Remote production and mobile contribution over 5G networks: scenarios, requirements and approaches for broadcast quality media streaming

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***Abstract*— Media applications are amongst the most demanding services requiring high amounts of network capacity as well as extremely low latency for synchronous audio-visual streaming in production quality. Recent technological advances in the 5G domain hold the promise to unlock the potential of the media industry by offering high quality media services through dynamic efficient resource allocation. Actual implementations are now required to validate whether advanced media applications can be realised benefiting from ultra-low latency, very-high bandwidth and flexible dynamic configuration offered by these new 5G networks. A truly integrated approach is needed that focuses on the media applications not only on the management of generic network functions and the orchestration of resources at the various radio, fronthaul/backhaul, edge and core network segments. The H2020 5G PPP Phase 2 project 5G-MEDIA [1] leverages new options for more flexible, ad-hoc and cost-effective production workflows by replacing dedicated lines and hardware equipment with software functions (VNFs) facilitating (semi-) automated smart production in remote locations. Highly scalable virtualized media services deployed on or close to the edge reduce complexity for the user, ensure operational reliability and increase the Quality of Experience (QoE). Virtual compression engines have the potential to replace dedicated encoder/decoder hardware while the network optimisation (Cognitive Network Optimizer) in combination with the Quality of Service (QoS) monitoring helps to overcome the current internet best-effort principle and ensures that the required performance needs are met at all times.**

Keywords—Remote production, smart production, mobile contribution, broadcasting, SDN, NFV, edge computing, NFVI, VNF, FaaS.

I. Introduction

Today broadcast productions of events are characterized by large teams required on location, one or several OB vans, and long preparation times for the placement and adjustment of the audio and video equipment. A TV production (e.g. in an OB van) is a very complex and elaborate event as depicted in *Figure 1*. It shows the necessary equipment as well as the signals among devices and the workflows established for production. Cameras capture the events and send these signals to the OB van. Once there the operator applies a remote control solution that includes several options like colour correction, camera colour balance or adjusting focus. The video switcher switches between different sources (i.e. cameras) and uploads or changes graphics. The audio switcher manages all audio signals in the event like microphones, camera audio, etc. Inside the OB van the directing team manages the whole proceedings and produces the program. Once the TV signal (program signal) is produced, it is contributed to the broadcaster's site in order to get broadcasted/distributed to the public. More equipment comes into play here before like signal synchronizers, repeat servers, pre-selectors, rasterizers, waveform monitors, intercom signals, etc. Besides the organisation of the equipment and signals, the crew on site (television presenter, camera operators, directing team, technical team, audio and video engineers, etc.) has to be considered. They all have to move to the venue in order to work for a TV production: Therefore, another time-consuming part is the set-up and facilitation of the places to carry out the work.

Today dedicated connections are established between the event location or venue and the broadcaster's site to guarantee the required high performance and quality of the transmission. Bandwidth requirements for a normal TV production can easily get into the range of several gigabits per second. This level of bandwidth capacity is currently only available in limited/metropolitan areas at very high costs. [2] These aspects increase the expense of a TV production considerably and so it is often only feasible if the production recurs regularly and the price-performance ratio is large enough. Therefore, considering all these issues, the steadily rising cost pressure and complexity forces broadcasters to look for new, low-cost and time-saving production methods like remote and smart production. In a remote production, the control room at the broadcaster's facilities is used. The control of (some of) the equipment on the venue happens remotely from this room. Therefore, less equipment and crew need to be present on site during the production process.

Smart mobile production/contribution on the other hand addresses the needs of mobile reporters in the field who need to transfer content to the studio by fulfilling the high broadcasting requirements. It is also relevant for the transfer of user-generated content from the public. Due to slow internet connections and bad reception conditions such video streams often have poor or unreliable quality and cannot be broadcasted. Yet they are often included in broadcast programs (e.g. news shows) as it is the only available footage of an important or newsworthy event. Therefore, if possible interviews on the street are pre-recorded and then, only later, are processed and edited in the studio. Our proposal is to improve the engineering design based on QoS (Quality of Service) and QoE (Quality of Experience) criteria that help to increase end-user satisfaction. There are several proposals in this field whereas many are based on a CDN (Content Distribution Network) solution like [3]. In the described use case we aim at using these advancements for contribution in a 5G environment.

