5G City: A novel 5G-enabled architecture for ultra-high definition and immersive media on city infrastructure

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Abstract—**The rapid adoption of cutting edge media services such as ultra-high definition (UHD/4K) video and immersive media i.e, virtual and augmented reality (VR/AR), will demand large investments in a scalable, ubiquitous, and robust communication infrastructure and services. The H2020 5GCity project aims to solve such issues and beyond while designing, developing, and deploying a sliceable, distributed cloud & edge and radio 5G-platform with neutral hosting capability to support the sharing between information technology (IT) infrastructure owners and media service providers i.e., vertical media actors. In this paper we discuss how 5G technology will facilitate the rise of highly demanding media use cases and its implication on how service providers typically operate (in terms of business model). After a brief introduction of the 5GCity's architecture we present how three media-related use cases will be deployed in the cities of Barcelona, Bristol and Lucca by considering the project's architecture and the underlying neutral host parading to understand the benefits of such model for infrastructure owners and media service providers.**

Keywords—5G, 5GCity, ultra-high definition, immersive media.

I. INTRODUCTION

The next generation media services such as ultra-high definition (UHD/4K) and immersive media, for example augmented reality (AR) and virtual reality (VR), are expected to become mainstream among mobile users [1]. However, communication providers will face huge demands in terms of ubiquitous coverage and performance requirements, such as low system delays and ultra-high throughput. Furthermore, vertical media actors will also face challenges in the management of massive amount of data produced and consumed.

The prediction of more than 11 billion of mobile users connected by the year 2020 [2] is paving the way to the 5th generation (5G) networks. 5G technologies will decouple hardware and software by offering a new networking flexibility and higher transmission performance compared its predecessors [3]. As a result, the initiatives 5GPPP-EU [4], IMT2020-ITU [5], 5G Americas [6] are promoting and supporting the realization of 5G networks by 2020 and beyond. One of the essential features of 5G networks is infrastructure sharing, however, within 5G infrastructures, network sharing should evolve beyond traditional infrastructure sharing models such as site, mast, RAN and core network sharing [7]. Network sharing models should adopt the trend towards cloudification/virtualization which will become one of the pillars of 5G networks. The flexibility offered by such technologies, specifically, software defined networks (SDN) and network function virtualization (NFV) can be used to develop virtual frameworks, or "network slice" consisting of a set of logically segmented virtualized resources (i.e., compute, storage, and network) that share the same physical infrastructure [7, 8, 9, 10]. This infrastructure flexibility allows to customize the network slice, in terms of resources and their placement, and in term of verticals or application services that must exploit it. Furthermore, the separation between the control and user plane, enabled by SDN, will increase even further the network flexibility and efficiency. 5G networks will also move computing and storage resources to peripheral areas of the network (i.e., multi-access edge computing (MEC)) to be closer to users to reduce the latency and traffic aggregation required by many digital services (e.g., vertical media actors, energy industry etc.) [7, 8]. Hence, 5G networks will not only provide higher data rates and lower latency than 4G networks but also a fully customizable, sliceable, and flexible infrastructure that will open business opportunities for current stagnated telecom market and new players or verticals actors (i.e., industries) to flourish [9, 10, 11, 12].

The rest of this paper is organized as follow: Section II presents the current media technology. Section III presents 5G and neutral host for media. Section IV discusses the 5GCity architecture. Section V describes the 5G testbeds. Section VI describes the media use cases. Finally, the last section concludes the paper.

II. CHALLENGES OF NEW MEDIA SERVICES

The increasing demand of video production and distribution by the adoption of ultra-high definition (UHD/4K) and immersive reality (AR/VR) services will require higher flexibility and bandwidth requirements [1, 12, 13]. Hence, in the last few years the broadcasting industry is adopting IP as transport technology to provide flexible and agnostic video distribution. In this section we introduce some background about video-over-IP and the network requirements for video production and distribution to be used by our 5GCity media use cases.

