabling wireless innovation through local licensing', Ofcom (UK), July 2019 https://www.ofcom.org.uk/consultations-and-statements/category-1/enabling-opportunities-for-innovation

[15] ERC Recommendation 25-10: 'Frequency Ranges for the Use of Terrestrial Audio and Video Programme Making and Special Events (PMSE) applications'. https://www.ecodocdb.dk/download/d3599aad-a5b6/Rec2510.pdf

[16] EBU Tech 3371: 'Minimum user requirements regarding to build and manage IP-based media facility', https://tech.ebu.ch/publications/tech3371

[17] Road to 5G: Introduction and Migration, GSMA Whitepaper, April 2018, https://www.gsma.com/futurenetworks/wp-content/uploads/2018/04/Road-to-5G-Introduction-and-Migration_FINAL.pdf

[18] 3GPP TS 22.261 'Service requirements for the 5G system', https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3107

[19] 3GPP TS 22.104 'Service requirements for cyber-physical control applications in vertical domains', https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3528

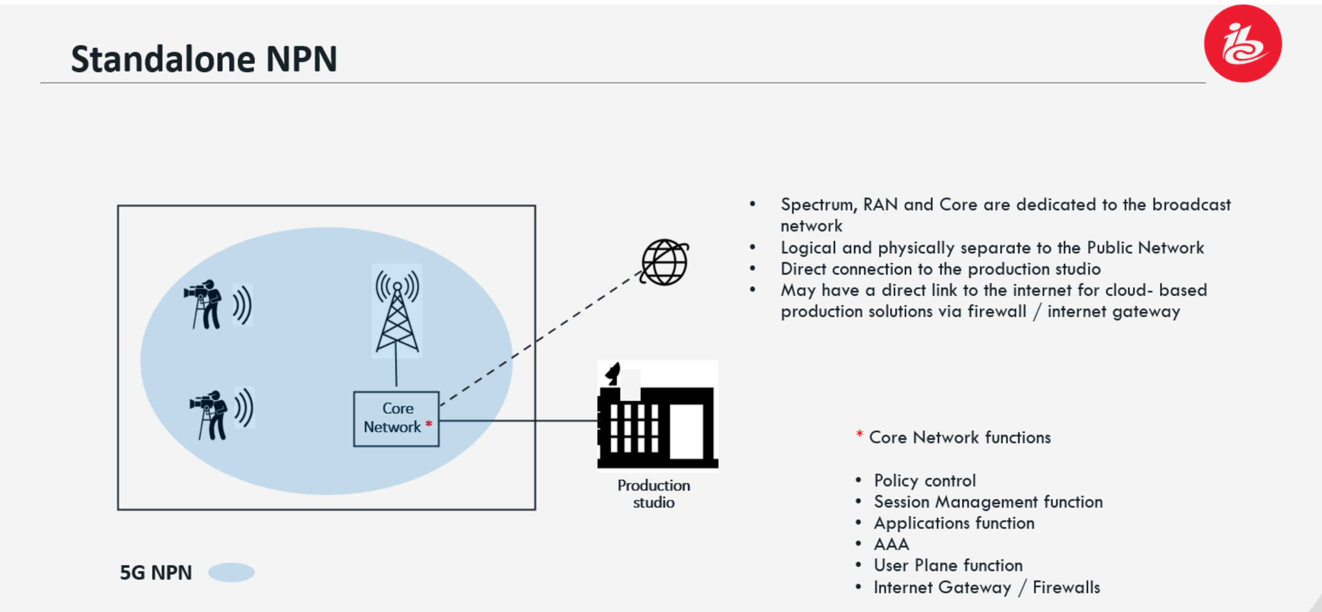
Annex A: R&D projects, tests and trials of 5G in content production

