5G key technology enableRs for Emerging media COntent pRoDuction services

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[1] CO = Confidential, only members of the consortium (including the Commission Services)

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Abstract

The ecosystem of using 5G in professional content production has been described. A generic model for the analysis of business relations in 5G-based production use cases has been developed and applied to the three 5G-RECORDS use cases. Possible evolution of the use cases has been outlined. Five different 5G network configurations have been considered (best effort, QoS-enabled, network slicing, PNI-NPN, and SNPN) including their applicability in production use cases. Commercial availability of 5G network functions and services was briefly discussed. The role of 5G components developed or enhanced in the Project has been outlined, including their potential to be commercialised as products or services. Some elements of the regulatory framework have been discussed, in particular those that directly impact the business potential of 5G SNPNs in professional content production, such as access to and the use of radio spectrum, and access to the numbering resource. Recommendations to the regulators regarding spectrum access and use have been formulated. A brief overall assessment of the current state of the market has been provided.

Keywords

5G, content production, contribution, business analysis, 5G components, live audio production, multiple cameras wireless studio, live immersive media services, network configurations, non-public networks, spectrum access, regulatory framework

Disclaimer

Executive Summary

Successful adoption of 5G in professional content production requires a functioning ecosystem. This ecosystem is rather complex and includes stakeholders from media production sector, telecom industry, new solutions providers, and regulators.

Beyond technical performance of 5G systems and networks, viable business models are key for their adoption in professional content production. This is still a nascent market and new business models need to be developed in collaboration between the stakeholders.

Different actors bring different competences and technical resources. They may be subject to different regulatory conditions and may have different mindsets, different business practices, objectives, and priorities, and even use the equipment in different ways.

For example, broadcasters and other content producers, broadcast equipment providers, and specialised production infrastructure providers. They are comfortable with using various technologies, ad-hoc and tailor-made solutions where required for a particular production. They may be experienced in self-provisioning the necessary connectivity and using radio spectrum. They are also accustomed to commissioning dedicated connectivity services where this is justified for operational or commercial reasons.

Media producers are interested in 5G as a candidate technology to support IP, cloud-based and remote production workflow. They seek to benefit from a global 5G standard and hardware ecosystem, while retaining the flexibility to provide tailored solutions for specific production use cases. They are open to use any 5G network configuration - whether PLMN or NPN - that meets the technical and operational requirements and is commercially available and attractive.

MNOs and telecom equipment vendors are typically focused on high-volume services, such as consumer broadband, based on global standards and benefiting from economies of scale. They seek to leverage their investments and secure revenues over a longer period of time. Consequently, MNOs tend to implement 5G in such a way that favour their main business case, rather than tailored to the verticals' requirements.

The challenge is to find such arrangements where these differences can be overcome, where business objectives are aligned across the value chain to enable the necessary investments.

Regulatory conditions may facilitate or constrain 5G deployments in content production. Especially, access to spectrum and numbering resources are key enablers of wider use of NPNs. The Project has found that some requirements specific to professional content production concerning spectrum access cannot be met under the current regulation. This has been presented to the European regulators, but further engagement will be required.

There is a considerable interest in the industry for using 5G in content production. A number of tests and trials have been carried out, including those conducted in 5G-RECORDS. However, commercial offers have so far been mainly limited to those solutions that are achievable using best-effort PLMNs, such as bonded cellular solutions. MNOs have been reluctant to offer tailored solutions with guaranteed QoS. Network slicing and 5G NPNs are not yet commercially available but there are some signs that this is beginning to change.

As we accumulate the knowledge and experience from numerous tests and trials it is also important to increase awareness amongst the relevant stakeholders, in particular amongst content producers, telecom operators and the regulators.

Content producers need to learn about 5G, both its capabilities and limitations, and how this technology can support the IP and cloud-based production workflows.

The telecom industry needs to seize the opportunity for expanding their market towards professional content production sector and make 5G attractive to content producers, both technically and commercially.

Regulators need to understand that content producers have some requirements that require using SNPNs as they cannot be met by PLMNs. Furthermore, there are also some specific requirements regarding spectrum access and numbering for 5G NPNs. Accommodating these requirements in the regulation would facilitate the adoption of 5G in professional content production.

It can be assumed that the market will continue to develop as the current issues are gradually resolved and advanced functionality become available in 5G networks and devices.

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AAC	Advanced Audio Coding
AF	Application function
AMWA	Advanced Media Workflow Association
AWS	Amazon Web Services
CAGR	Compound annual growth rate
CEPT	European Conference of Postal and Telecommunications Administrations (*Conférence européenne des administrations des postes et des télécommunications*)
CBRS	Citizens broadband radio service
COFDM	Coded orthogonal frequency division multiplexing
CPE	Customer premises equipment
DMZ	'Demilitarised zone' subnetwork
eLSA	Evolved licensed shared access
EMF	Electro-magnetic field
E2E	End-to-end
E-OSS	Enterprise operations support system
FCC	Federal Communications Commission in the USA
FTTH	Fibre to the home
FVV	Free-viewpoint video system
FWA	Fixed wireless access
GAA	Generally authorised access (in CBRS)
GCP	Google cloud platform
GPU	Graphical processing unit
HD	High definition
HDR	High dynamic ratio
HEVC	High Efficiency Video Coding
IaaS	Infrastructure-as-a-service
ICT	Information and communications technology
IEM	In-ear monitors
IFB	Interruptible fold back
KPI	Key performance indicator
LSA	Licensed shared access
MCR	Master control room
MEC	Multi-edge computing
MG	Media gateway
MHz/POP	Megahertz per population
MNO	Mobile network operator
MOCG	Media operational control gateway
MQTT	Message queuing telemetry transport
MVNO	Mobile virtual network operator
NMOS	Networked media open specifications
NPN	Non-public network
NSA	Non-standalone
OB	Outside broadcast
PA	Public address system
PAL	Priority access licensed (in CBRS)
PCM	Pulse-code modulation
PER	Packet error ratio
PLMN	Public land mobile network
PMSE	Programme making and special events
PNI-NPN	Public network integrated non-public network
PTP	Precision time protocol
QoS	Quality of Service
RAN	Radio access network
RGB	Red, green and blue (image)
RIST	Reliable Internet stream transport
RSC	Radio Spectrum Committee of the European Union
RSPG	Radio Spectrum Policy Group of the European Union

RTP	Real-time transport protocol
RTT	Round trip time
SA	Standalone
SAS	Spectrum access system
SDN	Software defined networking
SIM	Subscriber identification module
SLA	Service-level agreement
SMPTE	Society of Motion Pictures and Television Engineers
SNPN	Standalone non-public network
SRT	Secure reliable transport protocol
SSV	Standard smart venue
TDD	Ime division duplex
UAS	Unmanned aerial systems
UC	Use case
UE	User equipment
UHD	Ultra-high definition
UHF	Ultra-high frequency band (300 MHz - 3 GHz)
UL/DL	Uplink/downlink
UPF	User plane function
URLLC	Ultra-reliable and low latency communication
VHF	Very high frequency band (30 - 300 MHz)
VNF	Virtual network function

1 The Ecosystem

There are different ways for 5G to be successfully adopted in professional content production. However, in all cases the key prerequisites are the ability of the 5G system to meet the technical and operational requirements of the production use case and the viability of business arrangements.

The 5G-RECORDS project carried a study out into the nature of the ecosystem and the underlying business drivers. These are some of the main findings resulting from that study.

The ecosystem is complex. A detailed description is provided in the deliverable D2.2[2].[1] The main actors include:

- Equipment vendors, including both hardware and software providers. It may be useful to distinguish between telecommunications network equipment (e.g. RAN and Core vendors, networking equipment such as routers and switches, ICT-related such as servers, hard disk drives, etc.), broadcast equipment associated with content capture (e.g. cameras, microphones, lights, sensors, etc.) and other specialist production equipment and software (e.g. media gateways and orchestrators).
- Venue owners and infrastructure facility providers. These entities own the infrastructure facilities that can be used for hosting the computing, storage, and passive network components (e.g. transmitter masts, street cabinets, lamp posts, buildings, power supply).
- ICT infrastructure providers, including all types of network operators (fixed and mobile, PLMNs and NPNs), cloud providers, edge providers, and data centres – all entities that provide the network resources.
- Service providers - the entities that use the network and other resources to create tailored technical services for content production. The type of services they offer can be, for example, on-site Internet access and connectivity optimised for content production use cases, or MEC capability hosting the specialised editing. These services allow content providers to focus on their core business without the need to deal with all technical aspects related to content production.
- Content producers as they use the network resources, hardware and software, and specialised services to produce creative output, in particular the audio-visual works in television, radio, music and video, and the associated metadata. Production teams usually consist of technical staff who are responsible for operating user equipment and other technical aspects of content creation, and the editorial staff who are responsible for the creative aspects of the output, including producers, designers, and directors.
- Regulators, who play an essential role in provisioning the necessary radio spectrum and issuing authorisations for spectrum use. They also enforce other relevant regulation which may be related to network operation (e.g. numbering and network codes, roaming, network neutrality and traffic prioritisation, security, and planning permissions), privacy and data protection, and EMF exposure limits.
- End users - In professional content production these are, ultimately, the content producers and broadcasters.

[2] Regulatory framework and business models for 5G content production, Deliverable 2.2,5G-RECORDS project https://www.5g-records.eu/Deliverables/5G-RECORDS_D2.2_v1.1_web.pdf.

The use of 5G in content production presumes an interaction between two well-established but fundamentally different sectors – telecommunications and media production.

Media production stakeholders include broadcasters and other content producers, production equipment, software providers, and specialised connectivity providers.

There are many different production use cases and some of them have rather demanding technical and operational requirements, usually linked to the production of high value content. Content producers use a range of different technologies, some of which are purpose-built and proprietary. Media production professionals are accustomed to using dedicated, often self-provisioned, connectivity solutions including access to spectrum (i.e. PMSE). They also commission connectivity services where this is justified for operational or commercial reasons.

From the professional content producers' perspective, 5G is a candidate technology to support IP-, cloud-based, and remote production workflows. They expect high production quality and the ability to control it, operational flexibility and to enable new production possibilities and lower costs.

It is also quite common in the current content production sector to use a range of different, sometimes rather complex business arrangements tailored to a specific production. It is expected that additional flexibility will be obtained by the adoption of 5G.

On the telecommunications' side, the main actors are telecom equipment and software providers, and public mobile network operators (MNOs). They primary focus on high-volume consumer broadband applications, based on global standards and economies of scale. This is also apparent in the prevalent business models adopted by the MNOs as they are looking to leverage their investments in 5G.

However, MNOs have limited experience with tailored solutions for verticals, in particular, those that do not have the scale comparable to the consumer market.

An important observation is that different stakeholders in the ecosystem may be subject to different regulatory conditions and may have different business practices, objectives, and priorities. The challenge is to find such arrangements where business objectives are aligned across the value chain, and the potential market opportunity justifies the required investments.

Currently, commercially available 5G solutions for content production are mostly reliant on PLMNs which can meet only some of the production requirements. More demanding use case require advanced 5G functionalities, such as network slicing, which are not yet commercially available. Consequently, there has been only a limited take-up of 5G in professional content production beyond cellular bonded services which are widely used in contribution use cases.

However, content producers understand that 5G as a technology can be deployed in different ways. While some requirements can be met by PLMNs, other are better accommodated using NPNs, whether standalone or in combination with PLMNs. This is why NPNs are currently being investigated for a range of different use cases and are seen as a promising implementation of 5G technologies for content production. Therefore, a large part of the work in 5G-RECORDS is related to NPNs.

While there has been a number of successful trials using 5G NPNs in content production, there are still certain regulatory and commercial issues that need to be addressed for the market to develop in that area (e.g. access to radio spectrum for SNPNs, the availability of 5G hardware and software solutions for content production, and the emergence of viable business models).

2 Business aspects of 5G-RECORDS use cases[3]

This chapter contains a description of the three 5G-RECORDS use cases from a business point of view. The basis for the analysis is the requirements defined in the deliverable D2.1 *Use cases, requirements and KPIs*. [2]

It is recognised that each of these three use cases, and indeed most use cases in professional content production can be implemented in a variety of different ways, depending on the technical and commercial options available to the producers in any given situation. Consequently, this chapter provides only some illustrative examples.

However, these examples are presented using a general methodology - developed by the consortium - which allows business analysis to be carried out for any production use cases, either in terms of roles of different actors in the value chain, their business relationships, content flow, or a flow of revenues.

2.1 A model for a business description of use cases and scenarios

2.1.1 The need for a general model

Professional content production is the core activity in the media vertical. There is a wide range of different production use cases and scenarios in terms of their complexity and the value of the content. This results in different technical, operational, and business requirements.

Furthermore, in most cases a production use case can be realised in different ways, as different actors in the ecosystem can play different roles while some technical requirements can be met by several technologies and network configurations.

This makes a business analysis of 5G-based content production rather challenging as the outcome for individual actors in the value chain depends on their business requirements, the viability of the considered business arrangements, and the availability of different possible technical and operational solutions.

To facilitate as far as possible a systematic analysis of different use cases and scenarios from the business point of view, the project has adopted a common methodology which consists of three main steps:

1. Business requirements defined by the content producer.
2. Description of a value chain that needs to be established to satisfy the business requirements.
3. Analysis of the business arrangements between different actors in the value chain.

For this analysis only those business requirements that can be accommodated by technology used in content production are considered. Other kinds of business requirements such as, for example, the acquisition of talent or content rights, or the requirements in content distribution are of course relevant but considered out of scope of this analysis.

As mentioned before, the value chain is likely to look different for different kinds of production. There are also different possible implementations of a particular production use case or scenario. Nevertheless, it can be assumed that at a sufficiently high abstraction level some elements are common to most of production use cases and scenarios. This allows for a general model, i.e. a template, to be used to describe a variety of different use cases and scenarios.

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[3] The use cases are described in detail in the deliverable D2.1 *Use cases, requirements and KPIs* - see https://www.5g-records.eu/Deliverables/5G-RECORDS_D2.1_v2.0_web.pdf. Limited excerpts from that deliverable were used in this document to illustrate some specific aspects of the use cases.

Once the value chain has been defined (step 2 above), it can be analysed in detail, including various implementation aspects that may be specific to this particular use case or scenario implementation.

2.1.2 5G-RECORDS common template

The project has developed the following model for the description of use cases:

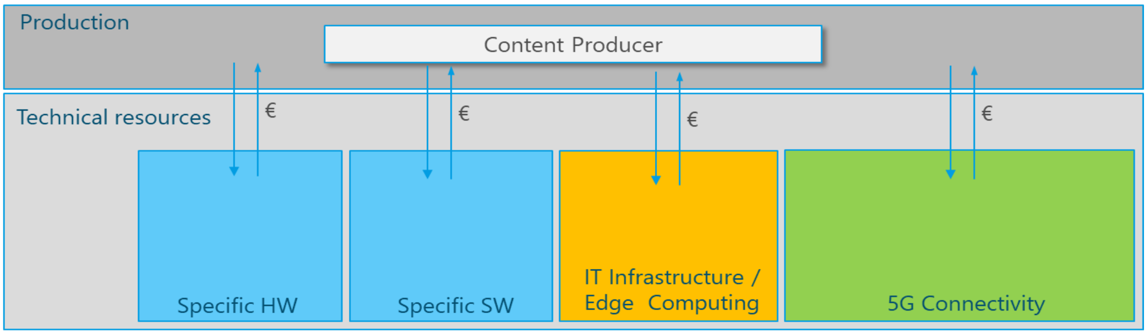

Figure 1: Acquisition of technical resources for content production

The content producer requires various technical resources, including equipment and services, which fall into the following categories:

- specific production-related hardware
- specific production-related software
- IT infrastructure which may include edge computing
- 5G connectivity

These technical resources are normally provided in exchange for remuneration leading to a business relationship between the content producer and resource providers. Therefore, the template requires to indicate for such business relationships the direction of goods or services as well as the direction of revenues.

