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Architectures for Scalable Content Delivery over 5G Networks

Sofia Rodriguez, Julianne Lee, Emilio Martinez-Rubio
University of California, Los Angeles, Department of Computer Science; University of Cambridge, Computer Laboratory

Abstract—The 5G advent is stimulating research and development of new solutions and tools to serve the Media & Entertainment industry in oder to cope with all the demanding requirements for very high volume (downlink and uplink), for service fruition across multiple devices, for anytime and anywhere coverage, for Quality of Service and security.

In this paper, we focus on scenarios and requirements to implement orchestrated virtual CDNs in 5G networks used to distribute ultra-high-definition media contents. This work originates from the research activities within the H2020 5GMEDIA project, in which We are designing a solution across the edge Point of Presence (PoP) and core data-centers of an operator network, to allow the distribution of UHD media contents from central production centers to end users. Our vCDN solution can elastically cross various anchor points for fixed and/or mobile broadband services down till personal devices, both fixed and mobile to properly serve users attached to the 5G network. The work reports on results of our initial design phases and focuses on the specific scenarios and requirements in our scope. The implementation of the designed virtual CDN solution powered by the 5G-MEDIA management and orchestration platform is an ongoing task, which - once completed - will allow us to validate the proposed scenarios and service orchestration approaches through the 5G-MEDIA in the project testbeds.

I. INTRODUCTION

Stimulated by the 5G rise, the Media & Entertainment industry is rapidly converging towards the development of ultra-high definition media (UHD) delivery services to be consumed over new categories of devices like UHD TV screens for Video on Demand (VoD), high-end smartphones, tablets, etc. Market analyses [1] show that Internet video to TV is continuing to increase 3.6-fold by 2021, and is estimated to reach 26% of consumer Internet video traffic by 2021, up from 24% in 2016; Ultra-High Definition (UHD) media contents will be 30% of VoD traffic in 2021, up from 2% in 2016. Media content distribution capabilities, both in space and time, increasingly rely on a content aware network that is open to potentially everybody and pervasive in all areas of the Internet. Leveraging on open standards, interfaces and protocols, the Telcos, manufacturers and content providers have new opportunities to more actively participate in the value chain and design the necessary functions for replication, distribution and adaptation of contents, without the need to be attached to legacy Content Distribution Networks (CDN). Recent studies by Cisco [1] show that 71% of all Internet traffic will cross CDNs by 2021 globally, up from 52% in 2016; therefore, CDNs are a critical enabler for any media traffic distribution in next generation networks.

5G is bringing new solutions to serve the M&E industry demand for seamless and optimized network services from edge to core. 5G will provide substantial capabilities to match the M&Es traffic volumes (both down-link and uplink), to reach any device, anytime, anywhere. Multi-Access Edge Computing (MEC), SDN& NFV are key enabling technologies in this context due to the efficient management and elastic orchestration of media and network resources involved in the media content distribution.

In this paper, we describe the scenarios and requirements identified in the H2020 5G-MEDIA project [2] for implementing orchestrated virtual CDNs (vCDN) in 5G network for the distribution of ultra-high-definition media contents. In 5G-MEDIA, a 5G PPP Phase 2 project started on July 2017, We are designing a solution across the edge Point of Presence (PoP) and core data-centers of an operator network, to allow the distribution of UHD media contents from central production centers to end users. Our vCDN is supposed to elastically cross various anchor points for fixed and/or mobile broadband services down till personal devices, both fixed (in the home) and mobile (while the user is on the move in the 5G network) to properly serve users attached to the 5G network without the enforcement of a binding to todays legacy CDN providers.

This paper is organized as follows. In Sec. II, we present the general requirements for the distribution of UHD media over networks, mostly derived from the background experience in the field by broadcasters participating to this research work. In Sec. III, we describe the scenarios for UHD media distribution over 5G Networks, distinguishing a couple of representative scenarios under development in the 5G-MEDIA project. In Sec. IV, the platform and service requirements for

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running vCDN over 5G networks are presented, while in sec. V the 5G-MEDIA architecture is presented capable to support UHD video distribution. In sec. VI, we derive some conclusions and reference to ongoing next steps in terms of development and validation activities on teh 5G-MEDIA testbed.