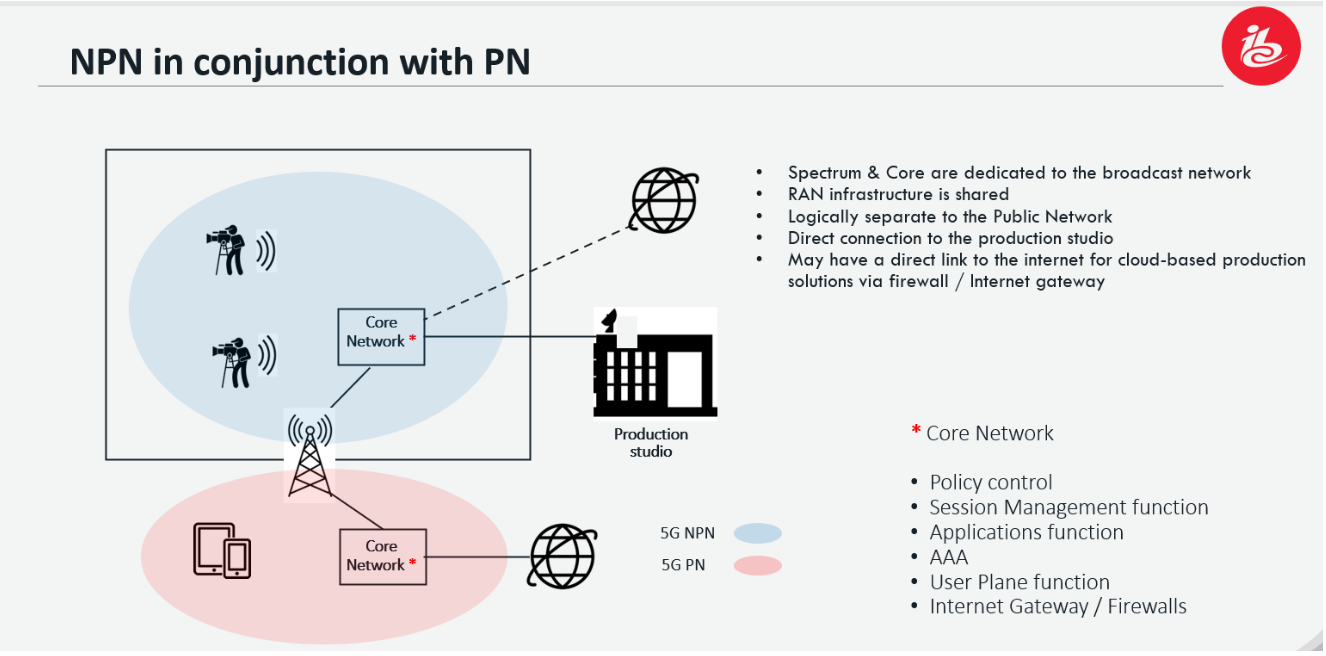
- PMSE-xG project in Germany http://www.pmse-xg.de/publications.html
- Live Interactive PMSE Services (LIPS) project in Germany http://www.lips-project.de/
- EU-Funded project 5G-MEDIA: http://www.5gmedia.eu
- https://www.global5g.org/5g-media-mobile-contribution-remote-and-smart-production-broadcasting
- EE / BT Sports trial: https://www.mirror.co.uk/tech/ee-tests-5g-bt-sport-13628481
- BBC trial on augmented reality https://www.bbc.co.uk/rd/blog/2019-02-5g-mobile-augmented-reality-bath
- Media Broadcast trial of 5G campus network https://tmbroadcast.com/index.php/media-broadcast-introduce-5g-campus-networks-solutions-munich-media-days/
- Deutsche Telecom 5G contribution trial at Berlin marathon: https://www.fiercewireless.com/5g/deutsche-telekom-uses-5g-to-transmit-live-tv-images-at-berlin-marathon
- RTVE trial of TV contribution over 5G https://www.ibc.org/tech-advances/rtve-demos-world-first-stand-alone-5g-broadcast/4004.article
- Swisscom/ NuLink 5G PROLIVE project in Switzerland https://www.swisscom.ch/fr/about/news/2020/01/24-private-5g-network.html
- Sony / Verizon / NBC Sports trial at NFL https://www.sportspromedia.com/news/nfl-football-nbc-sports-verizon-sony-5g-technology-trial
- BT Sport trial of distributed production https://www.svgeurope.org/blog/headlines/bt-sport-radicalises-entire-channel-production-with-decentralised-remote-production-operation/
- Telia Norway, animation film production https://youtu.be/cQQIlmOAsuU
- Music festival production https://youtu.be/A5eJ6gih9MY
  Telia article https://www.telia.no/magasinet/forst-ute-med-a-bruke-5g-i-videoproduksjon/
- IBC Accelerator https://www.ibc.org/ibc-showcase/ibc-accelerators-5g-remote-production/6126.article
- Horizon 2020 project 5G-RECORDS https://www.5g-records.eu/

Annex B: Non-public network architectures

The IBC Accelerator Infrastructure Workstream working group on 5G remote production has developed the following types of non-public 5G network architecture*:

- Standalone non-public network (NPN)– All infrastructure is physically separate from the public network (PN)
- Non-public network in conjunction with public networks - Use shared infrastructure where it makes commercial and technical sense
- NPN deployed in a public network (Type A)– Uses the same physical and logical infrastructure and PLMN but traffic differentiated from the PN traffic prioritization at the radio interface
- NPN deployed in a public network (Type B) – Uses the same physical infrastructure throughout but is logically separated from the PN by utilizing network slicing





