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Deployment and Trial of 5G for media content production in 5G-RECORDS

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ABSTRACT

The fifth generation (5G) of mobile communications has revolutionized the telecommunications industry, allowing to explore the opportunities that this new technology brings to different verticals. 5G-RECORDS explores the possibilities that 5G may bring to the professional audio-visual (AV) content production sector. This work describes, in the context of the 5G-RECORDS project, three different use cases that target the integration and validation of 5G and media technologies in end-to-end infrastructures to meet the requirements of the emerging market players in Europe for professional content production. 5G-RECORDS use cases focus on live audio production, multiple camera wireless studio and live immersive media production. Special emphasis is placed on the deployment of 5G Non-Public Networks (NPNs), which give the content producers control over the network in terms of performance, privacy, data security and compliance.

Keywords: *5G, professional content production, technology enablers, components, end-to-end infrastructure, non-public networks, mmWaves, audio-visual requirements.*

1. INTRODUCTION

5G-RECORDS is a European H2020 project that aims to explore the opportunities that new 5G technology brings to the professional audio-visual (AV) content production sector. The 5G specifications allow for the deployment of specialist networks based on the same technologies as those operated by Mobile Network Operators (MNO). This offers the opportunity for content producers to build and operate their own networks to support their business requirements. 5G Non-Public Networks (NPNs) have been deployed and demonstrated to broaden the opportunities that MNOs provide in terms of performance, privacy, data security and compliance. They aim to provide improved performance in terms of bandwidth, latency, accurate timing support, quality of service (QoS) assurance and scenario flexibility.

The capabilities provided by 5G networks have opened ways to new use cases. 5G-RECORDS has considered three use cases to deploy three challenging scenarios in professional content production: live audio production, multiple camera wireless studio and live immersive media production.

2. OVERVIEW

To ensure the successful demonstration of the 5G-RECORDS use cases, the project gathered a set of experienced partners whose expertise covers both 5G and content production value chains. Together, they have designed the main components and the architecture for each use case, also identifying the benefits for users, requirements, and technical enablers. Scenarios and workflows have been defined to understand the nature of each use case, identifying the specific Key Performance Indicators (KPIs) required to measure the performance of the proposed solutions. After the development and integration process, trials have been successfully deployed and demonstrated to validate the three use cases.

2.1. Consortium

The 5G-RECORDS consortium consists of two

5G infrastructure manufacturers (Ericsson and Nokia), four partners that provide 5G core technologies (Cumucore, RED Technologies and Accelleran) and a major telecom operator (Telefonica). The content production sector is represented by four major European public broadcasters (EBU, RAI, BBC and TV2) and three leading media technology companies (Sennheiser, LiveU, and Bisect). The consortium also includes two universities (Universidad Politécnica de Valencia and Universidad Politécnica de Madrid) and one research center (Eurecom).

In addition, the project has a strong Advisory Board to monitor, evaluate and propose improvements to the work in progress and respond to the results achieved. It is composed of seven companies belonging to both 5G mobile communications and content production sectors: Amarisoft, BT Sports, SWR, RTVE, NEP Group, Nevion, ZDF and ATEME.

2.2. Objectives

The main objectives of the project were: (i) to design and develop 5G components based on 3GPP Rel-15 and 16, (ii) to integrate the developed 5G components into end-to-end (E2E) 5G infrastructures, (iii) to validate the 5G components in the context of the considered use cases, (iv) to demonstrate the potential value that 5G brings to the content production sector, and (v) to maximize the impact of project results and influence standardization and technical solutions.

These objectives were fulfilled via the execution and validation of the three use cases that cover different aspects of the media industry, i.e., live audio production, live wireless studio production and contribution, and immersive experience.

2.3. Challenges

The 5G-RECORDS project dealt with several technical and management challenges related to:

(a) IP network configuration: one major challenge in initially setting up the E2E application was the IP network configuration of several 5G system (5GS) components. This is related to the fact that mobile networks today include significant restrictions on IP traffic e.g., due to security considerations in public networks. Furthermore, Network Address Translation (NAT) is typically an inherent function in today's mobile networks, which is not required in local networks.