II. Distribution of UHD media over networks

The advent of more and more powerful hand-held devices capable of 4K and UHD video capture & play is progressively moving the UHD media distribution fruition from the usage on fixed stations (e.g. UHD TV screens at home) to mobile devices in the coverage of new broadband networks (e.g. smartphones or pads attached to advanced 4G and 5G networks).

To cope with this new usage scenarios and media quality targets, the standards for HTML5 [4] and MPEG-4 [5], H.264/H.265[6] are generally appropriate for cross-device distribution of content over the Internet. Nevertheless, suitable combinations of media container formats, transport protocols and media coding schemes need to be defined to ensure interoperability and maintain perceptive quality. In fact, IP-based delivery mechanisms need to follow the multimedia transport with the consumers Internet connection and their individual network access. Special requirements emerge with High Definition-Formats from UHD and HDR, HFR to 360 Video. While the media transmission for download, pseudo streaming or live streaming can occur through different protocols (HTTP, QUIC [8], WebRTC[7], SRT[9]), bottlenecks need to be compensated by load balancing and caching in CDNs or via more intelligent client based transport mechanisms like Adaptive Streaming.

However, these mechanisms are often not sufficient to resolve the causes of congestion in the network. To improve video quality perceived by the users of video streaming, different approaches based on SDN platform have been proposed to adapt routing paths dynamically (e.g. as those defined in [3]). The traditional streaming protocols like RTP or RTMP have been deprecated due to insufficient support in todays CDN-infrastructure. Besides benefits of todays stateof-the-art Adaptive Streaming over HTTP, new Peer to Peer (P2P) service providers enter the stage with rising browsersupport of the Realtime Communication Protocol (WebRTC). New Upcoming protocols like Google QUIC using multiple parallel UDP-streams to gain higher QoS-precedence need to be investigated in terms of Caching-efficiency in an Endto-End public streaming scenario. After an industry wide adoption of HLS in iOS, Android and HTML5-browsers supporting Media Source Extensions (MSE) the shift from MPEG-TS packaging to the ISO Base Media Fileformat (ISOBMFF, [10]) was introduced with the Standardization of Dynamic Adaptive Streaming over HTTP (MPEG-DASH, [11]) within SmartTV-domain. Thereupon Apple and Microsoft committed the future media delivery to the Common Media Application Format (MPEG-CMAF).

Nevertheless, defining inter-operable encoding profiles, being suitable for a wide range of todays Internet connectivities on a given end-users device population to reach a maximum target audience at reasonable costs with good Quality of Experience (QoE), still remains the key challenge.

The following encoding profiles (see Table. I and Table. II) represent typical state of the art streaming profiles for public service broadcasting networks. These parameters are generally subject to regular review and testing by broadcasters to ensure a maximum coverage of end-devices operating in various broadband situations.

TABLE I
Characteristics of video streaming over PC, Tablet, Smartphone

Type	Resolution	Interlacing/ Frame rate (fps)	Video bitrate (kbit/s)	Audio bitrate stereo (kbit/s)
XXL	1920x1080	25p/50p	6500	160
	1920x1080	25p	5500	96
XL	1280x720	25p	5500	96
	1280x720	25p/50p	5000	160
	1280x720	25p/50p	3584	160
L	960x540	25p/50p	2500	160
	960x540	25p/50p	1800	160
	960x540	25p	1300	64
	640x360	25p/50p	1024	160
	640x360	25p	700	64
M	512x288	25p	512	96
	480x270	25p	550	48
	480x270	25p	256	64
S	320x180	12,5p	128	56
	Audio Only			56