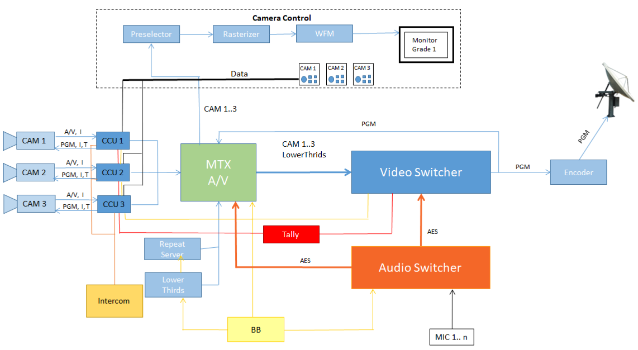

Fig. 1: Equipment and signals in a typical TV production

5G networks promise significantly reduced latency and vastly increased capacity for delivering high bandwidth data streams at low latency and with high reliability. 5G-MEDIA aims to overcome the limitations posed today on traditional broadcast productions by implementing orchestrated mobile contribution, remote and smart production over 5G networks for low-latency and high-bandwidth media streaming. 5G-MEDIA enables remote productions from anywhere without the need for dedicated infrastructure, like encoding hardware, mixing desks and intercom-systems to be specifically deployed for the event. Cameras and audio equipment at the venue are connected via a 5G network to virtual media production applications deployed and orchestrated by the 5G-MEDIA Service Virtualisation Platform (SVP) to ensure that the media processing functions are embedded within the network and cloud infrastructure enabling low latency and high throughput as required by live streaming and media processing.

The objective of this paper is to discuss how 5G technologies/networks can benefit media applications and services as they have very high demands regarding bandwidth, latency and availability. We describe the innovations achieved using a media-specific platform and the respective services and applications and illustrate how 5G technologies are implemented and used here to meet the requirements of today's and future media applications regarding remote production and mobile contribution in broadcasting. The paper is organized as follows: Section II specifies the defined use case and scenarios for broadcasting in 5G-MEDIA. Section III deals with their specific requirements regarding the application, infrastructure and platform. Section IV describes which concepts, functions and tools are applied in 5G-MEDIA to exploit the full potential of the use case. Finally, Section V concludes the paper.

II. Scenarios on Remote Production and Moble Contribution

A. *Scenario I: Remote Production*

The first scenario "Remote Production" deals with the production of large-scale live events (e.g. a football game in a stadium) using minimal equipment and personnel on site *(Figure 2)*. This is accomplished by remotely controlling the equipment and audio/video signals over the network from the broadcaster's facilities. The camera signals are transferred to the 5G MEDIA gateway which is a Physical Network Function (PNF) and responsible for the SDI (Serial Data Interface)-to-IP signal conversion. SDI is the predominant transmission standard in current broadcast production and most cameras used today have an SDI-out, making a gateway necessary to bridge to IP. The gateway connects the event location with the 5G-MEDIA network using SMPTE (Society of Motion Picture and Television Engineers) ST 2110 Professional Media Over Managed IP Networks which is a new suite of standards for uncompressed video transport. It specifies the carriage, synchronization, and description of separate elementary essence streams over IP for real-time production, playout, and other professional media applications [4]. For transfer to the receiving side, the video streams (audio is embedded) are compressed and encoded to adapt them to the available WAN bandwidth (which is typically limited and expensive) and then transmitted to the studio where the signals are decompressed and decoded for further use by the broadcaster. In Scenario 1a) this is achieved by deploying vCompression Engines (media-specific virtual functions) at the network edge. They replace typically used dedicated hardware systems that compress and encode the video streams for transport over the network as well as decompress and decode the video back to the original format at the broadcaster's facilities. Typical standards that are used for WAN transmissions are JPEG2000 or H.264, with H.265 looming ahead. At the receiving side another gateway converts the IP signal back to SDI to allow further processing (e.g. video switching) by the broadcaster.