In some cases the content producer may self-provide some of the resources (e.g. in-house developed software, or connectivity via own network). In other cases the content producer will enter business arrangements with different providers.

5G connectivity requires two essential inputs: network and spectrum.

A network typically consists of RAN and core networks, which may be supplied by different vendors. Different 5G network configurations are described in chapter 3 while some aspects of spectrum access are covered in chapter 5.

In case of a public network, MNOs provide end-to-end connectivity in their own radio spectrum. A non-public network may be provided in different ways using either dedicated spectrum or the spectrum leased from an MNO. NPN operation may be de-coupled from spectrum licensing so that the network operator is different from the spectrum owner. Depending on the use case, an SNPN may be interconnected with a PLMN.

A generic example of how the template could be used may look like this:

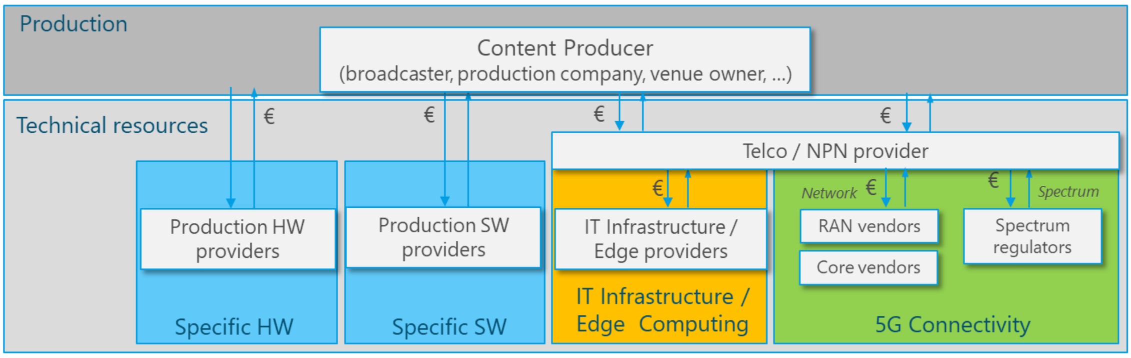

Figure 2: The role of telecom network operators and NPN providers

In this example, an MNO or NPN provider also act as intermediaries between IT infrastructure /edge computing providers and the content producer.

The model can be extended to include the delivery of content to end user.

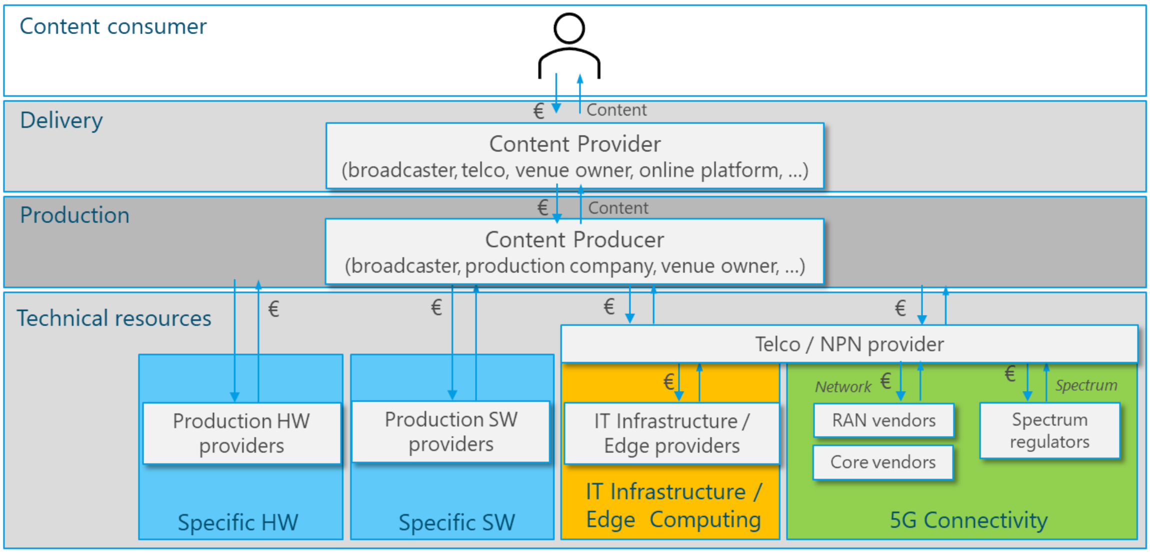

Figure 3: The extended model - from the acquisition of technical resources to content delivery to the end user

The model above allows business analysis to be carried out for any production use cases, either in terms of roles that different actors play in the value chain, their business relationships, content flow, or a flow of revenues.

The three 5G-RECORDS use cases have been described following this model. This chapter presents the description and insights for each use case.

If required, the model could be further refined e.g. for value chain optimisation, resource allocation, or to analyse the impact of regulation on the value chain.

2.2 Use case 1: Live audio production

In a typical live audio production, such as a concert, musical, theatre or studio performance, one or several artists are performing (i.e., acting, dancing, singing, or playing music instruments) live either to create content that can be used later or to entertain an interested audience that can be live on site or follow the content live via stream. Figure 4 depicts this scenario as well as the key enabler technologies that allows its deployment within 5G-RECORDS.This scenario has considered four roles.

- Role A: main user of any on-stage equipment.
- Role B: the producer that is responsible for any further creative processing of captured audio data to create a final consumable product.
- Role C: Distributor that delivers the product for example via local PA system, broadcasting, or internet stream by a distributor.
- Role D: the consumer.

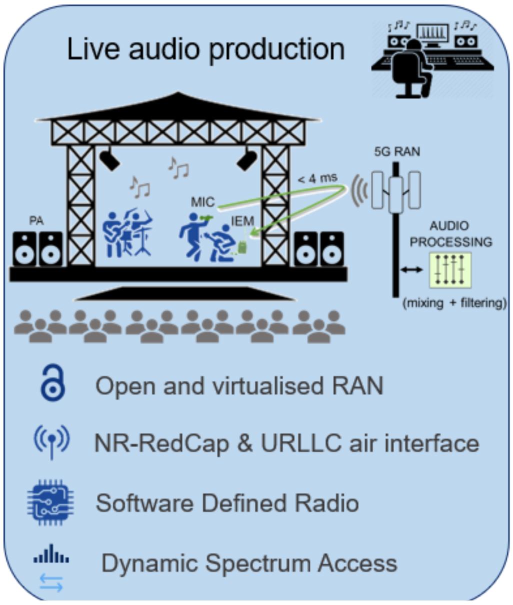

Figure 4: Use case 1 - Key enablers

2.2.1 Requirements

For a live audio production, equipment from multiple vendors/providers is needed.

A performer on the stage typically needs:

- Wireless transmitters for the performers on stage. This could be a handheld microphone, a bodypack transmitter with a lavalier/headset microphone connected or an instrument transmitter.
- IEM receivers to hear an individual monitoring mix.

In most productions there will be more than one performer on the stage.

There is an additional need onsite for:

- PA systems to provide the audio to the audience,
- mixing consoles to generate IEM- and PA- mixes,
- lighting systems & effects,
- microphone receivers,
- IEM transmitters,
- antenna systems to transmit/receive all wireless signals.

There is a variety of different scenarios for live audio production: some of them use fixed installations while others are nomadic setups which are exclusively configured for a specific event and a limited period of time.

Especially for nomadic setups an easy and fast configuration is essential because this defines how much time is needed prior to the event which could, therefore, influence the overall production cost. From a business perspective, there is of course a cost requirement that potential 5G wireless systems must meet to compete with traditional wireless audio devices.

Since there might be other (wired) audio systems like a PA system or remote production tools involved interworking of transport and control protocols is important to allow seamless workflows. The native IP support of 5G technology might cover this demand.

A wireless system for a professional live audio production must fulfil a number of technical requirements to deliver the expected performance. These requirements are listed in the following tables, which are explained in detail in deliverable D2.1. [2]

Table 1: System parameters in Use case 1

Characteristic system parameter		**Comment**
Mouth-to-ear latency	< 4 ms	Maximum application latency tolerated by a live performer between their analogue audio source (wireless microphone) and their analogue audio output (IEM). It includes two times network latency + audio processing time. Ideal latency would be < 2ms as 2 to 5ms latency can cause change in tone. However, <2ms may not be achievable.
Audio data rate	2.4 Mbit/s	Different user data rates per audio stream need to be supported for different audio demands (e.g. compressed vs. uncompressed audio).
Device must be remote-controllable	≤ 50 kbit/s (Control data rate)	Data rate per control link (UL/DL).
Number of audio streams	20 microphones 10 IEM	Simultaneous audio links.
Service area	30 m x 30 m	Event area, indoor and outdoor. Typical heights of indoor stages: 5 m to 10 m.
User speed	≤ 5 km/h	Devices/artists can move.
Reliability	99.9999%	A high reliability for the audio transmission is needed to guarantee that no noticeable artefacts will be introduced to the audio signal.
Security / Integrity	The audio application data is encrypted	In some of the applications.

Table 2: Performance KPIs in Use case 1

KPI	Limits	Description
Network latency	< 1 ms	Consists of E2E latency and transfer interval. It is assumed that 2ms are left for audio processing within the mixing console. This is the latency from the application layer on UE side to the application layer on a device connected via UPF to the 5G core (or the other direction).
Synchronicity	<500 ns	The absolute difference between any synchronized clock in the network and the time master must be below the limit.
Packet error ratio	$< 10^{-6}$	The packet error ratio (PER) of the system shall be below 10^{-6} for a packet size corresponding to 1 ms audio data. Further, a consecutive minimum continuous error-free duration ≥ 100 ms must be ensured. This is because, to make packet errors inaudible, error concealment is used at application level. Every concealment is capable of handling one specific kind of error distribution.

2.2.2 Business Relations

Live audio production could be realized in a variety of different deployments using 5G cellular technology. It is assumed that – to achieve the forementioned challenging requirements – a non-public network is needed.

Below we describe three different deployment scenarios and the resulting business relations.

In deployment A (Figure 55) a venue owner produces the concert and owns all the necessary equipment. The PMSE equipment (mics, IEMs, speakers) is provided by PMSE equipment manufacturers while the private 5G network is provided by a company specialized on private 5G networks. The venue owner will take care of a spectrum licence from the national regulator to operate their private 5G network at their location.

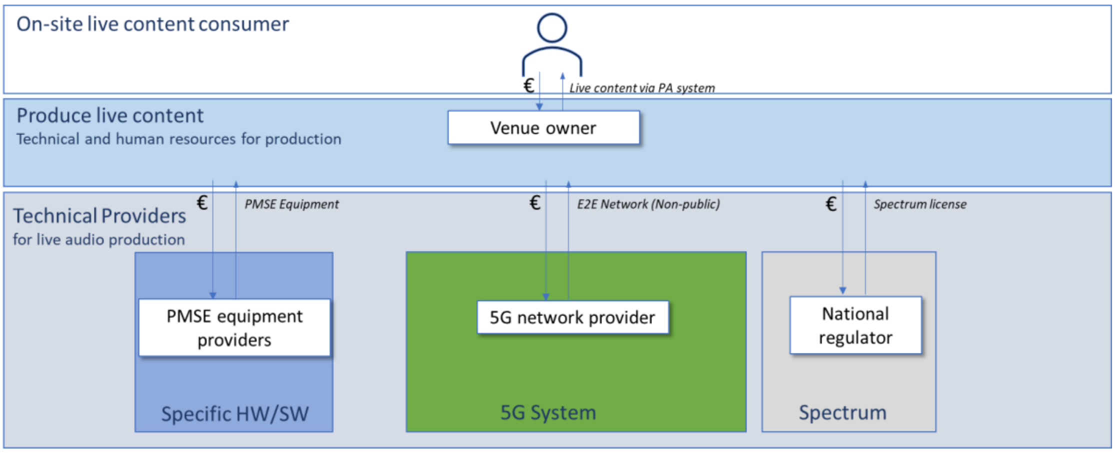

Figure 5: Use case 1 - Deployment scenario A

Figure 6 shows deployment scenario B in which the producer of the concert is not the venue owner. Scenario B differs from scenario A in terms of the network provider. The private 5G network is rented from a telco operator who also temporarily provides the spectrum for the production. One option of this deployment could involve an PNI-NPN.

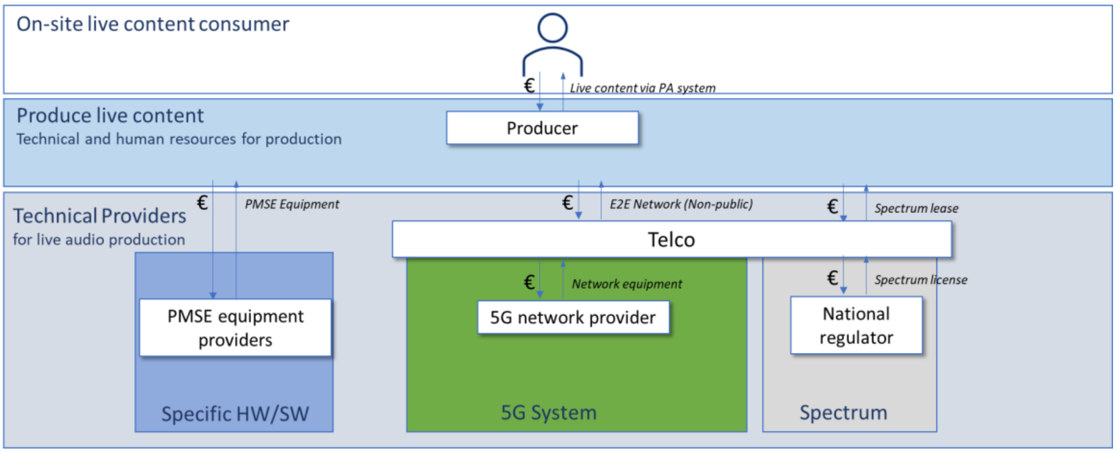

Figure 6: Use case 1 - Deployment scenario B

Deployment C (Figure 77) shows again a scenario where the producer does not own the venue. In contrast to scenario B, the producer deploys their own private 5G network at the production site. Since the producer is not the venue owner, a permanent frequency lease from the national regulator for that venue would not be appropriate. Instead, the producer obtains the spectrum via a shared spectrum access provider only for the duration of the event.

All these business relations could involve a one-time purchase of equipment or any kind of rental model.