TABLE II
Hybrid Broadcast Broadband TV streaming profiles

Type	Resolution	Interlacing/ Frame rate (fps)	Video bitrate (kbit/s)	Audio bitrate stereo (kbit/s)
XXL	1920x1280	25p/50p	6500	192
	1920x1280	25p	5500	96
	1280x720	25p	5500	96
XL	1280x720	25p/50p	5000	192

	1280x720	25p/50p	3584	192
L	960x540	25p/50p	1800	192
	960x540	25p	1300	64
L+	720x576	25p	1536	192
L	640x360	25p/50p	1024	192
	640x360	25p	700	64

For adaptive delivery using HLS or MPEG-DASH various encoding constraints apply to support a wide range of devices with efficient single multi-format transcoding as provided in todays GPU-based or CPU-based encoders (Elemental, KeePixo, Ateme, Thomson, Telestream) or Open Source Frameworks (ffmpeg, x264, x265, mp4box, dashcast). Generally the Encoding needs to be aligned to the Group of Picture (GOP) used within the encoding for dynamic onthe-fly segmentation over all resolutions to be represented in the adaptive media playback. A reasonable trade-off between coding efficiency, real-time delay, caching performance and seeking responsiveness can be obtained using segmentdurations from 4 Seconds to 6 Seconds which may contain multiply Fragments each following a GOP-Size from 1 to 2 Seconds. The overall end-to-end latency of a complete transmission change over the open Internet shall not exceed 30 Seconds for adaptive streaming and 5 to 7 Seconds for single bitrate streaming.

Optimised Adaptive Low Latency Streaming can be provided at less than 5 Seconds using MPEG-DASH and/or MPEG-CMAF over Low Latency-CDN configurations (e.g. Akamai Media Services Live v4.x) at least for modern Media Players which support an extended download strategies with requesting partial segment fragments at durations of minimal one GOP exposing HTTP 1.1 byte range requests and chunked transfer coding.

Even higher demands in bitrates, latency and cachingperformance need to be faced for the of distribution UHD or 360 and VR over IP without network-layer QoS in the predominant unicast domain over the open Internet. Although H.265 or AV1 provide higher coding efficiency, broadcasters are facing an escalation of traffic costs over next decade with Ultra High Resolutions (UHD), High Dynamic Range (HDR) and High Framerate (HFR) in the combination with an ever growing audience preferring OTT over linear TV introduced by the younger generation from 19-24. Having overcome the container issue with CMAF, the road to royalty free codecs seems to have been determined by the Open Media Alliance in favor of AV1. Unfortunately this will imply once again a ”two-world” UHD-distribution with H.265 on the TV-domain and AV1 on the PC and Mobile-domain.

Based on the aforementioned considerations, one main issue in designing UHD distribution for mobile devices is to make available a synchronization mechanism between the different vCaches that a user is visiting through handover while moving. There is the need for an algorithm/function in charge of maintaining a tight synchronization in every buffer, which may depend on the user or be coordinated by the Origin UHD Server. A first goal could be to achieve synchronization in the order of 33-40ms, independent of the device resolution (from 1920x1080 for HD to 320x200 in low res). This is a one frame accuracy synchronization. The size of cache should be large enough to allow such tight synchronization and replica of contents. On the other hand, caches need to be monitored to verify the efficiency of the bitrate for the resolution chosen. If such bitrate is being not meet or if it is possible to scale the streaming up to better resolutions (e.g. after a congestion is solved), a transcoding function serving the cache need to be configured to produce and store a different bitrate. If needed, the new transcoder can be instantiated and properly configured on the fly.