In Scenario 1b) the same setup applies but the directed picture is created in the cloud (not at the broadcaster's facilities as before) with the help of the Media Process Engine (MPE) which serves as a video switcher to change between signals. It is controlled by a director back at the broadcaster's facilities on the basis of the preview streams he receives. The final broadcast stream is created with the MPE and can then be used for further processing or distribution. The final broadcast stream is also transferred in a highly compressed version to the broadcaster and to the crew on site to see what is going live at all times. In Scenario 1c) the before mentioned scenario is extended by Cognitive Services which use deep learning neural networks to analyse the media content. In this scenario a speech-to-text engine is used that converts the spoken words in the video into written text that can then be added as subtitles to the video stream/final broadcast stream. This stream could be distributed as a second stream application or presented to the commentary as an accessibility feature. The deployment of the virtual Cognitive Services at the edge prevents the video stream from being sent to a central cloud for processing and therefore avoids any delays and saves bandwidth as well as additional costs.

In all three scenarios control signals (voice orders, data control signals) and preview streams are transferred via the 5G-MEDIA network between the broadcasting centre and the remote site where they will be forwarded to the respective equipment and personnel.

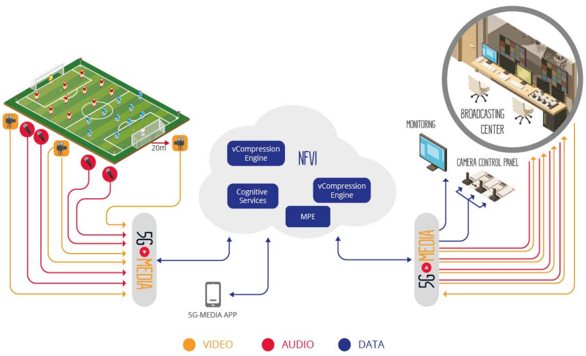

Fig. 2: 5G-MEDIA Scenario on Remote Production and Mobile Contribution

B. *Scenario II: Mobile Contribution*

The second scenario "Mobile Contribution" deals with the streaming of live events via smartphone *(Figure 2)*. Journalists or spectators (producing user-generated content) use a smartphone app to connect to the 5G-MEDIA network for live streaming video and/or audio to the broadcasting centre. The signal is compressed and encoded on the smartphone for transmission. Then the stream passes through a Cognitive Service function where it is enriched with additional information. In our case a face recognition service is applied that tags and identifies people in the video and provides the broadcaster with supplemental information and metadata from a database for further value-added services to enhance the viewing experience. At the network edge near the receiver a vCompression Engine decodes and decompresses the stream for further use and processing at the broadcaster.

III. Application and Platform Requirements

Media applications are amongst the most challenging (network) services and typically pose very high demands on the network and the management of the underlying computing resources. These demands comprise application and platform requirements which we defined for the use case as follows.

A. *Application Requirements*

The application requirements consist of network and video specific requirements. The network requirements are: a maximum end-to-end network latency (RTT) <= 50ms and a minimum end-to-end connection bandwidth (per stream) depending on the used compression/codec ranging from 3 Gbit/s for uncompressed HD 1080p video to 15 Mbit/s when H.265/HEVC is used. The network has to be error-free and lossless allowing a maximum packet-loss rate of $< 10^{-12}$. The maximum network jitter/packet delay variation (PDV) should be < 10ms and Quality of Service should be implemented to classify and prioritise the audio video-streams due to the high requirements on latency, jitter and bandwidth. The video requirements concern the high-level demands of the actual video streams/streaming application. The maximum one-way latency of the end-to-end signal transport (video, audio and control data) is <= 500ms with some exceptions depending on the scenarios. For Scenario 1 the latency has to be <= 50ms for tight director-camera operator feedback (action sports) and can be as high as <= 500ms for loose director-camera operator feedback (anticipated camera shot planes). The MPE path has no latency constraint as long as the MPE latency is known by the orchestrator in order to compensate time difference. For Scenario 2 there are no timing constraints due to the very loose coupling between the reporter and the receiving broadcaster. The maximum end-to-end latency for the return video is <= 500ms because it typically uses less bandwidth due to a low-resolution proxy transfer. The maximum end-to-end latency for the intercom is <= 100ms [5]. The maximum end-to-end latency for control (tally, camera matching/colour correction, focus etc.) is <= 50ms (depending on the maximum network latency). A synchronisation of video and audio signals is also needed to allow for signal switching and prevent picture-sound de-synchronisation. This can be accomplished by synchronising the end devices via GPS using black burst, tri-level sync and/or PTP. Only if these network and video requirements are met a smooth and error-free transmission can be guaranteed which is needed for a live streaming event. Any issue with the transmission disturbs the viewing experience and renders the source material useless for the producer and is therefore unacceptable.