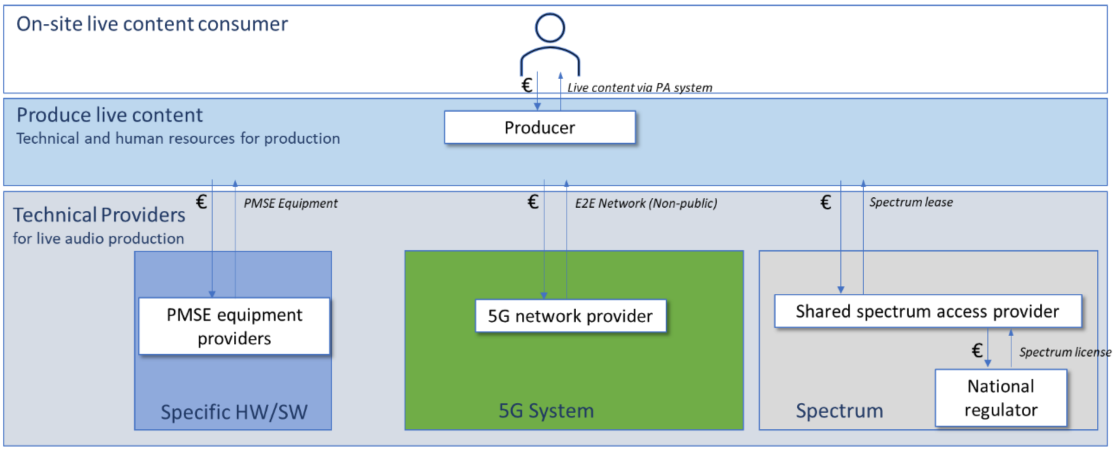

Figure 7: Use case 1 - Deployment scenario C

2.3 Use case 2: Multiple camera wireless studio

This use case is based around multi-camera audio and video production in a professional environment. This could be either in a fixed studio or deployed as part of an outside broadcast facility. It will enable existing technologies such as COFDM radio cameras to be replicated in terms of performance and capabilities by using 5G technology. In addition to the basic functions of sending video over a wireless link, it is anticipated that the return path will be utilised to send traffic in the reverse direction such as camera control, tally, prompting and talkback. This means that we can have a single link where multiple unidirectional links have been required in the past. In addition to this network slicing may be deployed to manage the different traffic on the network. This will prioritise the programme video over other traffic such as reverse video.

The use case will require radio links to integrate into existing studio facilities and perform with or exceed similar characteristics of existing production workflows. This requires the use of tools to integrate with protocols such as NMOS and ST2110 as well as control protocols for both network functions as well as UE functions.

There are two models for the facilities deployment which can be categorised as either fixed or nomadic. Fixed installations would include studios or other locations where a permanent network is installed and productions use it on a case by case basis. Nomadic installations would be used on outside broadcasts and would be rigged and derigged for a specific event. Typically, a fixed deployment would require longer term spectrum availability and management than a nomadic deployment which would be put in for a specific event and then removed at the end of an event. This could be for a period between 1 day and 1 month and so requires business and regulatory models that support this.

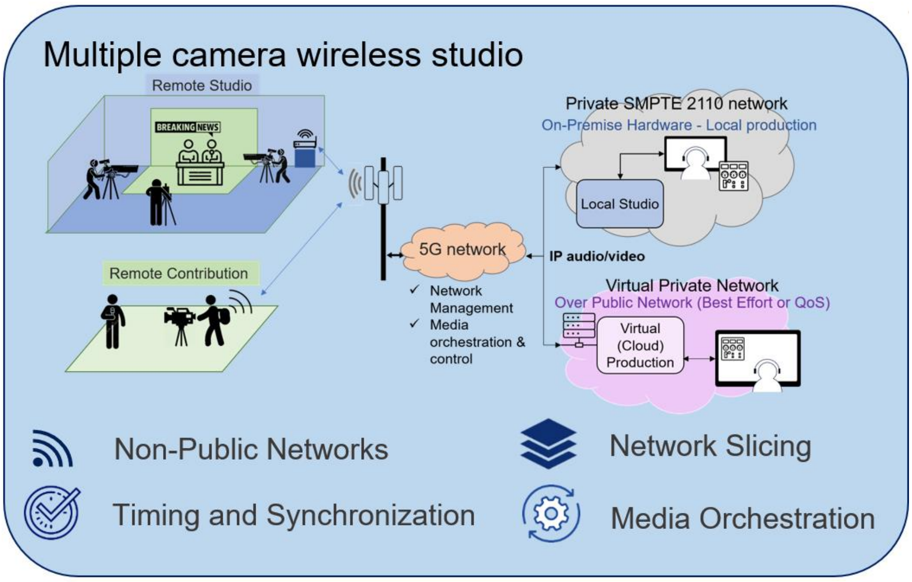

Figure 8: Use case 2 - Key enablers

A broadcaster will usually commission a programme, and this will then be passed to a production team. This team may be internal or external and are responsible for the complete delivery of the output. This will be split into editorial functions and technology and coordination. It is the responsibility of the production manager to manage the budget and allocate resources to meet the editorial ambition within the programme budget. The Production Manager will be responsible for specifying, booking and coordination of the technical facilities.

Technical facilities are usually provided by a studio or facilities company which is contracted by the production team. This facilities company will usually provide all the technical capabilities required by the production and will scale depending on the size of the operation. Specialist services may be subcontracted to third party experts, and it is not unusual to have multiple facilities providers supplying different services such as audio, video or RF management. Services may not be available on site for the whole of a production period, for instance lighting and sound may rig before cameras and comms services may only be on site for the duration of the live event and not for any rehearsal.

Technical services can be broken up into two main areas: engineering and operations.

Engineering will be the provision of the services and rigging and support of the technical facilities. This is coordinated by the engineering manager who will be responsible for all the technology for any particular production. If multiple venues are required there will an engineering manager allocated to each location.

Operations are the team who operates the technical equipment and usually reports to the Director who is responsible for selecting shots and locations. These staff are responsible for the control of the technical equipment and provide services such as camera operation, sound mixing and communications. They are often freelance and employed on a case-by-case basis.

Increasingly, we are seeing remote and hybrid production models which mean that the teams are split with some functions such as camera operations happening on location but others such as vision mixing being done from a different location.

On site provision of specialist kit is either from the facilities company and extra kit is hired from specialist hire companies. Cameras, audio, communications, RF and lighting may all come from separate specialist companies and will be configured by the engineering team before being handed over to the operations team.

RF on site can often be complex. On large events such as multi-sport games or music festivals it is often necessary to coordinate RF allocation across multiple users. RF is used for audio, cameras and control of kit and frequency bands vary from VHF, UHF and microwave. This is allocated by the local regulator and on large events an RF specialist will ensure the correct operation of all radio equipment.

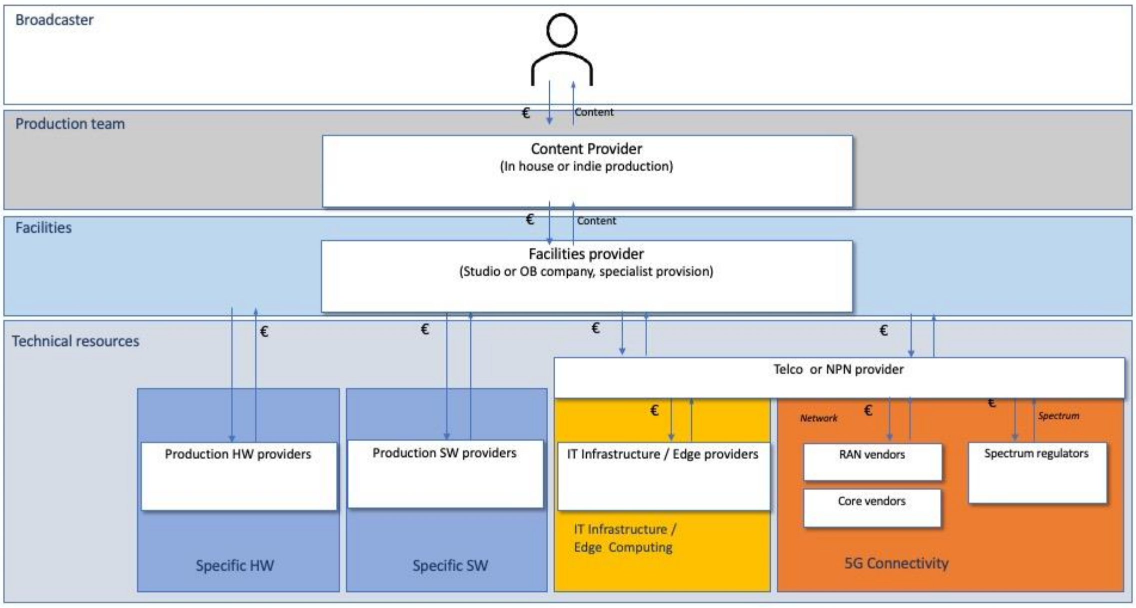

Figure 9: Use case 2 - Example deployment scenario

Different types of production have different requirements to support their operations and this can be seen in Table 3.

Table 3: Mapping of the requirements onto production types in Use case 2

Production Type	Cameras		Microphones		Type of IP network	Service areas	UE Mobility	Type of content	bandwidth		Latency		Duration of event (rig produce derig)
	Wired	Wireless	Wired	Wireless					UL	DL	UL	DL	
News Studio	5-6		10	5	wired	Studio 100m2	static	HQ talking heads	10	10	low		permanent
News OB	2-3	1-3	1	5	SNPN	Outdoor 500m2	5 m/s	Talking heads, reporting	10	10	med		Nomadic (<1 day) (fast deployment unplanned
News contribution		-1	1	2	PLMN	Long distance	nomadic	Talking heads	10	10	med		Nomadic (<1 day)
Magazine OB	2-3	1-2	2	5	SNPN	Outdoor 500 m/s	5 m/s	High quality talking heads, potentially more detail	20	20	med		Nomadic (1-2 days) (planned)
Sport OB (stadium)	10-40	2-5	>10	>10	SNPN	Stadium (field of play and touch lines)	5 m/s	Fast moving high detail	50	50	low	low	3 days to 2 weeks (highly planned)
Sport OB (wide area)	5	10	>10	>10	PLMN and mobile SNPN	Ski slope, cycle race, marathon	30 m/s	Fast moving high detail	20-50	20-50	low	low	2 weeks (highly planned)
Sport Pres	2-3	1	1	2	SNPN	Pop up studio (100 m2); Outdoors (500 m2)	static	Talking heads	20	20	med	med	1 -2 weeks (highly planned)
Light Entertainment	10	2	>10	>10	SNPN	Studio 1200 m2	5 m/s	Complex, high detail	50	50	low	low	3 days (planned)
Live Events	40	5	>10	>10	SNPN	Arena 5000 m2	5 m/s	Complex high detail	50	20	low	low	2 weeks (highly planned

2.3.1 Multicamera Remote Contribution Scenario

In this chapter the *multicamera remote contribution* scenario over 5G networks is analysed from the business point of view. This scenario aims to build up a flexible, nomadic, fast-setup contribution system able to exploit 5G network characteristics.

This scenario is mainly built supporting a live event (e.g. sport, entertainment) contributing to backstage and parallel distributed events in the same context of the main covered event.

Although commonly used as a news contribution use case this technology can also be used to cover a variety of live events staged over wide areas. Examples include sporting events such as marathons and cycle races which may be in urban environments. Events may include the national celebrations, cultural festivals and music events. Coverage needs to be mobile, reliable and flexible over the full extent of the production.

To illustrate this we have an example scenario which assumes 4 contribution teams, each with camera operators and presenters or performers. Contributions will be received and passed to a main control room. Additional production facilities may be located in the cloud.

In terms of signals exchanged in a typical remote production scenario, each remote presenter (or performer) is equipped with:

- A radio microphone to transmit audio to a receiver, usually attached to the camera. This is a low latency high quality audio signal and is then embedded with the pictures in a one way uplink;
- The intercom audio, also known as IFB (Interruptible Fold Back) for real time audio communication with the presenter or performer, typically originated in the production control room (downlink).

Each camera operator is equipped with:

- A full HD/ UHD professional camera (and camera rig): this is the source of the video and audio to be transmitted to the production control room;
- The intercom equipment: to manage the communication to/from the production control room. The intercom is generally used by the director to communicate instructions to the camera operator. Typically this is two-way, although camera operator-to-director communication is less frequently used;
- The radio microphone receiver for the audio from the presenter or performer;
- A 5G bonded video device: 5G equipment able to connect and exchange audio-video data with the 5G cell.

The production control room is equipped with:

- A bonded video HW & SW server to grant the data receiving / exchange from/to remote teams;
- The production control room intercom management system;
- The video mixer and all equipment for the management and recording of different sources.

Signals that are carried out by the 5G network are:

- Low Latency HEVC (High Efficiency Video Coding) coded video full HD/UHD with a TV production level quality, typically a minimum of 20Mbps (audio current default is AAC (Advanced Audio Coding) 192 kbps total for both 2 audio channels/single stereo) from the 5G video transmission unit to the control room;
- Real time AAC Audio with bitrate 192 kbps from the journalist/performer to the control room for the mixing management, embedded into the Full HD video stream from the camera to the 5G video transmission device;
- Real time bi-directional audio for the intercom between remote production staff and the production control room.

When the number of video sources is too high to be managed by a single control room an additional control room and mixer, perhaps cloud based, can be used to select sources arriving at the main control room.

Table 4: Technical (service) requirements in the multicamera remote contribution scenario

	Number	Type
Cameras	4	HD 1080p50
Microphones	4/8	Wireless
Smartphones	4	An intercom App for contributors
Integrated Intercom	x4	For the camera operator
Technical Support		Online/Onsite from the service provider
Receiving Server	4 input	In the main control room Input: DMZ IP connection Output: SDI or SMPTE 2110
(Optional) Mixer in the Cloud		

Table 5: Network requirements in the multicamera remote contribution scenario

	Requirements	
Upload bandwidth	4x20 Mbps	Bonding feature if available
Download bandwidth	4x1 Mbps	Intercom + other services (e.g. return video preview, additional Ethernet link)
End-to-end latency guaranteed	< 1 s	Glass to glass
Network latency	< 20 ms	
Mobility	Very slow / slow < 60 km/h	
Slicing	If available	QoS and Billing

Business analysis

In this scenario mapped into the ecosystem of the project we can evaluate the revenue exchange between different actors that could be part of the whole described system.

Considering that the transmission to the final user (and related business aspect) is out of scope of this use case, we can summarize revenue exchange in this type of schema:

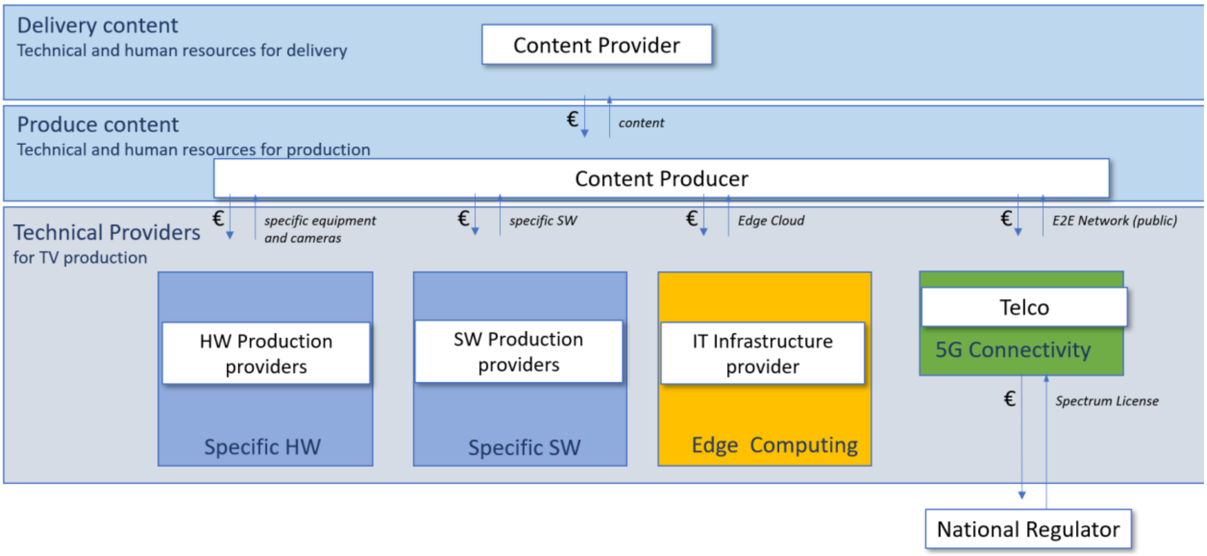

Figure 10: Use case 2 - Example deployment of the multicamera remote contribution scenario

2.4 Use case 3: Live immersive media services

This use case considers a real-time end-to-end FVV system including capturing, 5G contribution, virtual view synthesis on an edge server, 5G delivery, and visualization on the user's terminal. The system will generate in real-time a synthesized video stream from a free-moving virtual position. An FVV system generates synthetic views of a 3D scene from a virtual viewpoint chosen by the user (yellow camera) by combining the video information from several real (red, green, and blue) reference cameras.