(b) Spectrum licenses not available for trials and test-beds. Harmonising the spectrum used by Programme Making and Special Events (PMSE) equipment would contribute to allow economies of scale, foster cross-border portability of equipment and interoperability, improve the quality and efficiency of spectrum use, and providing legal certainty for access to relevant spectrum bands. Stakeholders must be conscious of the existing rules that may affect the use cases, and business aspects of 5G-based content production.

(c) 5G RAN functional splits: 5G-RECORDS deployed a disaggregated radio access network (RAN) for the live audio production use case. The interoperability between the gNodeB (gNB) distributed unit (DU) and centralized unit (CU) using the standardised 3GPP F1 interface posed a major challenge towards the overall integration process. This was due, in part, to the incompatibility issue related to Eurecom's cluster (deployed on OpenShift) and ACC cluster (deployed on Vanilla Kubernetes). The integration of this split involved the implementation of specific protocols and procedures.

(d) Integration of components given the high number and complexity of 5G-RECORDS components development, the integration of the 5G and media disaggregated components took more time than expected. For example, compatibility issues arose between the video streams generated and the decoder on the Media Gateway in the multiple camera wireless studio use case.

(e) Lack of availability of a 5G network with NEF/PCF (Network Exposure Function / Policy Control Function) APIs to provide QoS prioritization features. Because 5G Release 15 is significantly more basic in this respect, joint efforts between the use cases were needed for a possible interim REST API to access QoS flow functionality.

(a) Maturity of available technology and unavailability of equipment: The readiness of 5G ecosystem is not yet on-par with the demanded use case requirements. For instance, mmW solutions are limited to band configurations strongly focused on downlink capacity, and NSA only. Also, latency for live audio production use cases is still a major constraint for the success of live audio production performances. Ultra-Reliable Low Latency Communication (URLLC) features need to be further investigated and applied to this use case to attain the requested level of user experience. For the multiple camera wireless studio, only 1080p25 video material was available while Tektronix Prism network analyzer was able to receive but not decode this format. Moreover, IP/SDI converters were temporarily unavailable.

(b) Compliance with the use-case KPIs and desired system functionalities: for instance, the live audio production requires a mouth-to-ear latency lower than 4 milliseconds. The latency of the audio signal from the microphone to the IEM system is the most critical parameter and, if it exceeds a certain threshold, the artist will not be able to perform. Also, another challenge is to accurately synchronize all audio sources over the network to produce a combined audio mix. Finally, an additional challenge is the interconnection and transmission issues associated with the stringent latency and data rate requirements of Free ViewPoint Video (FVV) systems in the live immersive media production use case.

2.4. Achievements

The project achieved the objectives listed in section 2.2 and demonstrated significant outcomes in the different work categories. The project was highly focused on both 5G and media components design, development, testing and validation on E2E infrastructures. The general performance of all involved components was evaluated and optimized regarding the specific use-case KPIs and requirements. The main achievements of the project are summarized below:

- Proof-of-concept of remote live audio production, multiple camera wireless studio and immersive live production.
- Implementation, integration, and optimization of disaggregated 5G components.
- Optimization of 5G disaggregated testbed to reduce the end-to-end latency within the live audio production use case (latency reduction by factor of 10).
- Capturing the state-of-the-art of current 5G ecosystem and benchmarking towards use case requirements.
- Identification of remaining gaps and bottlenecks in 5G ecosystem.
- Cross-collaboration between the projects use cases to test the audio for local 5G TV production, serving as a proof-of-concept of audio and video transmission over the same private 5G network in TV production scenarios
- Fully remote-controlled trials and measurements
- Proof-of-concept of shared access to spectrum for a private 5G network
- Analysis of Precision Time Protocol (PTP) performances on 5G networks Release 15 and URLLC testbed Release 16.
- Development of an FVV system that work on live and offline content, adapted for 5G and cloud production.
- Design and validation of a 5G+MEC compact deployment that can be used in immersive media workloads.
- Deployment and testing of E2E transport slicing over a software-defined network (SDN), including automatic slice change.
- Pioneer tests on immersive content production over millimeter wave (mmW) 5G RAN.
- Analysis of the system performance and their inherent limitations.
- Analysis of how the systems will perform over the next generation of infrastructure elements.