B. *Platform Requirements*

The platform requirements encompass infrastructure and management demands. The infrastructure requirements mostly concern computational resources. Compression and transcoding of uncompressed HD audio-visual content during a live streaming event is very demanding and needs a lot of computational power and memory to run smoothly and error-free. Other functions like the Cognitive Services are also very demanding depending on the analysed content and actions to be performed. So current high-performance hardware and software (cf. virtualisation technology) is needed here. Moreover, the transmission of up to 3 video streams from the venue to the compression units requires a certain bandwidth also. Furthermore, the director needs to have control over the configuration of some functions in order to perform the remote production of a final broadcast stream. Finally, a smartphone application is used in Scenario 2 in order to perform the acquisition and streaming of audio-visual content.

The Management and Orchestration (MANO) functions are involved in this use case in two different time-frames: service deployment and service operation. In the service deployment DevOps capabilities like agility and elasticity are needed to be used in a highly automated environment. Continuous integration and continuous delivery, deployment and release are set as well. The developer must be able to specify the service capabilities, performance requirements as a service manifest to be used by the MANO optimisation algorithms as well as the VNF forwarding graph (VNFFG) pattern for the service. The developer is able to identify the role of existing PNFs in VNFFGs and to instantiate any VNFs that should be permanently running. The service operation deals with the session establishment where VNFFG instance creation should be supported and the online session management that comprises changing VNF parameters like transcoding values and triggering QoS prioritisation and traffic steering functions in the underlying network as required to provide and maintain QoS levels for broadcast media content. In order to perform this the service operator applies a central control unit used by the service provider to dynamically adapt the VNFFG. [6]

IV. 5G-MEDIA INNOVATIONS FOR REMOTE PRODUCTION AND MOBILE CONTRIBUTION

There are a number of 5G-MEDIA innovations that will be implemented and ultimately benefit remote production and mobile contribution for broadcasters: Virtual Functions/VNFs, Serverless Paradigm/FaaS and QoS and Control Management are the most relevant for this use case.

A. Virtual (Media) Functions/VNFs

One key challenge for the implementation of this use case in 5G-MEDIA is the virtualization and decentralisation of media services as virtual functions. As media applications pose high demands on the network and the underlying infrastructure, especially when it comes to broadcast quality audio and video content, a software-only approach is a very challenging task. But when accomplished such a setup brings great advantages over current approaches as it allows for optimal usage of network resources and ad-hoc instantiations of virtual media functions (media-specific VNFs) from a service catalogue where and when needed. This is achieved by applying Software Defined Networking (SDN) and Network Functions Virtualisation (NFV) concepts to media applications and flexibly as well as dynamically embedding them as VNFs. This allows for flexible developments via a DevOps environment which hides the complexity of service development and deployment on the underlying 5G network. Such a system design also allows for ad-hoc instantiations, setup and orchestration of VNFs/media services over heterogeneous nodes belonging to different administrative domains or infrastructure owners/operators. The 5G-MEDIA SVP orchestrates the deployment and scaling of the media applications, interacting automatically with the underlying network for the dynamic control of the network paths and forwarding graphs.