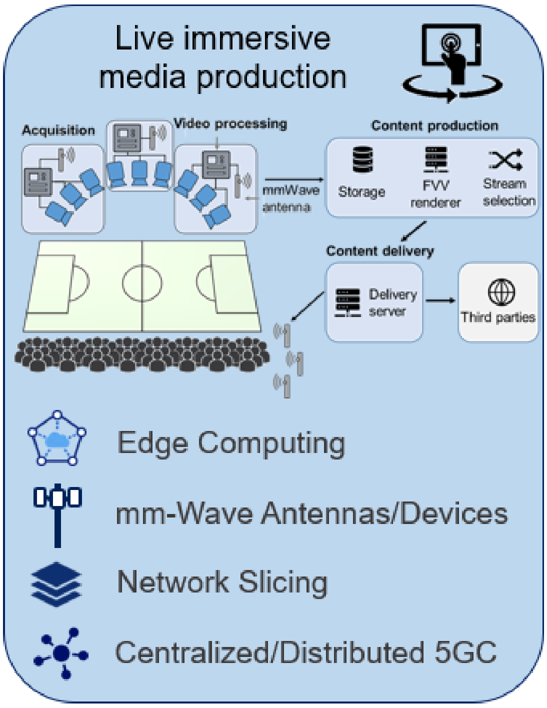

Figure 11: Use case 3 - Key enablers.

The proposed system builds upon an existing FVV prototype called FVV Live conceived for simple videoconferencing scenarios under controlled lighting. Instead, the envisaged use case targets, among other possibilities, the real-time immersive capture of sport or entertainment events (such as a basketball game, a dance performance, or a concert). It will be possible to reproduce content both live and offline (replay) of free-viewpoint trajectories around one specific area of the event (e.g., one basket of the court, the downstage, etc.). The content can then be distributed not only to people attending the event (local delivery), but also to third parties. Finally, it must be stressed, once more, that the position of the virtual camera can be freely chosen at any time.

2.4.1 FVV production scenario

The scenario assumes the FVV production of a live event (a concert, a sports match). An array of physical cameras is deployed around the scene of interest: stage, basketball key, gymnastics apparatus, etc. The image streams captured from the physical cameras are sent to an edge computing facility, where an intermediate point of view is generated, providing the functionality of a virtual camera that can be moved freely, remotely controlled by an operator using a production console. Finally, the rendered view is used for two purposes: *i)* it is included in the production pipeline of the live event, *ii)* it is streamed to live users attending the event to provide different views of the scene.

The focus of this FVV production scenario is providing maximum flexibility in the production value chain, from three perspectives: *deployment*, *production*, and *delivery*.

The *deployment* and calibration of the FVV cameras, together with the attached capture servers, can be done in a few hours, therefore being suitable for sporadic events (i.e., it is not assumed that the cameras are permanently installed in the event venue). The deployment of the FVV system must be accompanied by the commissioning of enough network and computing resources, either in a PLMN or with a nomadic NPN.

With one single set of physical cameras, it is possible to render as many virtual cameras as required, if there is enough computing power in the edge cloud. This gives more flexibility to the *production*: different content producers can use the same camera feed to generate completely different camera motion patterns, without needing to have access to the physical cameras.

Finally, these services are not only intended to be *delivered* to end users at home, but also to be included as added-value services to people attending the event onsite. E.g., instant replay of interesting game actions (for sports), or freedom to focus on a wide number of different parts of the scene (for concerts), can be added as part of the whole experience.

2.4.2 Requirements

The following signals are exchanged in the 5G network:

- RGB + Depth stream of each physical camera (uplink), in 1280x720 or 1920x1080 resolution, at 30 frames per second, compressed in H.264 (constant rate for RGB, lossless compression for depth). Each capture server handles and uploads the signal from three cameras, i.e., for each M cameras there are M/3 servers.
- Rendered view (downlink) and camera control signalling (uplink) for each of the production consoles.
- (Optionally) Rendered / produced view (downlink) for each of the end users attending the live event.

The following virtual network functions (VNFs) run in the edge cloud:

- One common Stream Selector VNF which receives the streams from the physical cameras and replicate them to the View Renderers.
- Several (N) View Renderer VNFs, each one having access to GPU computing power, to generate the virtual view.
- One common Media Delivery VNF, to deliver the rendered view to local users (downstream) and to remote content producers (upstream).

Each of the N View Renderers is controlled by a Production Console, running specific control software over a standard computer (e.g. a laptop).

A small deployment was assumed with 9 cameras, 3 capture servers, and 2 virtual renderers in parallel.

Table 6: Equipment used in FVV production scenario

Resource	No. of equipment	Type
Cameras	9	1920x1080 stereoscopic camera (e.g. ZED)
Capture Servers	3	Intel desktop with GPU capacity
UEs	5	5G modems (e.g. Askey RTL3800)
Production Consoles	2	Intel laptop (generic)

With that, the following onsite resources are needed:

Table 7: Network resources in the FVV production scenario

Resource	Guaranteed	Comment
Uplink bitrate (high priority)	150 Mbps	Per capture server
Downlink bitrate (high priority)	20 Mbps	Per production console
Downlink bitrate (best effort)	5 Mbps	Per local end user
End-to-end latency	40 ms	RTT UE to MEC
Backhaul connectivity	1 Gbps	
Quality of Service	QCI6 / AF41	For high-priority streams only

Table 8: Computing resources in the edge cloud in the FVV production scenario

Resource	Guaranteed	Comment
Virtual CPUs	32	Intel Xeon cores
Virtual GPUs	2	NVidia Tesla T4 or equivalent
Memory	96 GB	
Disk	400 GB	SDD

2.4.3 Business Relations

The production and delivery of FVV content can happen under a variety of combinations of technical and business actors. From a high-level perspective, the revenue exchange between them can be modelled by the following schema:

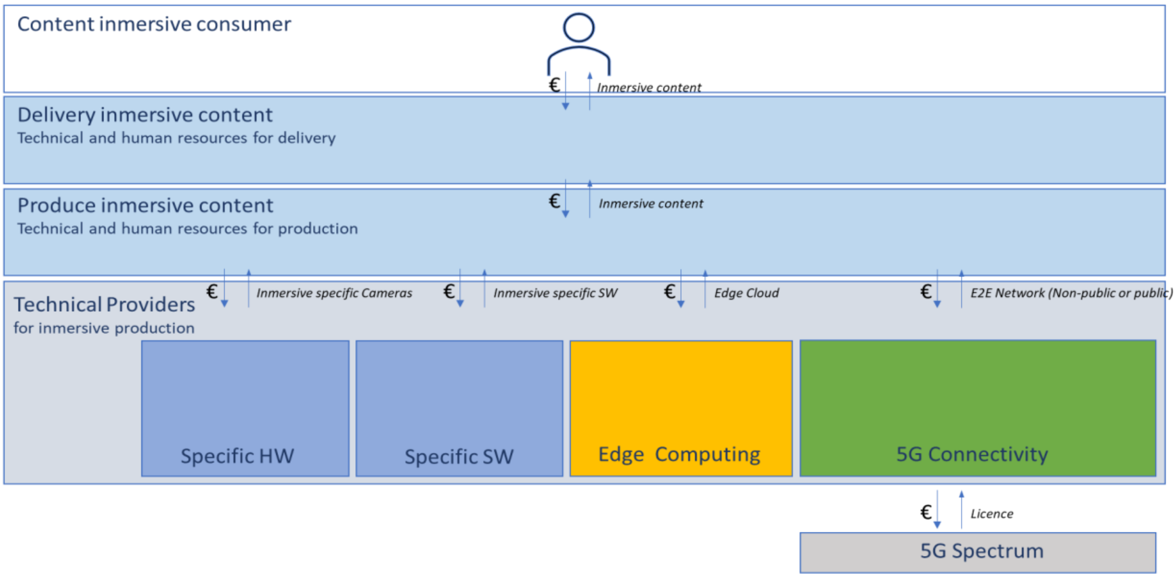

Figure 12: Business roles in the Use case 3

Four types of roles have been identified:

End Users: They consume the immersive content (Free Viewpoint Video), either on-site or off-site.

Deliver immersive content: They deliver the immersive content to the end user, either as an added-value service to the live event (on-site users), or as an additional content item within a content delivery catalogue (e.g. streaming platform subscription).

Produce immersive content: They use the video streams generated from the cameras to produce a Free-Viewpoint Video content. Its functions comprise: deploying and configuring the physical cameras, deploying the production VNFs on the edge computing facility, run the production console to generate the virtual camera streams, and integrate those streams, where appropriate, into the event production pipeline.

Technical Providers: They provide the required technology to support immersive media production:

- Specific production HW: stereoscopic cameras (e.g. stereolabs ZED), capture servers, production consoles, and 5G UEs.
- Specific production SW: Free-Viewpoint Video software to run on capture servers and on the VNFs: FVV Live software from Universidad Politécnica de Madrid.
- Edge computing: GPU-enabled computing capacity to run the production VNFs described above.

- 5G connectivity: it can be either public or NPN, in which case spectrum licensing is required. Due to the high-rate requirements of the scenario, at least 200 MHz of mmWave spectrum (Frequency Range 2) are required.

The industry and the different companies can adapt their models to assume one or more roles inside this value chain. Here are a set of common situations, but the variety to choose an option will relate to the ambition of each company and the regulatory possibilities in each country.

To further analyse the different options, and considering the flexibility included in this use case (as described in 2.4.1), we will break down the value chain into three layers: deployment, production, and delivery.

Deployment

For the lower layers, where all the technical assets are situated, there could be many options of who are the actors assuming one or more roles. Regarding the provisioning of infrastructure for the production (5G and edge), two options have been considered in the use case: using a public network (“5G Theatre”, see D2.1) or a NPN (“5G Festival”).

In the “5G Theatre” scenario, it is assumed that the production is done in an area where there is existing 5G and edge infrastructure provided by a Telco. Then the producer needs to rent cloud and connectivity capacity, to run the appropriate production software (as well as installing and operating the appropriate HW and SW, i.e. cameras and capture servers, onsite).

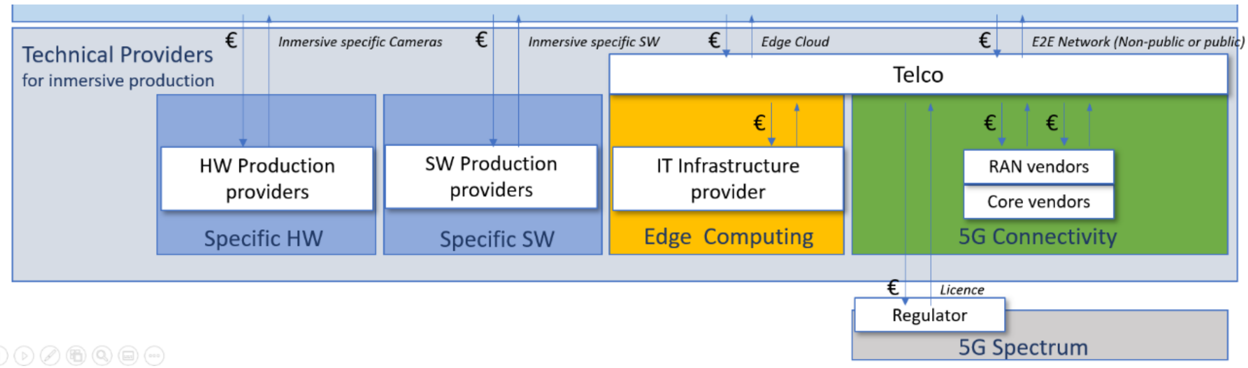

Figure 13: Use case 3 - "5G Theatre" scenario

In the “5G Festival” scenario, it is assumed that the production is done in an area without sufficient 5G coverage and/or access to edge resources. In such case, an additional actor is needed to deploy and configure an NPN with edge computing capacities to support the FVV production service.

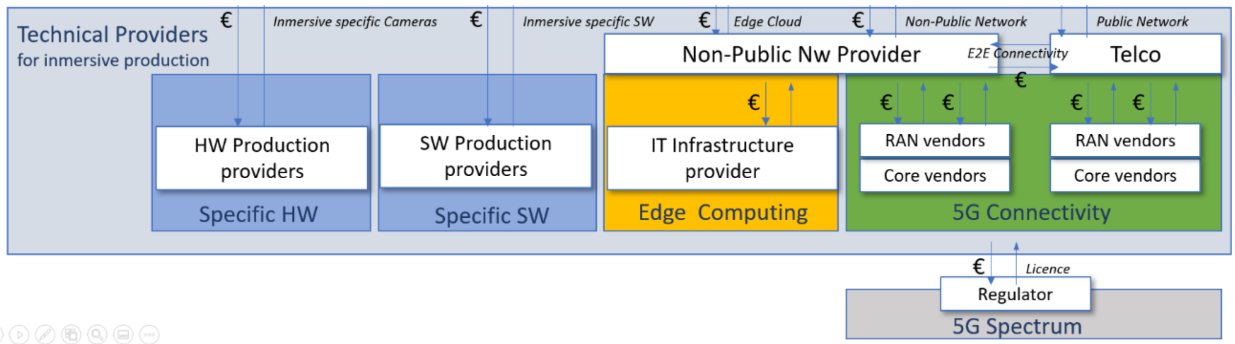

Figure 14: Use case 3 - "5G Festival" scenario

Production

In the previous diagrams, it is assumed that the content producer is individually acquiring the specific hardware, software, and infrastructure. However, there are models where the service is completely provided by a service provider, removing all the complexity to the owners of the content. This service provider will provide access to one or several virtual cameras to the content producer, abstracting from the technical complexity underneath.

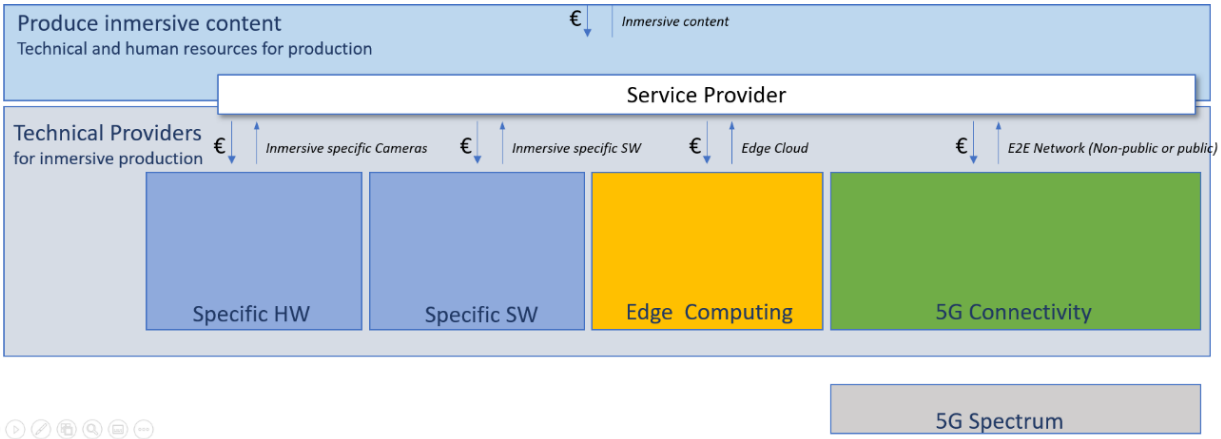

Figure 15. Use case 3 - Production segment

Delivery

Finally, on top of this value chain, there could exist many possibilities as well, being one or more companies who are the producer, deliver or own the content. For example, in case of the immersive content recorded in the venue and delivered in the same venue, there could be business models where the venue owners are the ones situated in all the upper layers of this model of value chain.