3. KEY TECHNOLOGY ENABLERS

Traditional public mobile networks may not be able to fulfil the requirements of certain type of applications that rely on low latency, high bandwidth, reliability, service prioritization or business-critical data privacy. Conversely, **5G Non-Public Networks (NPNs)** are tailored to satisfy the needs of a specific industry, such as media organizations, allowing them to deploy fixed and nomadic networks with coverage ranging from small areas to entire premises. NPNs benefits include the deployment of 5G systems for private use. The project put special emphasis on the deployment of NPNs to exploit the opportunities they provide in terms of performance, privacy, data security and compliance. They are useful for content producers as they allow dedicated 5G connectivity for a restricted number of users in a more secure environment. Dedicated resources allow users to tune the network based on their own requirements.

For media production, this enables the deployment of networks in a production environment to connect various devices such as microphones, monitors and cameras. NPNs provide dedicated connectivity to support the characteristics required such as low latency for audio equipment or high throughput for video transmission. Also, given the 5G duplex nature, it is possible to send audio and video in both directions, thus removing the need to have multiple radio connections for a single device. The deployment of NPNs goes hand in hand with the use of **network slicing for guaranteed Quality of Service (QoS)**, i.e., the virtual partition of the network that serves a specific purpose for an application or entity, usually with a set of guaranteed Key Performance Indicators (KPIs) and Quality of Service (QoS). A paramount connectivity requirement is to ensure that service level agreements (SLAs) for a given QoS are met for all services running in a slice, taking into consideration available network resources and capabilities. In this project, different network slices are tailored to specific use cases and allocated to the different users of the network to ensure the required Quality of Experience (QoE).

Further, **Multi-access Edge Computing (MEC)** is a great asset to seize new opportunities with applications for stadiums or localized events. MEC allows the deployment of computing power closer to the network endpoints in order to improve real-time processing capabilities and guarantee specific KPIs such as response time and latency. In this project, the implementation of new Virtual Network Functions (VNF) instantiated very near to the radio provides very low latency and enhanced performance video capabilities.

However, none of the previous advantages nor technologies would be useful without proper time synchronization and timing. Professional content production requires specific QoS and timing parameters. Live media content needs precision when sending information to enable production workflows. As transmission speed is considerably high, time synchronization is crucial. In 5G-RECORDS, the time synchronization of devices over the 5G network was tested in both non-optimized networks and Time Sensitive Networks (TSN).

Another key aspect of 5G-RECORDS was the implementation of solutions based on open-source software running on general-purpose processors. Live audio production disaggregated 5G tested relied on Software-Defined Radio (SDR) to deploy the gNB DU, providing developers and users with a great set of tools to (i) support a multi-vendor ecosystem, (ii) simplify network access, (iii) reduce cost, (iv) increase flexibility, and (v) accelerate the introduction of new services into the market. The use of Software Defined Networking (SDN) within live immersive media production has also been a cornerstone.

Dynamic Spectrum Access (DSA) was also demonstrated within the project to provide increased spectrum efficiency and network capacity within the live audio production. The deployment of a dynamic spectrum access server and client allowed the real-time adjustment of radio resources.

Finally, the use of mmW antennas and devices allowed the live immersive media production to explore the capabilities of the 5G new bands between 30- 300 GHz, based on Line-Of-Sight (LOS) paths, with larger bandwidth availability aimed at providing extreme capacity for the busiest locations.

4. 5G USE CASES FOR REAL MEDIA CONTENT PRODUCTION APPLICATIONS

4.1. Use Case 1: Live audio production

Today's typical professional live audio production combines several wireless and wired technologies to capture, produce, playback and distribute audio content. In a typical production setup, performers are equipped with PMSE equipment such as wireless microphones and in-ear monitoring (IEM) systems. 5G-RECORDS use case 1 (UC1) aimed to deploy a local 5G disaggregated testbed to provide a high-quality and low-latency audio production network based on open-source software solutions and a multivendor ecosystem.