The following media-specific VNFs are developed and used:

- The vCompression Engine is responsible for compression/decompression and encoding/decoding of the audio video content before and after the WAN transfer. It is based on open source encoding techniques and aims at using the latest video standards such as SMPTE 2110 and H.264/H.265. Depending on the coding parameters it requires high computational power and is an ambitious software-only approach. Typically, hardware en-/decoders are used today to fulfil this task. So a virtual software-only approach will boost flexibility and agility in remote production.
- The Media Process Engine (MPE) performs the switching and mixing of audio video signals. As the MPE placement is after the vCompression Engine, audio and video signals have to be switched/mixed in a format that allows to do that. Therefore, an intra frame compression is preferred here. The MPE can have two roles: serving as a video mixer and switching different video signals and as a broadcast router outputting auxiliary signals. The MPE VNF is also instantiated on demand and allows to virtualise and remote control the video switching altogether. The final broadcast stream is produced near the venue which reduces transmissions, bandwidth and latency to the broadcaster as well as equipment (cost). Today the MPE is typically a large hardware device which is fixed in a control room or OB van allowing for almost no flexibility.
- The Cognitive Services allow for (automatic) enrichment of video content with additional information such as speech-to-text and face recognition. The Speech-to-text Engine allows for the recognition and analysis of the audio video material's audio signal which will be decoded into text. This is used in the first scenario to automatically add subtitles to the video stream. The Image/Face Recognition Engine enables the detection of objects within the audio video material with a context-aware text-based output. Scenario 2 will make use of this by tagging and ultimately identifying people in the video and providing the broadcaster with supplemental information. Both services are based on the latest machine and deep learning techniques making a virtualized and cloud-based approach the most feasible. Also, as a VNF they can be instantiated and used when needed/triggered and quickly shut down when they are not needed anymore, saving costs and increasing flexibility.

B. Serverless Paradigm/FaaS

The 5G-MEDIA architecture introduces the concept of Serverless computing/Function-as-a-Service (FaaS) to the VNF management, complementing traditional VM-based VNFs with FaaS-based media specific functions, aiming at dramatically reducing development cycles and operational costs for users. In a traditional MANO stack, virtual functions are provisioned as VMs similarly to the VNFs without any regard to the function lifetime duration. In 5G-MEDIA short lived virtual functions that happen spontaneously and require an immediate setup of an elastic virtual infrastructure are to be provisioned on demand using the FaaS programming model.

Mobile contribution where a transmission lasts only a few minutes is an ideal candidate for FaaS. Probably many short clips are produced one after another by the mobile device of a journalist or spectator in the field. Then the respective VNFs should be instantiated. That can be the vCompression Engine for processing the video. Even better suited are the Cognitive Services for media enrichment which might be instantiated any time throughout the transmission to analyse the video and add supplemental information. Using the Face/Image Recognition Engine faces are extracted from the video stream on a frame by frame basis from the video segments. The extracted faces are being transferred to the cloud for further face recognition against a large database of celebrities, tagging of the celebrity images and automatically preparing additional background information on the person to be used by the director. [6] Regarding Scenario 2 a typical workflow could look like that: A journalist covers an important event and streams a live signal via smartphone app back to the broadcaster's facilities. The faces depicted in the video stream trigger the Face Recognition Engine and instantiates the FaaS service automatically. As soon as it is up and running the service starts working, tagging the people in the picture and sorting the material under the right tags in the broadcaster's archive. If the recognised content in the picture is part of a current story, another FaaS could notify an editor. Another scenario could look like that: If some news is breaking and the need for covering a short-dated press conference is required, a virtual instance of the Speech-to-Text Engine at the nearest edge is launched through FaaS to generate a transcript of the event and tag the material with additional meta information. The transcript and additional data can then be used for further covering the event, for example in a news overview or for an online summary.