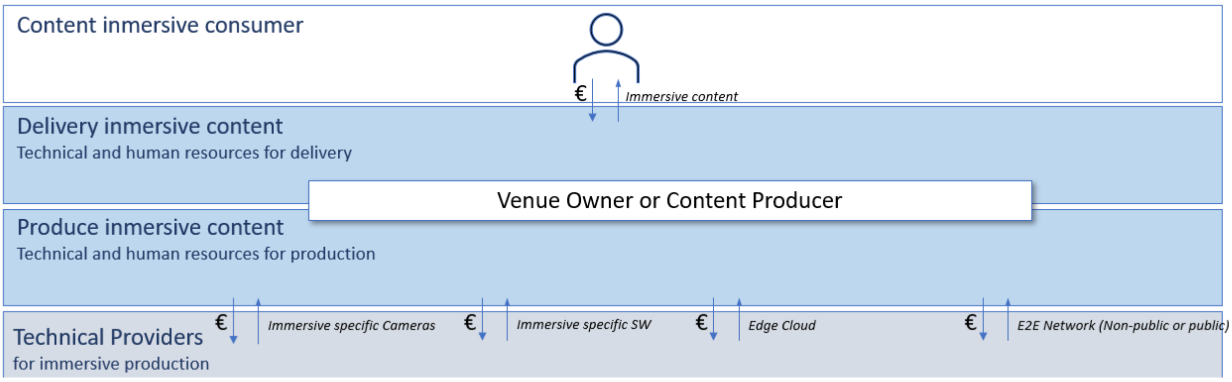

Figure 16. Use case 3 - Delivery segment

2.5 Evolution of production use cases

Use case 1 - Live Audio Production

Partly due to technical limitations of 5G technology and availability of 5G components, many business aspects are not yet explored in the context of very demanding use cases such as live audio production. A major open question is the commercial attractivity of a potential solution based on 5G compared to today’s highly specialized solutions. Answering this question is not straight forward since a potential 5G solution is not directly comparable to today available solutions in many aspects, e.g., scaling will follow different paradigms as 5G technology is a system-based approach. Also, it could be that 5G-based solutions will only become commercially attractive when considering synergistic effects by delivering multiple use cases in the same wireless network. General commercial pressure in media production will continue driving the exploration of such questions.

Use case 2 - Multimedia production

In the context of multi-camera remote television production, exploiting 5G networks can have a strong impact to the typical workflow of media production and technical facility providers.

Remote and distributed production is extremely challenging, and requires very low and stable latency, an ultra-reliable connectivity and very large bandwidth capacity to match their existing, creating multi-camera programs in real time with stability and very low latency capabilities.

5G, used in conjunction with network slicing and NPN technologies, could provide enough network capacity for the audio and video production workflow. There is a promise of guaranteeing network capacity in an economically viable way. To support the economic viability there are dependencies on the regulator, the local mobile network operator strategies as well as the competitive landscape. Additionally, broadcasters may be able to build and operate their own small scale 5G NPN networks that support different production scenarios.

This has some advantages over existing solutions by reducing the number of radio links required. For instance a COFDM solution requires a 1 to 1 relationship with the transmitter and receiver where as a 5G network can accommodate multiple cameras on a single network. We can also reduce the number of additional wireless links for activities such as camera control, tally and reverse video by using the 5G downlink.

As 5G network functionality improves and media production evolves we expect to see a number of key enablers to become available. This includes the distribution of PTP in 3GPP Release 17 as well as services such as enhanced uplink which will enable further integration of 5G networks into media production use cases,

Use case 3 - Live immersive media services

5G networks enable demanding content production use cases, such as live immersive media services. All immersive content production services share a common technical requirement: they are greedy in uplink capacity. Producing immersive content requires sending high-bitrate streams to the network, sometimes exceeding the capacity of existing 5G deployments. As we have seen in 5G-RECORDS, existing capacity enables a first generation of nomadic free-viewpoint-video production services. However, this high demanding and required services will demand from connectivity providers to ensure the desired quality. The next generation of 5G and 5G-advanced networks, aimed at industrial scenarios, need to adapt their commercial models to enable more advanced immersive media services.

That could be part of the reason why commercial deployments for immersive media are still scarce, focusing only on demonstration capabilities, mostly related to real time capture and delivery of human avatars, and free-viewpoint-video replay of sport scenes, only for selected competitions (NBA, tier-1 football leagues, Olympics). Even so the user demand is there and the interest for these new services is increasing. Therefore, we are experimenting an increase of the variety and availability of those services, which day by day help the immersive media technology mature, the networking uplink capacities increase, and the appropriate commercial models be developed.

3 Business validation of different 5G network configurations in content production

5G can be deployed in different ways and performance of a 5G system strongly depends on the chosen network configuration. From a commercial point of view, there are broadly two different types of 5G networks:

- Public mobile networks (PLMN) operated by an MNO and designed to provide a standard set of services such as voice and broadband data communications. These services are provided to the consumers and business users on a best-effort basis. Networks have a large area coverage and traffic is typically asymmetrical in favour of downlink.

  Technically, PLMNs could support traffic prioritisation, hence providing to some degree guaranteed QoS. The latest 3GPP specifications also include network slicing. However, these QoS enhancing features are only just becoming commercially available in the current 5G networks.

- Standalone non-public networks (SNPN) designed to meet a specific set of technical and operational requirements. SNPN can be deployed and operated by content producers themselves or by a third party. Typically, these networks provide local coverage, whether on permanently (e.g. in venues where productions take place regularly) or on a temporary basis.

  The main advantage of SNPN for content producers is the ability to ensure the required QoS, flexibility, and security.

These network configurations are described in detail in the deliverable D2.2.[1] The key insight is that the performance of a 5G network strongly depends on a network configuration, the implemented set of functionalities, and the spectrum used (the amount of spectrum, the frequency band(s), UL/DL ratio and frame structure).

It should be noted that all commercially available network configurations are used in content production use cases. However, they are not interchangeable, i.e. not all network configurations are capable of meeting the requirements of all use cases. This is illustrated in chapter 2 above where possible implementation of the three use cases are described as follows:

Table 9: Mapping 5G network configurations onto 5G-RECORDS use cases

	Best-effort	Traffic prioritisation	Network slicing	PNI-NPN	SNPN
Use case 1				✓	✓
Use case 2	✓		✓(LiveU)	✓*	✓
Use case 3	✓			✓	✓

* Use case 2 requires significant uplink capacity which is unlikely to be available in a typical public TDD network with the UL/DL ratio set in favour of downlink.[21] As the TDD frame structure in a public network cannot be adjusted to the requirements of the use case, the PNI-NPN would need to operate in a separate spectrum resource with a sufficient guard band as to avoid interference to the public network.

By choosing a particular network configuration a content provider also needs to accept inherent constraints in terms of QoS level, capacity, control, lead- and set-up time, extent of the coverage. This is illustrated in Figure 17 below.

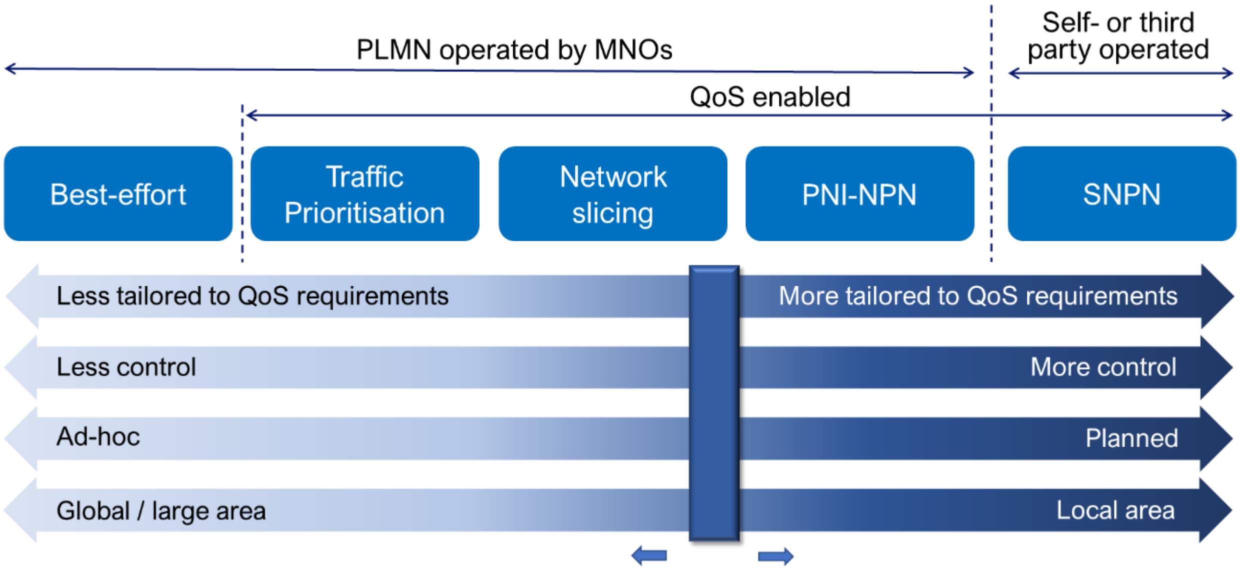

Figure 17: 5G Network configurations used in content production

Ultimately, a choice of network a configuration from content provider's perspective will be determined by the availability of a given solutions and an acceptable trade-off between different technical and operational requirements objectives.

One advantage of a 5G SNPN is the ability to slice the network for different services. For the purposes of this project we have looked at deploying network slicing to send signals with different levels of priority over different slices of the network. A complex production involves different signals (e.g. content related audio, video, and data, timing & sync, service links, remote control) which may have different QoS requirements and different priority. For example, an active camera and microphones have a higher priority than other cameras, microphones or other signals. Network slicing within SNPN allows to prioritise QoS for high priority streams such as the one from the active camera whereas streams from other cameras or ancillary traffic can be transmitted with a lower priority. This can be seen in Figure 18 below.

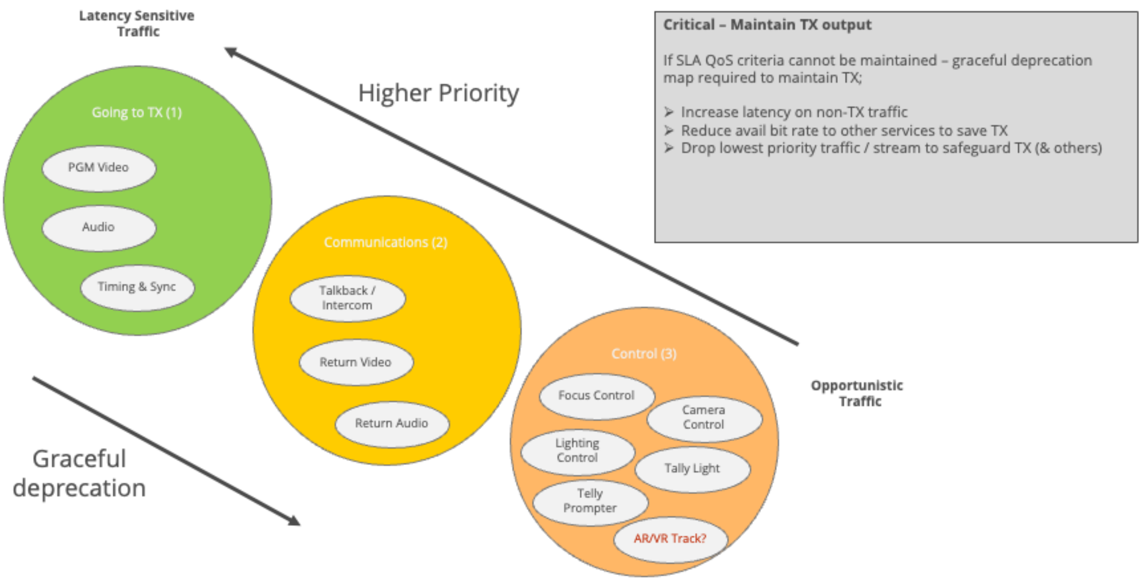

Figure 18: Traffic segmentation in content production use cases

The ability to differentiate between different signals according to their priority is also useful when the network capacity limitations require trade-offs with regard to their QoS. In such cases the higher priority signals can maintain the required QoS whereas for the lower priority signals the QoS may need to be degraded.

Network slicing is just starting to be rolled out on PLMNs on a limited number of MNO deployments. At this stage it is too early to explore the commercial opportunities in any detail but it is expected that similar QoS prioritisation may be possible.

4 Business validation of 5G components

In 5G-RECORDS, one of the most innovative elements are the 5G components that were developed or enhanced in the project. [3] Some of these components may have a potential to be developed into commercial products or services. As they have been optimised for content production use cases, this would facilitate the adoption of 5G in the professional content production sector.

The information in following text was provided by the partners leading the development of 5G components on the basis of their respective exploitation plans. The components are grouped according to the use case in which they are used.

4.1 5G components in Use case 1

Table 10: 5G components in Use case 1

Component	Category	Deployment location	In charge of
Local Audio Processing	End device	On-site	SEN
Audio User Terminal	End device	On-site	SEN, EUR
Remote Server	Media orchestrator & management Server	Internet	SEN
5G RAN (inc. Shared Access Client)	Network	On-site	ACC, EUR
5G Core	Network	On-site	CMC
Shared Access Server	Shared Access Server	RED Technologies premises	RED
Time Service	Time Service	On-site	SEN
Network Slice Management	Network Component	Cloud	CMC

5G Core

Cumucore has developed several new features on top of existing 5G core. They have implemented multi data flow capability and improved network slice management by adding graphical user interface. These features are now part of our regular product offering.

Network Slice Management

Networks slice management has been implemented as an application function (AF) on top of 5G Core. Network slice management AF has an open API that can be used to request specific dataflows from specific network slices for UEs or applications. Network slice management is now provided as a regular Cumucore product to our customers.

Shared Access Server

With the design and the development of the Spectrum Access System (SAS) for 5G-RECORDS, RED Technologies did enhance its expertise in its core domain, shared spectrum access, specifically with regards to spectrum leasing. Spectrum leasing is an essential and novel business opportunity in spectrum management. RED did demonstrate a reference implementation of spectrum leasing that can be adopted in licensed and shared spectrum in Europe but also in the US. In particular, we see business opportunities for CBRS (3550 - 3700 MHz) in the US and for the future pan-European 3800 - 4200 MHz frequency band currently being harmonized by the CEPT. We designed our SAS and its spectrum leasing feature in a way that is agnostic to the verticals using it, i.e., it was not designed to be specific to content production but can apply to other verticals such as industries or enterprises. Finally, being able to experiment under real-life conditions gives an undeniable advantage to RED Technologies for future deployments in Europe and abroad and constitutes a competitive advantage over competitors.

4.2 5G components in Use case 2

Table 11: 5G components in Use case 2

Component	Category	Deployment Location	In charge of
Media Gateway	Transport protocols conversion + codec capability + ST 2110 support	Where needed	BISECT
Media Operational Control Gateway	Intermediary between the devices on the 5G network and the applications that control and monitor them.	Where needed	BBC/BISECT
5G Network	Network	Aachen	EDD
5G Modem	Network equipment	Aachen	5COM
Encoder	Portable A/V encoder	where needed	EDD/Fivecomm
Master Control Room	Master Control, Switching Multiviewer, Recording, Audio Mixer, Replay, Playout, Graphics	Cloud or locally	EBU
LU800	Video tx + encoder	Aachen	LU
LU2000-SMPTE	Video rx + decoder	Turin	LU

Media Gateway

The main role of the Media Gateway (MG) is to adapt the media signals and to integrate the 5G network with the media production network, both when the latter is a SMPTE ST 2110-based production studio, or a cloud-based one. The MG supports the following formats:

- Video: HEVC, AVC, Uncompressed.
- Audio: Opus, PCM.
- Transport: Raw RTP, ST 2110, SRT, RIST

and is compatible with AMWA NMOS IS-04 and IS-05.

