On QoE-awareness through Virtualized Probes in 5G Networks

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***Abstract*—The advent of 5G Networks introduces significant challenges in almost every link of the network value chain. The demand for seamless connectivity, extremely low latency, high-speed data transfer and energy efficiency along with the exponential increase of interconnected devices will shape an ecosystem with such complexity that enforces the replacement of almost every current standard. It is therefore necessary to re-address all aspects of networking with Quality of Experience (QoE) amongst them. This paper aims to provide an overview of some exciting new technologies 5G networks are based upon and present a novel architectural component that will solve the thorny issue of QoE-awareness facilitated by the advanced virtualization and data management capabilities this novel user-centric networking paradigm supports.**

***Index Terms*—5G, SDN, NFV, C-RAN, MEC, QoE**

I. INTRODUCTION

Modern telecommunication networks need to rapidly evolve for accommodating the anticipated exponential increase of interconnected devices, the ever-growing user demand for data delivery as well as their expectation for constantly increased overall Quality of Experience (QoE) in all services and applications. Recent estimations have indicated that the annual global IP traffic will surpass the zettabyte threshold in 2016, is likely to be doubled in just three years reaching the two zettabyte milestone in 2019 with mobile and wireless devices being responsible for over half of it, despite the continuous increase of fixed broadband speeds globally [1]. These numbers might sound astonishingly high, but one should consider emerging technologies that will allow massive networks to be deployed consisting of scalable, uniformly-monitored, energy-efficient nodes, capable of Machine-to-Machine (M2M) communication, intelligent transportation systems with road-side service units and mission critical services.

The demand for such a complex wireless ecosystem paves the way for re-addressing the requirements of the upcoming 5th Generation (5G) Networks. Compared to the previous generation (4G) of cellular networks, 5G should support a substantial increase of connected devices and data rate (10-100 times the existing number), less than 1 millisecond end-to-end over-the-air latency, coverage and availability increase reaching 100% and 99.99% respectively, 1000 times larger throughput, real-time information processing and transmission, significantly lower network management operation and energy consumption costs and, last but not least, seamless integration of all current wireless technologies [2], [3], [4], [5].

As stated by the Next Generation Mobile Networks (NGMN) alliance, *"5G is an end-to-end ecosystem to enable a fully mobile and connected society. It empowers value creation towards customers and partners, through existing and emerging use cases, delivered with consistent experience, and enabled by sustainable business models"* [6]. This definition renders 5G to be a user-centric or even a human-centric network, rather than a provider-centric one, a shift that will play a vital role to user expectations, and consequently to the underlying design and implementation of its building blocks. In order to design 5G network components in a more user-oriented fashion, it is crucial to visualize the user demands together with the actual performance indicators of the infrastructure [7]. From a strict networking perspective, the low latency and high availability requirements along with the corresponding performance parameters such as geographical area coverage and peak data rate, especially when huge amounts of bursty and multimedia data are involved, are likely to increase infrastructure cost for ensuring efficient data delivery on a large scale network. Moreover, seamless handoff from one RAT to another should be supported even in cases of high-speed user equipment mobility. From a user perspective on the other hand, service reliability, coverage and data speed are those elements of paramount importance that might influence vendor switchover decisions, thus limit churn for efficient providers.

Provided that 5G networks are a-priori considered to be user-centric, the overall notion of QoE-based application delivery should be inherently supported in all layers of the actual framework and take under consideration the subjective nature of the particular attribute. On a recent definition given by Le Callet et al. [8], QoE is described as the degree of delight or annoyance of the user of an application or service, and is clearly stated that is influenced by the user's personal expectations, along with the actual application delivery characteristics. It is therefore essential for future networks to fully integrate specific QoE monitoring mechanisms [9], possibly based on transparent real-time data collection and storage, efficient big data and machine learning algorithms that will scrutinize the aforementioned data in search for patterns, and last but not least, certain functions that might enforce specific actions over the network components to arbitrary shift and reshape them.

The rest of the paper is organized as follows: Section 2 identifies elements that will have a significant affect on QoE in the 5G Network requirements and Section 3 describes the importance of virtualization technologies for 5G. Section 4 analyses the use of virtual probes for QoE monitoring along with their major characteristics, while Section 5 presents certain auxiliary technologies that will further improve QoE if utilized appropriate in 5G Networking. Finally Section 6 provides the overview and concludes the paper.