Video-over-IP can provide the convergence between video, metadata, and general data in economy of scale by integrating broadcasting industry in to a more massive IT industry. The network, transport, and application layers can implement key functionalities to deal with video production and distribution challenges.

The network layer can provide multicast routing (e.g., distance vector multicast routing protocol (DVMRP), protocol independent multicast (PIM), Internet group management protocol (IGMP), etc.) and quality-of-services (QoS) functions as type-of-service (ToS)/differentiated-services-code point (DSCP) which mark the packet's headers and maps them with lower-layer protocols (e.g., ethernet or multiprotocol label switching (MPLS)) to implement QoS rules and buffering. In addition, IP networks have been evolving its own architectures from traditional hierarchic ones to flatter ones, such as the leaf-and-spine, used in most of the big datacenter deployments nowadays facilitating horizontal data movement, useful for heavy load transactions between same level hosts.

The transport layer for video-over-IP prefers UDP for real-time video transport as it avoids unnecessary retransmission for live streams. The RFC3550 real-time protocol (RTP) was introduced to transport audio and media services using a timestamp field together with the RTP protocol for control purposes (RTCP). Recently, new extensions have appeared introducing new header options to support the adoption of services by broadcasters' workflows. Concretely, RTP1, RTP2, RTCP1 have been proposed to accommodate media specific info over IP, answering to specific challenges.

On upper layers, new standards were created to encapsulate audio (AES67-2013) and video (SMPTE 2022-6) to support the transport of high-quality media signals over IP networks. On the video side, SMPTE 2022-6 is focused on mapping serial digital interface (SDI) and high-definition serial digital interface (HDSDI) (opposite to raw video, audio and metadata mapping, known as essence mapping) within IP packets and further specific solutions to manage packet loss recovery using FEC (SMPTE 2022-5) and a seamless protection system (SMPTE 2022-7).

In 2014, the video services forum (VSF) has formed a new group (SVIP) looking at new encapsulation mechanisms for audio, video and auxiliary data into IP without using SDI framing (raw data) to develop or recommend a standard for video-over-IP without SDI encapsulation. It aims to study and document the requirements for video-over-IP/ethernet within plant (video, audio, auxiliary data, bundles, timing, sequencing, identities, and latency), to research current and proposed solutions to report on gaps between requirements and existing solutions (especially regarding existing SMPTE 2022 standards) and finally to propose a scope for follow-on activity if required.

In the media plane, protocols such as real-time streaming protocol (RTSP) for end-to-end session control or session description protocol (SDP) for service description provide capabilities for the stream management. Complementary, media wrappers aim to gather different types of program media and associated information, as well as generically identify this information. Several media wrapper formats are in use currently, but, for the media industry, it is important that they share some characteristics such as openness, extensibility, performance, etc. Media exchange formal (MXF) (a SMPTE standard) is a "container" format which supports several different streams of coded "essence", encoded in any of a variety of video and audio compression formats, together with a metadata wrapper which describes the material contained within the MXF file enable interoperability between different platforms. Also, data distribution service (DDS) (a machine-to-machine middleware standard from OMG) could be used to enable interoperable media exchange between actors. At the same time, EBU has launched the framework for interoperable media services (FIMS) which intends to answer to different interoperability issues between service-oriented architecture (SOA) proprietary systems by defining an open, consensual framework with standardized interfaces.

Format/ Technology	***Bandwidth (Uncompressed)***	***Bandwidth (Compressed) [13]***
Mobile Camera	-	10/20 Mbps [14]
HD1080i	1.5 Gbps	110 Mbps
HDSDI 3G	3 Gbps	150 Mbps
4K @30fps	6 Gbps	600 Mbps
4K VR	6+ Gbps	600 Mbps

Table 1:Video production requirements

Finally, here we introduce some numbers about video production and distribution used today by broadcasters and to be considered in our use cases. The first Table 1 introduces compressed and uncompressed video production bandwidth requirements per connection and video format or technology [12, 13]. Table 2 summarizes the bandwidth requirements per connection to be considered in the video distribution trials of our use cases (Provided by RAI TV R&D).