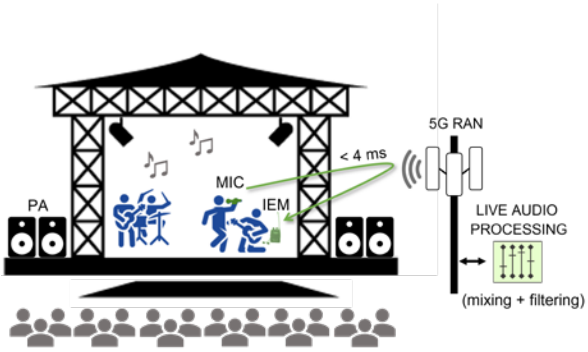

Fig. 1. Live audio production.

This use case allowed to capture and evaluate the state-of-the-art of available 5G components in the context of live audio production scenarios. The integration of 5G and audio components into the network was successfully demonstrated, allowing to study the performance of the E2E system when using a single UE, to measure deterministic audio streams through multiple 5G modems, and to conduct mobility tests to better understand the use-case KPIs in a more realistic environment.

5G-RECORDS has also shown that it was possible to integrate live audio production on network layer into multiple 5G testbeds. In a joint effort between UC1 and UC2, it was possible to demonstrate the delivery of audio and video over the same private 5G network in some TV production scenarios.

The main live audio production requirements within this project are reliability, latency and synchronicity.

- **Network latency:** UC1 efforts concentrated on extensive optimizations on the 5G components, interfaces and deployments to reduce the latency in a state-of-the-art 5GS. Network latency describes the latency of a continuous stream of audio data packets from the application layer on the User Equipment (UE) side to the application layer on the Local Audio Processing (LAP) side for uplink direction and the other way around for downlink direction. This use case requires a one-way network latency of below 1 millisecond (ms).

After multiple iterations, UC1 partners were able to reduce the one-way E2E network latency in the disaggregated 5G testbed to about 10 ms for a single audio UE and about 20 ms for up to three audio UEs. Those results are still far from the 1ms target, thus the availability and maturity of URLLC components are key to meet UC1 requirements. On the other hand, test results for the delivery of audio and video over the same 5G network for a local TV production showed that packets were faster than 75 ms.

- **Synchronicity:** needed to ensure low latency and high-quality audio transmission of all audio devices, that need to be synchronized to a common clock with a maximum deviation of 500 nanoseconds (ns). In the wired part of the production network, this can be achieved by using PTP over wired IP networks. For wireless devices it is required to synchronize with a similar accurate clock like the wired. Since no 5G components with PTP support were available until the end of the project, it was not possible to perform measurements that would show the needed performance.
- **Packet error ratio:** This use case requires a packet error ratio <10-6 to ensure a high-quality audio production. Furthermore, the distribution of the errors plays a role when it comes to the effect on audio quality. Short measurements with stationary devices in a controlled lab environment showed that the system can work without any packet errors at this point in time. However, it remains difficult to conclude about PER of a current 5GS in live stage environment since it is a parameter that is tightly bundled to latency.

4.2. Use Case 2: Multiple camera wireless studio

Live or pre-recorded media content production usually requires deploying a large number of equipment and crew on the event location or studio, all connected to the production facilities. This use case is based on multi-camera audio and video production in a professional environment. It aimed to replicate existing technologies such as COFDM radio cameras in terms of performance and capabilities using 5G technology. Furthermore, UC2 focused on exploring multi-location scenarios with production facilities local to an event as well as remote and distributed production models. In some additional scenarios, 5G based contribution solutions were integrated using different types of network configuration to provide contribution links into production centers.

Efforts within this use case were devoted to the development of the 5G 2110 Gateway, which acts as a media translator between different networks and the definition of the Operational Control Gateway architecture, including camera controls, timing & synchronization and device registration. These processes will be based on specialized technologies, such as NMOS, PTP, NTP, MQTT and so forth.

Following, KPIs that have been considered to evaluate the success of the use case are listed:

- **Glass-to-Glass latency:** the measured glass-to-glass latency for the wireless studio scenario was around 200 ms which could be further improved using more performant low-latency encoders.