II. IDENTIFYING ELEMENTS OF QOE IN THE 5G NETWORK REQUIREMENTS

The advent of 5G networks will introduce an ecosystem with substantially increased levels of user experience since most of the current limitations of conventional cellular systems will cease to exist. Bursty data traffic provisioning and native support for heterogeneous wireless networks will be integrated in the early deployment stages, while inefficient utilization of Mobile Base Station (MBS) processing capabilities, low latency and co-channel interference are going to be virtually eliminated. Such an advanced medium will no longer be physically responsible for low Quality of Service (QoS), however when examining user satisfaction the following generic characteristics should be taken under consideration:

A. Seamless Connectivity

5G User Equipment is required to support a huge variety of both hardware and software technologies to provide consistent and uninterrupted service with excellent quality. Limited hassles may be present, however all devices should be capable of tackling issues such as the unpredictable channel conditions, the high density of nodes per cell and the frequent starvation of spectrum resources. Provided that all wireless devices tend to frequently migrate from one cell to another, due to their highly mobile nature, an important parameter that will increase end-user experience is no other than encompassing certain handoff mechanisms in order to facilitate such transitions. In particular, certain network management decisions should be redesigned and possibly transformed into nimble functions, residing inside the closest network infrastructure element, the mobile terminal or maybe the application itself.

From the operator's side, service consistency as derived from the prerequisite for seamless connectivity, needs a self-healing network infrastructure design, able to locate a non-functional node, regardless of the failure reason, adjust the operating channels over neighboring cells and restore the end users connectivity. This approach increases network element redundancy, but can be proven challenging due to the necessity for frequent communication between cells and the computational overhead that all the previously mentioned processes introduce. An enhanced QoE-aware monitoring mechanism might prove to be useful on identifying compromised components, proactively redirect traffic and issue an alert towards the central network monitoring entity or simply save the particular report to an existing analytics database.

B. Customized Service Distribution

In a user-centric communication network, it is expected all available services, once initiated, to be correlated with a pre-existing or dynamically generated user profile. Especially when business models are involved, delivering personalized content, using different network resources per session, might be a necessity rather than a mere enhancement. Sackl et al. in [5] indicated significant shifts in customer behavior, priorities and expectations when increased quality comes with a price. Such preferences should be taken under consideration in 5G networks where the main notion is to specifically address the individual needs of all subscribers in the most efficient way.

Per-user service customization is not the only approach towards elevated QoE metrics. The application itself plays a vital role, since not all applications have identical requirements or influence factors despite yielding a similar degree of user satisfaction. These requirements may include system parameters and network conditions but more often are related to the service context itself.

C. Translucent Operability

Users always seem to prefer simplicity to complexity, thus a network that delivers a high level of services while in the same time remains cryptic in terms of functionality, error handling, resource allocation and traffic management is considered preferable to one that the end user may intervene to any network-related decision that could compromise the overall quality. Interactivity between the user and the network should not be deprecated, rather than limited to the absolute minimum. Quality feedback which will allow users to harness the benefits of a QoE-aware network and provide a solid experience is expected to be implemented. However, data collection must be conducted transparently and in a fully automated manner, for instance through deploying network probes or monitoring application and device-related metrics.

D. Energy Efficiency

Energy Efficiency in the communication chain is amongst the areas that will undergo major redesign for meeting the high requirements of 5G networking. As stated by Andrews et al. in [10], continuous increase of power consumption is not viable from logistical, cost and battery-technology point of view. Rapid increase of network density is directly linked to elevated energy demands in the Radio Access Network (RAN), while the necessity of user equipment for seamless connectivity and expected support of a broad spectrum of new applications, software and utilities increases the overall computational cost and diminishes the average battery duration per charge. Internet of Things (IoT) is another area that can be considered energy-sensitive, since wireless sensors often have limited operational capabilities due to inefficient batteries. Edge offloading, an approach that suggest moving several services in the operators domain rather than user equipment gains momentum as a satisfactory solution of power drain. The expected uplink and downlink decouple, where user equipment will be able of utilizing channels from different MBSs or signaling and data decoupling, which will allow on-demand power-off of inactive BS, are likely to increase end-user QoE in an indirect way, through extended battery life.