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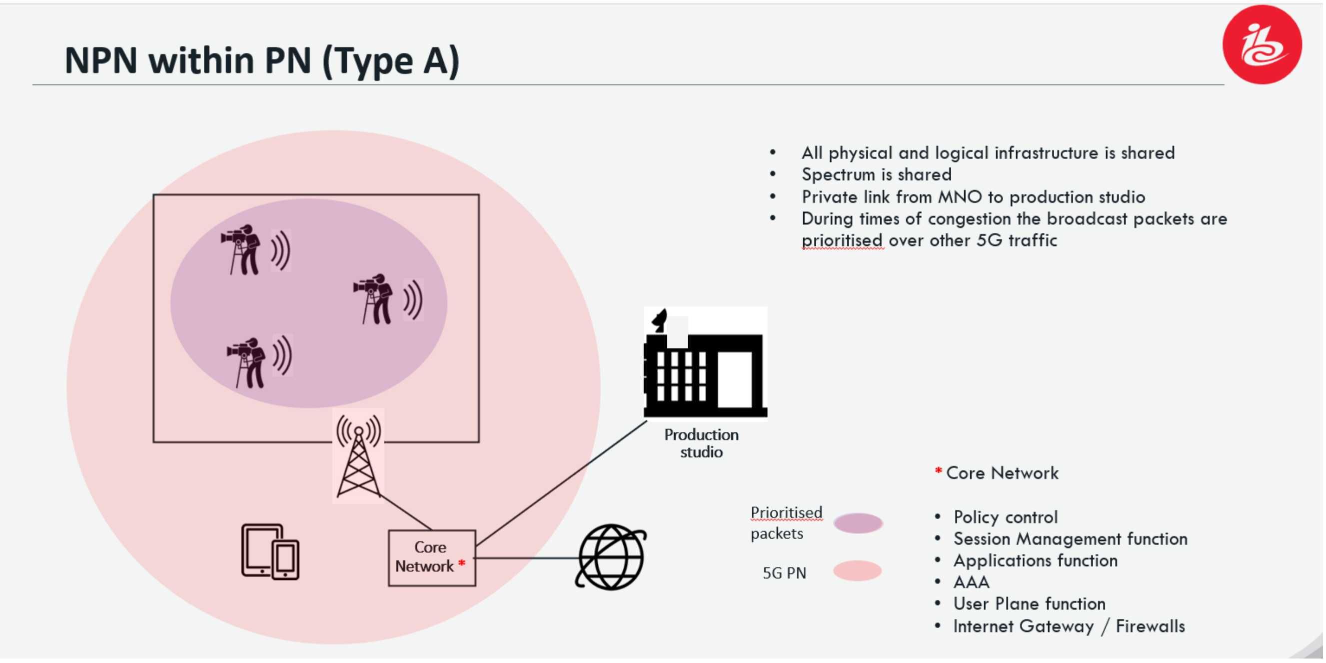
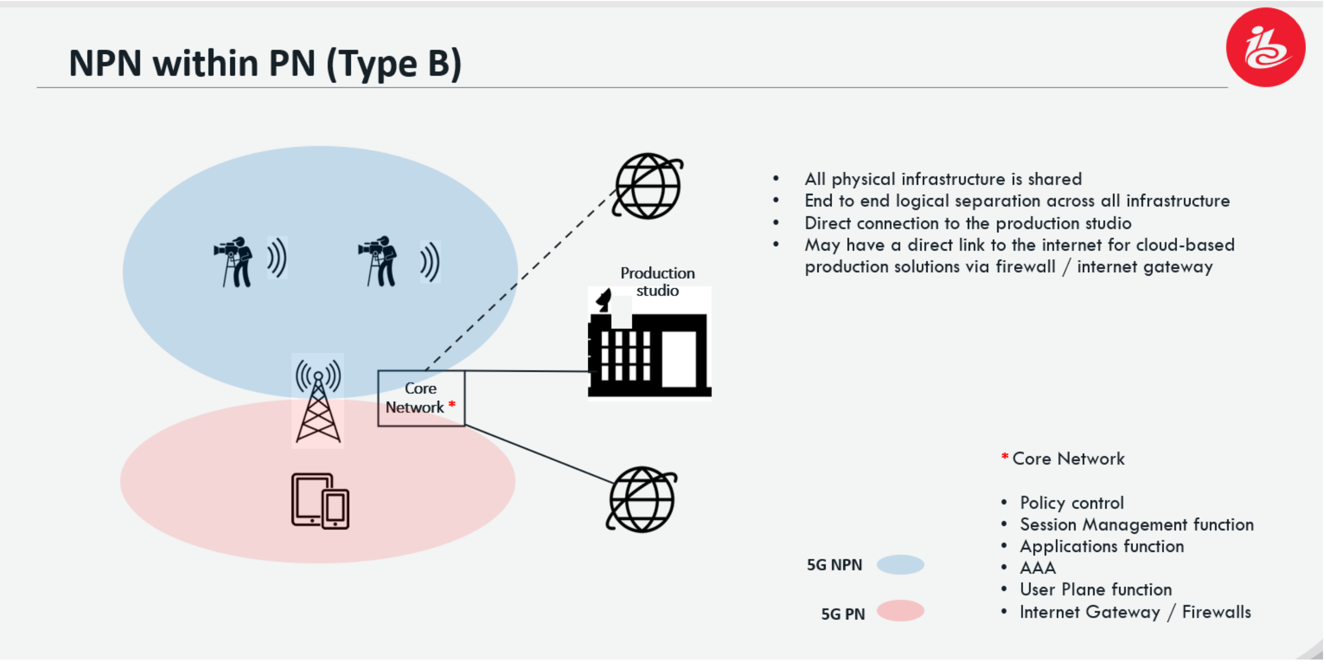