III. Scenarios for UHD media distribution over 5G Networks

The distribution of UHD media across networks with moving users requires a new approach to handling of aspects of dynamic network and media service re-configuration over time which are not possible with classical CDNs. Virtualization technologies and service chaining solutions for 5G networks can offer new opportunities to solve this problem. In 5G-MEDIA, we have elaborated a 5G management and orchestration control architecture whose functionalities capitalize on a split of three major functional layers: i) an *Application/Service Development Kit* (SDK) to enable access to media service development tools for vertical operators and broadcasters ; ii) a *Service Virtualization Platform* (SVP) to hosts the components related to the ETSI MANO framework for the lifecycle management of Network Services (NS), Virtual Network Functions (VNF) and for the end/to/end service orchestration tasks. It includes also the *Virtual Network Functions and the Media Application Repository* as well as the generic components that can be used across many applications (such as the monitoring, optimization and serverless functions); iii) different *Network Function Virtualization Infrastructures* (NFVIs) to provide cloud resources by different operators where to host media-specific VNFs. The 5G-MEDIA platform pioneers application of Function-as-aService (FaaS, [13]) to VNF management, complementing traditional VM based

VNFs with FaaS based media specific functions, aiming at dramatically reducing development cycles and slashing operational costs to 5G-MEDIA users. Our scenarios rely on the functionalities of the 5G-MEDIA SVP, which is capable of managing and orchestrating the media service across several edge Point of Presence (PoP) and core data-centers of an operator network, to allow the distribution of UHD media contents from central production centers to end users. The concept of media distribution supported by the 5G-MEDIA architecture is depicted in Fig. 1.

Supported by the new capabilities offered by the 5GMEDIA SVP, two different scenarios have been identified to implement orchestrated virtual CDNs in 5G network for the distribution of ultra-high-definition media contents.

A. Scenario I: My Screen Follows-me

The rationale for this scenario is to implement a *My Screen Follows-me* condition: users move in the 5G network and aim at having a seamless media experience from fixed video/audio device (e.g. at home) to personal mobile devices (e.g. tablets, smartphones). It is a scenario for moving users who want to continue the streaming of their media contents while crossing different network sections.

Depending on context and usage scenario, dynamically discovered media content will be made available on different devices (e.g. smart phones, TV screens, pads). New local caches and transcoders may need to be instantiated close to user to optimize the streamed content in terms of resolutions and audio/video quality. Mechanisms to dynamically adapt and reconfigure the network service across the infrastructure, e.g. based on Software Defined Networking and Network Function Virtualization tools/orchestrators, are used to guarantee the required QoS levels for the UHD streaming (4k/8k).

B. Scenario II: I-Director

The *I-Director* scenario applies more to a broadcast condition, e.g. related to big sport or arts events. These shows are occasions where millions of people consume the same content simultaneously. Todays mobile networks could not serve the needed bandwidth required to provide all the viewers with the media stream. Very high number of users, same content, simultaneously is posing a challenge in terms of quality and costs for the operators. We can offer the possibility to change the viewing experience for each viewer (e.g. interchangeable audio tracks, alternative video angles) involving the less possible resources in the content experiencing. The scenario envisages end users who can also access different add-on contents and e.g. get streams from different cameras, view linked information on the event, replay on particular viewpoints, etc.

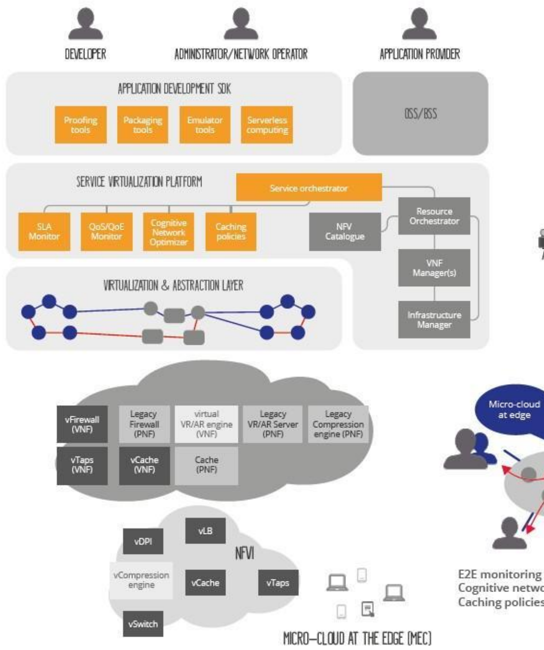

Fig. 1. UHD media distribution concept

IV. Platform and service requirements for 5G networks

From the scenarios sketched in Sec. III, several requirements have been identified for the SVP. In particular, to achieve the expected performances and QoE, the vCDN for UHD media distribution needs to fulfilling the following requirements for the service automation, flexibility and extensibility:

- The SVP must support automated orchestration and lifecycle management of media services and their components,

- The SVP must provide automated adaptation of service chains on the base of collected, aggregated statistics and monitoring data,
- The SVP must implement (via NFV MANO layer) automated dimensioning (scaling in/out) of media services on the base of collected, aggregated, statistics and monitoring data.

Operations to be performed on the service can be decided by the media service provider (MSP), who orchestrates *manually* the service via graphical user interfaces, or can be actuated by the 5G-MEDIA MAPE (Monitor, Adapt, Plan and Execute), the component within the SVP responsible for triggering in a predictive and self-healing manner the adaptation/dimensioning of the vCDN service. The system should be capable of completing the requested procedures according to requirements specified in the service and its components descriptors: VNF/App flavours, monitoring and configuration parameters. For instance, enough computational resources should be guaranteed, according to the media service provider policies, for the instantiation of a new edge vCache/vTranscoder, starting, once instantiated, a monitoring job on specific application level parameters, e.g. the number of incoming requests on the vCache/vTranscoder. Data collected at both the application (e.g. caches throughput, number of users connected to a cache etc..) and network (e.g. packets loss, latency etc.) layers are aggregated and analyzed by the Cognitive Network Optimiser (CNO) to trigger proper lifecycle management operations on the MANO framework for adapting the service to the current or predicted environment status. As examples of QoS and QoE parameters that can be monitored for UHD media use case, it can be considered:

- QoS parameters to measure on media server side:
  - Average Bit Rate, i.e. the average bandwidth being consumed by the video stream from origin server to the client viewing the content.
  - Round-Trip delay, i.e. the avg/min/max propagation time between the media client and the server.
  - Packet/frame loss rate, i.e. the average loss rate between the media client and the server.
  - Network hops, i.e. the number of hops crossed by the packets between the client and the server.
- QoE based metrics:
  - Start Time, i.e. the elapsed time from when play is pushed to when video starts on the screen.
  - Re-buffer Rate, i.e. the number of times a rebuffering event occurs during viewing.

V. The 5G-MEDIA architecture for UHD distribution over CDNs

A. Virtual CDN architecture and related components

Typically CDN architectures are design to allow the replication of contents in several caches structured in a hierarchy of mid and edge nodes, distributed in the CDN domain [12]. Differently from what already exists in literature, the vCDN solution we are designing in 5G-MEDIA aims at customizing the delivering of the service on the base of the users' location and preferences. For instance, leveraging on SDN/NFV consolidated mechanisms, the vCDN domain can be extended instantiating further vCaches for covering incoming user requests from different geographical areas, then in proximity to the en-users, or to serve an high demand in an already covered area. For such purposes, the vCDN architecture is enriched with novel components/functions classified in three different groups related to their applicability:

1) Application Layer Functions, i.e. functions completely devoted to the media streaming and related monitoring
2) Generic Media Functions, i.e. functions related to the content distribution
3) Network Layer Functions, i.e. functions needed to route and control the traffic across the network.