Furthermore, the introduction of a QoE-aware mechanism able to obtain real-time network datasets and utilizes them in proactive network management will add significant end-to-end complexity, since all network elements should extend energy provisioning for the expected control signaling overhead, while in the same time retain the standards of service to the highest possible level.

III. VIRTUALIZATION IN THE 5G ECOSYSTEM

Recent advances in mobile cloud computing infrastructure allowed scalable, on-demand access to a vast pool of configurable resources like processing speed, storage, networking and integrated applications over the Internet. This centralized operational model reduces cost, increases availability, disconnects services from the existing technology and offers flexibility in terms of provisioning. The cornerstone of cloud computing ecosystem is no other than virtualization and the possibilities this technology provides for fundamental changes in the network level that will probably shift the way that such services are provided [11].

A. Cloud Radio Access Network

Cloud Radio Access Network (C-RAN) is a novel mobile network architecture designed to address the challenges operators face while trying to support growing end-user numbers. As described by Panwar et al. in [4] the fundamental idea behind any C-RAN is to migrate to the cloud the majority of functions operating in an MBS thus split the nodes functionality into distinct control and data layers. This allows dynamic service allocation facilitating network scalability without the necessity for deployment of costly network devices. All MBSs are consisted by two main components: the Baseband Unit (BBU) responsible for implementing baseband processing using specific hardware and the Remote Radio Head (RRH) that contains all radio-related operations. In most C-RAN deployment paradigms the BBUs of conventional cell cites are separated from the analog radio access units and are placed in a centralized datacenter, while RRHs remain in the MBSs. The maximum distance between them is limited to approximately 40km due to processing and propagation delay. Rost et al. in [12] provide an excellent summary of the real-world advantages of C-RANs such as easy network management by assisting on-demand installation of virtual resources, cost reduction as a result of replacing the expensive MBS hardware with software equivalents and improved spectrum utilization due to increased cooperation and reduced interference.

However, there are still certain issues that need to be addressed, for instance the actual selection of functions that will be executed in the cloud and the corresponding MBS or certain security and privacy constrains inherited directly from the cloud computing infrastructure.

B. Software Defined Networking

Software Defined Networking (SDN) is an architectural framework for creating intelligent, flexible programmable networks by decoupling control and data forwarding functions. This approach enables the creation of a centralized yet abstract view of the underlying physical state and topology thus facilitating its agile and adaptive capabilities. There are three distinct parts of SDN architectures as described in [13]: (i) the software controller that maintains the global network view by holding network control functions (i.e network management and network operating system), (ii) the southbound part that provides a protocol along with the necessary interface between the controller and the SDN-enabled infrastructure and (iii) the northbound part that provides an interface between SDN applications and the controller. The SDN control plane can be implemented as pure software operating on industry-standard hardware, however this does not always apply to the forwarding plane. In high-performance and capacity implementations a specific agent is needed, therefore specialized hardware comes as prerequisite. This restriction however cannot diminish the frameworks potential to dramatically simplify network management and enable innovation and evolution. If clearly seen as a logical extension, SDN bridges the gap between provisioning functionality and QoE management, simply slicing the network, thus creating a virtualized control plane able to enforce management decisions to all interconnected parts. This will allow a unified, inexpensive and tailored configuration based on QoE-related, therefore user-centric rules and policies.

C. Network Function Virtualization

Network Function Virtualization (NFV) renders network functions once tied to specific hardware appliances to run on industry-standard cloud infrastructure operating in any data center. According to ETSI, the NFV architecture is composed by three key elements: the Virtual Network Functions (VNF), the Network Function Virtualization Infrastructure (NFVI), and NFV Management and Orchestration (NFV MANO) [14]. VNFs are the functional blocks within a network infrastructure that has well-defined external interfaces and functional behavior. A provided service is consisted by several VNFs whose number, type and ordering is determined by its functional and behavioral specification. The NFVI is the combination of both hardware and software resources that create the operating environment of VNFs. For achieving the necessary abstraction, a specific virtualization layer is utilized that divides virtual from physical resources. Last but not least, the NFV MANO overlooks the process of VNF provisioning along with all related operations, such as configuration, orchestration, lifecycle management and traditional network coordination.