Media Operational Control Gateway (MOCG)

The MOCG acts as an intermediary between the devices on the 5G network and the applications that control and monitor them. The MOCG functions include:

- Media device registration
- Discovery of media devices
- Connection of media devices
- Configuration and Control of media devices
- Monitoring of media devices
- Synchronisation of media and data flows
- Authentication and authorization
- Resource management and provisioning

This work builds on the work of the Advanced Media Workflow Association's Networked Media Open Specifications (AMWA NMOS), adapted for the use cases of the project, and in particular using a messaging protocol (MQTT) that is suited to 5G networks.

5G Network

The 5G test network is hosted in the Ericsson Eurolab office in Aachen. The test network is a 3GPP Release 15 Non-Public Network (NPN), in which all control plane and user plane functions are hosted on-premises. It consists of a SA 5G core and indoor radio dot system solution for the RAN. The control-plane functions are shared with other 5G tests networks located in Eurolab; therefore, the hardware infrastructure is shared with other networks. The network provides the UE by internet connectivity and connectivity to MEC via the local breakout functionality. Ericsson uses The Enterprise Operations Support system (E-OSS) to control the network. The test network provides 100 MHz of frequency in the NR band n78 (3.7-3.8 GHz).

Modem

This solution, developed for fixed wireless scenarios, connects via Ethernet the video encoder component and connects to the 5G network via its external antennas. The 5G modem has simplified its electronics while minimizing the power consumption and cost. The 5G modem is formed by to main components in turn, which are the 5G module, and a Raspberry Pi 4 that comes with a Linux distribution and permits to setup and configure the modem in an easy manner. Both components are integrated together and included as part of the final product in a steal or plastic case (depending on the needs of the scenario).

Table 12: Modem specifications for Use case 2

Technical Specifications	Description
5G native mode	Both 5G Non-Standalone (NSA) and 5G Standalone (SA) modes are supported. Option 3x, 3a and 2 network architectures.
5G New Radio (NR) Release	Release-15.
Sub-6 GHz frequency bands	n41/n77/n78/n79/n1/n3/n5/n7/n8/n20/n28/n38/n40
Antennas	Up to 6 antennas (external or internal) to support both mid- and low-bands.
SIMs	Dual SIM.
Ports	1 Ethernet port.
DL&UL	Up to 2.5 Gbps in the DL and 900 Mbps in the UL.

Encoder

The main platform of the prototype is a NVIDIA Xavier Developer Kit which provides the necessary I/O ports and power to the components while maintaining small form factor and weight. For the SDI Input of any source the prototype uses a Magewell ProCapture 4K PCIe Card which is mounted on the PCIe-Slot of the platform and fixated on a prototype case. The modem is mounted below the Xavier and connected via USB, providing enough space for the antennas and the battery in the prototype. The prototype should have two possibilities to be powered. The first option is the utilization of the camera's battery pack with an adapter cable to the Xavier platform. In the second option a 12V battery is powering the Xavier Unit.

MCR

It was decided to use an independent software vendor's solution already available on the market, integrate it into the use case's setup and test its interoperability with all applicable components of the use case.

Grass Valley Agile Media Processing Platform (GV AMPP) was selected as a proper candidate for the function of the virtual MCR (V-MCR). It may be hosted on any of the three major public cloud providers' platforms:

- Amazon Web Services (AWS)
- Microsoft Azure
- Google Cloud Platform (GCP)

It also supports on-prem / private cloud deployments.

GV AMPP realises its functions in form of applications, each performing some specific tasks. The main functions are:

- Master Control Switching
- Multiviewer
- Recording
- Audio Mixer
- Replay
- Playout
- Graphics

We will be concentrating on the first two functions (switching, multi-viewer) for the trials.

LiveU800

The LU800Pro (LU800, s.d.) is a portable multi-camera all-in-one production-level field unit. Inside 5G-RECORDS project, it is used to encode and transmit video flows captured from cameras to 5G network. This unit has embedded an HEVC H.265 real time video encoder and 5G/4G cellular modems. This specific unit has connectors for external antennas and can ingest up to 4 A/V streams, encoded them and transmit them simultaneously. It has up to 4 internal 5G modems embedded inside and can connect to two additional/other external modems via the ETH RJ45 connection. The LU800Pro also support LiveU IP-PIPE, which is a bi-directional connectivity in parallel to the transmitted video for any type of IP communication.

LU2000-SMPTE

LiveU LU2000-SMPTE is a Bonded Video Decoder that receives the video from the LiveU field encoders-transmitters and outputs it over compliant SMPTE A/V out. The LU2000-SMPTE received the IP packets containing the encoded-transmitted A/V packets from the LU800Pro over the cellular and then the public network, decodes them, outputs to the Eth using an integrated Nvidia RiverMax SMPTE board, synchs to the studio master PTP clock for this, connects to the LiveU audio server for the audio capabilities (IFB and intercom) and to any IP device that needs to use the IP-PIPE that it can establish with the field unit. The LU2000SMPTE A/V output implement compliance with 2110-10, 2110-20, 2110-30. It does not support metadata over SMPTE.

5G-RECORDS UC2 has showed that 5G S-NPN can bring benefits to the public service broadcasters that will keep experimenting with real live productions and start exploring also PNI-NPN for media production. Commercial opportunities are there also for media and telco technology providers and integrators. It is likely that the components developed in this project will be exploited in other EU projects, in commercial trials/pilots and further improved.

4.3 5G components in Use case 3

Table 13: 5G components in Use case 3

Component	Category	Deployment Location	in charge of
5G-Ready FVV Live	Free-Viewpoint Video Capture and Production system	Smart Venue & Near-Edge	UPM

Compact 5G Network (+ MEC)	Network	Smart Venue & Near-Edge	NOK
Media Delivery	VNF	Edge	NOK
Delivery cloud & SDN	Network component	Edge	TID

4.3.1 5G-Ready FVV Live

5G-Ready FVV Live is the evolution of FVV Live to be able to operate over a 5G infrastructure. FVV Live is a real-time operation Free View-Point Video system that allows real-time navigation through a scene using a virtual camera. FVV-Live system has been modified to integrate with a 5G network and some of its components have been migrated to the cloud as Virtual Network Functions (VNF). Additionally, new modules have been developed specifically to allow the system to work on a 5G and cloud-based environment. Although there are other systems in the market that offer a similar functionality (e.g. soccer replays, basketball) they require more complex and expensive hardware and only offer delayed replays of short duration. Our solution operates continuously and live, and requires a modest investment, as it is based entirely on consumer electronics components.

4.3.1.1 Market demands

There exists a real demand for new types of content specially for immersive content. This can be seen in the fact that immersive technologies have steadily grown in 2021 in different markets: entertainment, gaming, health… In this sense, Free view-point video is one of those immersive technologies with high potential: broadcasters are testing free view-point video technologies over different scenarios such as the last Tokyo Olympics. The fulfilment of such demand requires at the same time to address technological limitations, such as the need of reducing deployment costs so that free view-point video technologies can be introduced easily on productions, or the development of technologies capable of being integrated on cloud-based environments. In addition, there are no real-time free view-point solutions in the market so far.

4.3.1.2 Market potential

The total global media revenue in 2017 was of $1,900 billion, accounting for a share of 2.5% of the global GDP, and forecasts indicate a 4.4% CAGR rise over the five-year forecast period through 2022.[4] In addition, the context of media is rapidly evolving, pushed by the convergence across entertainment, technology and telecommunications. In this sense, digital media can be considered the driving forces behind industry expansion today. New forms of content consumption involving more immersive experiences have a high economic potential. Regarding free viewpoint video, broadcasters are already testing this form of immersive content over different scenarios.

4.3.1.3 Competitive advantages

In this scenario, 5G-Ready FVV Live has some advantages over its competitors:

- Operation in real-time, unlike other systems that require long processing times.
- Cost reduction due to the consumer-electronics based elements.
- Portable and easily deployable system.
- Scalability. Due to the reduced costs of the system components and the deployment, it is possible to scale the system and adapt to the specific scene demands
- Easy integration in other workflows, i.e., 5G networks that allows new production paradigms on the cloud.

4.3.2 End-to-end 5G solution for live immersive content production: compact 5G network, MEC, media delivery

Customer experience both in physical and virtual events is changing radically with the introduction of new digital platforms and technologies. Next-generation venues for sports and events must include added values for the audience, as well as good connectivity for uplink and downlink workloads. As stadium/venue operators compete more fiercely in the global market, onsite and remote entertainment solutions are playing a growing role in their strategy.

In this context, a reference Smart Venue to consider is Nokia Arena, in Tampere (Finland). Opened in December 2021, Nokia Arena will host over a million visitors annually and is the main venue for the 2022 IIHF Ice Hockey World Championship. The venue has up to 15,000 seats and will be a home for innovative digital experiences and various major sports, culture and entertainment events and conferences. Offering state-of-the-art digital experiences at scale for customers of all ages and nationalities. Nokia Arena's digital screens altogether encompass 1.2 billion pixels, creating a highly immersive customer experience. The venue has also 5G and LTE connectivity for the audience and to support the needs for each event.

Figure 19: Nokia Arena - Example of a smart venue

In 5G-RECORDS, Nokia has designed an end-to-end solution for advanced media production and delivery, which can be applied to both NPN and MNO deployments in Smart Venues, either permanent or ad-hoc, where high capacity is demanded (e.g. concerts, festivals, sport stadiums, etc.). This *blueprint design* supports high throughput (with special focus in the uplink), low latency and high processing power, as well as flexibility for the deployment. This design is suitable for several use cases which include real-time video capture and processing workloads, such as smart venues, and it can be applied both to MNOs and NPNs. In particular, the compact end-to-end solution (5G network, MEC, media delivery) designed in 5G-RECORDS allow to deploy Smart Venue capacities, similar to the ones existing in flagship venues such as the Nokia Arena, into nomadic ad-hoc deployments for temporary smart venues, such as music festivals or sport championships in tier-2 stadiums.

The solution provides service simultaneously to two types of end users:

- **End users** attending the event. To them, standard connectivity is provided. Besides, extra services can be added, such as access to different points of view of the event. Dimensioning rules for end user service can be derived from smart venue solutions (e.g. Nokia Arena).
- **Content producers** providing Free-Viewpoint-Video services, as well as other wireless content production capabilities. Dimensioning rules for them can be derived from the technical results of 5G-RECORDS.

The solution can be framed as Infrastructure-as-a-Service (IaaS), even though different commercialization options will arise depending on Nokia partnership structure at the given location. To obtain the cost model, the following elements must be dimensioned. Dimensioning rules will be a combination of standard Smart Venue deployments (SSV), plus the ones extracted from 5G-RECORDS results (5GR). The example shows standard dimensioning for > 1.000 users and 12 physical FVV cameras. Upscaling the number of users refer to SSV rules and is outside the scope of this exercise.

Table 14: Equipment used in Use case 3

Resource	Solution	SSV	5GR	Example
Downlink capacity	Nokia AirScale mmWave n257/n258 800 MHz total bandwidth	X	X	4 sectors
Uplink capacity			X	
Best-effort device#		X		
Priority device#			X	
UEs for production	FWA CPE (e.g. Nokia FastMile)		X	4 FWA CPEs
5G Core UPF	Nokia 5G NSA/SA Core	X	X	1 UPF
Content production MEC	Nokia AirFrame with NVIDIA TESLA GPU		X	4 Units
Content delivery MEC	Nokia AirFrame		X	1 Unit
Content delivery software	Nokia Media Delivery	X	X	5G-RECORDS configuration
Monitoring software	InfluxDB + Grafana Stack		X	5G-RECORDS configuration
Upstream connectivity	Fibre access (it could be FTTH for small scale deployments)	X	X	1-Gbps FTTH access

Additional recurring costs need to be considered:

- Installation, setup and teardown.
- Logistics (transport, storage, security, etc.).
- Energy consumption.
- Spectrum licensing.
- Deployment design, site evaluation and deployment planning.
- Operation and maintenance cost, including radio optimization and equipment calibration.

4.3.3 Delivery cloud & SDN

A key aspect of 5G-RECORDS is the implementation of solutions based on open-source software running on general purpose processors. It provides developers and users with a great set of tools to simplify network access, reduce cost, increase flexibility, and accelerate the introduction of new services into the market. In this context, the use of up-to-date Software Defined Networking (SDN) is a cornerstone to open the proprietary interfaces to control the RAN hardware/software.

SDN functionality will be able to establish and manage connections between the Near cloud, Central cloud instances, and external connections to the users. Also, SDN manages connectivity prioritization between the media delivery and the end users. Managing different types of QoS allow producers to evaluate impact in the service. End users in remote locations can access the delivery server via either network. The SDN will manage the allocation of each user to its specific slice. Public MM networks are publicly available on the internet (i.e. they provide public IP addresses) via routing; however, media delivery requests coming from the public internet will always be handled by the best effort slice.

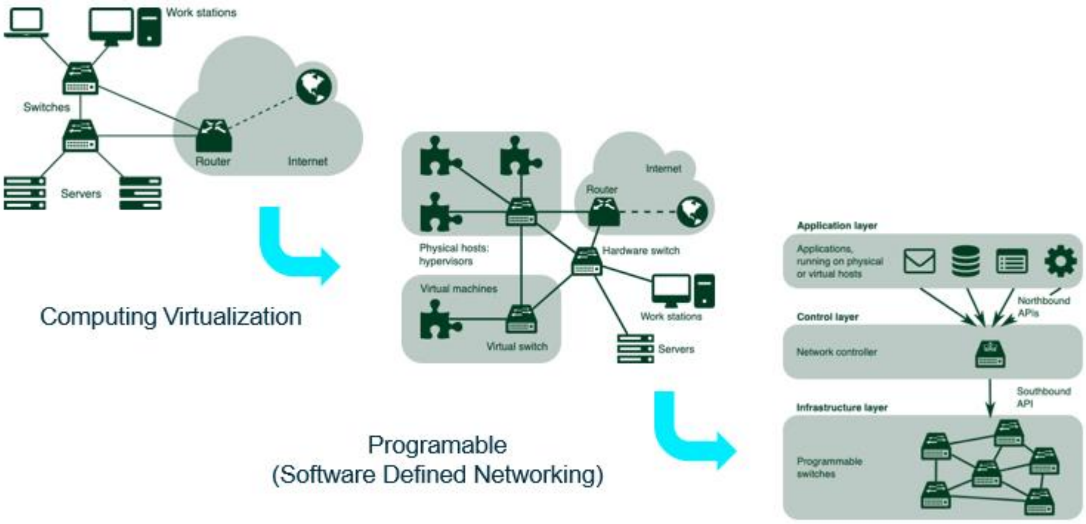

Figure 20: Delivery cloud and Software Defined Networking

This component has the ambition to simplify the complexity of setting a production but preserving the quality required, making more affordable and scalable deliver these sophisticated scenarios of immersive media production.

5 The impact of the regulatory framework on NPNs in content production

5G networks used in professional content production are subject to various kinds of regulation. As described in the deliverable D2.2 [1], regulation governs a number of different areas such as access to the radio spectrum and numbering resources, network deployment and operation, security, EMF limits, provision of services, content-related regulation, network neutrality, data protection, consumer protection, commercial relations between stakeholders, and possibly other. Furthermore, there are national rules, EU-wide, and international regulation (e.g. ITU Radio Regulations [5]). All this makes the regulatory framework quite complex.