Format/Technology	***Live Event***	***Video on Demand***
HDR	6 Mbps	6 Mbps
VR 360 (4K)	20 Mbps	20 Mbps
4K UHD (HDR)	20 Mbps	20 Mbps

Table 2:Video distribution requirements [14].

In the future when 8K will be offer we can expect higher bandwidth requirements and video processing capabilities [14].

III. H2020 5GCITY PROJECT

A. 5G Technology

Network infrastructure sharing is a fundamental element to unlock commercial take up of dense 5G wireless networks [8], as it would be unrealistic to expect the deployment of hundreds of vertically-isolated access networks in such dense environments. A neutral and sliceable 5G infrastructure is a promising solution for the given challenges faced by infrastructure providers [12] and vertical media actors with video streaming and production in dense device-to-device (D2D) communication deployed in urban environments [15, 16, 17, 18, 19].

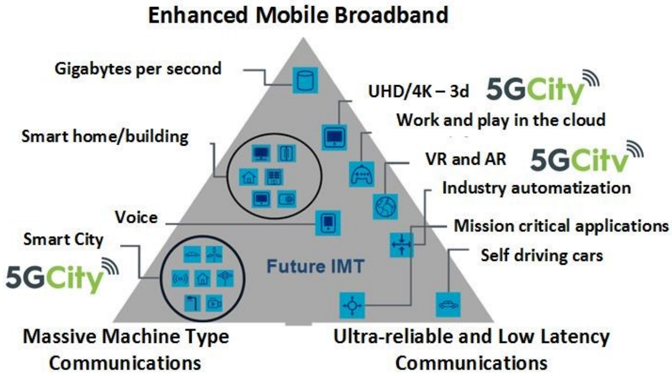

Figure 1 - 5G use cases scenarios and 5GCity use cases.

The driver for developing 5G is to increase mobile broadband capacity to provide specific functionality not only for consumers but also for industries and society in general. The 5G requirements must handle a variety of scenarios with very different specificities. Figure 1 represents typical 5G scenarios (use cases). Within 5GCity, three different enhanced mobile broadband (EMBb) scenarios are challenging the project's designed architecture and platform in different areas: video acquisition and production in live events, UHD real-time wireless transmission and UHD and immersive video distribution.

B. Project Background

5GCity, an ongoing H2020 project, aims to deploy and test the benefits of 5G technology by adding "neutral hosting" functionalities in the design, deployment, and development of a distributed cloud and radio platform [19, 20]. 5GCity architecture is the result of the integration between network functions virtualization (NFV), software defined networks (SDN) and multi-access edge computing (MEC) on distributed cloud and radio platform (Figure 2). So, it will allow infrastructure owners to monetize their investment and media service providers to deploy collaborative and innovative applications and finally improve the end user's quality of experience.

One collaborative and innovative media deployment with 5GCity architecture is the sharing of processing and caching capability into an integrated MEC with small cell radios to bring the network and video processing/production "closer" to the user while easing the density of small/macro cell deployments for urban environments.

5GCity architecture adapts distributed cloud technologies within 5G dense deployments in city-based environments building its combined edge and network infrastructure. It provides a multi-tenant, cost-effective platform for deploying virtualized heterogeneous services, including the multiple-radio access technology (multi-RAT) and virtualization technologies for the access network. 5GCity leverages its virtualization platform to enable the cities (or any infrastructure provider) to create dynamic end-to-end slices containing both virtualized edge and network resources and lease it to third-party operators. For example, a mobile operator can become a service provider in cities where it does not have infrastructure, with full management and control capabilities over the slice, further than the typical mobile virtual network operator (MVNO) use case.