Among the Application Layer functions, we have: the *UHD Streaming server*, i.e. the origin server which acts as the root server for media distribution and composed by functions for source transcoding, media streaming and users' preference and profiling control; the *Media library*, i.e. the function to store, organize and share media content to be requested on-demand by authorized end users; the *Content personalization server*, i.e. the function that offers different streams related to the various viewing angles and/or different audio tracks; the *Stats collector*, i.e the component in charge of monitoring specific application level parameters in all the nodes in the vCaches/vTranscoders hierarchies. These collected information are used by the Cognitive Network Optimizer to adapt the service delivery on the base of users requests and vCaches/vTranscoders health status; the *Application layer traffic steering*, i.e. the function in charge of balancing the incoming users requests between the vCaches and vTranscoders in the vCDN domain and determine which vCache/vTranscoder fits better the incoming user request for a media service, also in terms of proximity to the end user. The configuration of the traffic steering for the application layer is delegated to the Cognitive Network Optimizer, which will process application layer and infrastructure layer service monitoring stats to optimize the traffic flows instantiated in the 5G network.

In the Generic Media functions, we have: the *Edge Transcoding unit*, i.e. the transcoding unit deployed closed to the end user with the aims of reducing latency and offer a better QoS/QoE; the *Edge Cache*, i.e. the caches deployed closed to the end users with the aim of reducing latency and offer a better QoS/QoE.

At the Network Layer, we use *Network security functions* like for example vFirewalls, vDDoS, vIPS to regulate net-

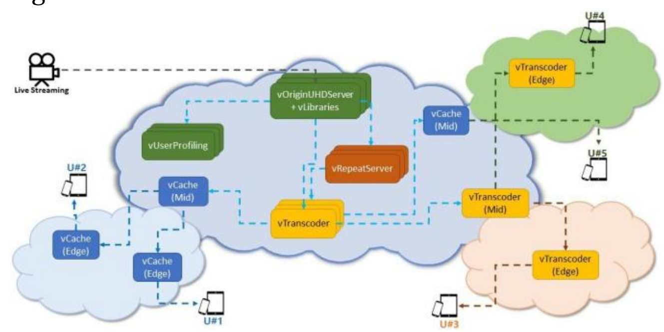

Fig. 2. Interaction between vCDN application and data-plane components

work flows and implement security belts to the network; *Traffic classification*, i.e. functions to inspect traffic and trigger appropriate traffic routing decisions at the application level: data collected and aggregated by proper QoS monitor functions will be consumed by the Cognitive Network Optimizer to select the best path along which the service will be delivered; *Traffic Steering and QoS Prioritization functions* to make use of queue management techniques and path selection, including the use of SDN controllers; *QoS Monitor* to collect and aggregate information/statistics from the network layer. The resulted data set can be consumed by the Cognitive Optimizer for the service chain optimization.

B. Typical forwarding graphs

With respect to the vCDN components classification, the interaction among them can be described through service forwarding graphs.

Interaction between vCDN application and data-plane components. The user, who is streaming the content on his/her device, (e.g. smartphones, tablet or smart TV) is connected to an edge vCache or vTranscoder (e.g. streaming VoD, instantaneous replay or live events). The vCache or the vTranscoder are deployed in proximity of the user in order to achieve the requirements due to the SLA. vCaches and vTranscoders can be deployed in a hierarchy (edge/access, metro region), where the edge entity is connected to a mid vCache/vTranscoder located in the core network. The core network hosts the vOriginServer and the related vTranscoders where the users requests are mapped, in sequence, through the edge and mid vCaches/vTranscoders. Upon the users selection of streaming for a specific replayed angle a vRepeatServer is instantiated as a service, and prepared to distribute to the specific location the requested angle and video fragment playback. This function is expected to be implemented through the FaaS layer via the processing of user Inputs (on-demand and asynchronous) and the execution of a workflow of Actions to retrieve video fragment from the origin library, its transcoding and appropriate caching along the path to end user. This workflow is depicted in Fig. 2.