This study sought to investigate how the regulatory framework affects business decisions in the professional production value chain and are there any regulatory issues that may facilitate, or hinder, the development of new business models supported by 5G.

The following observations have been helpful in the study:

- Although most of the regulatory texts are not specific to 5G, they nonetheless continue to apply as 5G is integrated into production workflows and business practices.
- The regulatory framework provides the conditions for business development, which may, or may not be aligned with technological capabilities.
- The regulatory texts tend to be quite stable and in force for long periods of time. Any change is subject to a well-defined legislative procedure. This allows businesses enough time to stay informed about and adjust to the changes.
- Consequently, in a day-to-day business of content production the stakeholders may not need to frequently engage with the regulators, except in some specific cases depending upon their role in the value chain and a particular use case.

Furthermore, it was noted that the regulatory conditions for 5G PLMNs are well established and there are no substantial differences between content production and other verticals using these networks.

In case of 5G SNPNs, however, the situation is quite different, in particular with respect to access to radio spectrum and numbering resources. As SNPNs are expected to play an important role in content production these issues will be further discussed in the following text. In particular it was found that the current spectrum access rules may not be suitable for certain 5G SNPN deployments that are common in professional content production.

It should also be noted that, while a technical definition of 'non-public networks' is provided in 3GPP TS 23.501 [6] and TS 22.261 (Release 16) [7], there is no commonly agreed regulatory definition of that term. Therefore, the Project has based its analysis on the clarification provided in the ECC Report 337 (section 2.2)[4].[8]

[4] 'Given … the 3GPP definition, the term "non-public network" could be understood as referring to a variety of networks that do **not** fit within the defined term of "public electronic communications network" as per Article 2(8) of the European Electronic Communications Code (EECC) [9], namely:

- *'public electronic communications network' means an electronic communications network* ***used wholly or mainly*** *for the provision of publicly available electronic communications services which support the transfer of information between network termination points.*

By implication, this could mean that **non-public** electronic communications network (ECN) is **not** wholly or mainly used for the provision of publicly available electronic communications services. However, a **non-public** electronic communications network may be realised using part or sharing components/part of the network elements of a public electronic communications network.

In general, however, non-public networks are used to provide services to enterprises and they are not used for providing services to the general public.

5.1 Access to spectrum for 5G SNPNs in content production

This section presents the findings related to:

- spectrum requirements for 5G SNPNs in content production
- the existing situation with respect to spectrum licensing for SNPNs in Europe.
- regulatory approaches that facilitate shared access to the spectrum
- the need to adapt the current regulation to the

5.1.1 Spectrum requirements

Spectrum access for 5G SNPNs is a prerequisite for a large scale adoption of 5G in professional content production. The following spectrum requirements have been identified:

- ***Sufficient amount of suitable spectrum*** needs to be available, taking into account
  - Physical characteristics of the band that need to correspond to the requirements of the use cases
  - 'High-quality' spectrum is required for high-quality high-value productions
  - Availability of 5G hardware in the bands
  - Minimum or no deployment constraints (e.g. those resulting from pre-defined UL/DL ratio, TDD arrangement)
  - Availability of the band for PMSE applications, including for short-term, temporary, and nomadic NPNs
- ***Ease of access, including***
  - 'Light' (simple and short) and automated licensing procedure
  - Effective interference management
  - Predictable and low costs
- ***International harmonization***
  - Harmonisation of frequency bands or tuning ranges for IP-based PMSE applications
  - Harmonisation of licensing regimes for SNPNs in different frequency bands and different countries
- ***Long-term viability*** of the band for PMSE applications and security of tenure
  - To stimulate investments in IP-based production technologies and the development of an ecosystem
- ***Support for innovation***
  - Innovative technical solutions and production workflows
  - Innovative business models
  - Innovative spectrum access models

Some of the above mentioned requirements are common to 5G NPNs intended for vertical use cases. However, some additional technical and operational requirements may be specific to professional content production, in particular the following:

- ***Flexibility of the local access to spectrum***
  - It should be possible to accommodate different requirements e.g. in terms of the amount of spectrum or the size of the network area, depending upon the production use case.
- ***Different types of spectrum use***
  - Permanent use at a fixed location (e.g. production studios, theatres, media campus,)
  - Occasional use at venues (e.g. sports arenas, festival venues - indoor or outdoor)
  - Ad-hoc use (e.g. news events, film/drama locations - indoor or outdoor)
  - Nomadic use - events (touring shows)
  - Moving events (e.g. cycling races)
- ***Variety of deployment modes***

  - NPN size and functionality depend on production requirements, resulting in different deployment options to meet these requirements
  - NPN can be deployed and operated by different actors in the value chain (e.g. content producer, venue owner, MNO, third party)

- ***Different duration of the license***
  - Long term / permanent - at a specific location
  - Short term / temporary - for a duration of a few days or weeks at a specific location
  - Nomadic - short term / temporary consecutive use at different locations

- ***Local coordination with other users (other NPNs)***
  - There might be multiple NPNs deployed on the same location by different operators

5.1.2 Spectrum for SNPNs in Europe

The Project has investigated the availability of spectrum for non-public networks in different EU countries[5], including spectrum fees. Where available, spectrum fees for conventional PMSE were included for comparison purposes.

It should be noted that in most cases spectrum access rules are designed for long term use at a given location and may not be suitable for short term temporary local or nomadic deployments.

5.1.2.1 Germany

The German telecoms regulator, BNetzA, reserved 100 MHz of spectrum (3700-3800 MHz band) for use by private companies.[10]

Access to the band is based on application and requires an individual authorization from BNetzA. The duration of the transferable license with spectrum fee for an applicant defined area is 10 years.

Applications are possible for regional and local assignments and can be submitted not only at the time when the corresponding regulation comes into force, but also at a later date.

5.1.2.2 France

In France, the regulator ARCEP has offered frequencies in the 2600 MHz TDD band (i.e. 40 MHz between 2575 - 2615 MHz) to metropolitan businesses.[11] The aim is to grant access to blocs of 5, 10, 15 or 20 MHz, in limited geographical areas and for maximum license duration of ten years. Each applicant has to specify the requested coverage area and justify the spectrum needs within that area.

There are several drawbacks of the current regime which hinder the development of 4G/5G non-public networks for professional use:

- Long time required to complete the licensing process (up to 6 months) as the applications are handled manually.
- The lack of compatible user equipment considering that non-public networks may require different TDD frame configurations than the mobile public networks as local licensing in 2.6 GHz TDD is unique to France.
- The spectrum fees which depend on the size of the licensed area with a general principle of ensuring a balance with pricing for an MNO having a national license and an enterprise with license for non-public network. This amounts to approximately 70,000 euros annually for a bandwidth of 20 MHz and an allotment zone of up to 100 km^2.

[5] This overview is based on the information from the EU Observatory (https://5gobservatory.eu/5g-private-licences-spectrum-in-europe/), national regulatory authorities and CEPT.

According to the feedback received by the regulator, this price is too high for small or medium size enterprises and areas as large as 100 km2 are inappropriate for some use cases such as campus or factory networks. Therefore, ARCEP has been asked to consider introducing the possibility of more affordable local licenses and smaller coverage areas.

5.1.2.3 The Netherlands

In the Netherlands, spectrum at 3400-3450 MHz and 3750-3800 MHz is intended to be made available for local use.

5.1.2.4 Spain

In Spain, the new national Table of frequency allocations (*Cuadro Nacional de Atribución de Frecuencias* - CNAF), approved in June 2021 introduces a non-exclusive allocation of 20 MHz in the band n40 at 2.3 GHz (specifically, 2370-2790 MHz) for 5G NPNs. In this band, preference will be given to 5G private networks dedicated to the management of public utility services such as electricity, gas, and water. This spectrum is shared with Unmanned Aerial Systems (UAS) for drones (2390 - 2400 MHz) and TV services (2300 - 2500 MHz) as shown in Figure 21.

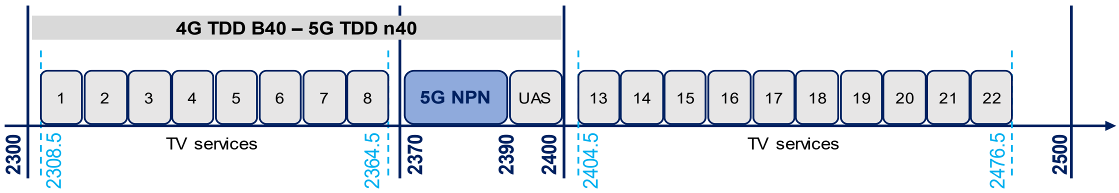

Figure 21: Frequency band assigned to 5G NPNs in Spain

Note that in Spain, n40 is used for 4G and 5G.

Furthermore, the CNAF provides a possibility, in addition to the 20 MHz allocation in the 2.3 GHz band, to use the 26 GHz band for the verticals. This has been proposed as the current allocation would not permit verticals to fully develop their services with 5G technology.

Access to spectrum requires authorization from the Ministry of Economic Affairs and Digital Transformation. Applicants are required to provide the following information:

- Frequency band, number of carriers and bandwidth.
- Main purpose of the activities.
- Exact location of the antennas, including installation maps and coordinates.
- Coverage of the 5G base station, both radius (km) and area (km^2).
- Antenna height from the ground, diagram, and tilt.
- Transmission power, gain, polarization, and beam width.
- Date of the start of the transmission and the desired duration of the license.
- Qualified person in charge.

5.1.2.5 Sweden

In Sweden, 80 MHz of spectrum (3720 - 3800 MHz) are reserved for local and regional licenses.

5.1.2.6 United Kingdom

In the UK, the regulator Ofcom [12] has released the 3.8-4.2 GHz band for local private and shared networks. The 3.8-4.2 GHz band will not be made available for national mobile broadband services.

The lower 26 GHz band will be reserved for private and shared access as well.

In the 3.8-4.2 MHz band Shared Access Licences are possible for fixed sites and fixed annual costs, as shown in Table 17. Application time 56 days.

Table 16: Annual spectrum costs for shared access licenses in the 3.8-4.2 GHz band in the UK

Channel size	Price per channel
2 x 3.3 MHz	£80
10 MHz	£80
20 MHz	£160
30 MHz	£240
40 MHz	£320
50 MHz	£400
60 MHz	£480
80 MHz	£640
100 MHz	£800

The current licensing regime for PMSE is as follows:

Licences issued by Ofcom are of two types:

- A general authorisation to use specific equipment types, defining technical parameters and frequencies which may include geographical exclusions. General Authorisation includes DECT, 2.4GHz WiFi and Short Range Devices.
- A licence for individually co-ordinated and exclusive assignments. The applicant requests individual frequencies and channels for specific locations and time periods from 48 hours up to one year. Generally, only indoor assignments are licensed for long periods up to one year to avoid sterilising spectrum and maximise temporary availability for other indoor and outdoor users.

Most PMSE spectrum use in the UK is subject to spectrum sharing arrangements with other spectrum owners, either co-channel or adjacent to PMSE. Applications for assignments in a given frequency range are first considered against the established sharing conditions with the other spectrum user.

The compatibility of the application is also considered against other existing PMSE assignments, co-channel and adjacent.

Automated co-ordination is carried out in real time licensing compatible assignments. Online payment is taken and licence documentation immediately emailed to the applicant so that PMSE licensees swiftly receive their authorisation.

However, for major events when spectrum demand is greatest from multiple PMSE licensees at a single location, general planning assumptions cannot be relied upon to meet the spectrum requirements. The automated application process is temporarily suspended for the location and a more detailed manual frequency planning exercise is carried out. In this way a more efficient and reliable frequency plan can be produced where automated methods would not satisfy the total spectrum demand.

The spectrum fee structure is as follows:

Multiple uncoordinated wireless microphones, 200kHz in 606-614MHz, 823-832MHz and 1785-1805MHz UK wide, annually – online, £75.

Individually co-ordinated and licensed assignments - online

Table 17: Spectrum costs for wireless microphones in the UK

Equipment	Duration hours	Frequency band	Channel Bandwidth	Cost
Wireless Microphone	48	470-1154MHz	200kHz	£8.50
Narrowband Talkback	48	65-470MHz	12.5kHz	£8.50
Wireless Camera	12	2-5GHz	10MHz	£12

5.1.2.7 EU / CEPT work on 3.8 - 4.2 GHz band

In Europe, the EU Commission has issued in December 2021 a Mandate to CEPT[6] to assess the technical feasibility of the shared use of the 3.8- 4.2 GHz frequency band by terrestrial wireless broadband systems providing local-area network connectivity with focus on vertical users and other terrestrial wireless use cases and, on that basis, deliver harmonised technical conditions for the shared use of the band.

This mandate follows on the third RSPG Opinion on 5G[7], which concludes that connectivity for vertical industries ('verticals') could be provided by mobile operator's solutions, third-party providers and directly by verticals themselves in EU-harmonised bands for electronic communications services or in dedicated spectrum for verticals. The RSPG recommends that Member States also consider other spectrum solutions including dedicated or shared spectrum for the business/sectoral needs ('verticals needs') that may not be met by mobile operators.

The final report from CEPT to the European Commission is foreseen in March 2024.

The Commission may consider using the results of this mandate to develop further regulation to facilitate a harmonised use of this band in the EU.

5.1.3 Shared access to spectrum for SNPNs

Spectrum sharing is a well established principle. However, as it is recognised in the RSPG Opinion on spectrum sharing[8], [it] *'is so far implemented in a rather static and conservative manner and needs to be developed, in particular for its potential to achieve more efficient use of radio spectrum, and to give incentives for innovation.'*

Two innovative approaches have been identified that provide shared access to spectrum for SNPNs:

- Citizens Broadband Radio Service (CBRS) in the United States [13]
- Licensed Shared Access (LSA) [14] and its possible evolution (eLSA) [15], [16], [17], in Europe

5.1.3.1 Citizens Broadband Radio Service (CBRS)

CBRS [13] operates in 150 MHz of spectrum in the 3.5 GHz band (3550 – 3700 MHz). As the primary users of that band - the U.S government and some other entities - do not use the band extensively, it was made available for shared private wireless broadband services.

Currently, CBRS is the most advanced real-life example of a shared access to spectrum. However, CBRS is specific to US and it may not be possible to replicate it in other countries.

CBRS is enabled by an automated licensing process which relies on a database(s) management system. Such an approach is generally seen as complex by the regulators as it involves a

[6] https://ec.europa.eu/newsroom/dae/redirection/document/82230

[7] RSPG Opinion on 5G implementation challenges (RSPG 3rd opinion on 5G), https://rspg-spectrum.eu/wp-content/uploads/2013/05/RSPG19-007final-3rd_opinion_on_5G.pdf

[8] SPG Opinion on Spectrum Sharing – Pioneer initiatives and bands, https://rspg-spectrum.eu/wp-content/uploads/2021/06/RSPG21-022final_RSPG_Opinion_Spectrum_Sharing.pdf

number of technical, regulatory and legal issues related to the operation of the database(s) as well as the question of compliance with functional and performance requirements in user devices. Nonetheless, CBRS provides a unique learning opportunity as the key principles are being tested in practice.

The mechanics of CBRS are implemented so as to protect the incumbent users but also to provide a fair access to spectrum for new users. CBRS is technologically neutral and supports 4G, 5G as well as proprietary technologies. It also allows 5G NPN deployments.

That band is available on both a licensed and unlicensed basis. Different applications are possible, including private wireless networks both fixed and mobile, and mobile network augmentation. With regards to mobile network augmentation, FCC rules currently prohibit high-power operations in CBRS spectrum, thus limiting the geographic reach of transmissions in the band.