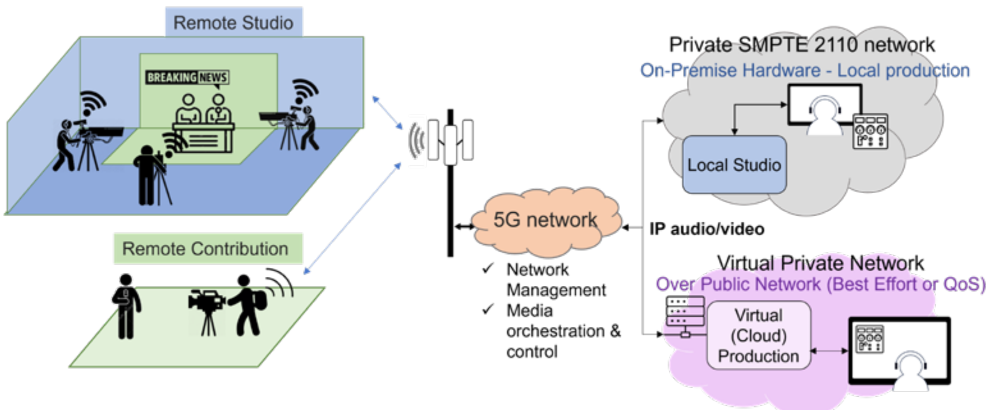

Fig. 2. Multiple camera wireless studio.

- **UL throughput, contribution latency and packet loss rate:** UL bandwidth for one audio/video/data stream over a single link reaching 50Mbps, and 4 simultaneous streams reaching a max of 60Mbps between all four for the contribution scenario. Contribution scenario UL latency was below 1 sec, tested at ~600 ms end-to-end, from image capture, through A/V encoding, to transmission over the 5G networks, through the public internet from one country to another (in the EU), to studio, to decoding, to output. Loss rate over this full end-to-end path was achieved by the network – at 0% or close to it.

- **Multi-camera contribution:** Multi-camera via specialized equipment was tested – up to 4 streams were measured.

- **Remote audio communication (remote contribution):** Remote audio communication was tested and achieved. Audio communications between remote producer/director and camera operator/reporter, in parallel to the UL video streams including when 4 streams were uplinked, was working from RAI studio all the way to the Aachen or TV2 labs over the labs 5G networks.

- **Cameras remote control (remote contribution):** Camera control was tested and passed. Camera control from RAI labs all the way over the full path to the Aachen labs and TV2 labs over their local 5G network was done using the LiveU IP-PIPE link via the Cyanview control boxes. Latency from sending the command from the RAI lab to receiving the visual feedback after the camera iris actually electro-mechanically responded and moved and the video captured, encoded, transmitted over the 5G UL, the public internet, back into the Rai and decoded there, was about 800 milliseconds.

4.3. Use Case 3: Live immersive media services

This use case considers a real-time E2E Free ViewPoint View (FVV) system aiming to cover multitudinary events on theater or stadium-like venues, that includes: (i) video capture, (ii) 5G contribution using mmW, (iii) virtual view synthesis on an edge server thanks to several VNFs, (iv) 5G delivery through VNFs and (v) visualization on users' terminals using the mmW link on-premise or the core network for remote attendees. The system finally delivers a synthesized virtual video, offering customers a high level of immersivity and groundbreaking QoE.

In addition, network slicing contributes to delivering assured QoS streams. Each user can access a specific angle live, offering a unique QoE.

Following, key KPIs that have been considered to evaluate the success of the use case are listed:

- ***Motion-to-photon latency:*** the time needed in the system for a specific user movement to be reflected on a display screen should be 170 ms or less. In the 5G network deployed in Segovia (phase 1 of UC3 trials), 290 ± 80 ms was achieved. In the compact 5G deployment in Madrid (phase 2 of UC3 trials), 210 ± 20 ms was achieved. The target was not achieved with the existing FVV + 5G network configuration. However, the obtained result (210 ± 20 ms) is close enough. The next generation of 5G networks with higher uplink capacity will be able to achieve the target of 170 ms.