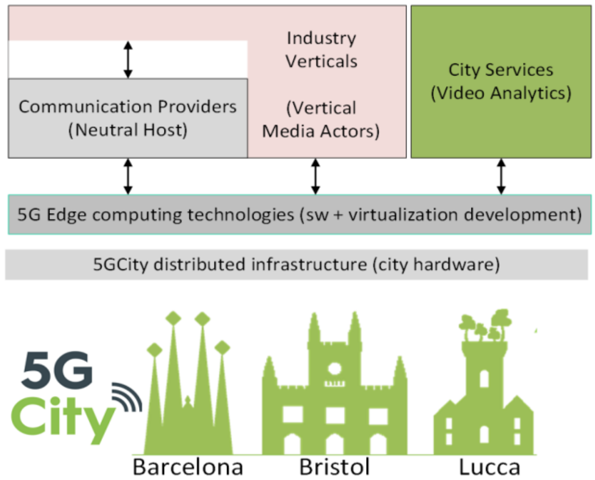

Figure 2 - H2020 5GCity project's architecture and actors.

IV. 5GCity Media Use Cases

To demonstrate the benefits of the 5GCity approach for infrastructure providers and UHD/4K and AR/VR media providers the project designed three realistic uses cases for deployment and test in three important European cities, Barcelona, Bristol and Lucca.

Different aspects of the media and entertainment industry are strictly integrated into 5GCity project and encompass most of the main use cases (UCs) pivoting around video acquisition, editing and delivery. This scenario is called the "media use case"; where three different use cases are considered:

UC#1: Real-time video acquisition and production in the edge/cloud: Video acquisition and production, supporting the broadcasting and live event production to achieve optimal user experience can create chances for revenues, while promoting users and community engagement experiences such as the ones provide by Facebook or YouTube.

Through 5GCity's platform, several dedicated network slices will be deployed, through NFV, offering dedicated 2-8 Mbps fronthaul links in a multi-RAT environment. With these networks, end-users will be able to connect to different WiFi access points and even small cells (LTE/5G) and leverage the low-latency communication link between edge applications and those running at 5GCity's core network. Crowdsourced video streams (from end-user's cell phones, for instance) will be pre-processed at the edge before being transmitted by a 1 Gbps link to the core or another edge datacenter. This use case intends to also showcase how infrastructure owners (venue) can monetize their IT and connectivity investment by renting these edge resources to other third-party entities requiring dedicated connections with a set of specific networks KPIs during specific events [22]. The envisioned scenario is very well known to media service providers as added throughput capacity at the front-haul link is always required during such crowded events.

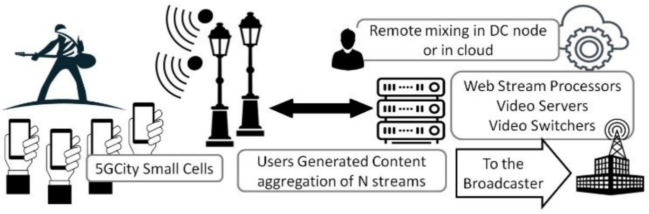

Figure 3 - 5GCity real-time video acquisition and production UC.

UC#2: UHD video distribution and immersive services: The immersive part of the project is designed to allow the end-user moving in a city to obtain additional content related to the surrounding environment (monuments, objects, etc.) by using smartphones and/or VR/AR/MR-like devices [1, 18, 21, 22, 23]. Also, with the production of video 360° to improve the immersion of the user experience. At the same time the visual search allows matching images or videos captured by the user, such as buildings, statues, paintings, with contents present in databases thanks to visual similarities. Additional content could be automatically retrieved, for example from television archives, in form of 2D video, panoramic video, and 3D models that will augment the reality in which the user is immersed. New UHD/4K contents will be available for the users, just to create "digital pills" in a hypothetical journey that include more information and A/V. This use case requires ultra-high bandwidth, to carry high quality UHD/4K video signals and a very low system latency, which should enable to implement effective interactive applications. 5GCity architecture facilitates both with its distributed cloud & edge and radio 5G-platform.