FaaS allows to provision VNFs on demand where function provisioning and deprovisioning is handled by a FaaS platform transparently providing for seamless elasticity and scalability. FaaS allows to define actions, organise them into sequences and create rules that define "if-this-then-that" type of policies to work in an event-driven manner. This approach saves bandwidth and eliminates that resources are wasted by only using the virtual infrastructure that is required when it is required. Being intrinsically more lightweight than a VM-based approach, a container-based FaaS technology is much more reactive which is a critical feature in the scenario. [6] Another benefit of FaaS comes from the billing model. For each VNF there exists a break-even point of time utilization after which FaaS is not justified economically. If, for example, a virtual function should run all the time, FaaS does not offer better cost efficiency than using traditional VMs. So, for temporary events as in Scenario 2 FaaS could pay off.

C. Network Control and Optimisation

In 5G-MEDIA comprehensive control and management functions are established. The Orchestrator is responsible for the management of the services/VNFs that are used in the different scenarios and allows for location-based service provisioning/allocation (at the edges) and service chaining. Once the media service is deployed in the virtualized infrastructure, the 5G-MEDIA platform provides mechanisms to flexibly adapt service operations to dynamic conditions and react upon events (e.g. to transparently accommodate auto-scaling of resources, VNF replacement, etc.) [7]. For all scenarios network and transmission optimisation is applied dynamically on the network level according to the specific demands and conditions of the stream to ensure that the best quality is delivered to the broadcaster. This is achieved with the help of the so-called Cognitive Network Optimiser (CNO).

The CNO is an optimisation and prediction engine that uses the raw measurement data from the QoS/QoE monitoring service. The CNO employs statistical analysis based on machine learning and optimization techniques for classifying network and computational resource service status, predicting/forecasting future resource conditions and triggering corrective actions for the running network services (NSs). The CNO consists of two main subcomponents: the first is the Machine Learning Engine (MLE) and the second is the Policy/Optimization Engine (POE).

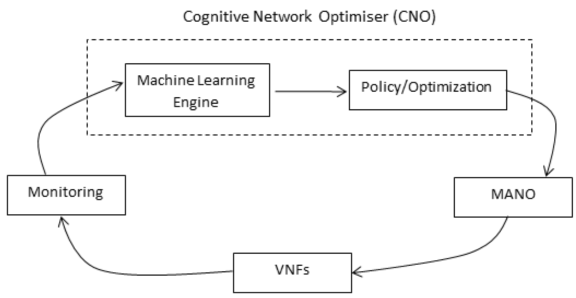

Fig. 3: Closed-loop system of the CNO

As shown in *Figure 3*, the MLE is tightly coupled with the QoS-Monitor which monitors the whole network. Based on the data from the QoS-Monitor, the MLE analyses and predicts resource demand and utilisation and evaluates SLA violation risks. It helps to deliver insights to the POE on both current performance metrics and forecasted changes in demand and expected performance levels. The outputs from the MLE provide the necessary inputs to the multi-objective optimization algorithms (Policy/Optimization Engine) that will determine the assignment of the available network and computational resources to maximise performance metrics within defined cost and QoS (e.g. latency, bandwidth) constraints.

As shown in *Figure 4*, the output of the CNO (Policy/Optimization Engine) is involved in triggering network-level MANO functions (via an appropriate API) to request the instantiation and the configuration of the VNF forwarding graph (VNFFG) in order to achieve the system performance goals, trading off between QoS and costs.

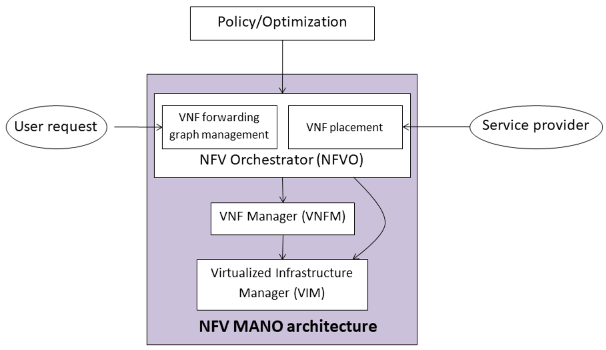

Fig. 4: Output of CNO component to trigger MANO functions

Based on *Figure 4*, possible optimization policies include:

- Service placement optimisation: at deployment time the service provider triggers the VNF placement component of NFVO to pre-deploy VNFs (which VNFI instance/edge nodes should house which VNFs) and make them available when user requests come.
- VNFFG optimisation: at demand time the user requests will be served by the VNFFG component. Based on the output of the policy/optimisation engine, the VNFFG component will determine which instances of VNFs should be interconnected as a VNF chain for a specific user session request.
- Infrastructure adaptation to overcome streaming difficulties: e.g. reserve bandwidth, set up expedited paths, reroute to avoid congestion or reroute other traffic to avoid congestion

In summary, the key novelty of our CNO design is a combination of machine learning and optimisation in a closed-loop control system (*Figure 3*). There are several works in literature showing that using service placement/selection optimisation would significantly improve system performance while satisfying cost constraints [8, 9]. However, those works assume that there is a perfect prediction component to forecast traffic demand and available computational/networking resources. In this work, we explicitly consider a MLE working together with the optimisation engine in a closed-loop system. Given feedback from the monitoring engine, MLE can gradually improve the learning process to provide more accurate inputs for the optimisation engine which eventually improves the overall system performance.

Regarding the use case on remote production and mobile contribution the CNO adjusts the networking graph dynamically according to the specific requirements and conditions of the streams. The MLE is used to predict user demands and available resources based on the QoS/QoE measurement data. This information together with application requirements (e.g. bandwidth and latency) is then used by the optimisation engine to determine the placement of the vCompression Engine VNF at the network edges (i.e. event and broadcaster's facility). It is also necessary for the infrastructure adaptation, e.g. reserving the bandwidth needed for the transmission between the vCompression Engines, set up a path with optimal latency, avoid congesting traffic (as video streams should always have the highest priority) and reroute the traffic in case of an error. The objective of the optimisation engine is to ensure that the best quality within a cost constraint (assume that the VNF deployment incurs a cost) is delivered to the broadcaster.

V. CONCLUSION

Media and broadcast applications are among the most demanding verticals in 5G. Especially in contribution and remote production fast transmission speed, high bandwidth and low latency are required Technological advancements in 5G promise to leverage and foster the development in the media industry as the content produced and transferred is growing exponentially and the capacity demands steadily rise (e.g. 4K, 8K (UHD), 12K). 5G promises to significantly reduce latency and vastly increase capacity for delivering high bandwidth data streams and so offers the chance to deliver high quality media services through dynamic efficient resource allocation.

In this paper we presented the 5G-MEDIA use case on remote production and mobile contribution and which innovations we plan to achieve in the context of the 5G PPP 5G-MEDIA Phase 2 project to enable the development and operation of media services. We described in detail how we plan to use the 5G-MEDIA platform for remote production and mobile contribution in broadcasting and which specific concepts, developments and advancement we will develop and use regarding management, orchestration, service instantiation and deployment. We apply SDN and NFV concepts to media applications to flexibly and dynamically embed them as virtual network functions (replacing dedicated hardware equipment) and deliver media services in an on-demand and ad-hoc approach. The usage of the FaaS approach for short lived virtual functions that happen spontaneously and require immediate setup of elastic virtual infrastructure and are to be provisioned on demand saves capacity and resources. This promises an ease of production through less equipment and personnel on site, more flexible production workflows, reduced costs, better utilisation and optimal connectivity where and when needed. Furthermore, a service virtualisation platform is developed that will orchestrate the deployment and scaling of the media applications close to traffic sources and sinks. By automatically configuring network paths and virtual slices by applying different advanced optimisation techniques 5G-MEDIA will deliver the required network capacity and performance levels where they are needed at any given moment. This is to be achieved with the help of comprehensive (QoS) monitoring and the Cognitive Network Optimiser (CNO) which is responsible for the optimisation of the network resources and network path computation by flexibly adapting service operations to dynamic conditions and react upon events. The combination of all these different 5G capabilities and technologies will help boost the media industry as a whole and remote and mobile broadcast production in particular.

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