It is obvious that NFV and SDN have a lot in common, provided they both advocate in favor of replacing current networking elements with open software and standard network hardware. Both approaches also leverage virtualization to achieve their specific goals. In fact, those two frameworks often are considered complementary, hence their combination leads to a more robust system where an SDN controller may be integrated inside the value chain of an NFV deployment hence benefit from its advanced reliability and elasticity features.

D. Mobile-Edge Computing

Mobile-Edge Computing (MEC) is a network deployment paradigm which introduces of the concepts of cloud computing to the mobile network ecosystem. As clearly stated in [15] it can be seen as a cloud server operating at the edge of a mobile network, performing specific tasks that could not be achieved with conventional network infrastructure. The enormous benefits of utilizing generic virtualization principals in telecommunications lead network operators to embrace such standards and deploy Virtual Machines (VMs) capable of processing specialized tasks on top of commodity hardware servers [16]. To further enhance their position in the profitable market of service providing, Telcos have started identifying networking hot spots called Points-of-Presence (PoP), and run their own services on site by deploying micro data centers, hoping in the long run to also rent those resources to third party investors [17]. The deployment of such infrastructure changes the traditional approach of utilizing dedicated hardware for all access-related actions, an outdated concept dating back to the pre-smartphone era where voice quality was the key requirement for service design.

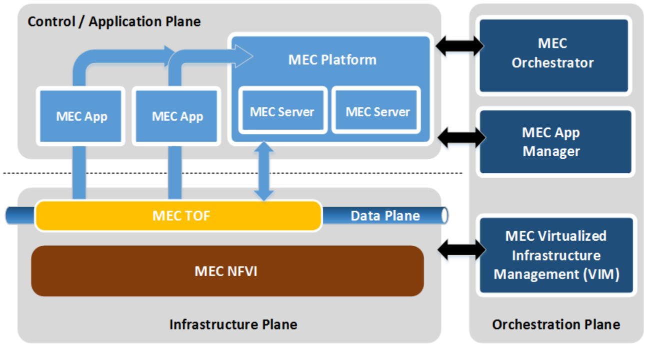

Fig. 1: Abstract Mobile-Edge Computing architecture

An abstract MEC architectural blueprint is shown in Figure 1. In parallel with [15], the paradigm components spread over several networking layers thus facilitating information and control flow in a seamless manner. The fundamental element of MEC is the MEC application server, which runs on top of the MEC NFVI infrastructure and provides services to the end-users, implemented as individual MEC Applications (MEC Apps). MEC Apps share communication interfaces with the MEC Platform, where MEC Services are hosted. The later provide services to the Apps and act as an API intermediate between the MEC Platform and App. MEC Services nodes are possible to operate locally inside the deployed micro data center or remotely in the cloud. Both MEC App and MEC Services incorporate interfaces to the Traffic Offload Function (TOF) which is located in the Data Plane and prioritizes traffic via transparent, policy-based packet monitoring and redirection. This element simplifies MECs' integration to the RAN and plays a vital role as a generic monitoring-assisting node, since it is capable of accessing (uplink and/or downlink) U-plane traffic, redirect it to an application that may simply analyse it, modify or shape it and then send it back to the original Packet Data Network (PDN).

IV. vPROBE DEPLOYMENT FOR QoE MONITORING

In mobile networks, services involving traffic management, Deep Packet Inspection (DPI) and content optimization have been traditionally deployed on the Internet side of Gateway GPRS Support Node (GGSN)/ Packet Data Network Gateway (P-GW), for instance in the S/Gi-LAN. Even though the industry recognizes the utility of these services, the significant data transfer volumes and the desire of operators to differentiate from their competitors on the basis of QoE, deploying such solutions in a scalable fashion is becoming increasingly challenging and expensive. The lack of accurate visibility of RAN conditions renders traffic management and transport or content optimization, without compromising the balance between network efficiency and QoE, a rather challenging task. Moreover, the shift towards Internet Protocol (IP) utilization in the evolution from Universal Mobile Telecommunications System (UMTS) to Long Term Evolution (LTE) and eventually to 5G provides opportunities of pushing these services into the RAN and towards the Edge of the Network. Taking under consideration that 5G PPP in [18] recognized MEC as one of the key emerging technologies for 5G evolution, the original notion of deploying QoE monitoring probes using this platform is amplified even further.