The video 360 material is produced with specific camera systems which have a minimum of two sensors, and two lenses, to have a field of view (FoV) as large as the whole spherical horizon around the camera. The different video contributions needed to be processed in suitable applications where the stitching of the different images, the color correction, the projection – usually in the equirectangular format – and the coding were performed. These systems lacked in synchronization among the cameras, which caused artifacts with moving objects. More recent products consist in a single system equipped with several sensors hardware synchronized. Some examples are: the Nikon Key Mission 360 with two sensors, the Orah 4i with four and the Nokia Ozo with eight sensors.

To generate video 360 material to be used as VoD, the Nikon system will be used both because of it easiness of handling and primarily because, being an "action cam" system, it is suitable for outdoor use. It records on an on-board micro-card from which the sequences can be transferred to an editing/processing machine for "makeup" and finally loaded on the video repository. To generate streaming material, the Orah 4i system will be used because it has an embedded streaming server capable to provide "live" video. This system requires electric power supply and must be used indoor. Both systems generate 4K sequences at 24/30 Hz with equirectangular projection which are undistinguishable from traditional UHDTV signals. For 360° video streaming, the distribution of live or VOD 360° video services over IP can follow two possible approaches [16, 17, 18, 19]:

1. "Viewport-Independent" approach
2. "Viewport-Dependent" approach with tiled encoding

In both cases, it is assumed that an equirectangular projection is used for conversion of the 360° video into a two-dimensional rectangular video before the encoding stage.

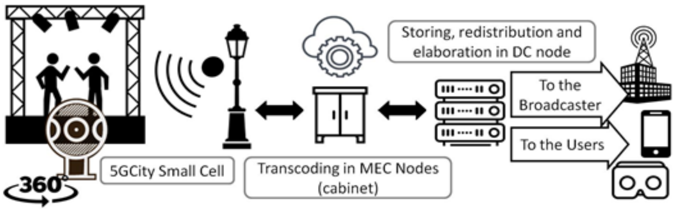

Figure 4 - 5GCity UHD video distribution and immersive UC

UC#3: Mobile Real-Time Transmission: Currently almost all TV stations are using what in popular language is called "backpack unit" for video transmission in remote areas. The backpack unit bundles multiple 4G connection together to transmit the video signal back to the TV station for further processing. The mobile real-time transmission Use Case will demonstrate how the 5GCity architecture will improve the available bandwidth of live connections (real-time transmission) leveraging on the capacity of 5G network. 5GCity system will enable the increase of bandwidth used for live connections, provisioning specific slices with a guaranteed QoS, enabling edge computing processing capabilities for production of video contents at the edge. Furthermore, 5GCity architecture enables required video processing at the very edge instead of TV station, reducing the high production cost of multi-camera events [15].

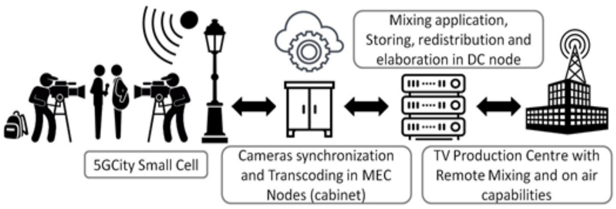

Figure 5 - 5GCity Mobile Real-time transmission UC.

UC	*Radio (Mbps)*	*Network (Gbps)*	*Edge (VM#)*	*Core (VM#)*	*Internet (Mbps)*
#1	UL:2-8	~2	1	1	50
#2	UL:100 DL: 20	~1	1	3	100
#3	UL:10	~0.1	1	1	50

Table 3: Some requirements for UCs production

Table 3 summarizes the minimal requirements for each UC. In terms of radio (wireless) bandwidth for video uploading (UL) and/or downloading (DL). Network bandwidth to transmit the video from the radio to edge and core datacenters. And, number virtual machines (VMs) placed in edge and core datacenters. And finally, the Internet connection required for remote control.