Cable network operators may build wireless networks in their cable footprints using CBRS spectrum, which would enable them to move their mobile customers' traffic onto their own wireless networks, thus reducing the transfers to their MVNO partners.

With regards to private wireless networking, CBRS is still in its early days. Expertise in spectrum use and network deployments comes at a premium. Enterprises lacking such know-how rely on the telecom industry to provide easy-to-implement solutions for their private wireless networks.

In CBRS, a spectrum manager known as the Spectrum Access System (CBRS SAS) mediates access to spectrum for new entrants in two priority levels or “tiers”, as follows:

- Priority Access Licensed (PAL) - this tier provides access to up to 70 MHz of licensed spectrum that resulted from an auction. PAL channels are awarded in 10 MHz license blocks.
- Generally Authorized Access (GAA) – this tier is accorded no interference protection. In reality, GAA spectrum quality is dependent on how many users require spectrum in a given location. The SAS uses the same 10 MHz unit as in the PAL layer to apportion spectrum to GAA users. However, as there are no rights to protection from interference all eligible GAA users have the same right to access the spectrum. If the GAA spectrum becomes crowded in certain locations and SAS will seek to 'maintain order' and avoid the band being rendered unusable due to excessive interference levels.

GAA users may use the CBRS band without paying licensing fees. However, every Base Station or CPE are mandated to register with one of the SAS (except for a very low transmitter power). As SASs are operated by commercial companies and it is not a free service, the SAS registration fees actually represent the cost for accessing the spectrum. SAS fees are in a matter of few $ per connected equipment. Even though SAS fees have been kept at reasonable levels, in some cases this cost is not negligible.

PAL users have obtained the spectrum through an auction and are required to pay a fee. Nevertheless, the license costs for PAL tend to be lower than those for exclusively licensed spectrum due to the tiered priority structure in the band.

The CBRS auction was unique in a number of ways, including the fact that many qualified bidders included non-traditional auction participants thanks in part to the smaller size of the licenses. Utilities, rural service providers, universities and others joined wireless and cable service providers in bidding.

Utility providers have expressed interest[9] in private wireless networks for utility-monitoring services while one major real estate company successfully bid to use CBRS spectrum for indoor wireless offerings.

The CBRS auction also offered up the most licenses ever auctioned in a single event (22 631 in total). 70 MHz of licensed spectrum was offered on a county basis across 3,233 areas, each

[9] See https://www.lightreading.com/gigabit/utilities/power-brokers-utilities-explore-their-role-in-4g-and-5g/d/d-id/753198

with seven 10-megahertz blocks available. The CBRS auction raised $4.58B and the average price per MHz-POP was $0.217 on all blocks sold in the auction. The achieved price was highest in densely populated areas and urban conglomerates.

CBRS supports PAL Secondary Market transactions after the initial PAL auctions. Basically, a licensee can resell or sublease all or part of its PALs. There, the SAS will help manage both partitioning and disaggregation. The former relates to leasing portions of a winner's market areas, while the latter is leasing portions of their CBRS spectrum blocks. As of today, no information is available about PAL Secondary Market transactions or the associated fees.

Furthermore, the SAS can enable a more granular leasing timeframes. Consequently, the SAS could potentially be used to manage spectrum access at specific locations such as venues. This is currently not possible with other kinds of spectrum leases.

5.1.3.2 LSA/eLSA

The Licensed Shared Access (LSA) [14] concept has been developed in CEPT a decade ago as a spectrum-sharing model that enables access, by additional LSA licensees, to spectrum already licensed to incumbent users . LSA foresees nation-wide, long-term sharing arrangements between incumbents and LSA licensees.

Subsequently, the LSA concept has been further developed in ETSI. The evolved LSA (eLSA) model [15], [16], [17] allows subleasing of spectrum from the incumbent (e.g. an MNO) to the vertical service provider, or local licensing by the regulator to the vertical service provider. It supports spectrum access for local permanent or temporary networks which require predictable levels of QoS privacy and security. This corresponds to the requirements for 5G NPNs used in professional content production.

Both LSA and eLSA have been described in some detail in the deliverable D2.2.

As of today, neither LSA nor eLSA have been implemented in practice, hence it is not possible to evaluate them from the business perspective.

5.1.4 Recommendations on spectrum access for 5G NPNs

On the basis of the above mentioned requirements and the review of the current licensing regimes in selected European countries, the 5G-RECORDS project recommends the following issues to be taken into account by the national spectrum regulators and in the ongoing work at the European level (CEPT, RSPG, RSC and the European Commission):

- Licensing options for NPNs should accommodate specific requirements in professional content production, in particular:
  - Temporary and nomadic licenses, in addition to fixed and long-term
  - Different tiers for different quality requirements and protection from interference
  - Flexible network deployments
  - 'Light' and automated licensing procedure
- This might be enabled by an evolution of the Licensed Shared Access (LSA) model.
- There is a need for a harmonized spectrum for 5G NPNs across the EU (e.g. the 3.8-4.2 GHz band)
  - To facilitate the development of an ecosystem, economies of scale and a long-term predictability
  - To facilitate cross-border PMSE operations
  - Technical conditions should ensure co-existence with the incumbent services

These recommendations have been submitted to the EU RSPG at their Stakeholder Workshop on 20 June 2022[10]. They are also included in the Project's dissemination activities.

[10] https://rspg-spectrum.eu/2022/06/rspg-public-stakeholder-workshop/

5.2 Access to the numbering resource for 5G SNPNs

The need for access to numbering resources for 5G NPNs has been identified in the deliverable D2.2. The main findings were that, according to the current regulation, allocation of the numbering resource is at the discretion of the national regulators who may decide to assign the right to some of this resource to NPN operators.

Meanwhile, further clarification was provided in the ECC Report 337 [8] which emphasises the need for a clear procedure and administration of NPN identifiers and examines the currently available solutions (CBRS [13] and MultiFire[11]).

The ECC Report 337 notes that *'generally, national regulatory authorities (NRAs) only assign E.164 numbering blocks to service providers intending to offer a publicly available (number-based) electronic communications services (ECS). Given that NPNs do not necessarily offer a publicly available ECS, some NRAs may consider such NPNs ineligible for an assignment of E.164 numbers. Nevertheless, the continued application of such policies may need to be reviewed as business models around NPNs evolve.'*

Different types of numbering resources might be required for SNPNs.

Recommendation ITU-T E.212 [18] defines the international identification plan for public networks and subscriptions. It assigns mobile country codes (MCCs) to countries (usually one MCC per country only), and the relevant national authorities subsequently assign mobile network codes (MNCs) to entities who meet the eligibility criteria. Due to the scarcity of this resource, the assignment of MNCs is normally restricted to MNOs only or MNOs and Mobile Virtual Network Operators (MVNOs) who meet certain specified criteria. This arrangement does not allow for individual MNCs to be assigned to NPNs.

Therefore, ITU-T E.212 recommends using shared MCCs and introduces a shared MCC 999 for internal use within a private network. MNCs under this MCC are not subject to assignment and therefore may not be globally unique as they should have significance only within that network. This is suitable for isolated NPNs but does not support interconnection (i.e. routing traffic between networks) or roaming.

Another issue with MCC 999 is that if two or more SNPNs in the same geographical area use the same MNC, this would cause malfunctioning of the networks as terminals of one SNPN may try to unsuccessfully connect to the adjacent SNPN. This could be avoided by coordination between SNPN operators.

Shared E.212 resources could also be assigned to a particular technology but this does not alleviate the above mentioned issues with shared MCCs.

The ECC Report 337 recognises that if the demand for MCCs and MNCs for NPN increases, innovative solutions will be required to increase the capacity for these assignments.

Recommendation ITU-T E.164 [19] defines the international public telecommunication numbering plan, which enables unique identification of individual subscribers.

Furthermore, whether NPNs require E.164 numbering resources depends also on how UEs are addressed within the NPNs. If communication remains within the NPN, a proprietary addressing and numbering scheme could be used and E.164 numbering resources would not be required.

However, if NPNs are interconnected with public networks they are likely to need public E.164 numbering resources in order to be able to call public network subscribers and to receive calls from public networks. Some machine-to-machine communications are also expected to require E.164 resources.

There could also be a need for user account identifiers on UEs. This information is usually stored inside the SIM. A corresponding numbering scheme is defined in Recommendation ITU-T E.118. [20]

[11] https://www.mfa-tech.org/

When SNPNs are used in professional content production, the requirement for access to the numbering resource will depend on the use case. In particular, how are UEs within the network addressed, whether or not interconnection with other networks is required, and whether multiple profiles need to be stored on the same UEs.

Furthermore, when two or more NPNs operate in the same or adjacent geographical areas care should be taken that they have different MCC-MNC identifiers.

As there are no internationally agreed numbering schemes for SNPNs and the procedures are likely to differ from one country to another, the competent national authorities[12] are the only entities capable of providing the relevant information, guidance, and indeed assigning the required numbers.

[12] For example, in Germany Bundesnetzagentur is assigning numbering resources to private 5G networks in the 3700-3800 MHz frequency band, www.bundesnetzagentur.de/DE/Fachthemen/Telekommunikation/Nummerierung/Campusnetze/start.html

6 Discussion

Beyond technical performance of 5G systems and networks, viable business models are a key prerequisite for their adoption in professional content production. These business models can only be developed in collaboration between key stakeholders. In the course of the project several different areas have been studied that are relevant for a business analysis. Some of the main findings are presented below.

The ecosystem and business opportunities

Successful adoption of 5G in professional content production requires a functioning ecosystem. As described in the deliverable D2.2. and in chapter 1 above, this ecosystem is rather complex and includes stakeholders from media production sector, telecom industry, new solution providers, and regulators. Different actors bring different competences and technical resources.

Actors from the media production sector are typically broadcasters and other content production companies, broadcast equipment providers and specialised production infrastructure providers. As every production is different and may come with specific technical, operational, and commercial requirements the actors from the media production sector are comfortable with using various technologies, tailor-made and ad-hoc solutions where required for a particular production. They are often experienced in self-provisioning the necessary connectivity, including network planning and deployment in licensed or unlicensed spectrum. This may be supplemented by commissioned dedicated connectivity services.

Media producers are interested in 5G as a candidate technology to support IP, cloud-based and remote production workflow. They will use it where it provides sufficiently high quality and flexibility and is commercially available and attractive.

The most prominent actors from the telecommunications sector are network operators and equipment vendors. Their main focus is on high-volume telecommunications services such as consumer broadband applications based on global standards and benefiting from economies of scale. They may have limited experience in providing tailored solutions for verticals, such as professional content production. They seek to leverage their network investments and where scale and clear revenue opportunities over a longer period of time come as premium. Therefore, in particular MNOs tend to implement 5G in such a way that favour their main business case.

An important observation is that different stakeholders in the ecosystem may be subject to different regulatory conditions and may have different mindsets, different business practices, objectives, and priorities and even use the equipment in different ways. For example, MNOs are typically focused on long-term PLMN deployments whereas content producers are accustomed to temporary deployments tailored to a particular event or a venue. The challenge is to find such arrangements where business objectives are aligned across the value chain, and the potential market opportunity justifies the required investments.

However, 5G is a flexible technology that can be implemented in different ways and networks can be adapted to the specific requirements of a production use case. This opens an opportunity not only for the MNOs and the established equipment vendors to extend their portfolios for new actors that are bringing to the market specialist equipment, software, and connectivity solutions. These are often deployed in non-public networks where non-traditional infrastructure and facilities providers can play a significant role.

The main appeal comes from the opportunity to benefit from a global 5G standard and hardware ecosystem, while retaining the flexibility to provide tailored solutions for specific production use cases.

Methodology

There are many different production use cases. It was observed that even within a broadly defined use case there are differences between individual productions in terms of specific technical, operational, and commercial requirements, scale, and the value of the content.

Furthermore, each use case can be implemented in different ways, different actors can play different roles, while some technical requirements can be met by different technologies and network configurations.

This is why the value proposition of 5G in professional content production and business potential for different actors must be assessed on a case by case basis. However, the project has not been able to identify a readily available methodology for such an assessment.

Nevertheless, it was noted that, to a greater or lesser degree, some elements are common to a majority of production use cases and scenarios. For example, every production requires technical resources such as hardware, software, IT infrastructure, and connectivity and is produced in a given venue[13]. These resources are used to produce content which is then distributed to the audience.

The above observation allowed the project to create a generic presentation of a production value chain from a business perspective. It was also possible to identify the hand-over points between different actors where commercial transactions take place, i.e. goods and services are exchanged for some remuneration. This approach was applied on the three 5G-Records use cases and it was possible to differentiate between different possible implementations of each use case. The analysis was qualitative as the project as not in a possession of relevant market data.

Nevertheless, it was verified that the model allows to analyse the entire production value chain, or some parts of it, taking into account the respective roles of different actors, possible business arrangements, and revenue flows. It also allows to identify where in the value chain the regulation might have an impact on business arrangements. The level of detail can be adjusted according to the requirements of the analysis to be carried out.

The project tentatively concludes that this model can be applied to any production use case.

The impact of regulation

Regulatory conditions and requirements must be taken into account when considering the use of 5G in professional content production. The regulatory framework has been analysed in detail in the deliverable D2.2. One of the key findings is that regulation may facilitate or constrain different 5G deployments.

Notably, spectrum access for 5G NPNs is a prerequisite for a wider adoption of 5G in professional content production. The project has identified a number of requirements that would facilitate this process (see chapter 5 above). Some of these requirements cannot be met under the current regulation.

Therefore, the project has started to engage with the European regulators in order to make them aware of these requirements and ensure that they are accommodated in the relevant regulatory texts. Beyond the lifetime of the project this engagement will need to be carried on by the individual partners.

Current state of play

Although a number of tests and trials of 5G in content production have been carried out and there is a considerable interest in the industry, commercial offers have for the most part been

[13] Except the production of entirely animated or VR content.

limited to those solutions that are achievable using best-effort PLMNs. Bonded cellular solutions are well established and widely used for some production use cases

At the same time, MNOs have been reluctant to offer tailored solutions with guaranteed QoS required for demanding production use cases. Network slicing is not yet commercially available.

There is also a growing interest in SNPNs not only for content production but across different other vertical sectors. However, there are a number of issues that still need to be resolved for SNPNs to be commercially available on a large scale. This in particular includes the availability of suitable spectrum for SNPNs and licensing conditions adequate for content production use cases.

Furthermore, 5G hardware capable of operating in that spectrum and providing the required functionality will be powered by dedicated software solutions which allow integration in IP and cloud based production workflows. This will provide an opportunity for 5G components developed or enhanced in the project to contribute to the development of the ecosystem. Exploitation potential of these components is elaborated on in chapter 4.

As we accumulate the knowledge and experience from numerous tests and trials it is also important to increase awareness amongst the relevant stakeholders, in particular amongst content producers, telecom operators and the regulators.

Content producers need to understand what 5G as a technology can and cannot do in content production, including various deployment options - both PLMN-based and SNPNs - and how they can be integrated in the production workflows.

The telecom industry needs to understand the technical and business requirements in content production. Production use cases are demanding in terms of performance quality and reliability. 5G has a great potential but for most use cases there are alternatives. However, where 5G solutions are made attractive to content producers, both technically and commercially, this will result in new market opportunities and revenue streams.

Regulators need to understand that content producers have some requirements that require using SNPNs as they cannot be met by PLMNs. Furthermore, there are also some specific requirements regarding spectrum access and numbering for 5G NPNs. Accommodating these requirements in the regulation would facilitate the adoption of 5G in professional content production.

It can be assumed that the market will continue to develop as the current issues are gradually resolved and advanced functionality become available in 5G networks and user equipment.

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