In current generation networks traditional Network Performance Monitoring and Diagnostics (NPMD) vendors, such as Viavi Solutions (formerly JDSU), MEC frontrunners, such as Vasona Networks and Saguna Networks, DPI/traffic management vendors, such as Sandvine, Procera Networks and Allot Communications, and other players of the network visibility ecosystem, such as Brocade and Avvasi, deploy probe and DPI solutions of both passive and active nature involving specialized hardware and software packages. The installation of those probes/DPIs takes place in front or in the rear of the P-GW each with certain strengths and weaknesses. In particular, the former approach allows access to large traffic percentage however it proves difficult to ensure that the tapping/interception of traffic is reliable and efficient enough, while the later only has limited visibility of the control plane.

The MEC paradigm described in the previous section provides a solid example of future 5G Networks architecture. The integrated TOF service along with the fact that it integrates micro data centers in all major PoPs fully capable of supporting VMs of certain capacity, render the deployment of QoE-monitoring Virtual Probe (vProbe) a rather easier task. The proposed vProbe instantiation schema is presented in Figure 2 with the overall action to be set in a micro data center of a PoP (μDC-POP). The technical requirements this proposal meets are quite important.

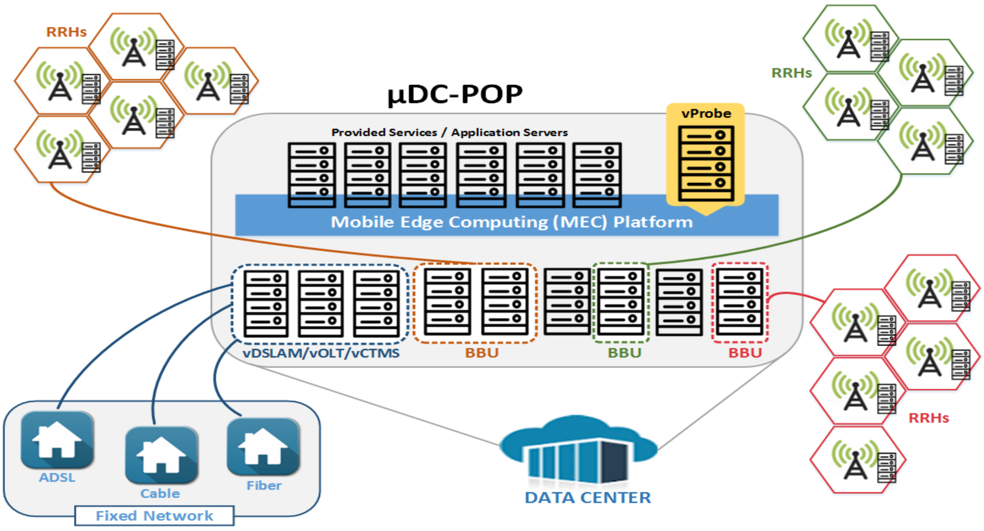

Fig. 2: Deployment of *vProbe* on Mobile-Edge Computing for monitoring QoE

A. *Network Awareness*

It is essential for an efficient QoE monitoring Probe to be aware of the RAN type, the radio resource allocation and the cell topology for adapting to service delivery characteristics. Transport Layer optimization metrics initially focused on Transmission Control Protocol (TCP), but with future support for User Datagram Protocol (UDP) and Stream Control Transmission Protocol (SCTP) is considered a must, provided that the network objective is to achieve high speeds with congestion control and low latency.

B. *User Behavior Identification*

The vProbe needs access to subscriber identifiers and device identifiers to monitor aspects influencing QoE and if necessary to apply traffic policies with the corresponding granularity. In addition, it needs to be robust to mobility effects and collect the new sets of metrics especially when the provided service is maintained in a per-flow basis.