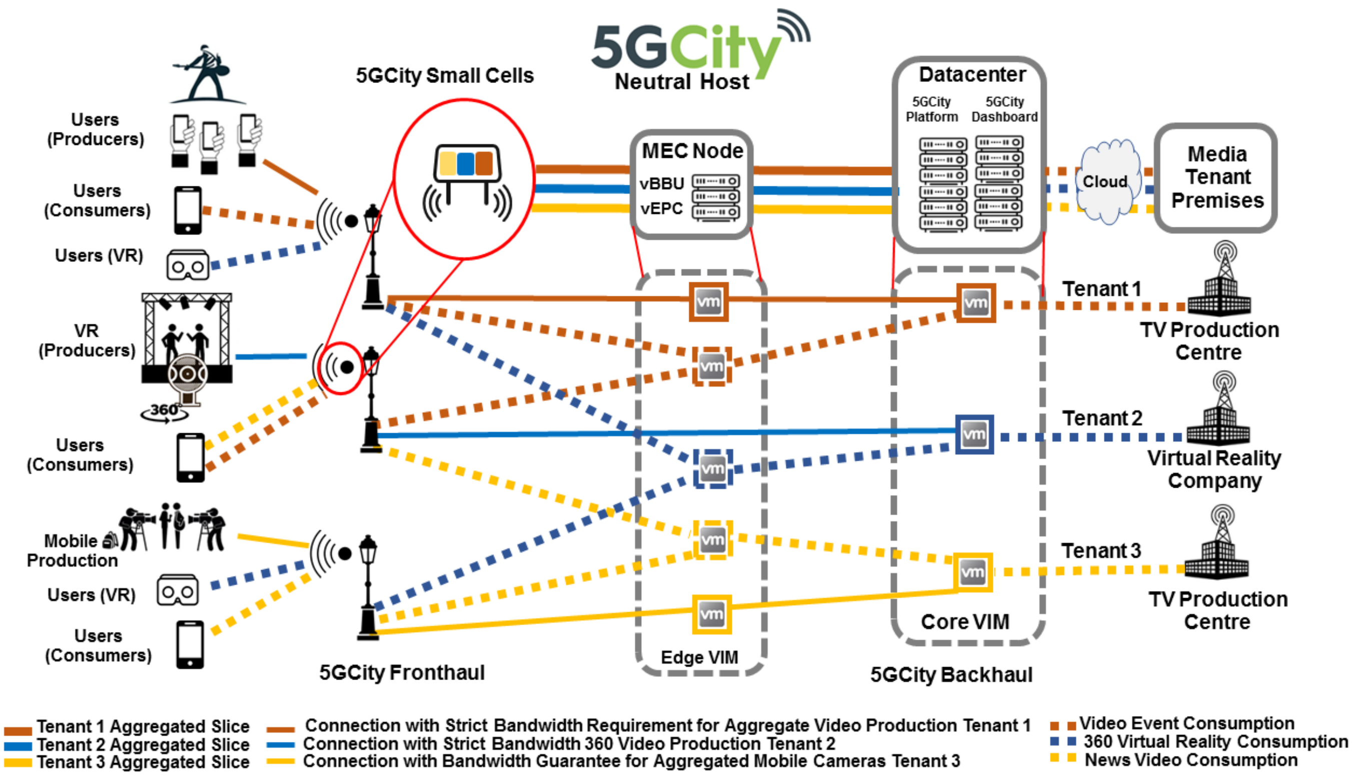

Figure 6 - 5GCity neutral host deployment with media use cases.

In the next section we use the given requirements to construct an illustrative example of the 5GCity UCs deployments.

V. 5GCITY USE CASE DEPLOYMENTS

Figure 6 shows the deployment of three 5GCity media UCs in a sliceable 5GCity infrastructure consisting of a Datacenter, MEC node, and wireless access deployments. The shown infrastructure encompasses compute resources at Datacenter & MEC node and network resources stretching from lamp-posts to the Datacenter. The 5GCity platform and 5GCity Dashboard are deployed at the Datacenter. 5GCity Dashboard is the front-end to 5GCity platform that enables customizable slicing of infrastructure, application service deployment across the slice and access to slice and service controls and management to the slice owner.