- **Uplink bitrate:** critical KPI for the deployment of FVV cameras in the field

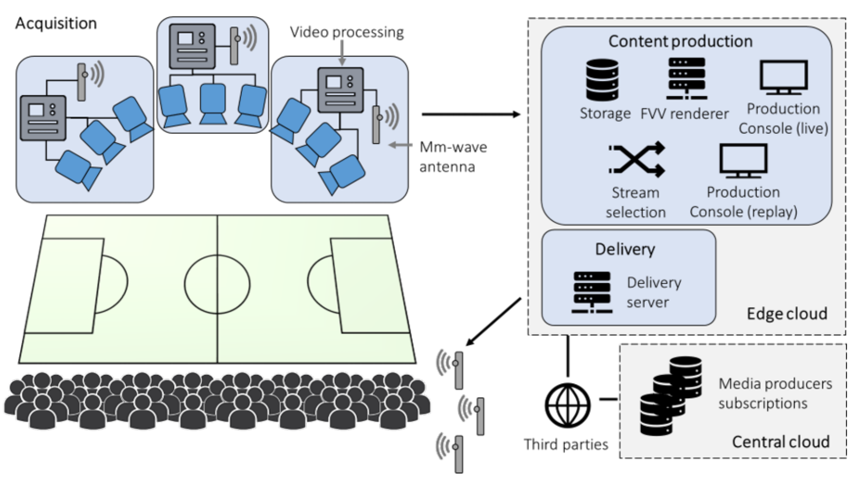

Fig. 3. Live immersive media production

that enables FVV production. Each camera stream (RGB+Depth) should be less than 100 Mbps, and ideally less than 50 Mbps. As proved in the final field trial, it is possible to obtain functional FVV production over a moderately complex scene using a configuration of 720p15. This results in 25 Mbps of average bitrate, which is clearly within the ideal target bitrate.

- **Round-trip Time (RTT):** defined as the time it takes for a packet to go from the sending endpoint (UE) to the receiving endpoint (MEC) and back. It is required a low delay to support interactivity and low motion-to-photon latency. The RTT between the UE and the MEC should be less than 40 ms, in this specific live immersive media production environment is about 12 ms in idle conditions, and 25 ms in load conditions.

5. 5G-RECORDS COMPONENTS

A key aspect of 5G-RECORDS was the development of both 5G and media components. Some of the components used in this project have been enhanced and adapted from previous commercial or research products to fit the use case, while others have been specifically developed from scratch.

The development of these components and their integration into the 5G network was the core of the 5G-RECORDS technical activities in order to provide the functionalities requested for the use cases validation.

Table 1, Table 2 and Table 3 present the list of components per use case and their role. [1]

Table 1. List of components for live audio production use case

Component	Partner	Role
Local Audio Processing*	SENNHEISER	Stationary device connected wired to the 5GS. Located on-site to allow low-latency interaction with the wireless audio equipment. Network audio streams from microphones are received, mixed, and sent to IEM receivers in the 5G network.
Audio User Terminal	SENNHEISER	5G-enabled microphones and IEMs. The audio part is based on a custom developed hardware. The audio- and the 5G-part are connected by a 1 Gbps Ethernet connection. IP audio streams can be received or transmitted, and the audio network device converts between analogue and IP domain.
Media Orchestration and Control Gateway*	SENNHEISER	It advertises the audio network devices capabilities. Based on the desired configuration, it sets up the audio network devices accordingly. It terminates audio data flows.
5G RAN (inc. Shared Access Client)	EURECOM, ACCELLERAN	Support of E2E SA setup based on a 5G CN and SA capable COTS UE devices. It consists of Eurecom's Radio Units (RU) and Distributed Unit (DU) based on OpenAirInterface (OAI) and Accelleran's Centralised Unit (CU). DU/CU communication over the F1 interface.
5G Core	CUMUCORE	3GPP Rel-15 compliant 5G Core including dynamic network features. It is capable to connect local data network directly to UPF, which enables local audio mixing. Support of Network Slice lifecycle functionality and PCF functionality to dynamically create data flows.
Shared Access Server	RED TECHNOLOGIES	It determines the maximum allowed transmission power of each device, determines the protection zone contour and identifies the most suitable frequencies.