C. *Content Awareness*

Content metrics and the corresponding data flow inspection is amongst the main tasks of vProbe, for properly identify the characteristics of the traffic, which application consumes it and whether or not the content is subdue to optimization for instance when Adaptive Bitrate Streaming (ABR) video is delivered.

D. *Orchestration and Scaling*

The vProbe should be capable of dynamically monitor service instantiation and decommission, check traffic and cell congestion levels, identifying load balancing and support state migration to a different μDC-POP.

MEC infrastructure will most probably fully support all previous requirements by exposing API that provides network and UE information, protocol information and resource utilization. In addition, metrics for goodput, throughput, bytes-in-flight, TCP efficiency and buffer delay along with several other Key Point Indicators (KPIs) and Key Quality Indicators (KQIs) are able to be retrieved in a direct fashion and then handled to the corresponding repository for storage and further analysis.

Moreover, with the content providers migration to encrypted traffic, QoE monitoring needs to evolve by not totally depending on the application layer, but seek out new methods of efficient calculation of end user experience through transport layer inspection.

V. AUXILIARY FACILITATORS FOR QOE-AWARE 5G NETWORKS

A. *Big Data Analytics*

As the number of interconnected devices rises, the amount of user and network-related traffic that flows through participating nodes increases exponentially. This stunning data growth has immensely impacted organizations whose infrastructure and traditional structured, non-real time data, management systems seem to unable to keep up. The obvious solution (apart from investing vast amounts of money in datacenter deployment) would be to move their analytics to the cloud where they may instantly benefit from on-demand scalability and contemporary data management techniques.

From a vendor's point of view, using Big Data analytics will improve customer interaction along with internal network operations both having a substantial impact on end-user QoE. Tracking down patterns in user-generated datasets may be an indicator of human behavior, habits and preferences allowing providers to obtain a much more personalized profile overview for existing subscribers. This may be utilized in various applications, from recommendation engines matching advertisements to individuals having similar interests thus generating additional revenue streams, to functions that allow intelligent network configuration based on prior historic insights in a massive scale. It is therefore essential to first define certain meaningful end-to-end quality KPIs/KQIs that would ensure decisions based on the actual end user demands in terms of quality (i.e. stalling percentage in video reproduction on a mobile terminal), rather than the current QoS-bound ones.

B. Service Level Agreements

A Service Level Agreement (SLA) specifies the performance level that a service provider of any kind agrees to deliver on its partners. SLA management is important as the service ecosystem has a multitude of suppliers and partners whose involvement is crucial to deliver the agreed service quality [19]. Currently, certain KPIs/KQIs are contracted between the provider and the partner as indicators of unproblematic service flows. Every policy includes different parameters per service or customer and once contracted, these indicators should not be breached. The requirements in such SLAs are nowadays described and agreed over inaccurate if not obsolete QoS terms, which fail to directly be correlated to the actual QoE levels of end-users.

SLA-based service management in 5G networks is a huge challenge spanning a range of activities, from software installation and configuration to collect metrics, resource status and performance data acquisition, storage and analysis, to real-time network configuration based on information produced by popular applications, all deployed in a tremendous scale. The main idea should be no other than identify different KPIs/KQIs for functionalities associated with the entire service value chain in terms of QoE, translate these identifiers to terms which provide a common ground for all involved stakeholders and only then devise methods for evaluating QoE in the various interconnection points. On the other hand, researchers have already proposed models for SLA-based resource provisioning and task scheduling together with the necessary cost minimization algorithms as stated by Alrokayan et al. in [20]. However, the majority of the existing solutions are considered layer-bound and yet improper for a network having the requirement that 5G designers envision.

VI. CONCLUSION

5G Networks will be an amalgam of fascinating platforms and deployment approaches such as C-RAN, SDN/NFV and MEC, all combined in a user-centric ecosystem. Increased QoE for the end user through seamless connectivity, personalized services and intelligent network administration is envisioned to be the epitome of this endeavor. This paper presented a new virtualized node, the vProbe, along with its technological enablers, which is located in the MEC Platform, exploits its intrinsic capabilities and cooperates with other architectural elements towards delivering optimal QoE monitoring.

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