Interaction between control-plane (SVP) and vCDN components. As shown in Fig. 3, the MANO control plane is responsible for the traffic steering of the different users requests by offering a DNS service coupled with a stats

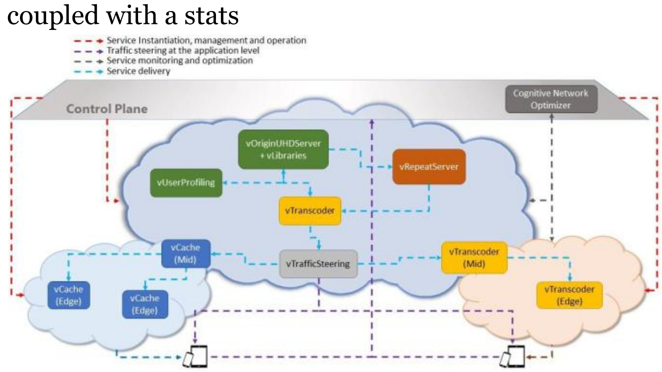

Fig. 3. Interaction between control-plane (SVP) and vCDN components

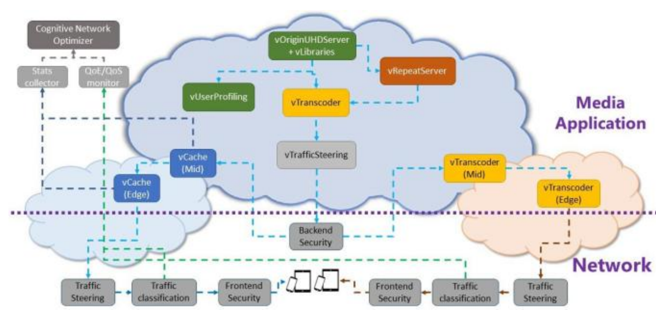

Fig. 4.Interaction between network and application layer functions

collector and QoE/QoS monitoring services. The stats collector and the monitoring services act as source of data to be processed by the Cognitive Network

Optimiser, which is in charge of optimizing the service and offer to the user the best QoE. The users requests are then redirect to the proper vCache/vTranscoder deployed in the edge, while the vTrafficSteering in the core network is in charge of delivering the media content through the selected mid/edge vCache/vTranscoder hierarchy.

Interaction between network and application layer functions. In order to guarantee to the users a proper level of security at the network level, the user should transfer and consume data through a set of frontend/backend security VNFs (e.g. vFirewall, vDDoS, vIPS). At the same time, the monitoring services in the control plane consume data from Traffic Classification mechanisms deployed at the network level, in order to inspect the packets consumed by the users and to extrapolate statistics/information about the QoE/QoS. Moreover, at the network level, the QoS Prioritization and Traffic Steering VNFs are responsible for configuring the underlying connectivity in the network nodes, in order to deliver the service (in terms of packets consumed by the users) along the selected/computed paths/flows (see Fig. 4).

VI. CONCLUSIONS

In this paper we have described scenarios and requirements for orchestrated virtual CDNs in 5G network used to distribute ultra-high-definition media contents. The work originates in the 5G PPP Phase 2 5G-MEDIA in which We are designing an open vCDN capable to automatically deploy CDN elements in the form of virtualized functions to serve users moving across various anchor points from fixed to mobile broadband networks. The two main scenarios of our framework have been introduced together with requirements and network functions used to dynamically adapt and reconfigure the network service across the infrastructure.

This work reports only initial design results of our work. The implementation of the described virtual CDN solution for 5G networks is an ongoing task which plans to be released in an initial version for teh scenario "*My screen follows me*" by the end of Q3-2018. One key challenge for our implementation is the de-centralisation and virtualization of network caching and media processing services, which allows to optimize network resource usage. Another important challenge is the proper selection of open interfaces and protocols for media streaming which can be best suited to control/monitor multiple media network services both at House-to-Edge PoP and Edge PoP-to-Edge PoP/Midtier/Core PoP. Also, it is key to achieve benefits in terms of QoS/QoE for end-users, and cover aspects of security, privacy and trust of the distribution of UHD media contents. All these elements have been considered in the design phase and will be validated in tests planned in the 5G-MEDIA testbed which will be reported in the near future.

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