1 New 5G and media components fully developed during the project are marked with an asterisk (*).

Table 2. List of components for multiple camera wireless studio use case

Component	Partner	Role
Media devices	ALL	Media capturing and additional devices (cameras, microphones, RCPs, etc.)
Media gateway*	BISECT	Bridges the media devices, 5G network and production network & devices together by encoding/decoding and translating transport protocols
Media Orchestration and Control Gateway*	BBC, BISECT	Manages discovery, registration, authentication interconnection, configuration, control and monitoring of devices
Network slice management/NEF	ERICSSON	Manages the network slicing functionality based on QoS
5G network	ERICSSON	The backbone of all the communications of the use case
5G modem	FIVECOMM	Connects the cameras to the 5G network
5G camera interface unit*	FIVECOMM ERICSSON	Device that combines a video/audio encoder with the 5G modem, attached to the back of the camera
MCR	EBU	Virtual, cloud media production software
LU800	LIVEU	Encodes media from cameras and connects them to the 5G network for remote contribution scenarios
LU2000-SMPTE	LIVEU	Decodes the LU800 streams and outputs ST2110 for remote contribution scenarios

Table 3. List of components for live immersive media production use case

Component	Partner	Role
5G-Ready FVV Live	UNIVERSIDAD POLITÉCNICA DE MADRID	Immersive technology that allows the user to freely move around the scene. It is composed of cameras, capture servers, view renderer, virtual camera control system
Compact 5G Network & Multi-Access Edge Computing (MEC)	NOKIA	5G mmWave RAN provides service to the FVV System. By moving part of the processing to the MEC, makes it possible to distribute the computational load
Media Delivery*	NOKIA	Subsystem to delivery to third parties (content producers, broadcasters) in contribution quality and delivery to event attendees in streaming quality
Delivery cloud & End-to-End SDN*	TELEFONICA	Edge solution to ensure compute, storage and network capacity with SDN capabilities to handle the E2E transport slicing

6. TRIALS

Several tests and final trials were successfully deployed to assess and validate the 5G-RECORDS components and E2E solutions in the context of the three project use cases. These trials allowed project partners to study to which degree 5G fulfills the technical KPIs and requirements of the project use cases in the context of professional content production.

6.1 Use Case 1: Live Audio Production

UC1 disaggregated testbed was located in Sophia Antipolis, France, using Eurecom's infrastructure. It integrated the 5G-enabled microphones and IEM systems from Sennheiser, the COTS RUs and the open-source OAI gNB-DU from Eurecom, the CU from Accelleran, the compact 5GC from Cumucore and spectrum sharing management technologies from RED Technologies. After extensive interoperability optimizations, several tests were conducted to study the performance of the E2E system when using single and multiple UEs.

During the trials, UC1 partners identified that some components introduced significant latency jitter into the processing and forwarding of audio IP packets in the 5GS. Even if the UC1 network has evolved gradually during the project to reduce latency, the one-way network latency achieved was finally about 10 ms for a single audio UE and about 20 ms for up to three audio UEs. As introduced in Section 2.3, the availability and maturity of available 5G components remained a major constraint until the end of the project. For instance, the COTS 5G modems had a major influence on the support for specific features and achievable KPIs.

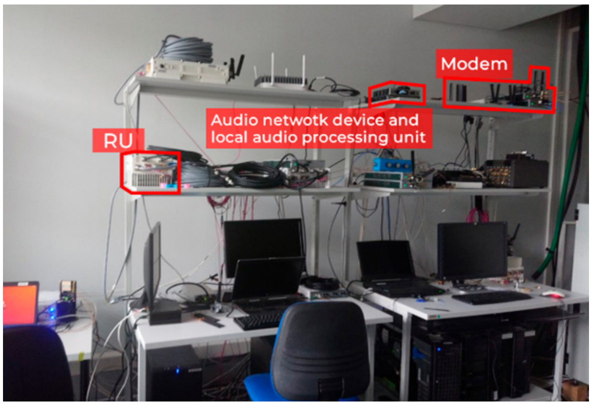

Figure 4. Lab room at Eurecom with radio unit, modem, audio network device and local audio processing unit.