Such a three-tier infrastructure setup offers four innovations for media industry: delay reduction, flexibility, integration and collaboration between media production and consumption (i.e., video post-production and broadcasting). Delay reduction is made possible by deploying compute resources at the edge VIM rather than core VIM on the MEC nodes closer to the production and consumption area and 5G fronthaul. Flexibility is enabled by the 5GCity dashboard supported by intelligent resource scheduling algorithm that will configure the slice capacity and availability for any of the tenants as per requirement. In the UC example, TV production and broadcasting companies or any media vertical can request and have a dedicated slice provisioned from the 5GCity platform operator, also assumed to be 5G infrastructure owner. The integration and collaboration between production and consumption is nurtured when the slice is customized to provide optimized content placement (or cached content) and resource elasticity (e.g., additional capacity for slice), not only to aggregate the production but also to improve the QoE of end users or consumers of the video.

The Illustrative example presented on Figure 6 shows three tenants sharing a 5G neutral infrastructure. The first tenant is the UC#1 that deploys and connects the virtual machines (VMs) in edge VIM and core VIM to host an application for multiple users (e.g., 20-50 mobile phones with 2-8 Mbps UL) acting as producers or recorders of a live event. The VMs at the edge VIM and core VIM will aggregate and synchronize the video contribution in the 5GCity MEC node and host a virtualized video server for processing, switching, and editing in the datacenter which is accessed and operated remotely by TV producers. This interconnection connection will demand some large network bandwidth during the event (i.e., ~2 Gbps). Then, for immediate broadcasting or streaming for users or consumers, the producers will use the same slice with additional resources at the edge VIM in the 5GCity MEC node to host and cache video contents populated based on the demand. The flexibility and intelligence of 5GCity Dashboard could allow the fast allocation of more resources (processing and bandwidth) for production in case of an increase in the demand (more users recording the event) or more users requesting to stream.

The tenant 2 is the UC#2 which consist of production and streaming of virtual reality or 360-degree video to users.

Slice#2 will allocate resources for production in a VM at the edge VIM for transcoding, and VMs at core VIM for storing, redistribution and elaboration with the remote intervention of a broadcaster or a virtual reality company. Given that the delay and flexibility demand, the tenant 2 will also request for network resources at all lamp-posts, hooked up with Slice#2 computing resources at edge VIM, to make the processed 360-degree videos available for all the VR users.

The tenant 3 (slice#3) can be the same company of tenant 1 but requesting mobile news or event coverage. In this case, a dedicated slice is defined with guaranteed bandwidth connection with resources or VMs at both VIMs, the edge VIM for camera synchronization and transcoding and the core VIM, for remote video mixing applications, storing, redistribution, and final elaboration. Given that breaking news can happen in matter of minutes or hours, the dashboard will be able to slice the infrastructure based on a short period of time.

Finally, the resulted video content will be placed in VMs on the edge VIM for consumers or local channels requesting the news or event coverage. The 5GCity dashboard will provide resource allocation and temporary schedule to handle the different demands and avoid collision or any capacity crunch of the shared infrastructure. As a result, 5GCity model will save time and money for small and large TV and media production and broadcasting companies and will also open many opportunities for new services.

VI. CONCLUSION

Ultra-high definition video services and immersive reality production and consumption in dense urban environments will demand flexible, low-delay, and high-throughput wireless and IT infrastructure by leading to large investments for network operators and media producers. H2020 project 5GCity aims to deal with those issues by designing, developing, and deploying a neutral and sliceable cloud & radio platform i.e., neutral host.

To demonstrate the benefits of our proposed 5GCity neutral host platform, we introduced three innovative use cases for ultra-high definition video and immersive reality production and distribution. A 5GCity neutral host platform can provide flexible infrastructure sharing to reduce the dense small-cell deployments and the necessity for large investment for network operators and media producer (media verticals). Finally, 5GCity project plans to demonstrate the ambitious use cases in real-life deployments in three different European cities to validate the proposed neutral host platform.

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