NPN within PN (Type A)
All physical and logical infrastructure is shared
Spectrum is shared
Private link from MNO to production studio
During times of congestion the broadcast packets are prioritised over other 5G traffic
Production studio
Core Network *
Prioritised packets
5G PN
* Core Network
Policy control
Session Management function
Applications function
AAA
User Plane function
Internet Gateway / Firewalls


NPN within PN (Type B)
All physical infrastructure is shared
End to end logical separation across all infrastructure
Direct connection to the production studio
May have a direct link to the internet for cloud-based production solutions via firewall / internet gateway
Production studio
Core Network *
* Core Network
Policy control
Session Management function
Applications function
AAA
User Plane function
Internet Gateway / Firewalls
5G NPN
5G PN

Annex C: Spectrum access options for non-public 5G networks (NPNs)

Available spectrum access options for NPNs depend on the underlying NPN deployment model and on applicable spectrum regulation.

As described in § 4.2, there are two basic NPNs deployment models:

- Standalone NPNs (SNPNs): isolated private networks with no dependency on public networks;
- Public Network Integrated NPNs (PNI-NPNs): networks made available by a public network (PLMN), perhaps offered as a network slice of a PLMN. These two models differ in the level of integration with regards to public networks (PLMNs):

For SNPNs, the network operator (e.g. content production company or a 3rd party) is responsible for obtaining access to spectrum for the network. Depending on national spectrum regulation, the following options are possible:

a) Use of unlicensed spectrum; it could be a feasible solution for small productions in locations where contention for spectrum is low

b) When national regulatory approaches allow, request a dedicated local license. For instance, in Germany BNetzA has allocated spectrum for local private networks deployed by vertical industries in IMT bands (3.7 – 3.8 GHz). Alternatively, in the UK OFCOM has issued rules and mechanism that allow access to spectrum that an MNO is not utilizing, i.e. spectrum that is not being used by an MNO can be repurposed for local private use.

c) Spectrum sharing in bands already being use by an incumbent[20]. Approaches such as LSA (in Europe) [10] [11] and CBRS (in the USA) [13] allow network operators local and temporary use of an incumbent's spectrum under oversight of the national regulatory authority (NRA).

d) Spectrum leasing; incumbents (including MNOs) can lease out or trade part of their licensed spectrum to another network operator in a defined area and for a defined period of time.

Analysis of some of the abovementioned options is provided in [12].

For PNI-NPNs, a distinction has to be made between 'virtual' networks, i.e. those that are made available as a network slice of a public network, and 'hybrid' networks, i.e. those implemented partly by an MNO and partly by a 3rd party. For instance, a hybrid 'PNI-NPN' can be based on the MNO's network infrastructure supplemented by on-site components, e.g. a local user plane function (UPF), MEC provided by the 3rd party. Different hybrid deployments are possible, with different 5GCore network functions (NFs) being operated either by the MNO or by the 3rd party.

For virtual PNI-NPNs (network slices of a public network) the content producer does not need to invest in spectrum resources or own network infrastructure. The spectrum is part of the MNOs spectrum pool.

For hybrid PNI-NPN spectrum, spectrum is either made available by the MNO under commercial agreement or, as in the SNPN case, made available by the local network operator using any of the spectrum access options a) to d).

Maximising the economic benefits of NPNs for content production would require coordination on an international level, ideally to align spectrum access rules and available bands across national borders.

[20] In licensed shared spectrum, the holders of an exclusive licence to use a frequency band are called the incumbents and are the primary users of the band.