In addition, UC1 partners were able to conduct mobility tests to better understand the use-case KPIs in a more realistic environment. For that one UE was connected to the 5G network and moved around in the lab premises (see Figure 3). Also, UC1 team was able to collaborate with UC2 partners during the trial in Tivoli Garden to demonstrate the delivery of audio and video over the same 5G network, and to conduct latency measurements as part of the evaluation of the state-of-the-art 5G components. Test results for the delivery of audio and video over the same 5G network for a local TV production during the Tivoli trial showed that packets were faster than 75 ms.

Figure 5 Mobile audio UE modem on a trolley; corridor for mobility trial.

6.2 Use Case 2: Multiple Camera Wireless Studio

Several tests were performed by UC2 towards the technology validation and execution of the final trial at Tivoli Garden, Copenhagen. Despite several setbacks due to development and integration delays and consortium amendments, it was possible to perform the desired tests and trials in the second phase of the project, which focused on PTP performance, remote production, local production, gateways, camera controls, glass-to-glass latency measurement, among other topics in Aachen, Turin, Copenhagen and Valencia. The PTP tests were successful in demonstrating that PTP over 5G is sufficient for frame-level synchronization. It was also demonstrated that the basic PTP performance can be greatly enhanced by client ––––tweaking and using advanced TSN features (from about 117 μs to 3,6 μs median offset).

Regarding local and remote production, several tests have been performed to stress the complete production chain to prepare it for the trial in Tivoli.

In the last tests performed in Aachen, Germany, UC2 team was able to integrate the media gateway into the infrastructure. The tests allowed the team to study the traffic behavior and extract different KPIs (frame delay, interarrival, packet latency, etc.). In summary, the most important KPIs such as E2E latency and uplink throughput have been measured and validated, with a glass-to-glass latency of around 200 ms and 50 Mbps per video stream.

Later, the final trial in Tivoli was performed, in which the E2E system was tested. The trial was a success, as professional content production could be carried out thanks to the developed components (such as the encoder-5G smart board, media gateway, MOCG, etc.) via 5G connection, both the local studio at Tivoli and the remote contribution from RAI lab.

Fig. 6. Overview of the Tivoli trial. Media gateway and cloud production (top) and video cameras with 5G interface units (bottom).

6.3. Use case 3: Live immersive media production

During the final UC3 field trial, the viability of a full E2E FVV live deployment to stream and record an event over a 5G network was demonstrated. The trial was chiefly intended to bring the use case into a real environment and validate each of the modules and components. This final trial was successful and provided relevant information as a result of all the work carried out during the project. The event consisted in a live music performance by professional artists which was produced as a FVV service in real-time and streamed to the final user. The event took place in Nokia premises in Madrid (Spain), and the FVV content was also recorded to demonstrate the FVV playback functionality of the system. Furthermore, Grafana dashboards were shown and monitored during the whole session. The results collected provide useful insights on options to reduce, if necessary, the amount of data to deliver FVV providing the highest possible quality to the end users. Also, they can help define trajectories that can be appealing for the users. Regarding the delivery network, with the results obtained during the final trial for UC3, we can certify that the expected KPIs have been met for four different scenarios and the whole setup is working as expected with two QoS slices.

Fig.7. Trial music show.

Fig. 8. Trial Location.

7. CONCLUSIONS

5G-RECORDS aimed at exploring the opportunities that 5G technology components, integrated into NPNs, bring to professional audio-visual content production. 5G-RECORDS partners worked for 26 months to exploit the potential of 5G to greatly facilitate and possibly even revolutionize media content production. During this time, 5G-RECORDS proved that

5G components and NPNs can be used successfully within several content production scenarios, providing in most cases the required performance and functionalities expected from the network. However, some aspects of the technology are yet in a very early stage of maturity and, therefore, it is necessary to further work around these limitations by developing new, non-existing features or improving the current ones. This is the case of use cases like live audio production use cases since extensive effort and development of the ecosystem is still needed to make 5G technology feasible for such use cases. In any case, 5G-RECORDS consortium dedicated great efforts in developing and integrating components and features in the 5G infrastructures to meet the requirements of 5G-RECORDS use cases. All these technical efforts have culminated in several successful final trials which have demonstrated that 5G media content production is a reality, but of course not trivial yet.

Thus, this project could serve as a good starting and reference point for the professional media content production industry, opening doors to build future projects on the base of 5G-RECORDS.

8. REFERENCES

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